BUREAU OF AIRCRAFT PRODUCTION

INSPECTION DEPARTMENT

INFORMATION FOR INSPECTORS OF AIRPLANE WOOD

Prepared at

THE FOREST PRODUCTS LABORATORY
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

WASHINGTON
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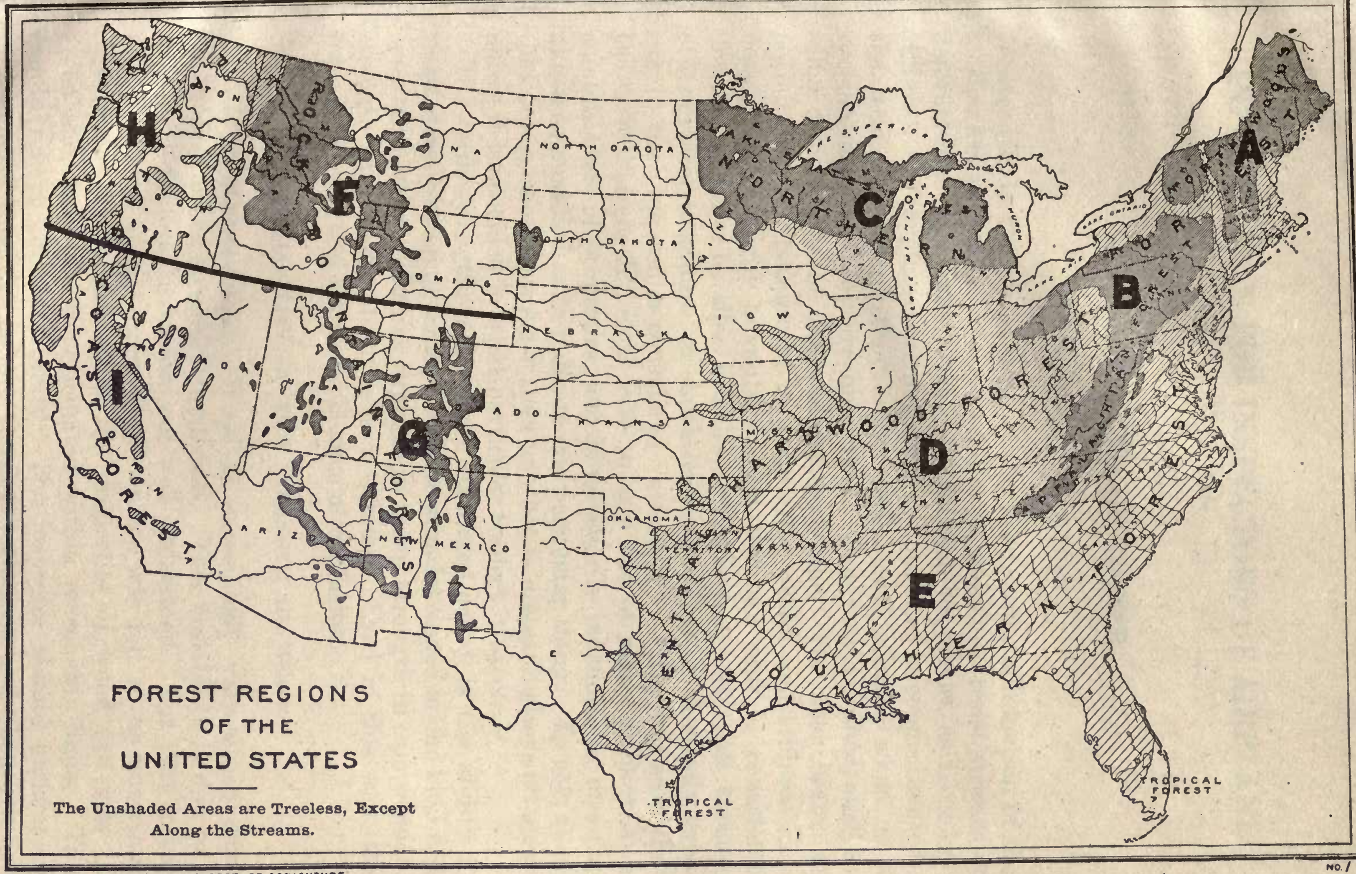

Map of the United States showing forest regions referred to in text and indicated in text and on map by letters A to I.

INFORMATION FOR INSPECTORS OF AIRPLANE WOOD.

THE STRENGTH OF TIMBER.

MEANING OF STRENGTH.

Strength, in the broad sense of the word, is the summation of the mechanical properties of a material or its ability to resist stresses or deformations of various sorts. While such properties as hardness, stiffness, and toughness are not always thought of in connection with the term "strength," they are unconsciously included when, in a specific instance, they are important. This may be illustrated by some comparisons of oak and longleaf pine. For floor beams or posts, the pine, because of its supporting power and stiffness as a beam, has a slight advantage over the oak and is considered "stronger." For handles, vehicles, or implement parts, oak, because of its greater toughness, or shock-resisting ability, is decidedly superior to the pine and is considered "stronger." Thus it is seen that the term "strength" may refer to any one of many properties or combinations of properties, and is necessarily indefinite in meaning unless so modified as to indicate one particular thing. To say, then, that one species is stronger than another is a meaningless statement unless it is specified in what particular respect it excels.

The term strength, in its more restricted sense, is the ability to resist stress of a single kind, or the stresses developed in one kind of a constructional member, as strength in shear, strength in compression, strength as a beam, strength as a column. Used in this way, the term is specific and allows no chance of confusion.

VARIABILITY OF THE STRENGTH OF WOOD.

Wood nonhomogeneous.—Wood is exceedingly variable as compared with other structural materials. This variability is due to a number of factors, heretofore not well understood. For that reason any judgment of the strength of a piece was felt to be uncertain. The causes for variations in the properties of wood can now be given and their effects anticipated within reasonable limits. This should relieve the uncertainty. The inspector should understand in a general way the factors causing variations and their relation to the strength of the wood.

Variation of strength with locality of growth.—In some cases the locality of growth has an influence on the strength of the timber. For example, tests show a marked difference in strength between the Rocky Mountain and Coast types of Douglas fir in favor of the Coast type.

This influence of locality is usually overestimated. Different stands of the same species grown in the same section of the country may show as great differences as stands grown in widely separated regions, so that as a rule locality of growth can be neglected.

Variation of strength with position in the tree.—In some instances specimens from different parts of the same tree have been found to show considerable difference in strength. In most cases, however, the wood of the highest specific gravity has the best mechanical properties regardless of its position in the tree. Where this is not the case, the toughest or most shock-resistant material is found near the butt. Above a height of 10 or 12 feet variations of mechanical strength correspond to the variations of specific gravity. Some variations with position in cross section or distance from the pith of the tree have been found which could not be entirely accounted for by differences in specific gravity.

Variation of strength with rate of growth.—Strength is not definitely proportional to rate of growth, either directly or inversely.

Timber of any species which has grown with exceptional slowness is usually below the average of the species in strength values.

Among many of the hardwood species, material of very rapid growth is usually above the average in strength properties. Notable exceptions to this are found, however, and rapid growth is no assurance of excellence of material unless accompanied by relatively high specific gravity. This is particularly true of ash.

In the coniferous species, material of very rapid growth is very likely to be quite brash and below the average strength.

Variation of strength with amount of summer wood.—In many species the proportion of summer wood is indicative of the specific gravity, and different proportions of summer wood are usually accompanied by different specific gravities and strength values. However, proportion of summer wood is not a sufficiently accurate indicator of strength to permit its use as the sole criterion for the acceptance or rejection of airplane material. After some practice the inspector should be able, through observation of the proportion of summer wood, to decide whether any particular piece is considerably below, considerably above, or near the required specific gravity. Caution must be observed in applying this to ash, and perhaps to other hardwoods, since rapid-growth ash is sometimes very low in specific gravity in spite of a large proportion of summer wood. In such cases careful examination will show that the summer wood is less dense than usual.

Variation of strength with specific gravity.—A piece of clear, sound, straight-grained wood of any species is not necessarily a good stick of timber. To determine the quality of an individual stick by means of mechanical tests is extremely difficult, because the variations in strength of timber due to variations in moisture content, temperature, speed of test, etc., are so great. Furthermore, a test for one strength property does not always indicate what the other properties of the timber are. Without actual and complete tests, the best criterion of the strength properties of any piece of timber is its specific gravity or weight per unit volume, weight being taken when the wood is completely dry and volume when the wood is at some definite condition of seasoning or moisture content. Specification No. 20505A gives the method to be followed in obtaining specific gravity based on "oven-dry volume." Specific gravity based on oven-dry volume is greater than that based on the volume at any other moisture condition in proportion to the shrinkage which takes place as the moisture is driven out and the wood is reduced to the oven-dry condition.

Accurate determinations made at the Forest Products Laboratory on seven species of wood, including both hardwoods and conifers, showed a range of only about $4\frac{1}{2}$ per cent in the density of the wood substance, or material of which the cell walls is composed. Since the density of wood substance is so nearly constant, it may be said that the specific gravity of a given piece of wood is a measure of the amount of wood substance contained in a unit volume of it. Very careful analysis based on the vast amount of data available at the Forest Products Laboratory have shown that wood of high specific gravity has greater strength than that of low specific gravity. Some fairly definite mathematical relations between specific gravity and the various strength properties have been worked out. Some of the strength properties (strength in compression parallel to grain and modulus of elasticity) vary directly as the first power of the specific gravity; others, however, vary with higher powers of the specific gravity, i. e., the strength property changes more rapidly than the specific gravity, a 10 per cent increase of specific gravity resulting in an increase in the strength properties of 15 per cent to even 30 per cent.

The rate of change in strength with changes of specific gravity is usually greater in individual specimens of a single species than in the averages for a number of species. This is illustrated by a comparison of figures 1 and 2. Figure 1 indicates that the modulus of rupture varies as the 5/4 power of the specific gravity when various species are considered, while figure 2 indicates that the relation of the same property of individual specimens of white ash is best expressed by an equation involving the 3/2 power of specific gravity.

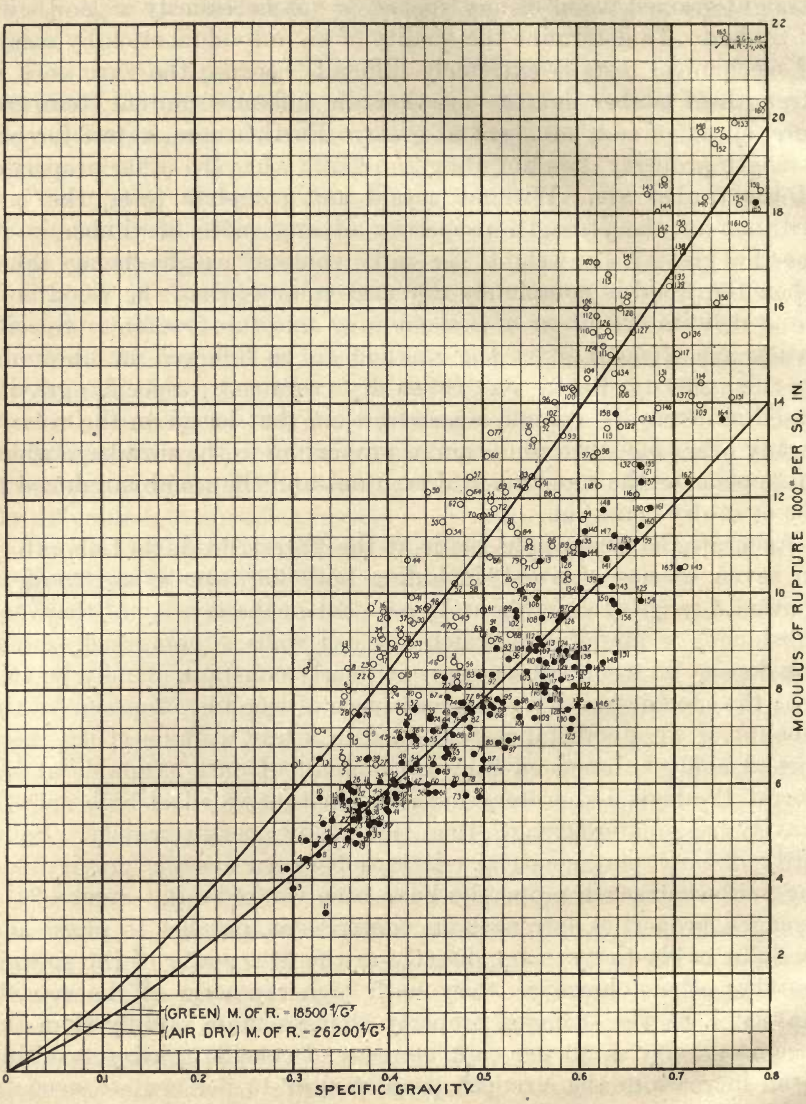

FIG. 1.—Relation between the modulus of rupture and specific gravity of various American woods.

Modulus of rupture of spruce and of numerous other species has been found to vary as the 3/2 power of the specific gravity. Shock-resisting ability and other important properties vary as even higher powers of specific gravity. If an important airplane part is from

List of species and reference numbers for Fig. 1.

HARDWOODS.

Species.	Locality.	Reference No.
Alder, red	Washington	30
Ash:		
Biltmore	Tennessee	91
Black	Michigan	60
Black	Wisconsin	70
Blue	Kentucky	99
Green	Louisiana	93
Green	Missouri	100
Pumpkin	Missouri	79
White	Arkansas	106
White	New York	128
White	West Virginia	83
Aspen	Wisconsin	23
Largetooth	Wisconsin	20
Basswood	Pennsylvania	12
Basswood	Wisconsin	5
Beech	Indiana	110
Beech	Pennsylvania	98
Birch:		
Paper	Wisconsin	73
Sweet	Pennsylvania	129
Yellow	Pennsylvania	107
Yellow	Wisconsin	103
Buckeye, yellow	Tennessee	9
Buckthorn, cascara	Oregon	84a
Butternut	Tennessee	27
Butternut	Wisconsin	21
Chinquapin, western	Oregon	46b
Cherry:		
Black	Pennsylvania	72
Wild red	Tennessee	24
Chestnut	Maryland	46
Chestnut	Tennessee	40
Cottonwood, black	Washington	6
Cucumber tree	Tennessee	59
Dogwood:		
Flowering	Tennessee	151
Western	Oregon	125a
Elder, pale	Oregon	69a
Elm:		
Cork	Wisconsin, Marathon County.	126
Cork	Wisconsin, Rusk County	
Slippery	Indiana	102
Slippery	Wisconsin	74
White	Pennsylvania	55
White	Wisconsin	53
Greenheart		165
Gum:		
Black	Tennessee	68
Blue (Eucalyptus)	California	147
Cotton	Louisiana	76
Red	Missouri	54
Hackberry	Indiana	90
Hackberry	Wisconsin	78
Haw, pear	Wisconsin	146
Hickory:		
Big shellbark	Mississippi	135
Big shellbark	Ohio	154
Bitternut	Ohio	139
Mockernut	Mississippi	144
Mockernut	Pennsylvania	159
Mockernut	West Virginia	155
Nutmeg	Mississippi	112
Pignut	Mississippi	148
Pignut	Ohio	157
Hickory—Continued.		
Pignut	Pennsylvania	160
Pignut	West Virginia	161
Shagbark	Mississippi	140
Shagbark	Ohio	152
Shagbark	Pennsylvania	143
Shagbark	West Virginia	153
Water	Mississippi	141
Holly, American	Tennessee	87
Hornbeam	Tennessee	149
Laurel, mountain	Tennessee	145
Locust:		
Black	Tennessee	158
Honey	Indiana	162
Madrona	California	101
Madrona	Oregon	128a
Magnolia	Louisiana	66
Maple:		
Oregon	Washington	58
Red	Pennsylvania	69
Red	Wisconsin	92
Silver	Wisconsin	56
Sugar	Indiana	104
Sugar	Pennsylvania	108
Sugar	Wisconsin	124
Oak:		
Bur	Wisconsin	125
California black	California	80
Canyon live	California	163
Chestnut	Tennessee	121
Cow	Louisiana	133
Laurel	Louisiana	116
Post	Arkansas	130
Post	Louisiana	137
Red	Arkansas	119
Red	Indiana	118
Red	Louisiana	117
Red	Tennessee	97
Highland Spanish	Louisiana	94
Lowland Spanish	Louisiana	142
Swamp white	Indiana	150
Tanbark	California	115
Water	Louisiana	111
White	Arkansas	132
White	Indiana	138
White	Louisiana, Richland Parish.	136
White	Louisiana, Winn Parish.	131
Willow	Louisiana	109
Yellow	Arkansas	122
Yellow	Wisconsin	105
Osage orange	Indiana	164
Poplar, yellow (tulip tree)	Tennessee	35
Rhododendron, great	Tennessee	85
Sassafras	Tenne see	51
Serviceberry	Tennessee	156
Silverbell tree	Tennessee	49
Sourwood	Tennessee	89
Sumac, staghorn	Wisconsin	61
Sycamore	Indiana	63
Sycamore	Tennessee	65
Umbrella, Fraser	Tennessee	45
Willow:		
Black	Wisconsin	11
Western black	Oregon	43a
Witch hazel	Tennessee	114

List of species and reference numbers for Fig. 1—Continued.

CONIFERS.

Species.	Locality.	Reference No.	Species.	Locality.	Reference No.
Cedar:			Pine—Continued.		
Incense	California	26	Lodgepole	Montana, Jefferson County	40a
Western red	Montana	2	Lodgepole	Wyoming	34
Western red	Washington	10	Longleaf	Florida	123
White	Wisconsin	1	Longleaf	Louisiana, Lake Charles.	113
Cypress, bald	Louisiana	62	Longleaf	Louisiana, Tangipahoa Parish.	96
Douglas fir	California	45a	Longleaf	Mississippi	95
Douglas fir	Oregon	67a	Norway	Wisconsin	57
Douglas fir	Washington, Chehalis County.	46a	Pitch	Tennessee	71
Douglas fir	Washington, Lewis County	75	Pond	Florida	86
Douglas fir	Washington, and Oregon.	67	Shortleaf	Arkansas	77
Douglas fir	Wyoming	84	Sugar	California	22
Fir:			Table Mountain	Tennessee	82
Alpine	Colorado	4	Western white	Montana	42
Amabilis	Oregon	39	Western yellow	Arizona	19
Amabilis	Washington	18	Western	California	37
Balsam	Wisconsin	14	Western	Colorado	41
Grand	Montana	36	Western	Montana	32
Noble	Oregon	16	White	Wisconsin	25
White	California	17	Redwood	California, Albion.	28
Hemlock:			Redwood	California, Korbel.	13
Black	Montana	47	Spruce:		
Eastern	Tennessee	52	Engelmann	Colorado, Grand County.	8
Eastern	Wisconsin	15	Engelmann	Colorado, San Migel County	3
Western	Washington	50	Red	New Hampshire.	44
Larch, western	Montana	84	Red	Tennessee	29
Larch, western	Washington	64	White	New Hampshire.	7
Pine:			White	Wisconsin	38
Cuban	Florida	127	Tamarack	Wisconsin	81
Jack	Wisconsin	43	Yew, western	Washington	134
Jeffrey	California	33			
Loblolly	Florida	88			
Lodgepole	Colorado	31			
Lodgepole	Montana, Gallatin County.	35a			
Lodgepole	Montana, Granite County.	41a			

wood 10 per cent below the specific gravity given in the specifications, it will not be just 10 per cent but at least 14.5 per cent inferior and perhaps more, depending on which particular property is of greatest importance in the part in question. If the specific gravity is 20 per cent low, the inferiority will not be less than 28.4 per cent. The lighter pieces of wood are usually exceedingly brash, especially when dry. The importance of admitting no material for airplane construction of lower specific gravity than given in the specifications is evident.

The minimum strength values which may be expected of a particular lot of lumber can be raised a good deal by eliminating a relatively small portion of the lighter material. This lightweight material can as a rule be detected by visual inspection. In order to train the visual inspection and to pass judgment on questionable individual pieces, frequent specific gravity determinations are necessary.

A specific gravity determination is relatively simple to make, and it is probably a better criterion of all the qualities of the piece than any single mechanical test which is likely to be applied; also, the specific gravity determinations need no adjustment such as would

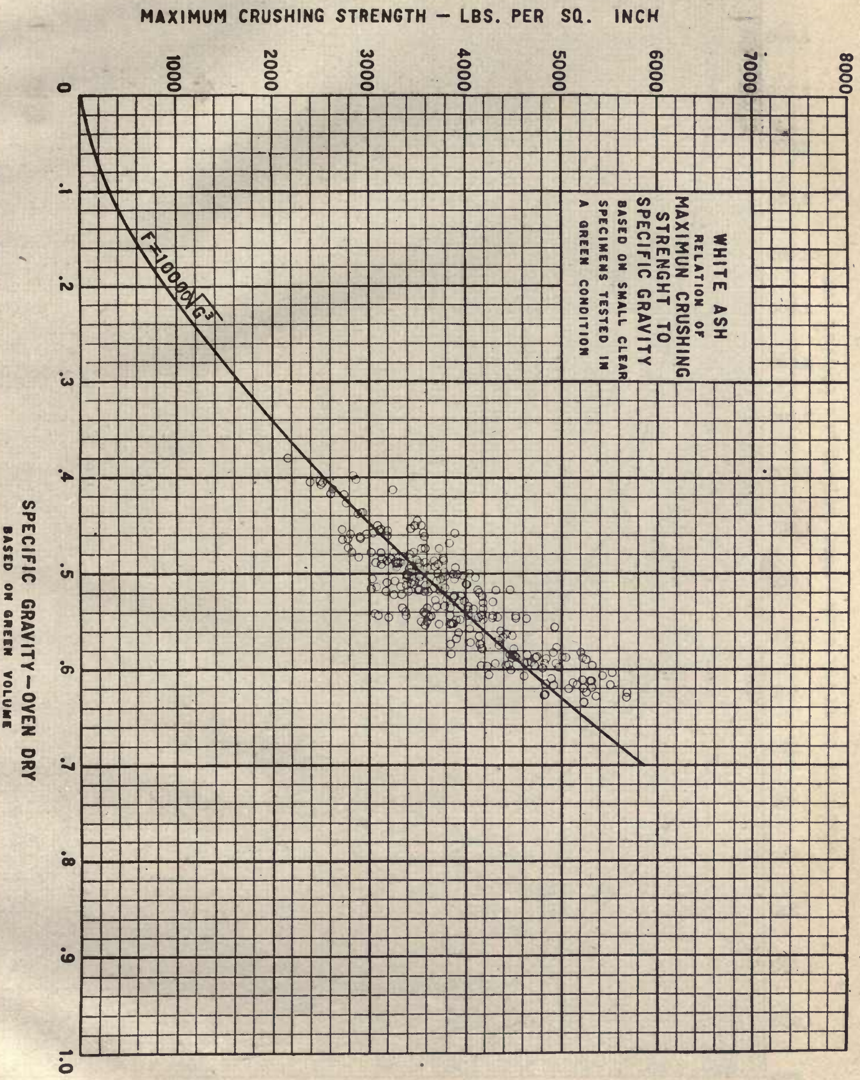

Fig. 2.

be necessary on account of the varied conditions of a mechanical test.

Variation of strength with moisture content.—When a piece of green or wet wood is dried, no change in mechanical properties takes place until the fiber-saturation point is reached. (For a definition of fiber-saturation point see p. 31.) The changes beyond this point for small test specimens free from defects and very carefully dried are illustrated in figures 3 and 4. These figures show that the moisture content at the fiber-saturation point differs for different species and

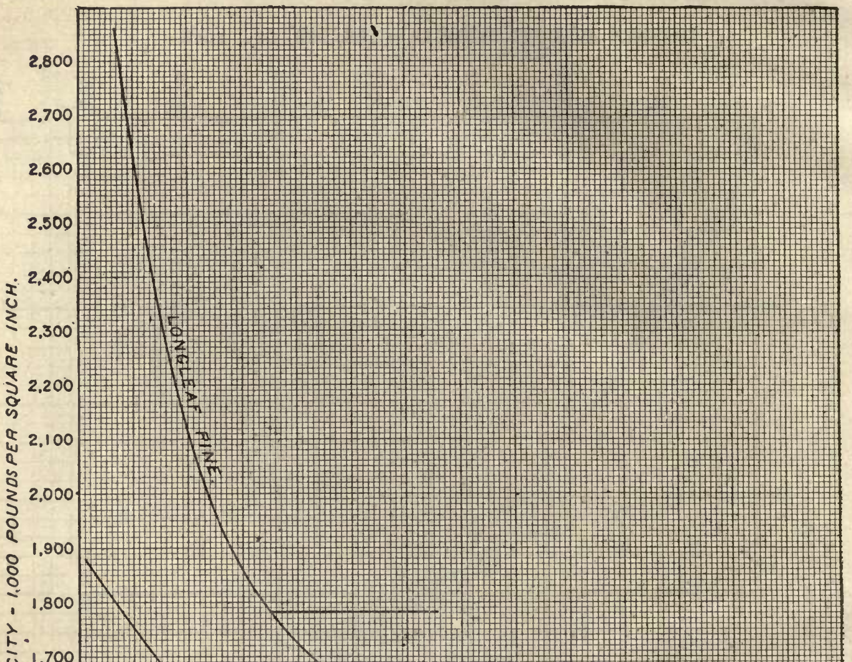

FIG. 3.—Relation between the stiffness (modulus of elasticity) in bending and moisture content, for three species.

that, apparently, the increase of strength does not in all cases begin at the fiber-saturation point. It will be noted that the influence of moisture is smaller in tests of shearing strength and compression perpendicular to the grain than in bending and compression parallel to the grain. Furthermore, there is no definite break at or near the fiber-saturation point in the moisture-strength curves for shear and

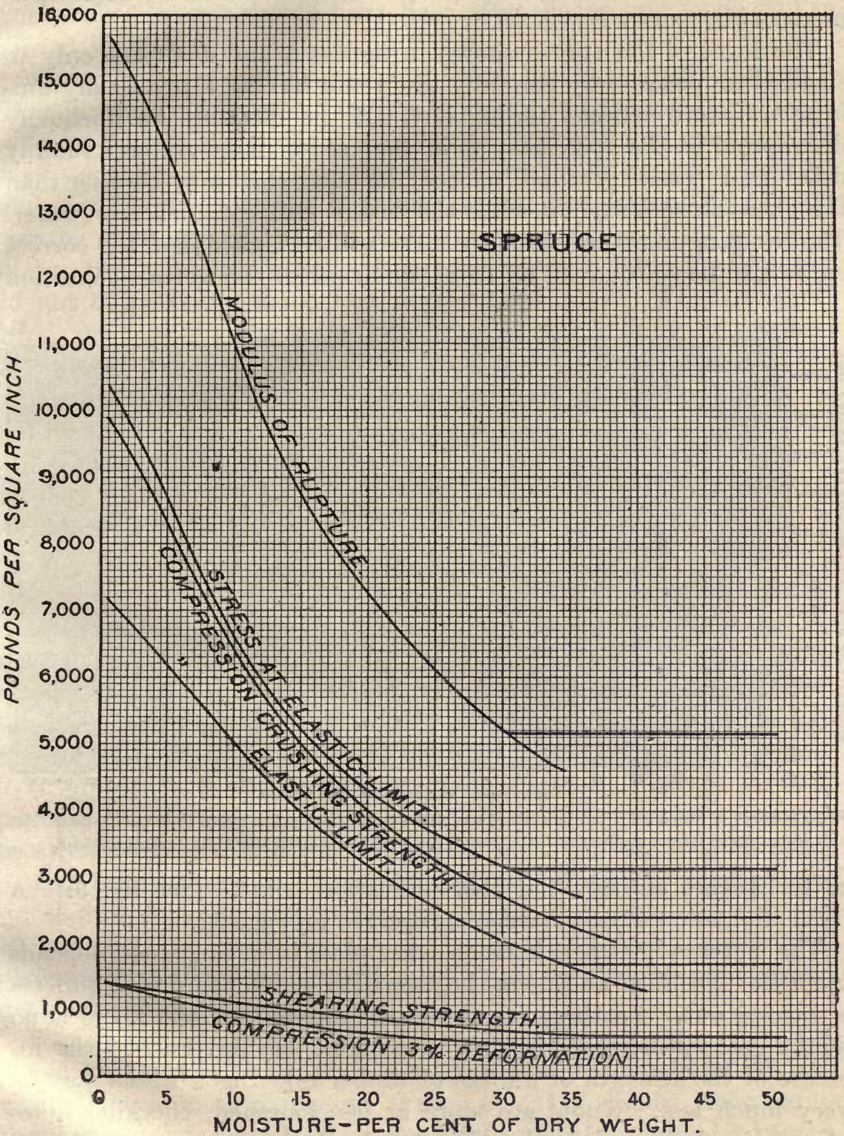

FIG. 4.—Comparison of the relations between strength and moisture content for red spruce in various kinds of tests. (The lowest curve is for compression at right angles to grain.)

compression perpendicular to the grain. In the case of shear this failure to show large increases in strength is probably due to checks which form as the material dries.

The moisture content at the fiber-saturation point varies not only with the species but with different specimens of the same species. The percentage change of strength which results from a given change of moisture also varies with the species and with individual sepcimens of the species.

The form of the curves shown in figures 3 and 4 applies only to small clear pieces very carefully dried and having a practically uniform moisture content throughout. If the moisture be unequally distributed in the specimen, as in the case of large timbers rapidly dried or of "case-hardened" pieces, the outer shell may be drier than the fiber-saturation point while the inside still contains free water. The resulting moisture-strength curve will be higher than the correct curve and be so rounded off from the driest to the wettest condition

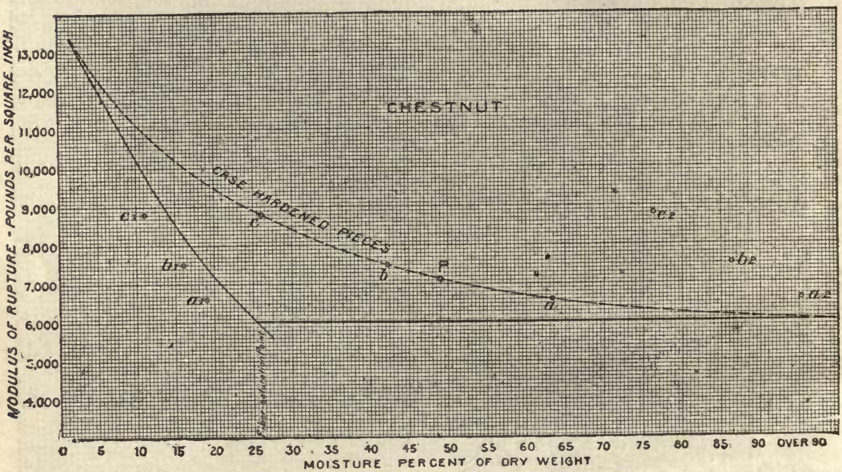

FIG. 5.—Effect of case-hardening upon the form of the moisture-strength curve in bending tests. The upper curve is from casehardened specimens, the lower curve from uniformly dried specimens.

as to obscure entirely the fiber-saturation point. (See fig. 5.) A fuller discussion of case hardening is given on page 32.

The increase in strength which takes place in drying wood depends upon the specimen and upon the care with which the drying process is carried out. Furthermore, while the strength of the fibers is no doubt greatly increased by any reasonable drying process, the increase of the strength of a piece of timber taken as a whole may be very much less. Knots are more or less loosened, checking takes place, and shakes are further developed. In large bridge and building timbers these effects are so great that it is not considered safe to figure on such timbers having greater strength when dry than when green. When the pieces are small and practically free from defects, as in airplane construction, proper drying with careful control of temperature and humidity increases the strength of material very greatly. In whatever way wood is dried, upon its being resoaked and brought back to the original green or wet condition it is found to be weaker than it was originally. So when it is said that wood has been injured in the drying process, it must be taken to mean that it is weaker than it should have been after drying and while still in a dried condition.

When a stick of timber dries out below the fiber-saturation point (that is, when it has lost all its free moisture and the moisture begins to leave the cell walls) the timber begins to shrink and change in its mechanical properties. Also numerous stresses are set up within the timber. Under severe or improper drying conditions the stresses may be great enough to practically ruin the material for purposes where strength is important. Improper drying conditions, however, do not of necessity mean fast drying conditions. When properly dried, the timber gains in its fiber stress at elastic limit, its modulus of rupture, maximum crushing strength, etc. It bends farther at the elastic limit when dry than when green, but does not bend so far at the maximum load. After having been sent to the maximum load dry timber breaks more suddenly than green timber of the same species; that is, dry timber is more brash than green, although it withstands greater stresses and is stiffer.

DEFECTS AFFECTING STRENGTH.

Diagonal and spiral-grain.—Diagonal grain is produced when the saw cut is not made parallel to the direction of the fibers. It can usually be avoided by careful sawing unless it is caused by crooks in the log. Spiral-grain, on the other hand, results from a spiral arrangement of the wood fibers in the tree. If a log is spiral-grained it is impossible to secure straight-grained material, except in small pieces, from the spiral-grained part. The center part of a log may be straight-grained and the outer part spiral-grained or vice versa.

Such tests as have been made on material affected by diagonal and spiral-grain indicate that weakening begins at a slope of about 1 in 20 and increases quite rapidly as the slope becomes steeper. Experience in testing such material also shows that spiral-grain is more dangerous than diagonal grain.

When a beam in a horizontal position, as shown in figure 6, is subjected to a vertical load, grain running across the vertical faces at a given slope is more dangerous than grain at the same slope across the horizontal faces. It is preferable to give the annual layers or rings of growth the direction relative to load shown in figure 6 in material affected by spiral-grain, in order to minimize the weakening effect of the spiral grain.

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When the annual rings run diagonally across the end of a piece the true slope of diagonal grain can be obtained as shown by figure 7a. The direction of spiral-grain is not given correctly by resin ducts or by spreading of ink unless these tests be applied to a truly tangential (flat sawn) face. In figure 7, for instance, resin ducts or spreading

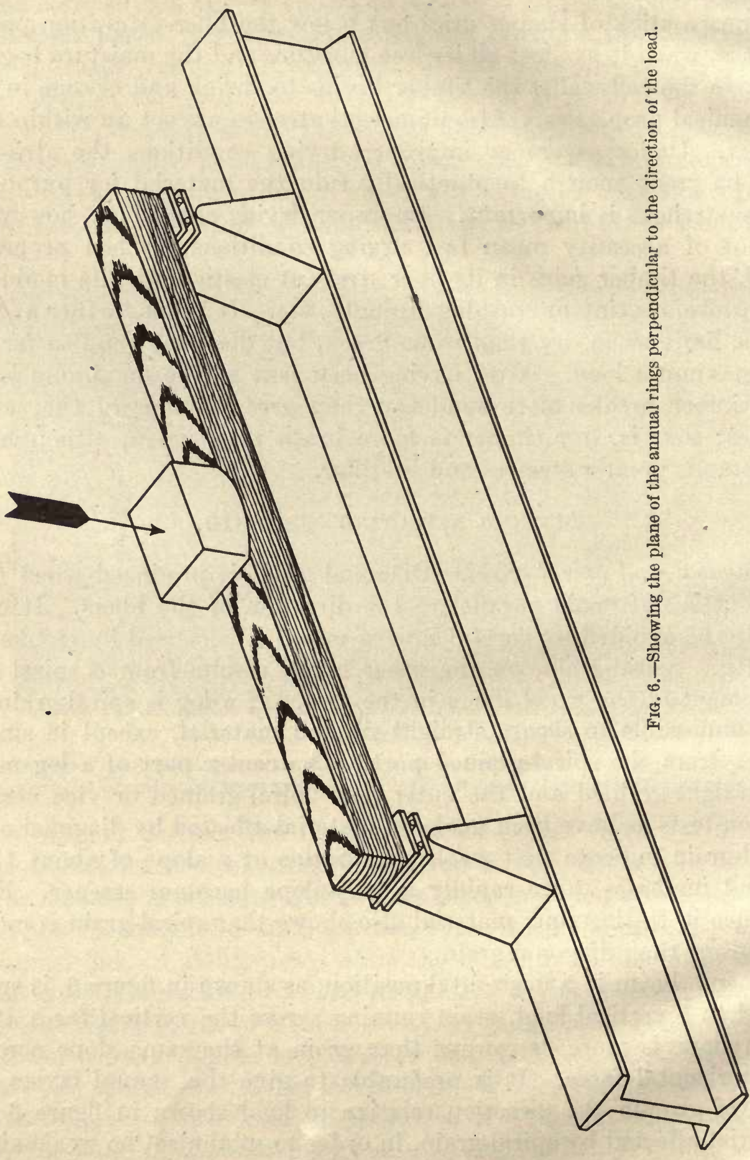

FIG. 6.—Showing the plane of the annual rings perpendicular to the direction of the load.

of ink would be practically parallel to the edges whether the material was spiral-grained or not. In such cases spiral-grain can be detected only by splitting on a radial line (fig. 7b), or by raising small splinters and observing if they have a tendency to tear deeper and deeper.

Knots.—The effect of knots depends upon their location with respect to the stresses to which the piece will be subjected, as well as upon their size and character. None but sound knots, firmly attached, should be permitted. Obviously, knots of any considerable size can not be allowed in any airplane parts because the parts themselves are comparatively small in cross-section. Since the weakening effect of knots results from their disturbance of the normal arrangement of fibers, their seriousness can best be decided from a considera-

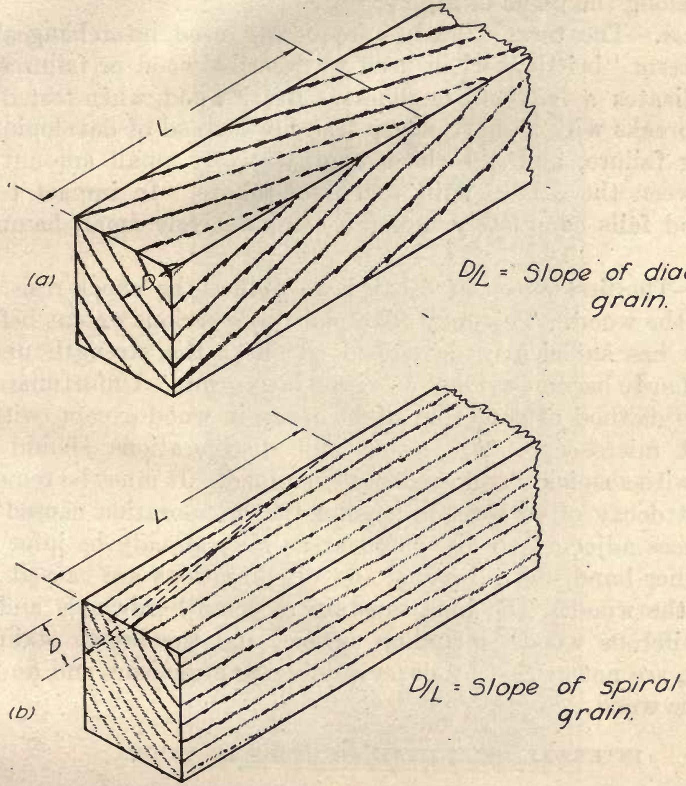

FIG. 7.—The measurement of the slope of diagonal and spiral grain.

tion of the grain. For description of defects in grain consult Inspection Manual, section QT–10a.

Compression failures.—All material containing compression failures should be carefully eliminated where shock-resisting ability is of importance. Such failures, fortunately, are not of very common occurrence. They may be due to injury by storm in the standing tree, to carelessness in felling trees across logs, or to unloading from a car upon a single skid, or they may result from injury during manufacture. Failures in hickory spokes attributed to brittleness have been found in some cases to have been due to compression failures which occurred during driving. Brittleness sometimes reported in mahogany veneer may be due to injury of the material while it is being brought to the mill.

While some compression failures are so pronounced as to be unmistakable, others are difficult to detect. They appear as wrinkles across the face of the piece. (See Fig. 8.) Compression failures, not readily apparent to the eye, may seriously reduce the bending strength of wood and its shock-resisting ability, complete failure occurring suddenly along the plane of injury.

Brashness.—The term "brash," frequently used interchangeably with the term "brittle," when used to describe wood or failures in wood, indicates a lack of toughness. Brash wood, when tested in bending, breaks with a short, sharp fracture instead of developing a splintering failure, and absorbs a comparatively small amount of work between the elastic limit and final failure. In impact tests brash wood fails completely under a comparatively small hammer drop.

Decay.—The first effect of decay is to reduce the shock-resisting ability of the wood. This may take place to a serious extent before the decay has sufficiently developed to affect the strength under static load or to become evident on visual inspection. Unfortunately, there is no method of detecting slight decay in wood except with a compound microscope. All stains and discolorations should be regarded with suspicion and carefully examined. It must be remembered that decay often spreads beyond the discoloration caused by t and pieces adjacent to discolored areas may already be infected. On the other hand, not all stains and discolorations are caused by decay of the wood. The blue sapstain of some hardwoods and of many coniferous woods, including spruce, and the brown stain of sugar pine are not caused by decay-producing organisms and do not weaken the wood.

INTERNAL OR INITIAL STRESSES IN WOOD.

Wood fibers under stress in the tree.—Wood products are quite similar to metal castings as regards internal stresses. It is probable that wood fibers are continually under stress of some kind. The fact that freshly cut logs of some species split through the center (this frequently happens as the result of heavy shocks or jars and without the use of a wedge) is evidence of some tensile stresses in the outer portion of the tree and compression in the inner portion.. These stresses are independent of the stresses due to the weight of the tree and pressure against it.

Internal stresses produced during drying.—The natural stresses may be partially or wholly relieved by sawing the tree into lumber, but

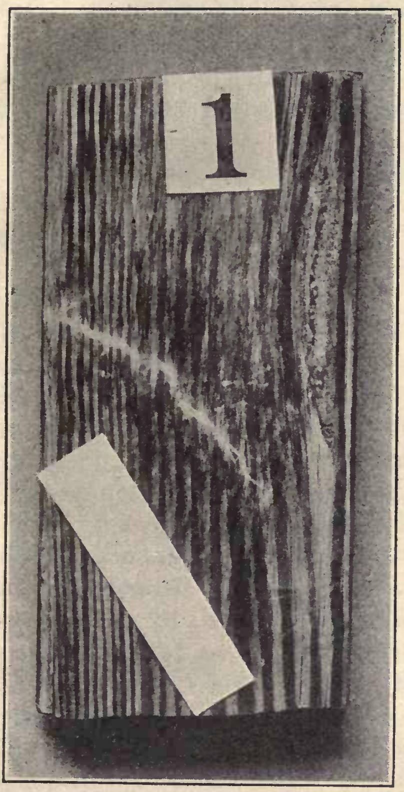

FIG. 8.—Compression failure in a piece of yellow pine flooring.

other stresses are likely to be introduced by subsequent seasoning. Checking, honeycombing, warping, twisting, etc., are manifestations of the internal stresses which are produced in the drying of wood or whenever any change of moisture content takes place. Presumably such stresses are due to unequal distribution of moisture and consequent unequal shrinkage combined with more or less inherent lack of homogeneity.

Air drying for a number of years, which is practiced in some woodworking industries, has for its object the equalization of moistures and the relief of the stresses induced in the early part of the drying. Careful and correct kiln drying followed by a period of seasoning under proper and controlled atmospheric conditions should produce results at least equal and probably superior to those obtained by long periods of air drying.

Relieving these internal stresses is important because they amount to an actual weakening of the material. If the fibers of a piece of wood are under stress when the piece is free, they are just that much less capable of resisting stresses of the same kind produced by exterior forces or loads applied to the piece.

Initial stresses produced in assembling.—When a member of any structure is stressed in assembling the structure and before any load is placed on it, it is said to be under initial stress. If the initial stress is of the same character as the stress for which the member is designed, it constitutes a weakening; for when the structure is loaded, the safe working stress of the member will be reached just that much sooner. If this initial stress is opposite in character to that for which the member is designed, it amounts to a strengthening of the member; for when the structure is loaded the initial stress must be overcome before the member takes any of the stress for which it is designed.

Many of the curved parts of an airplane frame could be simply sprung to place on assembly. Were this done, they would be subjected to initial stress and usually of the same sign to which the member would later be subjected. In order to avoid initial stress, such parts are steam bent before assembly. It is desirable, of course, that this bending be so done as not to injure the material and to leave little tendency to spring back from the curves to which it is bent. In order that the material may be made sufficiently plastic to accomplish this result it is essential that the steaming and bending be carried out while the wood is at a relatively high moisture content. If it is attempted on kiln-dry or thoroughly air-dry material, there is the tendency to spring back after the clamps are removed. Bending of such stock cannot be compared to a considerable part of the bending done in other woodworking industries, where the strength of the wood is very greatly damaged by the bending process but without destroying its usefulness for the purpose for which it is intended. Some of the unexpected failures of bent parts in airplanes have doubtless been due to the initial stresses set up in the member during the bending.

RECOMMENDED METHODS FOR DETERMINING WORKING STRESSES FOR TIMBER USED IN AIRPLANE CONSTRUCTION.

Table 1 gives strength values at 15 per cent moisture (which is probably close to the maximum moisture content of wood in a humid atmosphere) for use in airplane design, as well as the minimum specific gravity and average density which should be admitted. It is suggested that the working stresses for design be obtained by applying factors to the values for static load conditions as given in this table.

The factors to be applied, and consequently the exact stress to be used in design, of course, will depend largely on the conditions to which it is assumed the machine will be subjected in flight. If they are the most severe which the machine is ever expected to sustain while in flight, the working stresses can be relatively high. If, on the other hand, the assumed conditions are only moderately severe, the stresses must be made lower in order to take care of exceptional conditions which may occur. It must also be remembered that working stresses cannot be safely based on average strength figures, but must be lowered to a value which will be safe for the weakest piece likely to be accepted.

Nature of loading.—The time of duration of a stress on a timber is a very great factor in the size of the stress which will cause failure. A continuously applied load, greater in amount than the fiber stress at elastic limit as obtained by the ordinary static bending test, will ultimately cause failure.

The fiber stress at elastic limit in static bending for the dry material is usually somewhat more than nine-sixteenths of the modulus of rupture, and in compression parallel to the grain the elastic limit is usually more than two-thirds of the maximum crushing strength. Timber loaded slightly below the elastic limit will gradually give to loads and ultimately assume greater deflections than those computed by using the ordinary modulus of elasticity figures. In impact tests where a weight is dropped on the stick and the stress lasts for only a small fraction of a second, the stick is found to bend practically twice as far to the elastic limit as in static tests where the elastic limit is reached in about two minutes. The elastic stress developed in the stick under the blow is greater than the maximum stress obtained in the static test.

TABLE 1.—Properties of various woods—strength values at 15 per cent moisture, for use in airplane design.

Common and botanical names.	Specific gravity based on volume and weight when oven-dry.		Average weight at 15 per cent moisture, pounds per cubic foot.	Shrinkage from green to oven-dry condition.		Static bending.				Compression parallel to grain. Maximum crushing strength (pounds per square inch).	Compression perpendicular to grain. Fiber stress at elastic limit (pounds per square inch).	Shearing strength parallel to grain (pounds per square inch).	Side hardness. Load required to imbed 0.444-inch ball to one-half its diameter.
	Average.	Mini- mum per- mitted.		Radial.	Tangential.	Fiber stress at elastic limit (pounds per square inch).	Modulus of rupture (pounds per square inch).	Modulus of elasticity (1,000 pounds per square inch).	Work to maximum load (inch-pounds per cubic inch).				
HARDWOODS.				Per cent.	Per cent.								Pounds.
Ash, commercial white (Fraxinus americana, fraxinus lanceolata, fraxinus quadrangulata)	0.62	0.56	40	4.5	7.1	7,700	12,700	1,500	14.2	6,000	1,300	1,750	1,150
Ash, black (Fraxinus nigra)	.53	.48	35	5.0	7.8	5,800	10,500	1,400	14.1	4,900	800	1,350	740
Basswood (Tilia americana)	.40	.36	25	6.6	9.3	4,700	7.200	1,300	6.4	3,800	400	880	340
Beech (Fagus atropunicea)	.66	.60	41	4.8	10.6	7,400	12,600	1,500	13.3	5,900	1,100	1,700	1,060
Birch (Betula lutea, lenta)	.67	.61	43	7.0	8.5	8,400	13,500	1,800	17.6	6,600	1,000	1,620	1,070
Cherry, black (prunus scrotina)	.53	.48	35	3.7	7.1	7,300	10,600	1,400	12.0	5,800	700	1,500	830
Cottonwood (Populus deltoides)	.43	.39	28	3.9	9.2	4,500	7,000	1,200	7.3	3,800	400	800	380
Elm, rock (Ulmus racemosa)	.66	.60	44	4.8	8.1	6,700	12,500	1,400	19.3	5,800	1,200	1,650	1,200
Gum, red (Liquidambar styraciflua)	.53	.48	34	5.2	9.9	6,700	10,400	1,400	11.0	4,900	700	1,500	650
Hickory (true hickories) (Hicoria glabra, laciniosa, alba, ovata)	.81	.73	50	7.3	11.4	8,900	16,300	1,900	28.0	7,300	1,800	1,800	....
Mahagany (true) (Swietenia mahagoni)	.54	.50	36	3.5	4.2	7,000	10,000	1,300	9.1	5,500	1,000	1,420	860
Mahogany African (Khaya senegalensis)	.50	.46	34	4.8	5.5	7,100	10,400	1,400	10.3	5,100	900	1,270	730
Maple, hard (Acer saccharum)	.66	.60	42	4.8	9.2	8,100	12,900	1,600	12.9	6,500	1,200	1,990	1,200
Oak, commercial white (Quercus alba, macrocarpa, minor, michauxii)	.72	.65	46	5.3	9.2	6,700	12,000	1,400	12.7	5.900	1,300	1,760	1,270
Poplar, yellow (Liriodendron tulipifera)	.42	.38	28	4.1	6.9	4,800	7,500	1,300	6.2	4,100	400	900	370
Walnut, black (Juglans nigra)	.56	.52	38	5.2	7.1	7,900	11,900	1,500	13.1	6,100	1,000	1,300	950
CONIFERS.													
Cedar:													
Incense (Libocedrus decurrens)	.36	.32	26	3.3	3.7	4,900	7,100	1,000	6.0	4,300	600	850	430
Port Orford (Chamaecyparis lawsoniana)	.47	.42	31	5.2	8.1	6,200	10,300	1,700	9.7	5,300	700	1,160	580
Western red (Thuja plicata)	.34	.31	23	2.5	5.1	4,200	6,400	1,000	5.5	4,000	400	790	300
White (northern) (Thuja occidentalis)	.32	.29	22	2.1	4.9	4,200	5,800	750	5.1	3,400	350	800	300
Douglas fir (Pseudotsuga taxifolia)	.52	.47	34	5.0	7.9	6,800	9,700	1,780	7.2	6,000	750	1,020	580
Pine:													
Sugar (Pinus lambertiana)	.39	.36	27	2.9	5.6	5,300	7,400	1,100	5.0	4,300	540	950	410
Western white (Pinus monticola)	.45	.40	29	4.1	7.4	5,100	7,800	1,400	6.9	4,800	480	670	360
White (Pinus strobus)	.39	.36	27	2.2	5.9	5,100	7,400	1,200	6.1	4,500	530	850	380
Norway (Pinus resinosa)	.51	.46	33	4.6	7.2	7,900	10,900	1,700	6.1	6,100	720	1,150	540
Spruce, red, white, Sitka (Picea rubens, canadensis, sitchensis)	.41	.36	27	3.9	7.5	5,100	7,900	1,300	7.4	4,300	500	920	430
Cypress, bald (Taxodium distichum)	.47	.42	31	3.8	6.0	6,100	8,800	1,300	6.8	5,400	670	940	460

PUBLICATIONS ON THE MECHANICAL PROPERTIES OF WOOD.

1. Government publications:

Mechanical Properties of Wood Grown in the United States. Department of Agriculture Bulletin 556. 1917. 10 cents.

Strength of Wood as Influenced by Moisture. Forest Service Circular 108. 1907. 5 cents.

Timber: An Elementary Discussion of the Characteristics and Properties of Wood. Forest Service Bulletin 10. 1895. 10 cents.

The Commercial Hickories. Forest Service Bulletin 80. 1910. 15 cents.

Tests of Structural Timbers. Forest Service Bulletin 108. 1912. 20 cents.

Properties and Uses of Douglas Fir. Forest Service Bulletin 88. 1911. 15 cents.

NOTE.—The above publications may be obtained at the prices indicated from the Superintendent of Documents, Government Printing Office, Washington, D. C.

2. Papers prepared by the Forest Products Laboratory and published in various journals.

Variation in Weight and Strength of Timber. J. A. Newlin, in American Lumberman, January 22, 1916.

Effects of Different Methods of Drying on Strength of Wood. H. D. Tiemann, in Lumber World Review, April 24, 1915.

A Few Deductions from Strength Tests of American Woods. J. A. Newlin, in American Lumberman, January 16, 1915.

Factors Affecting Structural Timbers. H. S. Betts, in Engineering Record, August 29, 1914.

SHRINKAGE.

AMOUNT OF SHRINKAGE.

Ordinarily, when a piece of green lumber is dried no change in dimensions takes place until the fiber saturation point is reached. The wood then begins to shrink in cross-sectional area until no further moisture can be extracted from the cell walls. It also shrinks longitudinally, but in most cases the amount of longitudinal shrinkage is so small as to be negligible.

The shrinkage in cross-sectional area in drying from the green to the oven-dried condition, varies with different woods, ranging from as much as 22 per cent (based on the original area before drying begins) to as little as 6 per eent. When dry wood absorbs moisture it continues to swell until the fiber saturation point is reached. Figures 9, 10, and 11 illustrate the progress of shrinkage and swelling between zero moisture content and the fiber saturation point.

The shrinkage of wood, like its strength, is very closely related to its specific gravity. This is illustrated by figure 12. On this curve "Per cent shrinkage in volume" is the total shrinkage from fiber saturation to dryness. It will be noted that shrinkage, in general, increases with specific gravity. This relation in individual specimens of a single species (white ash) is shown in figure 13.

Radial shrinkage, or the shrinkage in width of quarter sawn boards, averages about three-fifths as great as tangential shrinkage, or the shrinkage in width of flat sawn boards.

SHRINKAGE OF PROPELLER STOCK.

Shrinkage and the various phenomena associated with it are of immense importance in connection with propeller manufacture. The following precautions in manufacturing propellers will assist in reducing to a minimum trouble from failure of glued joints, splitting of laminations, change of pitch, and imperfect alignment.

1. All material should be quarter-sawed if possible.
2. Quarter- and flat-sawed laminæ should not be used in the same propeller.

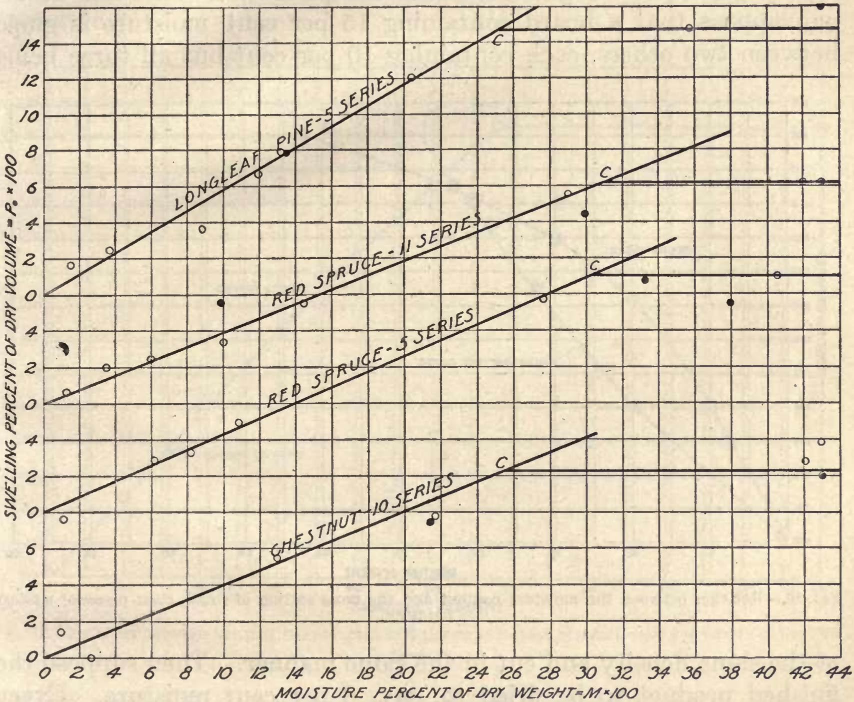

FIG. 9.—Relation between swelling and moisture. Each point is the average of from five to eleven specimens. Black dots indicate specimens that were kiln-dried and then allowed to reabsorb moisture. The fiber-saturation point is at c.

3. All laminæ should be brought to the same moisture content before gluing up.
4. All laminæ in the same propeller should have approximately the same specific gravity.
5. All laminæ in the same propeller should be of the same species.

Dry wood when exposed to very humid air absorbs moisture and swells. Wood dried in a normally dry atmosphere till its moisture content becomes practically constant, loses moisture and shrinks when exposed to extremely dry conditions. Two pieces of wood when exposed continuously to the same environment will eventually come to practically the same moisture content, irrespective of their relative moisture contents when first exposed to this environment.

Individual pieces of wood, even those of the same species, vary greatly in their rate of drying. Quarter-sawed pieces have a different drying rate from plain-sawed pieces. Dense pieces dry more slowly than those which are less dense.

Suppose that a flat-sawed board is glued between two quarter-sawed boards, all three having the same moisture content, say, 15 per cent, when glued up; or, suppose that under similar conditions a very dense piece is glued between two pieces which are less dense; or, suppose that a board containing 15 per cent moisture is glued between two others, each containing 10 per cent but all three being

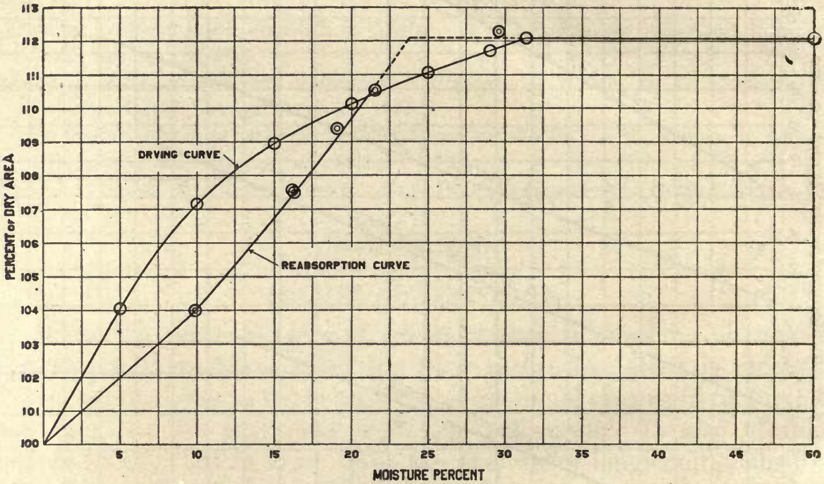

FIG. 10.—Relation between the moisture content and the cross section of small, clear pieces of western hemlock.

of the same density and cut in the same manner. Then suppose the finished product to be dried to, say, 8 per cent moisture. Every piece will shrink, but in each instance the center piece will tend to shrink more than the outside ones. The glued joint will be under a shearing stress, since the center piece has a tendency to move with respect to those on the outside. Under this condition the glued joint may give way entirely, it may partially hold, or it may hold perfectly. In either of the latter cases the center piece will be under stress in tension across the grain, and consequently, will have a tendency to split. This tendency may become localized and result in visible splitting, or it may remain distributed and cause a lessening of the cohesion between the wood fibers, but without visible effect.

If a combination of these three cases occurs, it may be much more serious in its effect than any one alone. For instance, suppose that in a propeller alternate laminations are of flat-sawed, dense boards, glued at a relatively high moisture content, while the others are quarter-sawed, less dense, and at a much lower moisture content when glued; the tendency of the flat-sawed laminations to shrink will be very much greater than that of the others, with the result that internal stresses of considerable magnitude will be set up.

It is not difficult to see how these internal stresses may combine with the stresses from external causes and with the continual vibration to produce failure under external loads which are considerably smaller than the propeller would safely resist if manufactured with proper care.

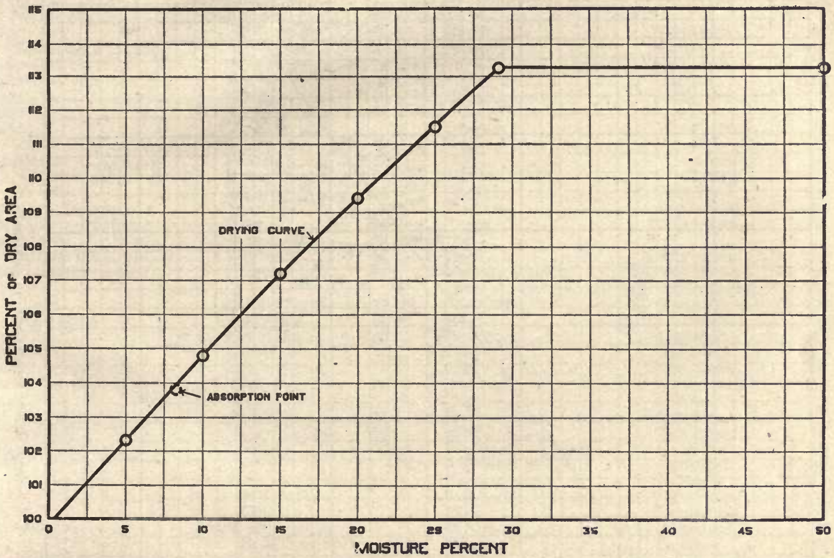

FIG. 11.—Relation between the moisture content and the cross section of small, clear specimens of western larch.

STORAGE OF STOCK BEFORE KILN-DRYING.

It may be necessary to have timber or lumber in storage several weeks or months before it is kiln-dried. Such stock is usually either green or only partly air seasoned and is subject to various forms of deterioration, such as staining, decay, severe checking, and especially in hardwood, insect attack. During warm humid weather staining may take place in a few days and decay may weaken the wood in a few months.

Proper piling of such stock will tend to reduce the deterioration to a minimum. All lumber or timber which is to be stored any length of time should be piled on solid foundations, with stickers between each two courses, and should have some protection from the sun and rain. Whenever possible, the stock should be piled in a shed with open sides. If this is not practicable, each pile should be covered so as

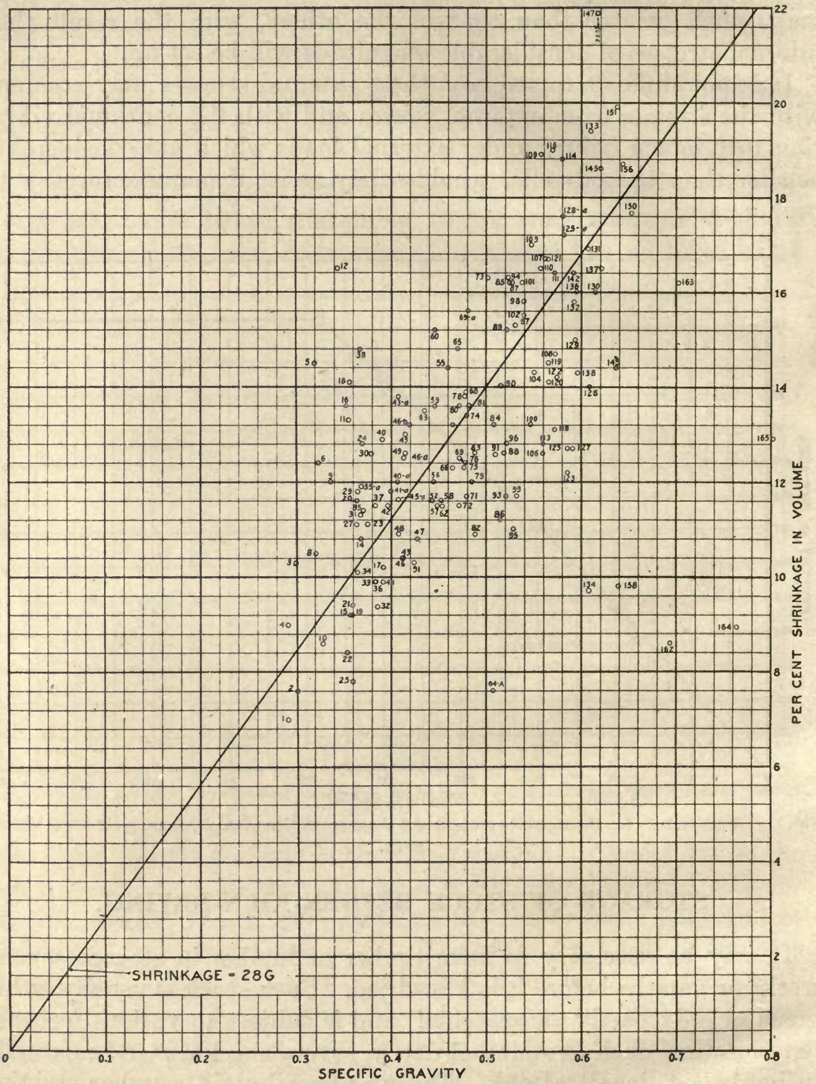

FIG. 12.—Relation between shrinkage in volume and specific gravity of various American woods.

to keep out rain and snow. Green hardwoods, especially oak, frequently check severely at the ends. This can be avoided to a large extent by coating the ends with linseed-oil paint.

List of species and reference numbers for Fig. 13.

HARDWOODS.

Species.	Locality.	Reference No.
Alder, red	Washington	30
Ash:		
Biltmore	Tennessee	91
Black	Michigan	60
Black	Wisconsin	70
Blue	Kentucky	99
Green	Louisiana	93
Green	Missouri	100
Pumpkin	Missouri	79
White	Arkansas	106
White	New York	128
White	West Virginia	83
Aspen	Wisconsin	23
Largetooth	Wisconsin	20
Basswood	Pennsylvania	12
Basswood	Wisconsin	5
Beech	Indiana	110
Beech	Pennsylvania	98
Birch:		
Paper	Wisconsin	73
Sweet	Pennsylvania	129
Yellow	Pennsylvania	107
Yellow	Wisconsin	103
Buckeye, yellow	Tennessee	9
Buckthorn, cascara	Oregon	84a
Butternut	Tennessee	27
Butternut	Wisconsin	21
Chinquapin, western	Oregon	46b
Cherry:		
Black	Pennsylvania	72
Wild red	Tennessee	24
Chestnut	Maryland	46
Chestnut	Tennessee	40
Cottonwood, black	Washington	6
Cucumber tree	Tennessee	59
Dogwood:		
Flowering	Tennessee	151
Western	Oregon	125a
Elder, pale	Oregon	69a
Elm:		
Cork	Wisconsin, Marathon County.	126
Cork	Wisconsin, Rusk County.	
Slippery	Indiana	102
Slippery	Wisconsin	74
White	Pennsylvania	55
White	Wisconsin	53
Greenheart		165
Gum:		
Black	Tennessee	68
Blue (Eucalyptus)	California	147
Cotton	Louisiana	76
Red	Missouri	54
Hackberry	Indiana	90
Hackberry	Wisconsin	78
Haw, pear	Wisconsin	146
Hickory:		
Big shellbark	Mississippi	135
Big shellbark	Ohio	154
Bitternut	Ohio	139
Mockernut	Mississippi	144
Mockernut	Pennsylvania	159
Mockernut	West Virginia	155
Nutmeg	Mississippi	112
Pignut	Mississippi	148
Pignut	Ohio	157
Hickory—Continued		
Pignut	Pennsylvania	160
Pignut	West Virginia	161
Shagbark	Mississippi	140
Shagbark	Ohio	152
Shagbark	Pennsylvania	143
Shagbark	West Virginia	153
Water	Mississippi	141
Holly, American	Tennessee	87
Hornbeam	Tennessee	149
Laurel, mountain	Tennessee	145
Locust:		
Black	Tennessee	158
Honey	Indiana	162
Madrona	California	101
Madrona	Oregon	128a
Magnolia	Louisiana	66
Maple:		
Oregon	Washington	58
Red	Pennsylvania	69
Red	Wisconsin	92
Silver	Wisconsin	56
Sugar	Indiana	104
Sugar	Pennsylvania	108
Sugar	Wisconsin	124
Oak:		
Bur	Wisconsin	125
California black	California	80
Canyon live	California	163
Chestnut	Tennessee	121
Cow	Louisiana	133
Laurel	Louisiana	116
Post	Arkansas	130
Post	Louisiana	137
Red	Arkansas	119
Red	Indiana	118
Red	Louisiana	117
Red	Tennessee	97
Highland Spanish	Louisiana	94
Lowland Spanish	Louisiana	142
Swamp white	Indiana	150
Tanbark	California	115
Water	Louisiana	111
White	Arkansas	132
White	Indiana	138
White	Louisiana, Richland Parish.	136
White	Louisiana, Winn Parish.	131
Willow	Louisiana	109
Yellow	Arkansas	122
Yellow	Wisconsin	105
Osage orange	Indiana	164
Poplar, yellow (tulip tree)	Tennessee	35
Rhododendron, great	Tennessee	85
Sassafras	Tennessee	51
Serviceberry	Tennessee	156
Silverbell tree	Tennessee	49
Sourwood	Tennessee	89
Sumac, staghorn	Wisconsin	61
Sycamore	Indiana	63
Sycamore	Tennessee	65
Umbrella, Fraser	Tennessee	45
Willow:		
Black	Wisconsin	11
Western black	Oregon	43a
Witch hazel	Tennessee	114

List of species and reference numbers for Fig. 13—Continued.

CONIFERS.

Species.	Locality.	Reference No.
Cedar:		
Incense	California	26
Western red	Montana	2
Western red	Washington	10
White	Wisconsin	1
Cypress, bald	Louisiana	62
Douglas fir	California	45a
Douglas fir	Oregon	67a
Douglas fir	Washington, Chehalis County.	46a
Douglas fir	Washington, Lewis County.	75
Douglas fir	Washington, and Oregon.	67
Douglas fir	Wyoming	48
Fir:		
Alpine	Colorado	4
Amabilis	Oregon	39
Amabilis	Washington	18
Balsam	Wisconsin	14
Grand	Montana	36
Noble	Oregon	16
White	California	17
Hemlock:		
Black	Montana	47
Eastern	Tennessee	52
Eastern	Wisconsin	15
Western	Washington	50
Larch, western	Montana	84
Larch, western	Washington	64
Pine:		
Cuban	Florida	127
Jack	Wisconsin	43
Jeffrey	California	33
Loblolly	Florida	88
Lodgepole	Colorado	31
Lodgepole	Montana, Gallatin County.	35a
Lodgepole	Montana, Granite County.	41a
Pine—Continued.		
Lodgepole	Montana, Jefferson County.	40a
Lodgepole	Wyoming	34
Longleaf	Florida	123
Longleaf	Louisiana, Lake Charles.	113
Longleaf	Louisiana, Tangipahoa Parish.	96
Longleaf	Mississippi	95
Norway	Wisconsin	57
Pitch	Tennessee	71
Pond	Florida	86
Shortleaf	Arkansas	77
Sugar	California	22
Table Mountain	Tennessee	82
Western white	Montana	42
Western yellow	Arizona	19
Western	California	37
Western	Colorado	41
Western	Montana	32
White	Wisconsin	25
Redwood	California, Albion.	28
Redwood	California, Korbel.	13
Spruce:		
Engelmann	Colorado, Grand County.	8
Engelmann	Colorado, San Miguel County.	3
Red	New Hampshire.	44
Red	Tennessee	29
White	New Hampshire.	7
White	Wisconsin	38
Tamarack	Wisconsin	81
Yew, western	Washington	134

Stock should be cut up into as small sizes as is practicable before kiln drying. Large pieces usually check severely because the outer portion dries and shrinks considerably faster than the inner core, which always dries slowly. Timbers which contain the pith and which are to be cut into smaller sizes later should at least be cut through the pith once, or better, be quartered before being stored away. This will avoid the large checks which are commonly produced in the seasoning of timbers containing the pith by reason of the tangential shrinkage being greater than the radial shrinkage.

RULES FOR PILING LUMBER AND TIMBERS.

1. The foundations should be strong, solid, and durable, preferably concrete piers with inverted rails or I beams for skids; if this is impracticable, creosoted or naturally durable wooden timbers should be used.

2. Each foundation should be level.

3. The foundations should not be over 4 feet apart for lumber, but may be farther apart for larger timbers. For woods which warp easily or for stock less than 1 inch in thickness foundations should not be over 3 feet apart.

4. If the piles are in the open, they should have a slope from front to rear of 1 inch for every foot in length.

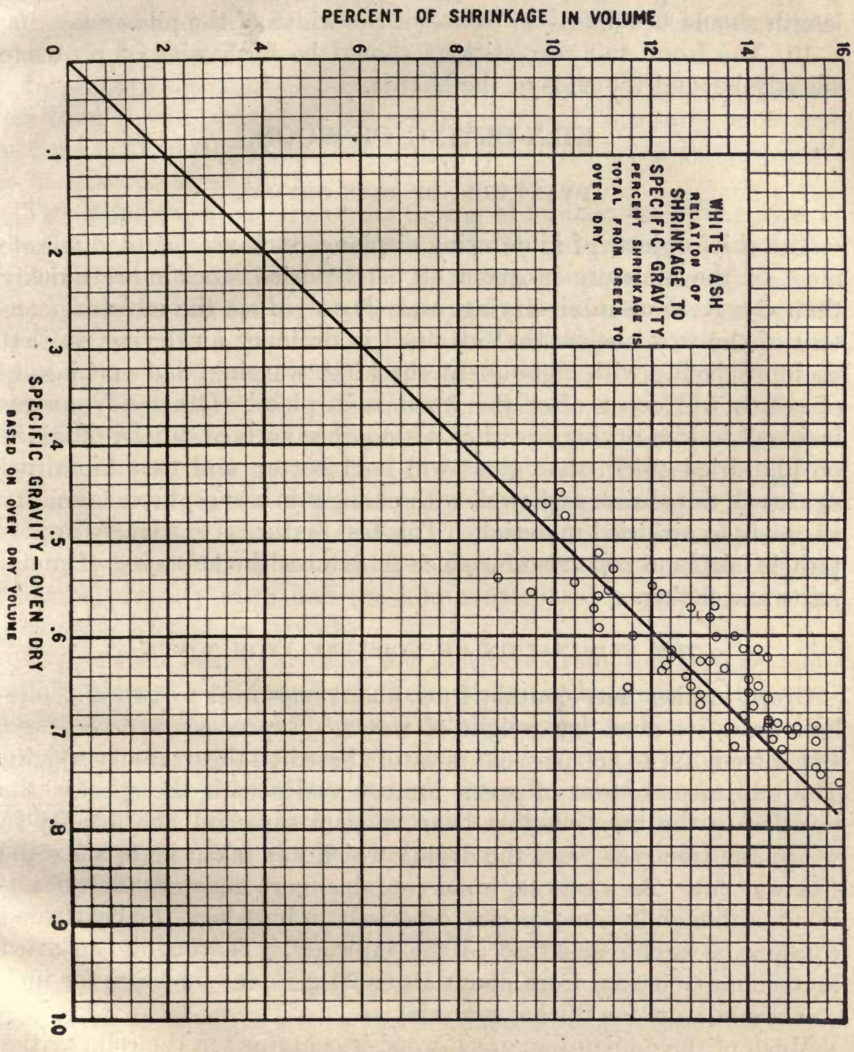

Fig. 13.

5. The foundations should be sufficiently high to allow the free circulation of air underneath the piles; and weeds or other obstructions to circulation should be removed.

6. Boards of equal length should be piled together with no free unsupported ends.

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7. A space of about three-fourths of an inch should be left between boards of each layer, and from 1 to 2 inches between timbers of each layer.

8. The stickers should be of uniform thickness, preferably seven-eighths of an inch for 1-inch lumber and 1½ inches for thicker stock.

9. Stickers should be placed immediately over the foundation beams and kept in vertical alignment throughout the piles. Their length should be slightly in excess of the width of the pile.

10. The front and rear stickers should be flush with or protrude slightly beyond the ends of the boards.

KILN-DRYING OF WOOD.

ADVANTAGES OF KILN-DRYING.

The chief objects of kiln-drying airplane stock are (*a*) to eliminate most of the moisture in green or partly dried stock more quickly than can be done in air-drying, and (*b*) to reduce the moisture content of the wood below that attained in ordinary air-drying, so that no more drying with consequent checking, warping, and opening up of seams will occur after the wood is in place. Other advantages incident to kiln-drying are that a smoother surface can be obtained on kiln-dried stock, that glues will hold better, and that kiln-dried stock will not shrink and swell with changes in atmospheric humidity as much as air-dried material. This last feature is extremely important in airplane construction since it reduces the loosening of metal parts and fittings.

THE ELIMINATION OF MOISTURE FROM WOOD.

Green lumber may contain from about one-third to two and one-half times its oven-dry weight of water. Expressed in percentage, this is from 33⅓ to 250 per cent moisture based on the oven-dry weight. The moisture content of green lumber varies with the species, the position in the tree, whether heartwood or sapwood, the locality in which the tree grew, and the drying which has taken place since the tree was cut. As a rule sapwood contains more moisture than heartwood, although in some species, especially in butt-logs, the heartwood contains as much moisture as the sapwood. Thoroughly air-dried lumber may contain from about 10 to 20 per cent moisture for inch stock, and more for thicker material.

Much of the moisture in green wood is contained in the cell cavities (like honey in a comb), and the rest is absorbed by the cell walls. When wood is drying the moisture first leaves the cell cavities and travels along the cell walls to the surface, where it is evaporated.

When the cell cavities are empty but the cell walls are still saturated a critical point is reached known as the fiber saturation point. Wood does not shrink or increase in strength while seasoning until it has dried below the fiber saturation point, which usually ranges between 25 and 30 per cent moisture but may be less or more, and in spruce usually is between 30 and 35 per cent. This has an important bearing on the drying operation, since no case-hardening, checking, or warping can occur so long as the moisture content is above the fiber saturation point in all parts of the stick.

In practice the stock should be dried to a moisture content slightly less than it will ultimately have when in use. This may be as low as 6 per cent to 10 per cent for interior work and not so low for wood to be exposed to weather.

Two steps are necessary in the drying of lumber—(*a*) the evaporation of moisture from the surface and (*b*) the passage of moisture from the interior to the surface. Heat hastens both these processes. For quick drying, as high a temperature should be maintained in the kiln as the wood will endure without injury. Some woods (especially coniferous woods) will endure higher temperatures than others. The General Specifications for Kiln-Drying Airplane Stock (No. 20500–A) give the temperatures at which a kiln should be operated to prevent injury to lumber to be used for airplanes.

The lumber in a kiln is heated and evaporation is caused by means of hot air passing through the piles. To insure proper drying throughout the piles a thorough circulation of air is necessary. The lumber must be properly piled and the kiln constructed so as to make the necessary circulation possible.

Dry hot air will evaporate the moisture from the surface more rapidly than it can pass from the interior to the surface, thus producing uneven drying with consequent damaging results. To prevent excessive evaporation and at the same time keep the lumber heated through, the air circulating through the piles must not be too dry; that is, it must have a certain humidity. Specification No. 20500–A gives the proper humidities at which to operate the kiln for drying airplane stock.

THREE ESSENTIAL QUALITIES OF THE DRY-KILN.

The merits of any method of drying airplane woods depend upon the extent to which it affects the mechanical properties of the stock and upon the uniformity of the drying. In order that complete retention of properties and uniform drying may be guaranteed, it is essential that the circulation, temperature, and humidity of the air be adequately controlled. In this connection circulation does not mean the passage of air through flues, ducts, or chimneys, but through the piles of lumber, and the terms temperature and humidity control apply to the air within the piles of lumber in the kiln.

Control of air circulation involves rate or speed, and uniformity. A uniform passage of air through all portions of the piles of lumber is the most essential quality in a kiln. If the circulation can be made both uniform and rapid, all portions of the pile will dry quickly and at the same rate. Furthermore, uniform and rapid circulation of air are necessary before the control of temperature and humidity within the piles of lumber is possible.

When unsaturated air at any given temperature enters a pile of lumber containing moisture, it exchanges heat for moisture, is cooled, and rapidly approaches saturation. With green wood and a sluggish circulation, the cooling is very rapid. The rate of cooling decreases as the lumber dries; and if the circulation is increased, the loss of heat in passing through the pile is less. So if the air moves rapidly through certain parts of the piles and slowly through others, the different parts of the piles will be at different temperatures. The temperature of the air within the lumber can not be maintained at any given value unless the circulation of air is uniform at all points in the pile. Even though the air moves at uniform speed from one side of a pile of lumber to the other, if the speed is too slow the air loses its heat and approaches saturation rapidly. In general, a wide variation in the temperature of the lumber in different parts of the kiln is proof of very uneven or slow circulation. Inadequate circulation and temperature control render the control of humidity and uniform drying impossible.

Humidity is of prime importance because the rate of drying and the prevention of checking and case-hardening are directly dependent thereon. It is generally true that the surface of the wood should not dry more rapidly than the moisture transfuses from the center to the surface. The rate of evaporation must be controlled and this can be done by means of the relative humidity. Stopping the circulation to obtain a high humidity or increasing the circulation by opening ventilators to reduce the humidity is not good practice. Humidity should be raised, if necessary, to check evaporation, without reducing the circulation.

DEFECTS DUE TO IMPROPER DRYING.

Case-hardening and honeycombing.—When the surface of a piece of lumber is dried more rapidly than the moisture can pass to it from the interior, unequal moisture conditions exist in the lumber. The moisture in the outer layers falls below the fiber saturation point. The outer layers, then tend to shrink but are held from shrinking by the more moist interior, which has not yet started to

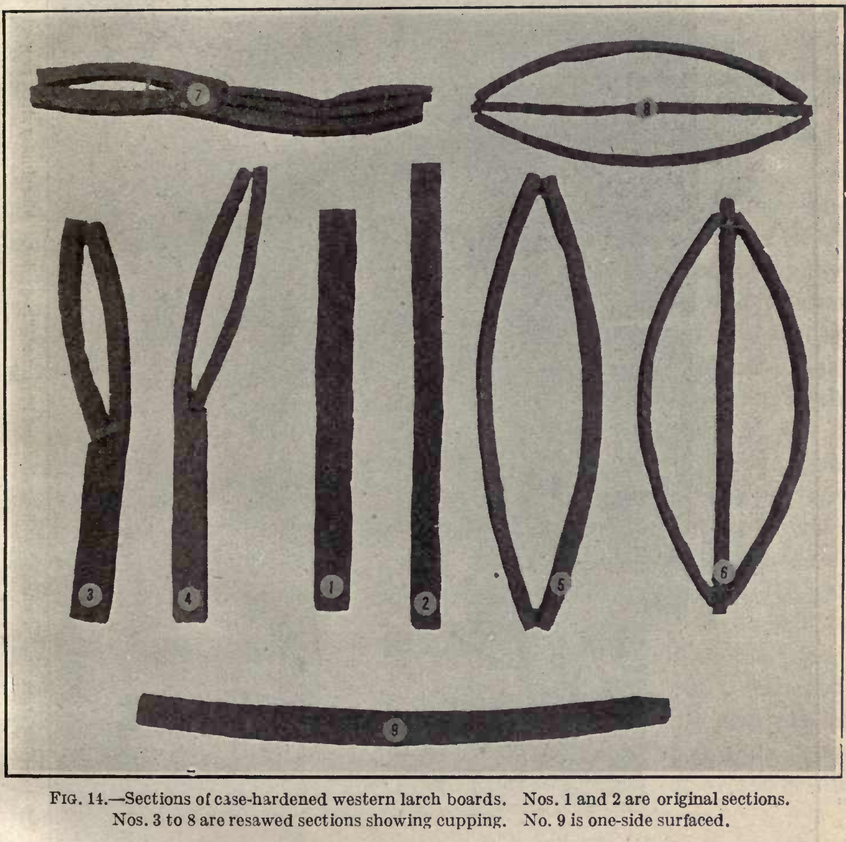

FIG. 14.—Sections of case-hardened western larch boards. Nos. 1 and 2 are original sections. Nos. 3 to 8 are resawed sections showing cupping. No. 9 is one-side surfaced.

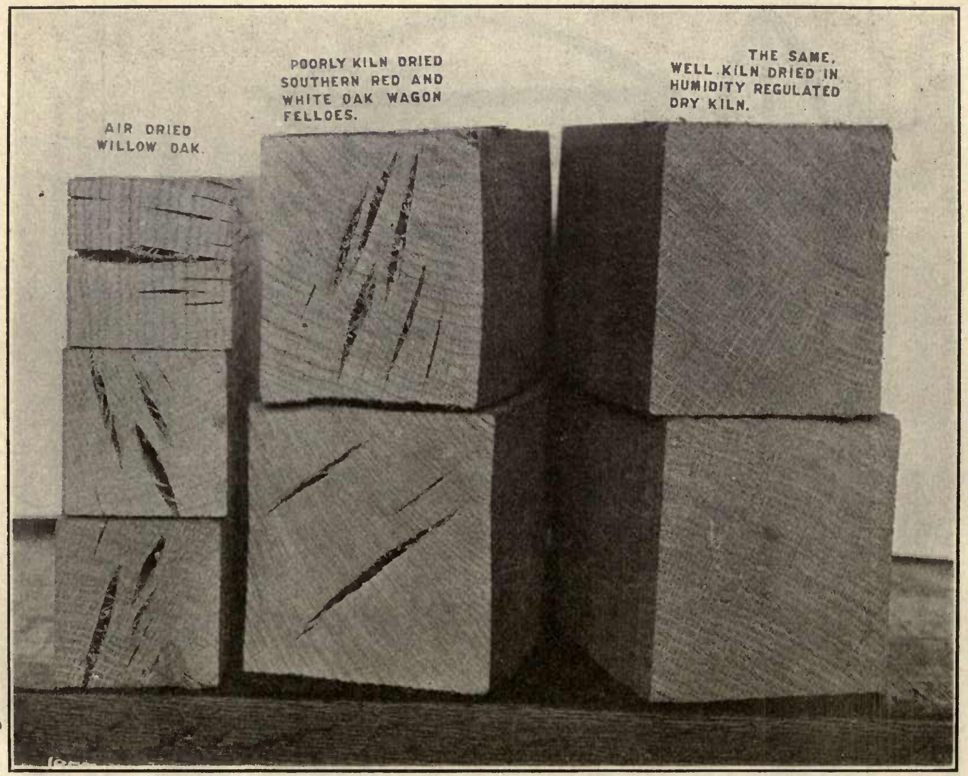

FIG. 15.—Oak stock honeycombed by air-drying and improper kiln-drying. Also similar stock properly dried.

shrink; so the surface either checks or dries in a stretched condition, usually both. Later, as the interior dries it also tends to shrink normally, but in turn is held by the outside, which has become "set" or "case-hardened." Consequently, the interior dries under tension, which draws the outer layers together closing up all checks and producing compression. Case-hardened lumber, when resawed, will invariably cup toward the inside if the interior of the lumber is dry. (Fig. 14.) If the tension in the interior of the wood is severe enough, it may produce radial checks which do not extend to the surface. Wood with such checks is said to be honeycombed or hollow-horned. (Fig. 15.) Case-hardening and honeycombing can practically be prevented by regulating the humidity so that the evaporation from the surface does not take place too rapidly.

If wood becomes case-hardened in kiln drying it may be brought back to normal condition by steaming, provided that checks and cracks have not developed. Steaming softens the outer fibers and relieves the stresses caused by the contraction of the outer shell. Care must be taken not to steam wood which has checked or honeycombed from case-hardeneing enough to part the fibers and weaken the piece. Steaming will close up the cracks but will not restore the strength of the piece. It will be much harder to detect cracks and checks due to case-hardening if they have been closed up again by steaming.

Collapse.—Collapse is abnormal shrinkage causing grooves to appear in the surface of the lumber or a general distortion of the surface. (Fig. 16.) It is produced when wet lumber is dried at too high a temperature. The heat and moisture cause the cell walls to become soft and plastic. As the water leaves the cell cavities the moist cell walls are drawn together if no air is present. This causes the cells to flatten, and a general reduction in the cross section takes place. Collapse occurs especially in such woods as western red cedar, redwood, white oak, and others which readily become soft and plastic when hot and moist. It can be avoided by not allowing the temperature to rise too high while the wood is still moist (at or above the fiber saturation point).

Brashness.—High temperature treatments of all kinds, whether steam or hot air, are injurious to lumber, causing it to turn darker and become brash. The injuries thus sustained increase with the temperature and length of time the wood is exposed to such severe conditions. No definite rule can be laid down as to what conditions of temperature wood will endure without becoming brash. If the temperature prescribed in Specification No. 20500–A is not exceeded, no difficulty will be experienced in this respect.

TESTING OF KILNS FOR DRYING AIRPLANE STOCK.

Kinds of tests.—Some kilns are better adapted than others to drying airplane stock. In many cases present trouble can be remedied when once understood by the operator. As assurance that the stock will be acceptable, however, careful check must be kept at all times on every kiln used for drying airplane woods. The following tests will aid the inspector in keeping check on any kiln:

I. Preliminary tests:
- *a.* Initial moisture conditions in the lumber.
- *b.* Preparation and placing of samples.
- *c.* Initial weights and placing of whole pieces.
- *d.* Determination of direction, uniformity, and rate of air circulation.
- *e.* Location and calibration of instruments.

II. Current tests:
- *a.* Determination of current temperatures.
- *b.* Determination of current humidities.
- *c.* Determination of circulation.
- *d.* Weighing of samples and determination of current moisture conditions.

III. Final tests:
- *a.* Average kiln-dry moisture condition of samples.
- *b.* Distribution of moisture in the kiln-dry samples.
- *c.* Determination of case-hardening in kiln-dry samples.
- *d.* Average kiln-dry moisture condition of whole pieces.
- *e.* Calculation of initial moisture condition of whole pieces.
- *f.* Distribution of moisture in kiln-dry whole pieces.
- *g.* Distribution of case-hardening in kiln-dry whole pieces.
- *h.* Determining the effects of the process on the toughness and strength of the kiln-dry stock.

Instruments.—In making these tests the following instruments and material are recommended:

1 sensitive equal arm balance (capacity 0.1 to 250 grams).
1 drying oven in which the air can be heated to and held at 212° F.
1 can of asphalt paint and a brush.
1 sensitive platform scale (capacity 0.01 to 250 pounds).
1 electric flash light (lantern type recommended).
12 packages of punk sticks.
3 accurate standardized ordianry glass thermometers (60° to 230° F. by 2° intervals).
2 accurate standardized glass wet and dry bulb hygrometers with extra wicks (60° to 230° F. by 2° intervals).
Access to a laboratory equipped with machines for making impact, static bending, hardness, compression parallel to the grain, and other tests.
Waxed or oiled paper.

METHODS.

I. Preliminary tests.—(*a*) Initial moisture condition: Select at least three representative pieces for each 5,000 board feet of stock to be dried. Cut about 2 feet from one end of each. Then cut a 1-inch section, a 24-inch sample, and a second 1-inch section in succession. Immediately weigh the two 1-inch sections to an accuracy

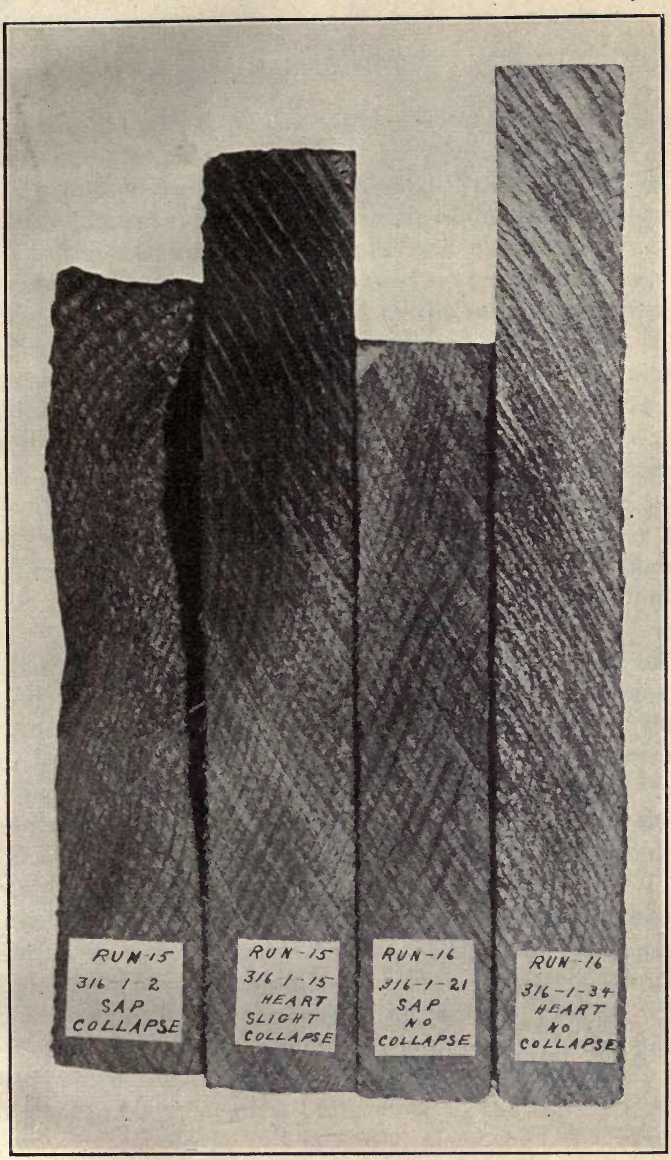

FIG. 16.—End view of 1-inch boards of western red cedar dried with and without collapse.

of one-tenth of 1 per cent. Mark the initial weights on the sections, and dry them to constant weight in the oven heated to 212° F. Reweigh them to the same accuracy and determine the per cent initial moisture content of the samples from the formula:

$$\text{Per cent initial moisture content} = \frac{\text{initial weight} - \text{oven dry weight}}{\text{oven dry weight}} \times 100$$

(*b*) Preparation and placing of samples: Immediately after cutting the 24-inch samples described under (*a*) paint the ends of the samples with a heavy coat of asphalt paint. Then weigh them separately on the platform scale to an accuracy of one-tenth of 1 per cent. Mark the initial weights on the samples and place them in the piles so as to come under the most severe, least severe, and average drying conditions, and so as to be subjected to the same drying conditions as the adjacent pieces. Where the circulation of air is vertical, place samples near the tops, centers, and bottoms of the piles; and where the circulation is lateral place them near the sides where the air enters and leaves the piles and near the centers of the piles.

(*c*) Initial weights and placing of whole pieces: In addition to test (*a*), it is desirable to select several representative whole pieces of stock and weigh them to an accuracy of one-tenth of 1 per cent on the platform scale. Mark the weights on the pieces and place them at various points near the tops, edges, bottoms, and centers of the piles.

(*d*) Determination of the direction, uniformity, and rate of air circulation: In order to insure correct placing of samples, whole pieces, and instruments it is necessary that the direction of the circulating air be known. To determine this light a few punk sticks, take the flash light, enter the kiln, close the door, and determine the direction, uniformity, and rate of motion of the circulating air in the spaces around the piles and through the piles by observing the smoke from the burning punk.

(*e*) Location and calibration of instruments: Having determined the direction in which the air passes through the piles, place tbe bulb of the recording thermometer in contact with a standardized glass thermometer close to the pile at the center of the side where the air enters the pile. If the circulation is up through the pile, place the thermometer bulbs close under the bottom center; if it is down through the lumber, place the bulbs close to the top center; and if the air moves through the pile laterally, place the bulbs close to the center of the side where the air enters the pile. It is also desirable to know the variation of temperature in different parts of the piles and kiln. To determine this variation, place several of the standardized thermometers in the tops, bottoms, edges, and centers of the piles and at different points in the kiln. In order to calibrate a recording thermometer, place the bulb in contact with a standardized glass thermometer in the kiln and adjust the stylus until it agrees with the glass thermometer. The temperature must not be fluctuating as is often the case where it is controlled by a thermostat. It is best to use a steady steam pressure in the heating pipes while calibrating instruments. Never attempt to calibrate a recording thermometer out of its place in the kiln.

To determine humidity, place the standardized glass wet and dry bulb hygrometer near the bulb of the recording thermometer, so as to indicate the humidity of the air entering the piles at the tops, bottoms, or edges as the case may be.

II. Current tests.—(*a*) Determination of current temperatures: If any part of a pile is exposed to direct radiation from the heating pipes, place a thermometer near the side so exposed. This will indicate whether or not any part is subject to higher temperature than that indicated by the recording instrument. If possible, allow no direct radiation on the lumber. The temperature of the air entering the piles must be known at all times, preferably by means of recording thermometers with extension bulbs which have been calibrated in place as directed under I (*e*).

The temperatures in the tops, bottoms, edges, and centers of the piles and at different points in the kiln should be determined occasionally by using standardized thermometers located as directed under I (*e*).

(*b*) Determination of current humidities: Never attempt to determine the relative humidity of the air where the bulbs of the hygrometer are exposed to direct radiation. Where direct radiation may take place, it is necessary to shield the hygrometer from the heating pipes before readings are taken. The relative humidity of the air entering the piles must be indicated at all times by means of standardized glass wet and dry bulb hygrometers placed as directed under I (*e*). Before reading the hygrometer, fan the bulbs briskly for about a minute, so that they are at the temperature of the air in the kiln. An air circulation of at least 15 feet per second past the wet bulb is necessary for an accurate humidity reading. The wick should be of thin silk or linen and it must be free from oil or dirt at all times. It should come into close contact with as much of the bulb as possible. Knowing the correct wet and dry bulb hygrometer readings, the relative humity may be determined from the humidity diagram in figure 17.

Relative humidity is shown on the horizontal scale and Fahrenheit temperature on the vertical scale. The curves running from the top left to the bottom right part of the chart are for various differences in the wet and dry bulb readings. The curves are numbered near the center of the chart above the heading "$(t—t_1)$ degrees Fahrenheit."

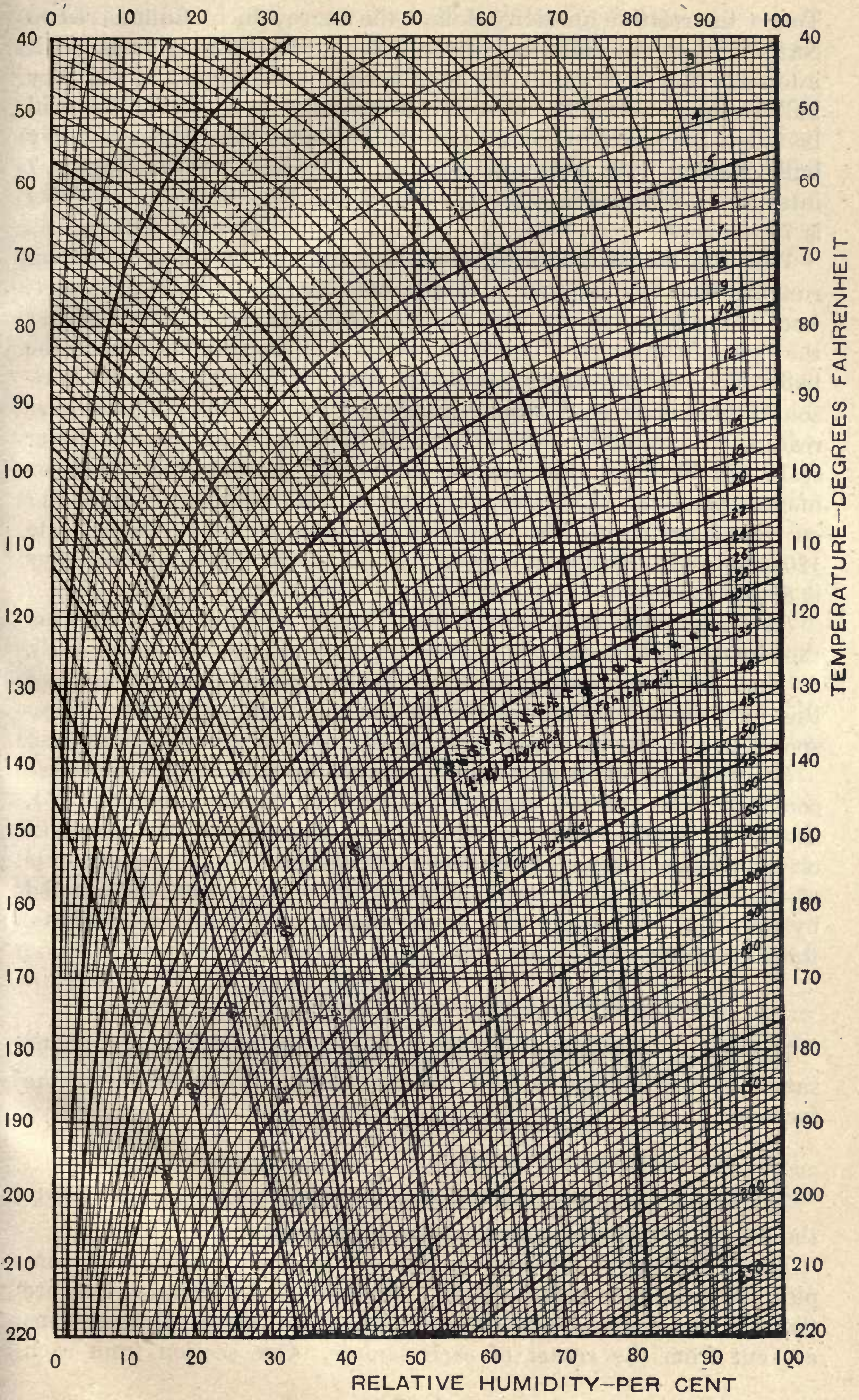
TEMPERATURE—DEGREES FAHRENHEIT
RELATIVE HUMIDITY—PER CENT

FIG. 17.

To get the relative humidity, follow the curve which is numbered to correspond to the difference of the wet and dry bulb readings till it intersects the horizontal line numbered to correspond to the dry bulb reading. Directly below this intersection in a vertical line will be found the relative humidity on the bottom scale. Example: Dry bulb reading 120; wet bulb reading 113; difference 7. Curve 7 intersects horizontal line 120 at vertical line 79. Relative humidity is 79 per cent.

When the humidity is desired in a Tiemann kiln use the set of curves running from the top right to the bottom left part of the chart. Locate the lower of the two thermometer readings on the scale at the right of the chart. This is the reading of the thermometer in the baffle box. Follow along parallel to the nearest curve till the horizontal line is crossed whose number is the higher thermometer reading. Vertically below this point of intersection on the lower scale will be found the relative humidity. Example: Baffle thermometer reading, 112°; flue thermometer reading 120°. Start at 112 on right-hand scale, follow parallel to curve 28 till horizontal line 120 is crossed. This point falls on vertical line 80. Relative humidity is 80 per cent.

(*c*) Determination of circulation: During each drying operation the circulation of the air should be tested several times as under I (*d*). As the lumber becomes drier, it has less cooling effect on the air, and this may change the circulation in the kiln. If this occurs, corresponding changes in the location of instruments should be made.

(*d*) Weighing of samples and determination of current moisture condition: The 24-inch samples, placed as directed under I (*b*), should be weighed daily to an accuracy of one-tenth of 1 per cent on the platform scale. From test I (*a*), the initial moisture contents of these samples are known. Their initial weights were deterimned by test I (*b*). Knowing their initial moisture contents and weights, their oven-dry weights may be computed from the formula:

$$\text{Oven-dry weight of sample} = \frac{\text{Initial weight}}{100 + \text{initial moisture content}} \times 100.$$

Having the calculated oven-dry weights and daily weights of the samples, their current moisture contents may be computed from the formula:

$$\text{Current moisture content of sample} = \frac{\text{current weight} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100.$$

Therefore, since the samples were cut from representative stock, the drying rate of the material is known currently.

III. *Final tests.*—(*a*) Average kiln-dry moisture condition of samples: When the current moisture contents of the samples indicate that the material is dried to the required point, three 1-inch sections are cut from the center of each sample. One section from each sample is used to determine the average kiln-dry moisture content of each sample by the method of test I (*a*). This test must be made immediately after sawing.

(*b*) Distribution of moisture in kiln-dry samples: A thin shell (about one-fourth inch) is split from the four outer surfaces of the second 1-inch section cut from each sample. The outsides and centers are tested for moisture content separately and immediately after sawing by the method of I (*a*). The results of this test show the distribution of moisture in cross sections of the samples. The difference between the moisture contents of the outer shells and the centers shows whether or not the distribution is sufficiently uniform across the sections.

(*c*) Determination of case-hardening in kiln-dry samples: The first indication of case-hardening is surface checking. The next sign of case-hardening is honeycombing or interior checking along the medullary rays. This defect can not always be detected by a superficial inspection. It is necessary to cut the stock to discover it. Occasionally it is evidenced by a bulging of the surface over the honeycombed part. Often neither of these defects is present. In this case the third 1-inch section from each sample is resawed two or three times from one end down to within about half an inch of the other end (see Fig. 14). If the material is case-hardened and dry, it will pinch the saw; if it is not dry at the time of sawing, the cupping of the outer prongs will increase upon further drying. If the kiln-dried samples show casehardening, the material should be steamed until the resawed sections do not pinch the saw in this test.

(*d*) Average kiln-dry moisture condition of the whole pieces: When the kiln is unloaded, the whole pieces from different parts of the piles and kiln are weighed and then cut as follows: Remove about 2 feet from one end and then cut off three 1-inch sections. The average kiln-dry moisture contents of the whole pieces are determined from one section as in test III (*a*). The other sections are used as stated in III (*f*) and III (*g*).

(*e*) Calculation of initial moisture condition of whole pieces: From the kiln-dry weights and kiln-dry moisture contents of the whole pieces, their oven-dry weights may be computed from the formula:

$$\text{Oven-dry weight of whole pieces} = \frac{\text{kiln-dry weight}}{100+\text{kiln-dry moisture content}} \times 100.$$

Knowing the initial weights and oven-dry weights of the whole pieces, their initial moisture contents are computed from the formula:

$$\text{Initial moisture content of whole piece} = \frac{\text{Initial weight} - \text{oven-dry weight}}{\text{Oven-dry weight.}} \times 100.$$

Therefore the initial and kiln-dry moisture conditions of the samples, whole pieces, and the average stock are known.

(*f*) Distribution of moisture in kiln-dry whole pieces: This test is a duplicate of test III (*b*).

(*g*) Determination of case-hardening in kiln-dry whole pieces: This test is a duplicate of test III (*c*).

(*h*) To determine the effect of drying on the strength of the stock: It is practically impossible to determine the effect of the process of drying on the properties of the stock by inspection unless some visible defect has developed. This is not usual, and as the inspector can not always resort to mechanical tests he should be able to show from his operation records that conditions in the kiln have been kept within the specifications recommended as safe for kiln-drying airplane stock.

TREATMENT OF WOOD AFTER REMOVAL FROM THE DRY KILN.

Lumber should be retained for at least two weeks after removal from the dry kiln in a shed or room where the conditions are approximately the same as in the shop where the material is to be worked up. The necessity for this will be understood upon consideration of the following facts: When lumber is drying in the kiln the outer surface is necessarily somewhat drier than the interior. In good methods of drying this difference is a minimum and in bad methods of drying it is excessive; but it exists to a certain extent in all methods of drying. When the lumber has been dried down to a point somewhat below the condition to which it will finally come when exposed to the normal shop working conditions, it will gradually reabsorb moisture on the outside. Thus, thoroughly kiln-dried lumber, if it has stood in an unheated room for some time, will be found to be drier on the inside than it is on the surface, though the difference is likely to be very small. Since differences in moisture content are indicative of internal stresses existing in the wood, it is evidently desirable to have the moisture distribution as uniform as possible before the lumber is made up into finished products; otherwise the adjustment of stresses, when the lumber has been cut up, will cause warping, checking, or other troubles.

Just how long lumber should remain in the shop air after being kiln-dried will depend, of course, upon a great many circumstances. Generally speaking, the longer it remains the better it will be, provided the moisture conditions of the room in which it is stored are suitable. The same kind of a test as has been explained for case-hardening occurring in the dry-kiln will apply as a test of the lumber after remaining in storage, to see whether the internal stresses have been neutralized.

Even if case-hardening has been removed in the dry kiln by resteaming at the end of the drying period, there may still exist within the lumber slight differences in moisture content which will gradually adjust themselves under proper storage conditions, so that material which has been steamed before removal from the kiln is also benefited by being allowed to stand in the room before it is manufactured.

Ideal conditions for the storage and manufacturing of lumber require regulation of the humidity, which should be kept slightly below that of the average conditions to which the lumber is to be subjected after it is put into service. The nearer these conditions are actually met in practice the better are the results to be expected, particularly where requirements are so exacting as in the construction of airplanes.

PUBLICATIONS ON KILN-DRYING WOODS.

1. Government publications:

The Theory of Drying and Its Application to the New Humidity-Regulated and Recirculating Dry Kiln. U. S. Department of Agriculture Bulletin 509. 1917. 5 cents.

The Seasoning of Wood. U. S. Department of Agriculture Bulletin 552. 1917. 10 cents.

Principles of Drying Lumber at Atmospheric Pressure and Humidity Diagram. Forest Service Bulletin 104. 1912. 5 cents.

Strength of Wood as Influenced by Moisture. Forest Service Circular 108. 1907. 5 cents.

NOTE.—The above publications may be obtained at the prices indicated from the Superintendent of Documents, Government Printing Office, Washington, D. C.

2. Papers Prepared by the Forest Products Laboratory and published in various journals:

Principles of Kiln Drying Lumber, Parts I and II. H. D. Tiemann, Lumber World Review, January 25, February 25, 1915.

The Kiln Drying of Lumber. H. D. Tiemann, American Lumberman, October 30, 1915.

The Circulation in Dry Kilns, Parts I and II. H. D. Tiemann, Lumber World Review, May 10, June 10, 1916.

Problems in Kiln-Drying Lumber. H. D. Tiemann, Lumber World Review, September 25, 1915.

Improvement in Forest Service Humidity-Regulated Kiln. H. D. Tiemann, American Lumberman, September 4, 1915.

Drying in Superheated Steam. H. D. Tiemann, Lumber World Review, August 10, 1916.

Kiln Drying of Gum. J. E. Imrie, American Lumberman, January 22, 1916.

Conditions which exist in Casehardened Wood. J. E. Imrie, Southern Lumberman, November 13, 1915.

The Casehardening of Wood. H. D. Tiemann, Lumber World Review, July 10, 1916.

How to Measure Conditions in Seasoned Lumber. J. E. Imrie, Hardwood Record, March 10, 1917; American Lumberman, March 10, 1917.

Experiments in Kiln Drying Southern Yellow Pine. J. E. Imrie, The St. Louis Lumberman, September 1, 1917; Lumber Trade Journal, September 1, 1917.

Effects of Different Methods of Drying on the Strength of Wood. H. D. Tiemann, Lumber World Review, April 24, 1915.

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3. Private publications:
The Kiln Drying of Lumber. H. D. Tiemann, J. B. Lippincott Co., Philadelphia. 1917.
Seasoning of Wood. J. B. Wagner, D. Van Nostrand Co., New York.

CHANGES OF MOISTURE IN WOOD WITH HUMIDITY OF AIR.

Wood is a hygroscopic material; that is, it has the property of absorbing moisture from the air or surrounding medium. It has already been explained that there are two different kinds of moisture found in wood, namely, free water, which occupies the openings in the cell structure of the wood, and hygroscopic water, which is actually taken into the cell walls and which upon being removed or added to wood causes shrinkage or swelling.

There is a definite moisture content to which wood will eventually come if it is held in an atmosphere which is at a constant humidity and temperature. The moisture content of wood will vary with the average atmospheric conditions, also with the size of the material. Thus, ordinary lumber which is stored in the open during the summer months for sufficient time will eventually attain a moisture content of from 8 to 15 per cent, and wood stored indoors in a heated building will in time fall to about 5 or 6 per cent because of the lower relative humidity. If the relative humidity is constant, an increase in temperature decreases the moisture-holding power of the wood. However, the moisture content is not appreciably affected by temperature within a range of 25° or 30° F.

Figure 18 shows the relation between the moisture content of wood and the humidity conditions of the atmosphere. The data for the curve were obtained by keeping the wood at a constant humidity and temperature until no further change in moisture occurred. This curve can be used as an aid in controlling the moisture conditions of wood, the approximate atmospheric condition being known, and in determining the proper humidities for storing lumber in order to secure a certain moisture content and uniform material for use in fine wood jointing, propellers, etc. It is of importance to have wood to be used for propellers of uniform moisture content. The curve may be used also to prepare wood for use in a given locality, such as the border States, where the humidity is usually very low. Propellers for use under such conditions should be made up at a low moisture content, in order that there may be less tendency for moisture changes to take place when they are put in service. It must be remembered that this curve must not be used for dry-kiln work because of the fact that the dry-kiln temperatures used are higher than those at which the data were collected. Furthermore, the curve represents the ultimate moisture content at a given temperature and humidity, and in the case of large pieces of wood this moisture content would not be reached for a long period of time. Kiln-drying tends to reduce the hygroscopic properties of wood, hence curves for kiln-dried wood are lower than the one given. For

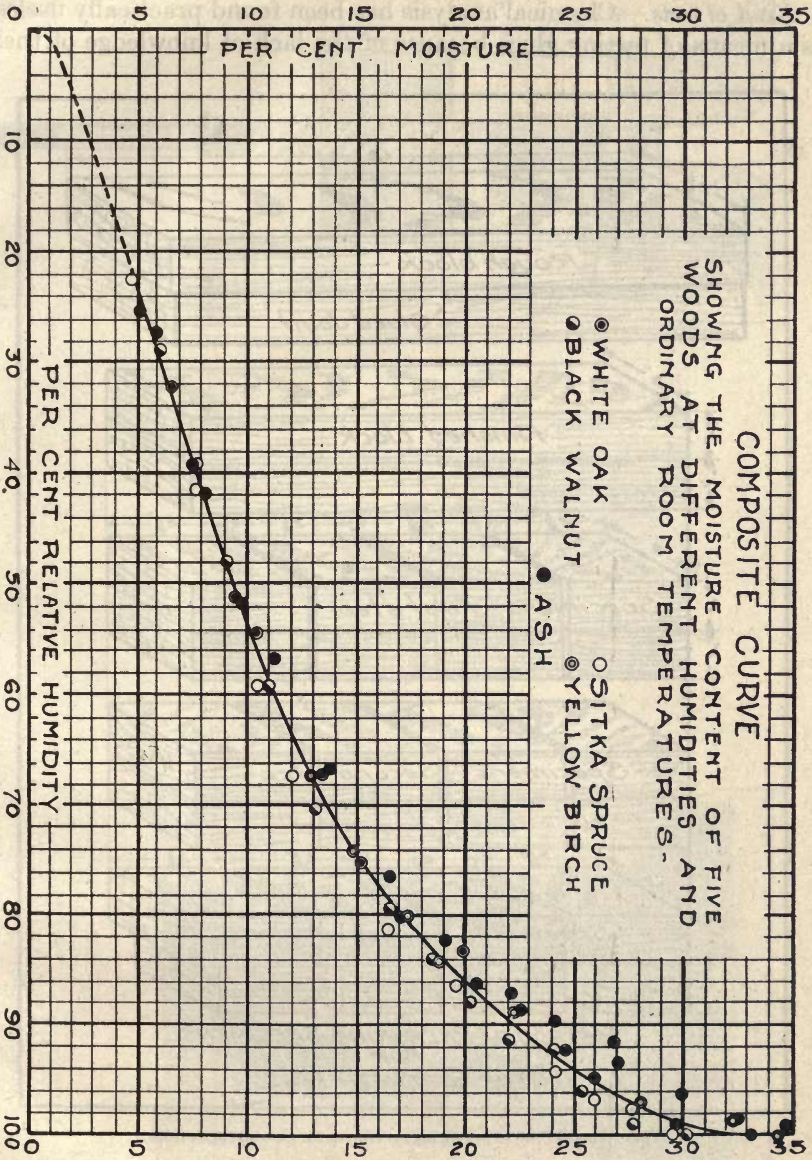


Fig. 18.—Composite curve of moisture content of five woods at different humidities and ordinary room temperature.

example, wood that had been dried to 2 per cent moisture, or less, if subjected to humidities between 30 and 70 per cent, would probably show a corresponding moisture content about 1½ to 2½ per cent lower than in the curve in Figure 18.

GLUING OF WOODS.

TESTING OF ANIMAL GLUE FOR AIRPLANE PROPELLERS.

Kind of tests.—Chemical analysis has been found practically useless as a means of testing glues because of the lack of knowledge of their

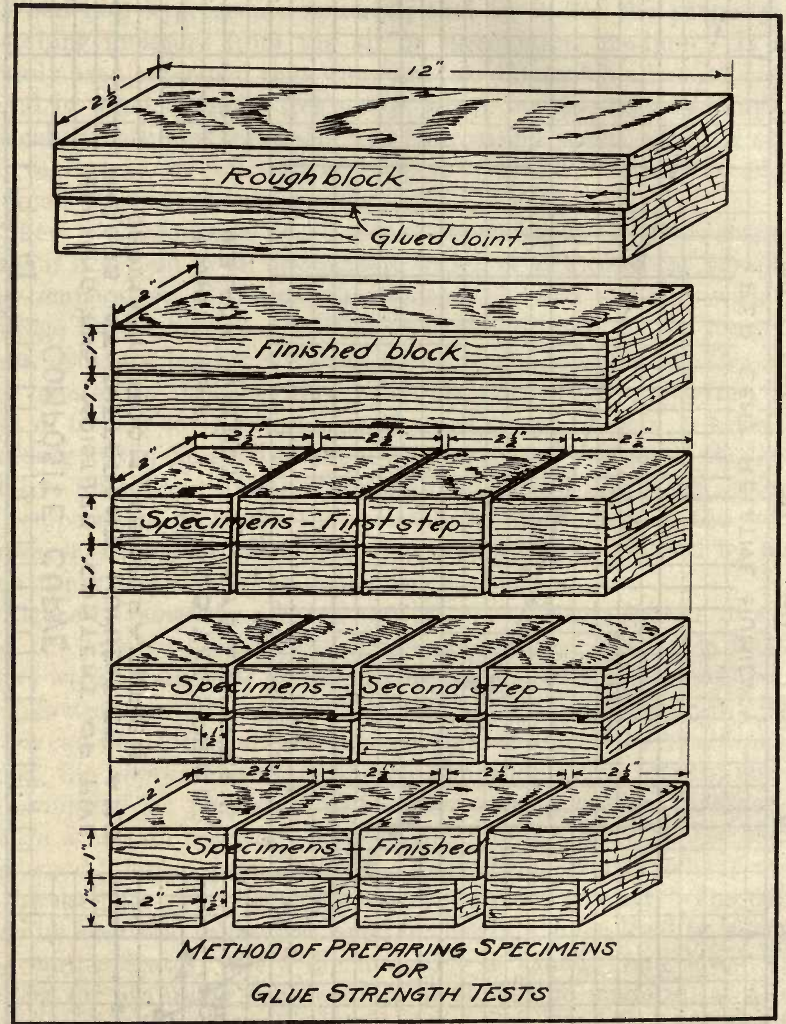


FIG. 19.—Method of preparing specimens for glue-strength tests.

chemical composition. Physical tests must, therefore, be relied upon. A considerable number of physical tests have been devised, some of which are important for one class of work and some for another. For judging the suitability of glue for high-grade joint work the tests considered most important are strength (adhesiveness), viscosity, jelly strength, odor, keeping qualities, grease, foam, and reaction to

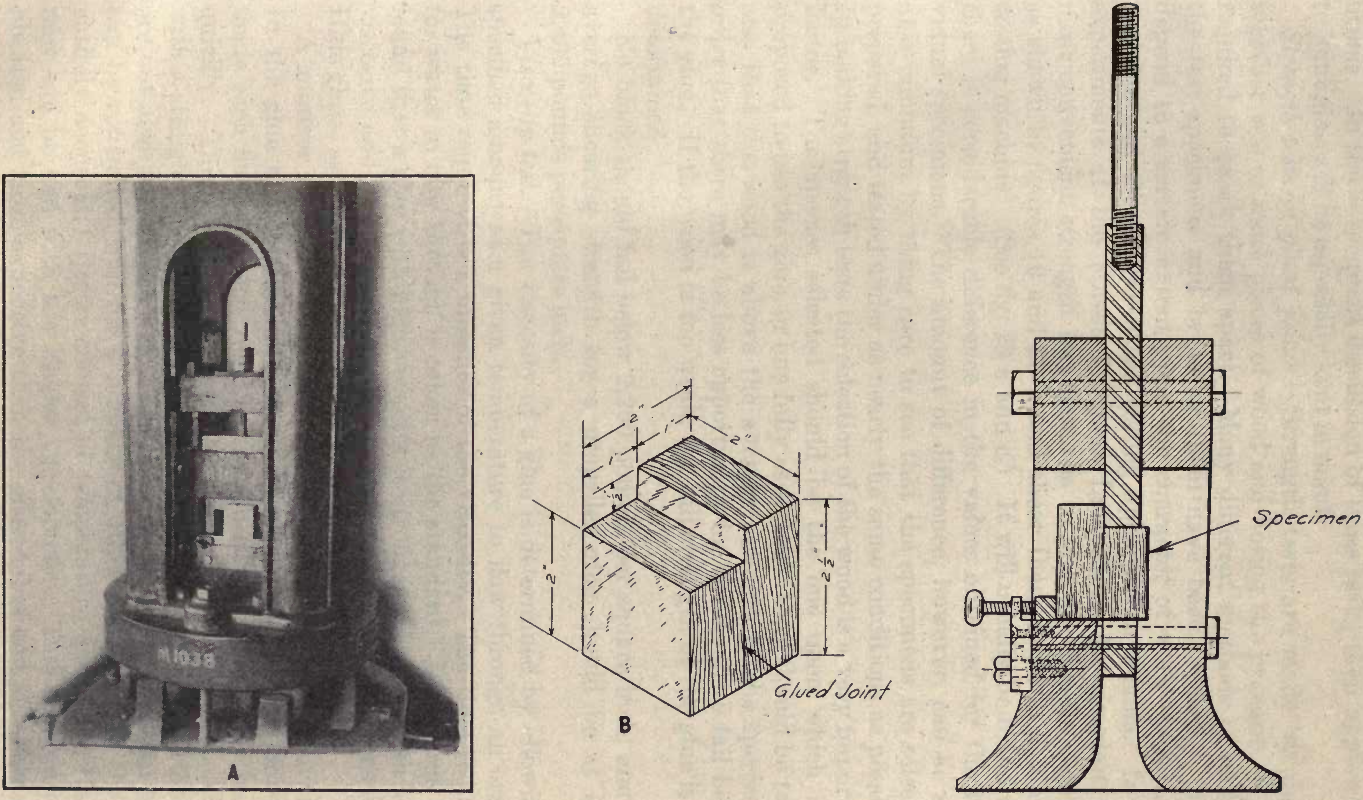
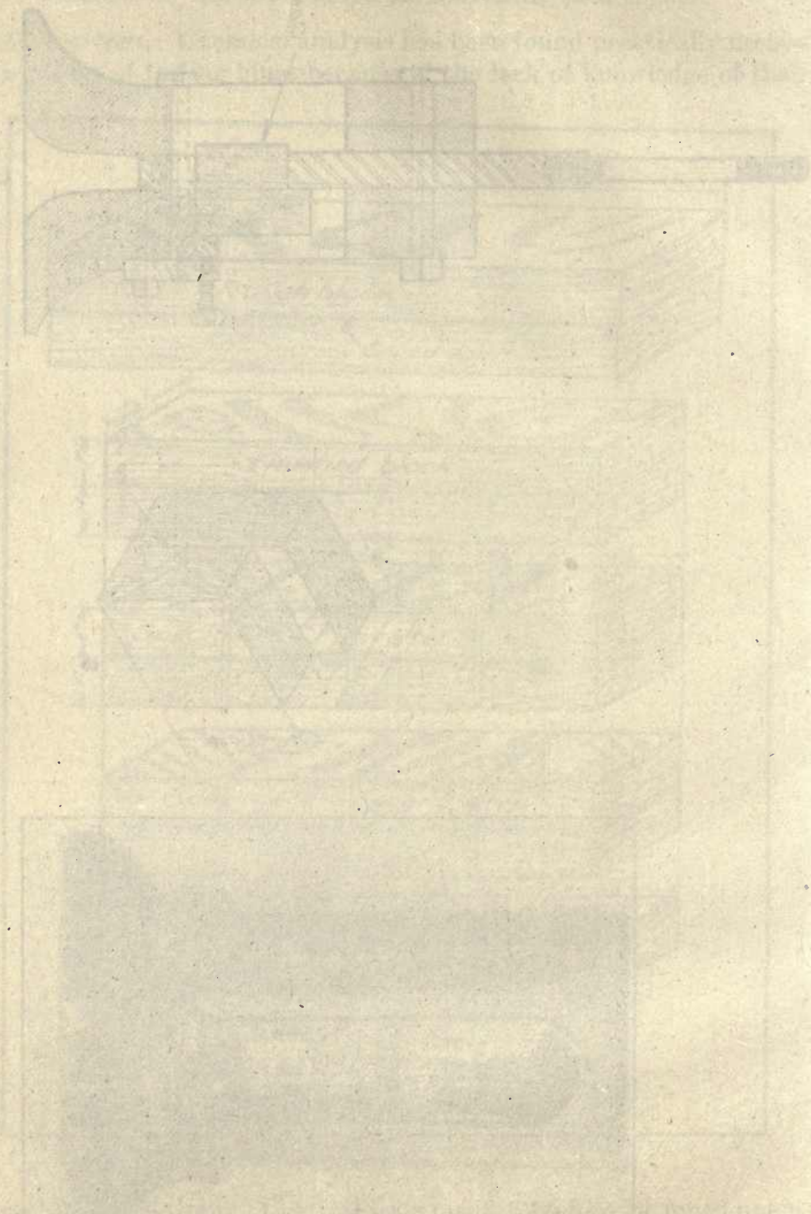


FIG. 20.—A. Testing machine with shearing tool in place. B. Finished specimen. C. Sectional view of shearing tool with test block in position.



litmus. In the subsequent discussion of these tests, their application to joint glue will be especially kept in mind.

Strength tests of glued joints.—Strength tests are made by gluing together two or more pieces of wood and noting the pressure or pull required to break them apart. Many different methods of making the test specimens and breaking them have been devised. These depend to a certain extent upon the character of work expected of the glue and the nature of the testing apparatus available. In the experiments at the Forest Products Laboratory the simplest and most convenient strength test found is to glue two blocks together as shown in figures 19 and 20 b and shear them apart in a timber-testing machine. (See fig. 20 a and c.) It will usually be found that there is considerable difference in the values obtained for the individual specimens. The amount of difference, however, can be kept at a minimum by using care to see that the specimens are selected, prepared, and tested under as nearly the same conditions as possible. In making strength tests the selection of the wood is a very important factor. The species selected should be the one upon which it is proposed to use the glue, or one fully as strong. Care should be taken also that the wood is above the average strength of the species, in order that there may be less opportunity for the wood to fail before the glue. If the wood is too weak, the full strength of the glue is not determined.

No block should fail below 2,200 pounds per square inch, and the average shearing strength for a propeller glue should be at least 2,400 pounds per square inch.

Viscosity test.—The viscosity of a glue is determined by allowing a specified amount at a given temperature to flow through an orifice. The time required is a measure of the viscosity. The time required for water to flow through is taken as the standard. In general, it is found that a glue with high viscosity is stronger than one with a low viscosity and will take more water, although there are exceptions. Hide glues, as a rule, have higher viscosities than bone glues.

A number of different shaped viscosimeters have been devised. In the glue manufacturer's laboratory, where many tests must be made each day, an instrument must be used which will give results quickly. This can be done with a pipette cut off at one end, or with a straight glass tube contracted at one end. These instruments are not always arranged so the temperature of the glue within them can be controlled, and for a number of other reasons they are not entirely accurate. Better control of temperature and greater accuracy can be had with the Engler viscosimeter. This is more complicated and more expensive than the glass tubes and also slower to operate, but it has the advantage, in addition to greater accuracy, of being an instrument which is in general use for testing many kinds of materials. The values obtained by its use are readily understood by laboratory men and can be readily checked. The instrument can be purchased standardized and ready for use.

Jelly strength.—The term "jelly strength" refers to the firmness or strength of the jelly formed by a glue solution of specified strength upon cooling. Strong glues usually have high jelly strength. There is no standard instrument for determining jelly strength and no standard unit for expressing it. In some laboratories the pressure required to break the surface of the jelly is measured. In others the depth to which a weight of special shape will sink is observed. Sometimes the jelly is cast in a conical shape, and the weight required to press the point of the cone a certain distance is taken. More common, however, is the finger test, in which the relative strength of two or more jellies is compared by pressing the jelly with the fingers. In making this test with any apparatus it is important that the conditions be very carefully controlled in order that comparative results may be obtained. The temperature of the jelly when tested is particularly important, as the relative strength of a number of jellies is not the same at different temperatures. In other words, the jelly strength of the different glues is not affected to the same extent by changes in temperature. The ideal condition is to cool and test the jellies in a room constantly maintained at the proper temperature. This is seldom practicable, however, and the jellies must be cooled in a refrigerator and tested in a warmer room. When this is done it is important that the test be made as quickly as possible after removing the jelly from the refrigerator, so that the temperature will be practically the same as it was in the refrigerator. The strength of the glue solution must always be the same, once a standard is adopted. For high-strength glues weaker solutions can be used than for low-strength glues.

Odor.—The odor of a glue is determined by smelling a hot solution, and gives some indication of its source or its condition. Glue which has an offensive odor is not considered of the highest grade. The bad odor may be due to the fact that partly decomposed stock was used, or that the glue itself is decaying. For high-grade work it is usually specified that the glue be sweet; that is, it must not have an offensive odor. The odor of different glues varies considerably, and it is difficult or impossible to express the different "shades." It is usually not difficult, however, to determine whether or not the odor is clean, or, as it is commonly called, sweet. The temperature and strength of solution are not usually specified.

Keeping quality.—The keeping quality of a glue is determined by allowing the jelly left from the jelly-strength test to stand in the laboratory at room temperature for a number of days. The odor and condition of the glue is noted at intervals. Glues with good keeping qualities will stand several days without developing an offensive odor or showing any appearance of decomposition.

Grease tests.—For joint work a small amount of grease in glue is not a serious objection. Too much grease, however, is objectionable, as grease has no adhesive properties. The grease can be determined by chemical means, if desired, but this is not necessary unless the exact amount of grease must be determined. The common method of testing for grease is to mix a little dye with the glue solution and paint it upon a piece of unsized white paper. If grease is present, the painted streak will have a mottled or spotted appearance. If there is no grease present, the streak will have a uniform appearance

Foaming.—Glue which foams badly is objectionable, because air bubbles are apt to get into the joint and thus reduce the area over which the glue is in contact with both faces. Foamy glue is especially undesirable for use in gluing machines, as in them the glue is agitated much more than when it is used by hand, and the danger of incorporating air bubbles is greater. The amount of foam is tested by beating the glue solution for a specified time with an egg beater or similar instrument, and then noting the height to which the foam rises and the quickness with which it subsides. Different laboratories do not make the test in exactly the same way, but in any laboratory, after a method is once adopted, it should be strictly adhered to thereafter. It is common to determine the foam on the solution used in the viscosity test.

Acid test.—By its reaction to litmus a glue shows whether it is acid, alkaline, or neutral. The test is made by dipping strips of red and blue litmus paper in the glue solution remaining after the viscosity test or some other test and noting the color change. An acid glue turns blue litmus red, an alkaline glue turns red litmus blue, and a neutral glue will not change the color of either red or blue litmus. A glue containing a slight amount of acid is slightly preferable to one which is neutral or alkaline, because it is not quite so favorable a medium for the growth of the organisms which cause the decay of glue.

Comparative results of tests on glues.—From the above description of the various glue tests, it is apparent that, for the most part, they give comparative rather than absolute results. It is rather difficult to compare the results of tests made by one laboratory with those of another, as the strength of solution, temperature, and manipulation are often different. For this reason, the most satisfactory method of purchasing glues is to specify that they must be equal to a standard sample which is furnished the bidder to test in any way he sees fit. The bidder should also be informed as to the methods the purchaser proposes to use in testing a glue submitted to him as equal to the standard sample.

PRECAUTIONS IN USING GLUE.

Preparation of glue.—In using hide glue there are a number of precautions that must be observed to obtain satisfactory results. If improperly used, a very high-grade glue may give poor joints. It is important, first, to find out the right proportion of glue and water to get the best results. This is largely a matter of experience, but it can also be determined by strength tests. When the right proportions have been decided upon, they should be strictly adhered to thereafter, and the glue and water should be weighed out when making up a new batch of glue, rather than measured or guessed at. Clean cold water should be put on the glue, which should be allowed to stand in a cool place until it is thoroughly water soaked and softened. This may take only an hour, or it may take all night, depending upon the size of the glue particles. When the glue is soft, it should be melted over a water bath, and the temperature not allowed to go higher than about 150° F. High temperatures and long-continued heating reduce the strength of the glue solution and are to be avoided. The glue pot should be kept covered as much as possible in order to prevent the formation of a skin or scum over the surface of the glue

Working temperature.—The room in which the glue is used should be as warm as possible without causing too much discomfort to the workmen, and it should be free from drafts. In a cold, drafty room the glue cools too quickly, and is apt to set before the joint has been put into the clamps. This results in weak joints. It is also considered good practice to warm the wood before applying the glue. Wood should never be glued when it is cold, and of course only thoroughly seasoned wood should be used. Since high-strength animal glues set so quickly on cooling, they should be applied and the joints clamped as quickly as consistent with good workmanship.

Clamping of glued joints.—In clamping glued joints the pressure should be evenly distributed over the joint, so that the faces will be in contact at all points. The amount of pressure which will give the best results is a question which has never been definitely settled. One experimenter found that a pressure of about 30 pounds per square inch gave better results on end joints than higher or lower pressures. Apparently no tests have yet been made to show the best pressure to use on edge or flat grain joints. In gluing veneers it is necessary to use high pressure in order to flatten out the irregularities of the laminations. Pressures as high as 150 or 200 pounds per square inch are sometimes used.

Glue-room sanitation.—Strict cleanliness of glue pots and apparatus and of the floors and tables of the glue room should be observed. Old glue soon becomes foul and affords a breeding place for the

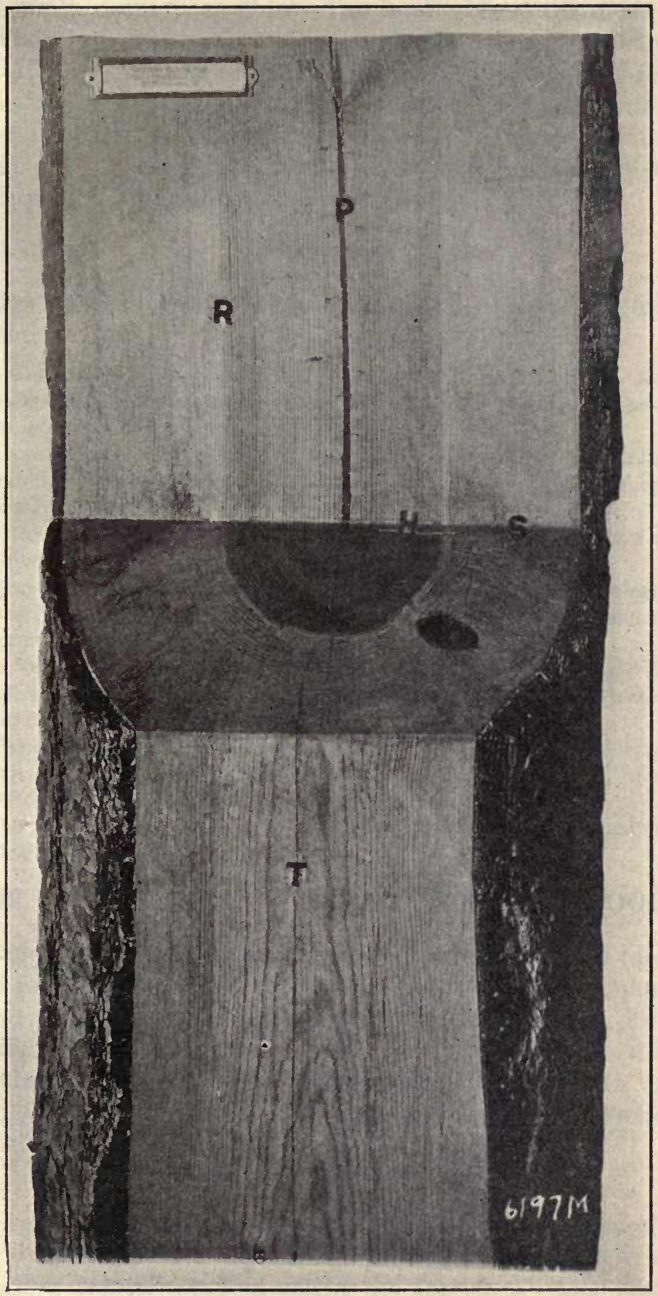


FIG. 21.—Section of western yellow pine log showing: Radial surface, R; tangential surface, T; heartwood, H; sapwood, S; pith, P. The annual rings are the concentric layers widest near the pith and becoming narrower toward the bark.

bacteria which decompose glue. The fresh glue is therefore in constant danger of becoming contaminated. Glue pots should be washed after every day's run in hot weather, and two or three times a week in cooler weather. Only enough glue for a day's run should be mixed at a time, so that mixed glue will not have to be held over from one day to another. If these sanitary precautions are not observed, poor joints are apt to be the result.

REFERENCES.

The glue user or inspector should read some or all of the following publications:

Glues and Gelatines. R. L. Fernbach, 200 pages, by D. Van Nostrand, New York. Discusses the manufacture, classification, testing, and analysis of glues and gelatines and gives information on substitutes.

Glue and Glue Testing. Samuel Rideal, 140 pages, published by Scott, Greenwood & Son, London. Discusses the manufacture, testing, and use of glues, especially the chemical side.

The Glue Book. J. A. Taggart, Toledo, Ohio, 85 pages. Discusses "how to select, prepare, and use glue."

Specifications and Tests of Glue. Linder and Frost, Proceedings American Society for Testing Materials, 1914, Part 2, pages 509 to 519. Gives the results of tests of cabinet glue.

A Study of Various Tests upon Glue. A. M. Gill, Journal of Industrial and Engineering Chemistry, Vol. 7 (1915), pages 102 to 106. Gives the results of tests made at Massachusetts Institute of Technology.

Glue for Use on Airplanes. P. A. Houseman, Journal of Industrial and Engineering Chemistry, Vol. 9 (1917), pages 359 to 360. Republished in Aviation, July 1, 1917, pages 494 to 495; and in Aerial Age Weekly, June 18, 1917, page 462.

The Grading and Use of Glues and Gelatine. Jerome Alexander, Journal of Society of Chemical Industry, Feb. 28, 1906.

THE STRUCTURE AND IDENTIFICATION OF WOOD.

A knowledge of the structure of wood is essential in the identification and proper selection of lumber used in airplanes. Color, odor, taste, and weight are also very helpful in identification, but these are usually more variable than the structure, and can not be described as accurately. Furthermore, these properties change with different treatments of the wood, while the structure remains the same, until disintegrated.

HEARTWOOD AND SAPWOOD.

Three regions are usually discernible in the end surface of a log; an inner dark core called the heartwood, the bark, and between the two a lighter colored portion called the sapwood. (See section of western yellow pine log, fig. 21.)

In some woods there is little difference in the color between the sapwood and the heartwood, there being no sharp line of demarcation between the two. The spruces, hemlock, Port Orford cedar, basswood, cottonwood, beech (white heart), and hackberry are examples of this class.

Sap stain, or blue stain, discolors the sapwood, especially in the pines, red gum and hackberry, but does not weaken it.

The width of the sapwood varies with the age and vigor of the tree, the distance from the stump, and the species. The inner portion of the sapwood of a living tree gradually changes to heartwood from year to year and in so doing usually becomes darker and more resistant to decay, but does not become stronger.

Certain species normally have very narrow sapwood, and others very wide sapwood, and this feature is often useful in identifying woods.

Species with very narrow sapwood, usually less than 1 inch wide: Arbor-vitæ, western red cedar, black ash, slippery elm.

Species with very wide sapwood, usually several inches: Maple, birch, white ash, green ash, hackberry, some hard pines.

ANNUAL RINGS.

Annual rings are the well-defined concentric layers of wood seen on cross-sections of timbers grown in temperate climates (see fig. 21). Woods grown in the Tropics usually show no well-defined annual rings because growth continues, more or less, during the entire year.

Wood can be cut in three distinct planes with respect to the annual layers of growth: Crosswise, exposing the transverse surface or end grain; lengthwise through the center or pith, exposing the radial, or "quartered," surface or edge grain, sometimes called "vertical grain"; and lengthwise, not through the center, exposing the tangential, or "bastard," surface or flat grain (see fig. 21).

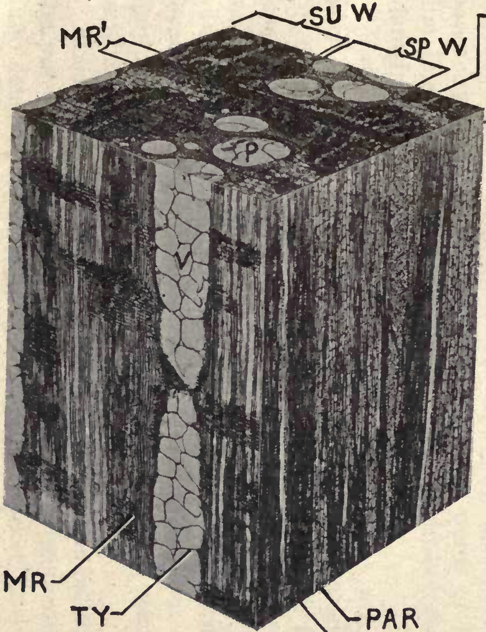
SPRINGWOOD AND SUMMERWOOD.

Springwood is the more porous and softer inner part of each annual ring formed during the early part of the growing season (see Pl. II).

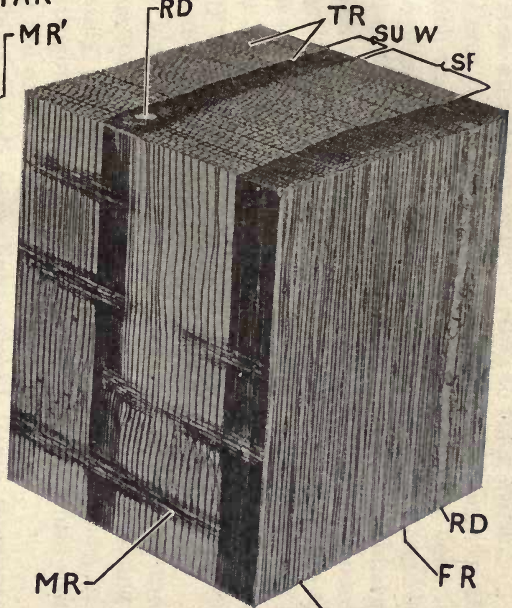
Summerwood is the less porous and denser outer part of each annual ring formed during the latter part of the growing season. The springwood and summerwood may each be sharply defined or the transition may be gradual. In some woods, for example, maple, birch, basswood, cottonwood, and red gum, the annual rings are of such uniform structure that the distinction between springwood and summerwood is not clear.

THE STRUCTURE OF HARDWOODS.

Our commercial woods can be divided into two distinct classes, the hardwoods, or woods from broad-leaved trees, and the conifers,



WHITE OAK.



SHORTLEAF PINE.

[Photographs of cubes of wood magnified about 25 diameters.]

In each cube the top view represents the transverse or end surface, the left view the radial or "quartered" surface, and the right view the tangential or "bastard" surface. SP W, spring wood; SU W, summer wood.

To the left a hardwood showing: V, vessels or pores; TY, tyloses in a vessel; PAR, parenchyma cells; the dark areas, WF, wood fibers; MR, small medullary rays; MR', large medullary rays.

To the right a coniferous wood showing: TR, tracheids, which comprise the bulk of the wood; RD, resin ducts; MR, ordinary medullary rays; FR, fusiform ray containing a horizontal resin duct.

The medullary rays are continuous from the starting point to the bark, and the vessels are continuous longitudinally, although the illustrations show them interrupted.

or woods from trees with needle or scale-like leaves. The conifers are also known as "softwoods," although some species, as the hard pine, tamarack, etc., are harder than basswood and cottonwood, which belong to the hardwood class.

All woods are composed of cells joined together by their walls similar to the cells of a honeycomb, but much smaller, more irregular in size, and longer in proportion to their width.

Pores or *vessels* are larger cells found only in the hardwoods, in which they are scattered among the smaller cells (see Pl. II, opposite page 50). The pores are visible without a hand lens on a smoothly cut end surface of oak, ash, elm, chestnut, hackberry, hickory, black walnut, and mahogany. In other hardwoods the pores can be seen distinctly only with a magnifying glass, but they are always larger than the surrounding cells. The size and arrangement of the pores differ in the various species and are valuable aids in identification. (See Key and illustrations.) On account of the presence of pores, hardwoods are also called porous woods.

Tyloses are frothlike growths in the pores of the heartwood and, occasionally, of the inner sapwood, often closing the pores completely (see Pl. II). The absence, or presence, of tyloses helps to distinguish certain woods, especially the white oaks (present) from the red oaks (absent).

Some woods have light-colored tissue (composed of very small parenchyma cells) extending around the pores or between them in fine lines. The arrangement of these light-colored lines helps to identify ash and hickory.

Medullary rays, hereafter referred to as rays, are narrow strips of cells extending radially in the wood at right angles to the grain. On the end surface they appear as lines crossing the annual rings (see Pl. II). They are largest in oak, in which they may be up to 4 inches wide with the grain, forming the beautiful "silver grain" of quarter-sawed oak. In beech, and to a less extent in maple, they form conspicuous "flakes" on the radial surface. In other woods they are less distinct on the radial surface, and often are not visible on the end surface without a lens.

Wood fibers are narrow, thick-walled fibrous cells scattered among the pores. They are too small to be recognized individually with a hand lens, collectively they form the darker and denser portions which give most of the weight and strength to wood (see Pl. II).

THE STRUCTURE OF CONIFERS.

In conifers the bulk of the wood is composed of fibrous cells (tracheids) which serve the combined purpose of the pores and wood fibers of hardwoods. They are of almost uniform width tangentially

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and are arranged in definite radial rows (see Pl. II and other illustrations of cross sections of conifers). On account of the absence of pores, the conifers are also called nonporous woods, although "porous" in the sense of containing empty spaces or absorbing liquids applies to both conifers and hardwoods. On a smoothly cut end surface the fibrous cells can be seen with a hand lens, resembling in their regularity the cells of a honeycomb. In the outer part of each annual ring they are flattened radially and thicker-walled, producing a denser band of summerwood.

Rays are also present in conifers but they are always very small, and on the end surface are invisible without a lens.

Resin ducts are passages extending vertically between the fibrous cells and radially within certain medullary rays. They serve for the conduction of resin and are present normally only in the pines, spruces, larches, or tamaracks, and Douglas fir (see illustrations of cross sections of these woods and Pl. II).

In the pines the resin ducts are plainly visible with a lens and occasionally, on a smoothly cut end surface, barely visible without a lens. On longitudinal surfaces they are often visible as characteristic brownish lines. In the spruces, larches, and Douglas fir they are smaller, less numerous, and in the cross section often in short tangential rows, appearing as whitish specks in the summerwood. On longitudinal surfaces of spruce and Douglas fir the resin ducts are less distinct than in the pines but can usually be found on careful examination. Since the resin ducts extend in the same direction as the fibers, the direction of the grain can be determined by them.

Exudations of resin at the ends and pitch pockets are common in woods containing resin ducts, and are not found in the cedars, cypress, redwood, hemlock, and balsam firs, which have no resin ducts. Oily exudations have been noted on the ends of Port Orford cedar stored in a warm place. The absence of exudations of resin, however, does not mean the absence of resin ducts. Resin will not exude, as a rule, on cuts made after the wood is seasoned; but warming pieces of pine, Douglas fir, larch, and spruce in an oven will usually cause enough resin to exude from the ends to form specks, thereby indicating the presence of resin ducts. This is especially true of pine and Douglas fir and to a less extent of spruce and larch.

PHYSICAL PROPERTIES USEFUL IN IDENTIFICATION.

Color.—Since wood turns darker on exposure to air and since all sapwood is light-colored, observations as to color should be made on freshly cut longitudinal surfaces of the heartwood. It is practically impossible to describe satisfactorily the different colors of wood, therefore comparisons should be made with known samples whenever possible.

Odor and taste.—Many species give off a characteristic odor when worked. Therefore, to get the odor, wood should be whittled, or better yet, sawed and the sawdust held to the nostrils. The taste of wood is usually similar to the odor, although in the cedars the taste is more spicy or bitter. Cypress has somewhat rancid odor but is practically tasteless. Odor and taste are more pronounced heartwood than in the sapwood.

Weight.—When wood is dry, its weight aids in identification, although a species is often highly variable in weight. For instance, the heavier grades of mahogany may weigh twice as much as the lighter grades, which often are sold under the name of "baywood."

No definite weight can properly be assigned to each species, and the following comparative classification is here used because it is more descriptive than the average weight expressed in pounds per cubic foot:

Very light, up to 19 pounds oven-dry weight per cubic foot original green volume.

Light, 19 to 22 pounds, oven-dry weight per cubic foot original green volume.

Moderately light, 22 to 26 pounds, oven-dry weight per cubic foot original green volume.

Moderately heavy, 26 to 31 pounds oven-dry weight per cubic foot original green volume.

Heavy, 31 to 37 pounds oven-dry weight per cubic foot original green volume.

Very heavy, 37 to 45 pounds oven-dry weight per cubic foot original green volume.

Very, very heavy, 45 or more pounds per cubic foot original green volume.

GRAIN AND TEXTURE.

In this publication "grain" is used with respect to the direction of the fibers, as straight, diagonal, cross, and spiral or twisted grain, and with respect to the plane in which lumber is cut, as end grain, flat grain, and edge (also known as "vertical" and "comb") grain. "Grain" has often been used to indicate the width of the rings, especially when there is a decided difference between spring wood and summer wood so as to make the rings conspicuous as in Douglas fir and yellow pine. However, to avoid confusion, it is better to express the width of the rings as narrow, medium, or wide, or as a certain number of rings per inch of radius.

"Texture" is here used to indicate the relative size of the pores of hardwoods or fibrous cells of tracheids; for instance, coarse texture for woods with large pores, such as oak, ash, chestnut, etc., and fine texture for hardwoods with comparatively small pores, such as maple, birch, red gum, etc., and all coniferous woods, although some conifers have slightly larger cells than others. In wood finishing, lumber with large pores has often been called "open-grained" or "coarsegrained" and with small pores "close-grained" or "fine-grained"; but the use of the word "grain" with so many different meanings is confusing and should be avoided if possible. "Texture" is also used to designate the even or uneven structure of the annual rings; wood with decided contrast between springwood and summerwood is said to have an uneven texture, as ash, oak, yellow pine, and Douglas fir; and wood with little contrast between springwood and summerwood is said to have an even texture, as white pine, Port Orford cedar, yellow poplar, and birch.

PROCEDURE IN IDENTIFYING WOOD.

If the color, odor, or general appearance is not sufficiently distinct to identify a sample of wood, the more detailed structure must be taken into consideration. The structure and other physical properties of the various species that the inspector is likely to meet are described in the following pages, and a key has been prepared which will aid in their identification. The illustrations of the woods are photographs of thin cross-sections magnified 15 diameters. They will prove helpful in studying the structure of each species or group of species.

The characteristic structure is usually seen to best advantage on a smoothly and freshly cut end surface across rings of average width. The area examined need not be large, but it is advisable to make observations at several places. Note first if pores are present. If pores can not be seen with the unaided eye, use a hand lens. A lens magnifying about 15 diameters is preferable for this work. The lens should be held close to the eye and then the object brought within focus, care being taken not to shut out the light too much. If pores are present, note whether the wood is ring porous or diffuse porous, etc., as outlined in the key, pages 55 to 58. If pores are not present, try to classify the wood according to the subdivisions under the conifers.

It is not expected that the key can be used successfully without some practice. The inspector should provide himself with known samples and study the illustrations of cross-sections in this book, so as to become familiar with what is meant by the terms used. Samples for comparison should be of heartwood of the tree trunk, showing average width of rings and at least 3 inches from the center or pith of the tree.

KEY FOR THE IDENTIFICATION OF WOOD USEFUL IN THE CONSTRUCTION OF AIRPLANES.[1]

HARDWOODS.

I. Wood with pores. The pores are conspicuously larger than the surrounding cells, although in some species they are not visible without magnification. Neither the pores nor other cells are in continuous radial rows. (For "Wood without pores" see II, p. 57.)

A. Ring-porous; that is, the pores at the beginning of each annual ring are comparatively large, forming a distinct porous ring, and decrease in size more or less abruptly toward the summerwood. (For Diffuse-porous see B, p. 56.)

1. Summerwood figured with wavy or branched radial bands visible without a lens on a smoothly cut end surface.

AA. Many rays very broad and conspicuous. Wood heavy to very heavy.
The Oaks.

(a_1) Pores in the summerwood very small and so numerous as to be exceedingly difficult to count under a lens; pores in the springwood of the heartwood densely plugged with tyloses, except in chestnut oak, in which they are more open. Heartwood brown, usually without reddish tinge.
The White-Oak Group, p. 59.

(b_1) Pores in the summerwood larger, distinctly visible with (sometimes without) a hand lens and not so numerous but that they can readily be counted under a lens; pores in the springwood mostly open; tyloses not abundant. Heartwood brown, with reddish tinge, especially in the vicinity of knots.
The Red Oak Group, p. 60.

BB. All rays very fine and inconspicuous. Color, grayish-brown. Wood moderately light.
Chestnut, p. 60.

2. Summerwood figured with long or short wavy *tangential* bands visible without a lens on a smoothly cut end surface.

AA. Careful examination with a hand lens shows that the pores of the summerwood are very numerous and joined so as to form more or less wavy tangential bands.

(a_1) Heartwood light- to deep-reddish brown. Rays not distinct without a lens.

(a_2) Large pores in the springwood usually in one row, except in very wide rings.

(a_3) Rows of pores in the springwood conspicuous because they are large enough to be plainly visible without a lens; they are mostly open, containing only a few tyloses; and they are fairly close together. Wood moderately heavy; fairly easy to cut.
White Elm, p. 61.

(b_3) Rows of pores in the springwood inconspicuous because they are small, being barely visible without a lens; they are mostly closed with tyloses, especially in the heartwood; and they are often somewhat separated. Wood heavy and difficult to cut.
Cork or Rock Elm, p. 61.

(b_2) Large pores in springwood in several rows; mostly open, containing few tyloses. Wood moderately heavy.
Slippery Elm, p. 61.

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[1] Unless otherwise directed, all observations as to structures should be made on the end surface of rings of average width cut smoothly with a very sharp knife; and all observations as to color should be made on freshly cut longitudinal surfaces of the heartwood.

(b_1) Heartwood yellowish- to greenish-gray. Rays distinct without a lens. Pores in the springwood mostly open, in several rows except in occasional narrow rings, where they may form only one row. Wood moderately heavy.

HACKBERRY, p. 61.
SUGARBERRY, p. 61.

BB. Careful examination with a hand lens shows the pores of the summerwood to be few and isolated (or occasionally in radial rows of 2 or 3), but surrounded by light-colored tissue (parenchyma), which also projects tangentially, often connecting pores widely separated, especially toward the outer portion of the annual ring.

(a_1) Projections of light-colored tissue from the pores of the outer summerwood comparatively long and distinct. Heartwood grayish-brown, occasionally with reddish tinge. Wood heavy and hard. Sapwood wide and usually present in wide boards.

WHITE ASH, p. 62.
GREEN ASH, p. 62.

(b_1) Projections of light-colored tissue from the pores of the outer summerwood short, often absent. Heartwood silvery-brown. Wood moderately heavy. Sapwood usually less than 1 inch wide and therefore scarce in lumber.

BLACK ASH, p. 62.

3. Summerwood not figured with radial or tangential bands distinctly visible without a lens. Pores in the summerwood comparatively few and isolated or in radial rows of 2 or 3.

AA. Under a lens numerous fine light-colored tangential lines (parenchyma) are plainly visible. Sapwood wide; heartwood reddish-brown. Wood very heavy to very, very heavy.

HICKORIES, p. 62.

BB. No fine lines of parenchyma visible except occasional short projections of parenchyma from the outermost pores of the summerwood. Sapwood narrow; heartwood silvery-brown. Wood moderately heavy.

BLACK ASH, p. 62.

B. Diffuse-porous; that is, the pores are of about uniform size and evenly distributed throughout the annual ring; or if they are slightly larger and more numerous in the springwood, they gradually decrease in size and number toward the outer edge of the ring.

1. Pores comparatively large and conspicuous, plainly visible without a lens

AA. Heartwood chocolate-brown. Wood heavy and hard.

BLACK WALNUT, p. 63.

BB. Heartwood reddish-brown. Many pores filled with dark amber-colored gum. Wood moderately heavy.

(a_1) Fine light-colored tangential lines indicating annual rings and varying from $\frac{1}{32}$ to $\frac{1}{2}$ inch apart, plainly visible without a lens.

(True) MAHOGANY, p. 63.

(b_1) No fine light-colored tangential lines present.

AFRICAN MAHOGANY, p. 64.

2. Pores not plainly visible without a lens (although barely visible under favorable conditions in birch and cottonwood).

AA. Numerous rays, broad and conspicuous, fully twice as wide as the largest pores, visible on the radial surface as "flakes" about $\frac{1}{8}$ inch wide with the grain; other rays very fine. Wood heavy, light reddish-brown.

BEECH, p. 64.

BB. Rays narrower, ranging from very distinct and same size as pores in maple and cherry, to barely visible with a lens, as in cottonwood.

(a_1) Heartwood light to deep reddish-brown.

(a_2) Rays very distinct without a lens and fully as wide as the largest pores.

(a_3) Heartwood deep reddish-brown. Pores slightly decreasing in size from inner to outer portion of each annual ring. The rays conspicuous on the radial surface, but not darker than the surrounding wood. Wood moderately heavy.

BLACK CHERRY, p. 64.

(b_3) Heartwood very light reddish-brown. Pores of uniform size throughout the annual ring. The rings defined by thin reddish-brown layers, usually conspicuous on the longitudinal surfaces. The rays conspicuous on the radial surface as reddish-brown flakes $\frac{1}{32}$ to $\frac{1}{16}$ inch wide with the grain; on the end surface only part of the rays broad, the others very fine, scarcely visible with a lens. Wood heavy; difficult to cut across the grain.

SUGAR MAPLE, p. 65.

(b_2) Rays not very distinct without a lens and narrower than the largest pores.

(a_3) Pores comparatively large under a lens, and barely visible without a lens under conditions of good light and a smoothly cut end surface, visible on a smooth longitudinal surface as fine grooves. Wood heavy.

SWEET BIRCH, p. 65.
YELLOW BIRCH, p. 65.

(b_3) Pores very small, barely visible with a lens. Heartwood often figured with irregular darker streaks; sapwood pinkish. Wood moderately heavy.

RED GUM, p. 66.

(b_1) Heartwood yellowish or brownish with greenish tinge. Wood moderately light.

YELLOW POPLAR, p. 66.
CUCUMBER, p. 66.

(Although cucumber averages slightly heavier than yellow poplar, there is no reliable means of distinguishing the two without a compound microscope.)

(c_1) Heartwood light-colored, almost white or grayish. Wood light and soft.

(a_2) Color creamy-white. Rays distinct without a lens, pores barely visible with a lens.

BASSWOOD, p. 66.

(b_2) Color grayish-white. Rays barely visible with a lens; pores very distinct with and barely visible without a lens.

COTTONWOOD, p. 67.

CONIFERS.

II. Wood without pores. The fibrous cells (tracheids) very small, barely visible with a lens; practically uniform in size excepting in the summerwood where they are narrower radially; arranged throughout in definite radial rows. Rays very fine.

A. Odor aromatic, resinous, or spicy; taste bitter or spicy. Resin ducts, pitch pockets, and exudations of resin on end surfaces entirely absent.

THE CEDARS.

1. Heartwood moderately dark to dark brown, with or without reddish tinge. Odor and taste like cedar shingles.

AA. Heartwood plain brown, rarely with reddish tinge. Wood very light.

ARBOR-VITÆ, p. 67.

BB. Heartwood reddish brown. Wood light.

(a_1) Medullary rays, as seen under a hand lens on freshly-split radial surface, orange-red with numerous very fine amber-colored specks of resin. Sapwood usually over 1½ inches wide.

INCENSE CEDAR, p. 68.

(b_1) Medullary rays, as seen under a hand lens on freshly-split radial surface, light brown, rarely containing amber-colored specks of resin. Sapwood usually less than 1 inch wide.

WESTERN RED CEDAR, p. 67.

2. Heartwood very pale brown. Wood moderately light to moderately heavy. Odor and taste not like cedar shingles, more spicy.

PORT ORFORD CEDAR, p. 68.

B. Odor neither aromatic nor spicy, but may be resinous or "pitchy"; taste neither bitter nor spicy. Resin ducts present; also occasionally, pitch pockets and exudations of resin from the ends.

1. Resin ducts very distinct and numerous, appearing in the end surface as minute openings, and often on the longitudinal surface as brownish lines.

The PINES.

AA. Summerwood inconspicuous and not appreciably harder than the springwood in cutting across the grain. Heartwood light reddish- or creamy-brown. Wood moderately light.

The WHITE PINE GROUP: EASTERN WHITE PINE, p. 68;
WESTERN WHITE PINE, p. 68; SUGAR PINE, p. 69.

BB. Summerwood conspicuously darker and harder than the springwood appearing as a glistening layer on the end or longitudinal surfaces.

The HARD PINES, p. 69.

(a_1) Wood moderately light. Summerwood narrow; some pieces approximating the white pines in appearance, although a thin layer of horny, glistening summerwood is nearly always present.

WESTERN YELLOW PINE, p. 69.

(b_1) Wood moderately heavy to heavy. Summerwood very pronounced.

NORWAY PINE, p. 69.
SHORTLEAF PINE, p. 69.
And other hard pines.

2. Resin ducts indistinct, not numerous, visible as whitish specks in the summerwood; pitch pockets and exudations of resin may be present.

AA. Heartwood reddish. Wood moderately heavy.

DOUGLAS FIR, p. 70.

BB. Heartwood pale reddish-brown. Wood moderately light.

SITKA SPRUCE, p. 70.

CC. Heartwood almost white. Wood moderately light.

WHITE SPRUCE, p. 70.
RED SPRUCE, p. 70.

C. Odor somewhat rancid; wood without characteristic taste. Resin ducts, pitch pockets, and exudations of resin absent. Highly variable in color from pale brown, or reddish-brown to almost black. Longitudinal surfaces feel and appear waxy. Weight variable from moderately light to heavy.

BALD CYPRESS, p. 71.

D. Odorless and tasteless. Resin ducts, pitch pockets, and exudations of resin absent. Heartwood moderately light to deep reddish-brown. Wood moderately light.

REDWOOD, p. 71.

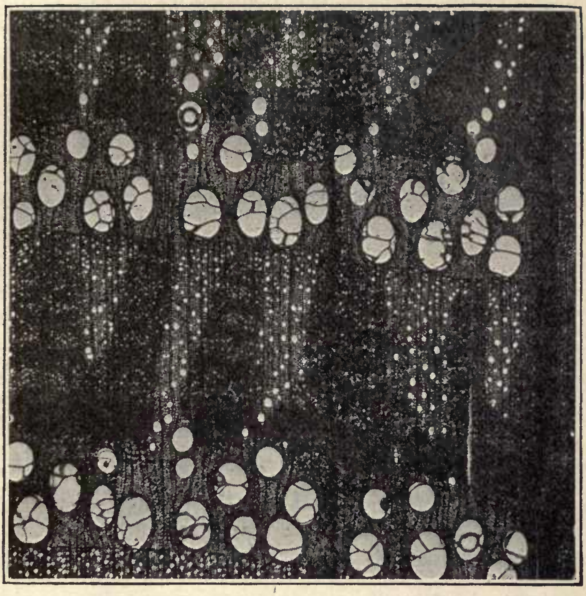

FIG. 22.—Post oak. Cross section magnified 15 diameters.

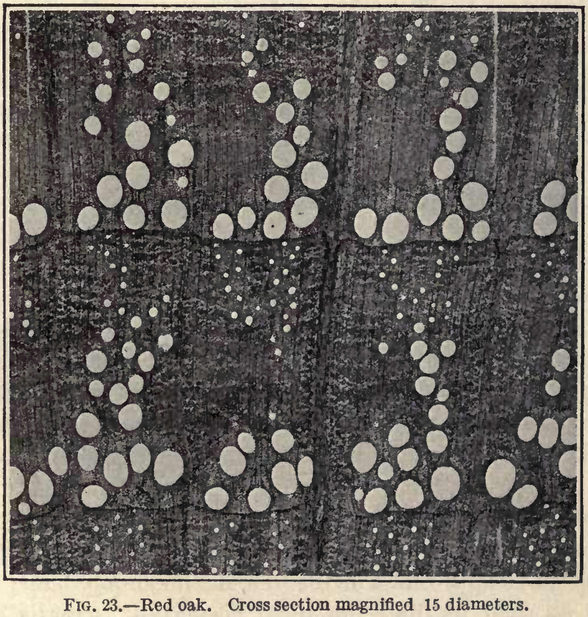

FIG. 23.—Red oak. Cross section magnified 15 diameters.

DESCRIPTION OF WOODS IN KEY.

The scientific names are those used by the Forest Service as given in Bulletin 17, "Check List of Forest Trees of the United States."

The letters after the names refer to the forest regions in which the trees grow, as indicated on the map, Pl. I, althought the geographic distribution of each species is not confined exactly to the limits of the regions indicated.

HARDWOODS.

THE WHITE OAK GROUP.

The following commercial species belong to the white oak group:

White Oak (*Quercus alba*). (A, B, D, E.)
Bur Oak (*Quercus macrocarpa*). (A, B, C, D.)
Swamp White Oak (*Quercus platanoides*). (A, B, D.)
Post Oak (*Quercus minor*). (B, D. E.)
Chinquapin Oak (*Quercus acuminata*). Yellow oak. (B, D.)
Cow Oak (*Quercus michauxii*). Basket oak. (E.)
Overcup Oak (*Quercus lyrata*). (E.)
Chestnut Oak (*Quercus prinus*). (B and adjacent territory.)

Most of the white oaks are so much alike in color and structure that no reliable means of identifying the wood of each species has been found. Chestnut oak can usually be distinguished from other white oaks by the more open pores of the springwood in the heartwood.

The woods of the white oak group are heavy and hard. The sapwood is mostly from 1 to 2 inches wide. The heartwood is grayish brown, usually without any reddish tinge. The dry wood is without characteristic odor or taste.

The annual rings are made very distinct by the large pores in the springwood, which form a porous ring from 1 to 3 spores wide. In the heartwood these pores are nearly all entirely filled with tyloses, except in chestnut oak, in which they are more open but not so much so as in the red oaks.

The pores of the summerwood are arranged in irregular, branched or wavy radial bands. They are very small and so numerous that they are difficult to count even under a good hand lens. This feature is an absolutely reliable means of distinguishing the white oak from the red oaks, the summerwood pores in the latter being larger and not so numerous. (Compare illustrations of white oak (Pl. II.) and post oak (fig. 22), with illustration of red oak (fig. 23), and also samples of the two groups.)

The most characteristic feature of all oak woods, including the red oak and live oak groups, is the presence of certain broad medullary rays, very conspicuous on the end surface and appearing on the radial surface as silvery "patches" from one-half an inch to 4 inches in height with the grain.

Chestnut resembles plain-sawed white oak but is lighter and has only very fine rays.

THE RED OAK GROUP.

The following commercial species belong to the red oak group:

RED OAK (*Quercus rubra*). (A, B, C, D.)
YELLOW OAK (*Quercus velutina*). Black oak. (A, B, D, E.)
TEXAN OAK (*Quercus texana*). (D, E.)
SPANISH OAK (*Quercus digitata*). (E.)
PIN OAK (*Quercus palustris*). (B, D.)
SCARLET OAK (*Quercus coccinea*). (B, D.)
BLACK JACK (*Quercus marilandica*). (B, D, E.)
WILLOW OAK (*Quercus phellos*). (E.)
WATER OAK (*Quercus nigra*). (E.)
LAUREL OAK (*Quercus laurifolia*). (E.)

The wood of the red oaks averages about as heavy as that of the white oaks. The sapwood is from 1 inch to 3 inches wide. The heartwood usually has a reddish tinge, although occasional pieces resemble white oak in color. The dry wood is without characteristic odor or taste, but unseasoned wood has a sour odor.

The annual rings average wider than in the white oaks, and as a rule are more distinct because the springwood consists of mostly open pores forming a porous ring from 2 to 4 (1 in narrow rings) pores wide. Black jack is an exception in that the springwood pores are mostly closed with tyloses as in the white oaks.

The pores in the summerwood are larger but less numerous than in the white oak group and can easily be counted under a hand lense. (Compare figs. 22 and 23.) An inspector should provide himself with a half-inch cube of heartwood of the white oak group and one of the red oak group, both showing rings of average width and cut smoothly across the ends. These cubes may be tied together, thus affording a convenient means of comparison.

CHESTNUT (*Castanea dentata*). (B, D.)

The wood of chestnut is moderately light and usually straight-grained. The sapwood is generally less than 1 inch wide. The heartwood is grayish brown, without characteristic odor but with a slight astringent taste due to the tannin in it.

The annual rings are made very distinct by a broad band of porous springwood, the pores being plainly visible without a lens. The pores in the summerwood are very numerous and arranged in irregular radial bands, similar to those in white oak. (See fig. 24.)

All the rays are very fine and not very distinct even with a lens.

The heartwood of the ashes, especially black ash, resembles chestnut somewhat; but the pores of the summerwood in the ashes are few and isolated; and never crowded and in radial bands, as in the chestnut. Plain-sawed oak is similar in appearance to chestnut but is much heavier and contains numerous broad and conspicuous rays.

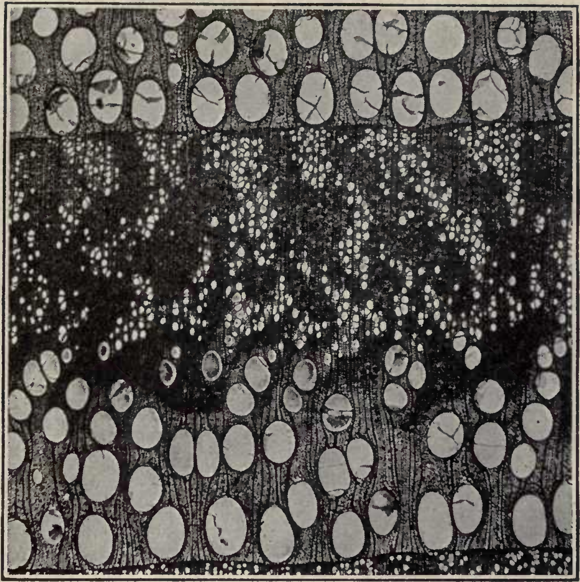

Fig. 24.—Chestnut. Cross section magnified 15 diameters.

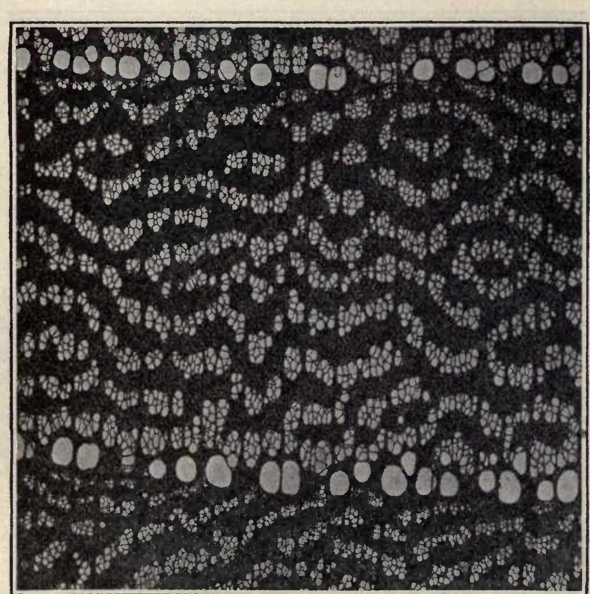

Fig. 25.—White elm. Cross section magnified 15 diameters.

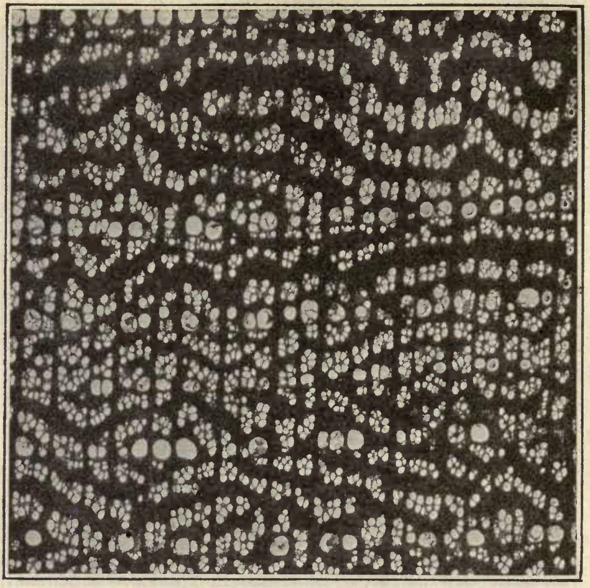

FIG. 26.—Cork elm. Cross section magnified 15 diameters

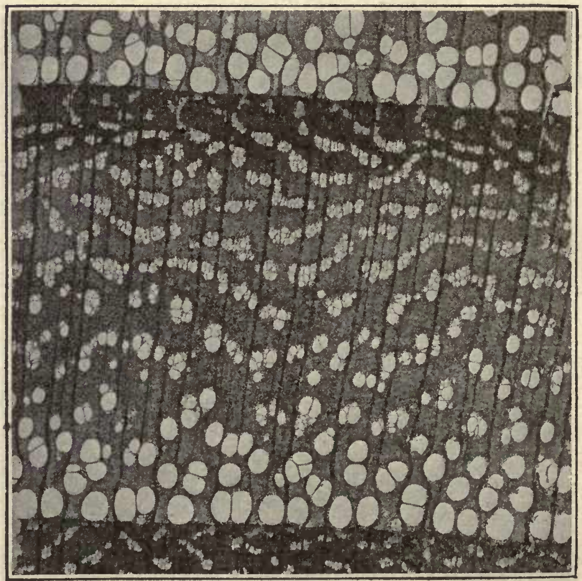

FIG. 27.—Slippery elm. Cross section magnified 15 diameters.

THE ELMS.

White Elm (*Ulmus americana*). (A, B, C, D, E.)
Slippery Elm (*Ulmus pubescens*). Red elm. (A, B, C, D, E.)
Cork Elm (*Ulmus racemosa*). Rock elm. (B. D.)

The wood of the white and slippery elms is moderately heavy and easy to work; that of the cork elm is heavier, harder, and ranks higher in mechanical properties.

The sapwood varies from about one-half inch wide in slippery elm to 2 or 3 inches wide in white elm, with cork elm intermediate. The heartwood is brownish, usually with a reddish tinge. The wood is considered practically tasteless and odorless, but slippery elm has a slight odor resembling that of the bark, which is familiar to many on account of its medicinal properties.

The annual rings are most conspicuously defined in slippery elm and least in cork elm. In slippery elm the springwood consists of several rows of large pores as a rule, but in white elm and cork elm only one row of large pores is present except in very wide annual rings. In cork elm the springwood pores are smaller than in white elm and usually filled with tyloses in the heartwood, so as to make them inconspicuous on a cross-section. (Compare figs. 25, 26, and 27.) This difference in the size and number of the pores of the springwood is probably the most reliable means of distinguishing the species of elm. The pores of the summerwood of all the elms are very numerous and joined in more or less continuous wavy tangential lines found in no other commercial wood except hackberry. Hackberry, however, has light gray heartwood tinged with green; and the rays are distinct without a lens, while in the elms they are not visible to the unaided eye.

Hackberry (*Celtis occidentalis*). Bastard elm. (B, D, E, F.)

The wood of hackberry is moderately heavy and fairly straight-grained. The sapwood is usually over 3 inches wide in saw logs and has a faint greenish yellow color or is blued with sap stain. The heartwood is light gray tinged with green. It is without characteristic odor or taste.

The annual rings are clearly defined but usually irregular in width and outline. The pores of the springwood are comparatively large, forming a zone several pores (in narrow rings one pore) wide. In the summerwood the pores are very numerous and arranged in more or less continuous wavy tangential lines as in elm. (See fig. 28.)

The rays in hackberry are distinct without a lens, which, together with the color, distinguishes it from the elms.

Sugarberry (*Celtis mississippienses*) (E and southern part of D) is very much like hackberry and is usually sold as such.

The sapwood of these species might be mistaken for ash sapwood, but the arrangement of the pores in the summerwood is entirely different. (Compare figs. 28 and 29.)

THE ASHES.

White Ash (*Fraxinus americana*). (A, B, C, D, E.)
Green Ash (*Fraxinus lanceolata*). (A, B, C, D, E.)
Black Ash (*Fraxinus nigra*). Brown ash. (A, C, and northern parts of B and D.)

The above three species comprise about 98 per cent of all the ash cut. The white ash and green ash are very much alike and are sold as "white ash" or "ash."

The sapwood of the white and green ashes is comparatively wide and white. The heartwood is grayish-brown, occasionally with a reddish tinge. In black ash the sapwood is narrow, usually less than 1 inch wide and the heartwood is silvery brown. Black ash averages considerably lighter in weight than the other two species. Ash wood, especially black ash, has a faint odor when worked, but for all practical purposes is considered odorless and tasteless.

All three species have definite annual rings made very conspicuous by several rows of large pores in the springwood. In the summerwood the pores are few, very small, and isolated, or occasionally two or three in a radial row. In the white and green ashes the summerwood pores are surrounded by light-colored tissue (parenchyma) which projects tangentially, producing light-colored lines often joining pores somewhat separated, especially in the outer portion of the annual ring. (This is not shown as clearly in the illustration of white ash, fig. 29, as it appears on a smoothly cut end surface.) In black ash wood the parenchyma is scant, and projects little, if any, from the pores. (Compare figs. 29 and 30.)

The rays in all the ashes are too fine to be distinctly visible without a lens.

Chestnut resembles the heartwood of the ashes, especially black ash, but is lighter in weight and has comparatively many pores in the summerwood, the pores being arranged in radial groups. (Compare figs. 24 and 30.) Elm can be distinguished from ash by the arrangement of the numerous summerwood pores in wavy tangential lines.

THE HICKORIES.

The following species of hickory are used commercially:

TRUE HICKORIES.

Shagbark (*Hicoria ovata*). (B, D, E.)
Big Shellbark (*Hicoria laciniosa*). (B, D.)
Pignut (*Hicoria glabra*). Black hickory. (B, D, E.)
Mockernut (*Hicoria alba*). (B, D, E.)

PECAN HICKORIES.

Bitternut (*Hicoria minima*). Pignut hickory. (A, B, D, E.)
Pecan (*Hicoria pecan*). (Western parts of D and E.)
Nutmeg Hickory (*Hicoria myristicæformis*). (E.)
Water Hickory (*Hicoria aquatica*). (E.)

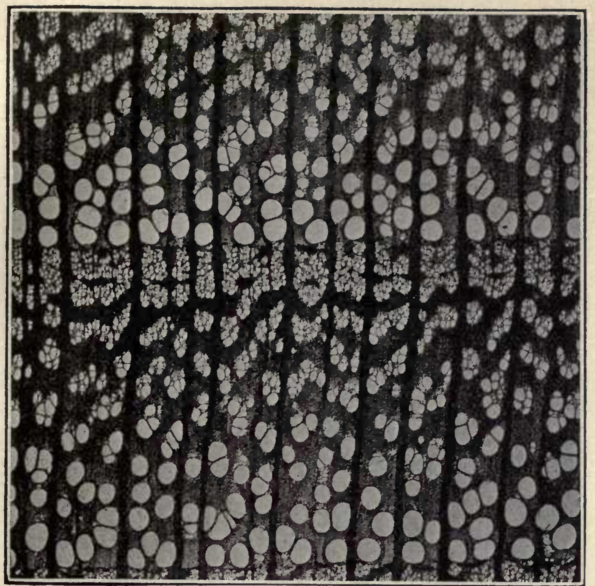

FIG. 28.—Hackberry. Cross section magnified 15 diameters.

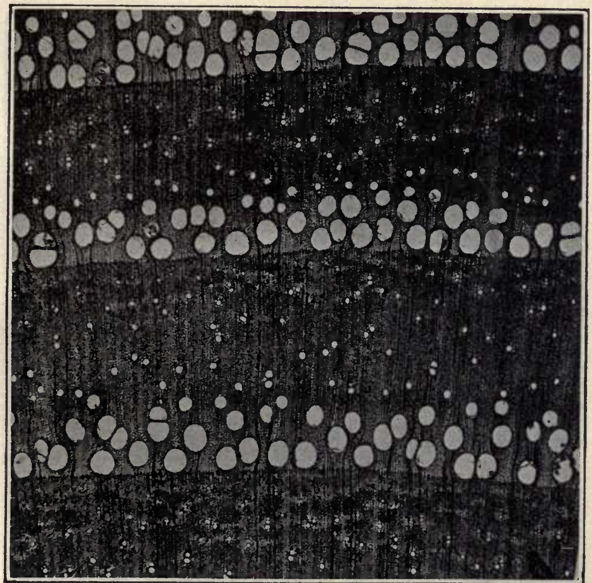

FIG. 29.—White ash. Cross section magnified 15 diameters.

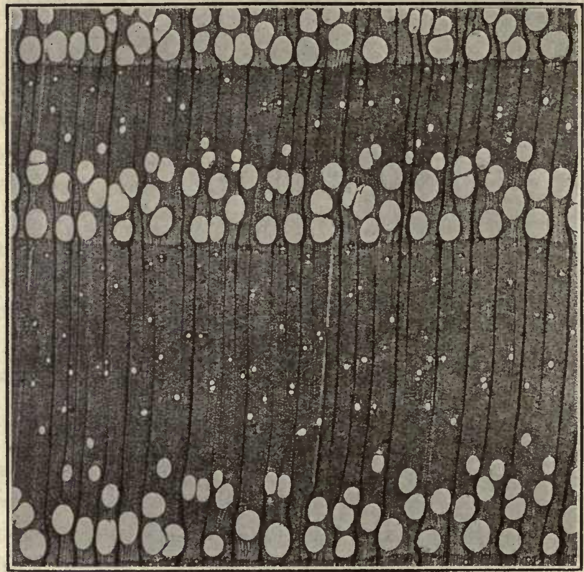

FIG. 30.—Black ash. Cross section magnified 15 diameters.

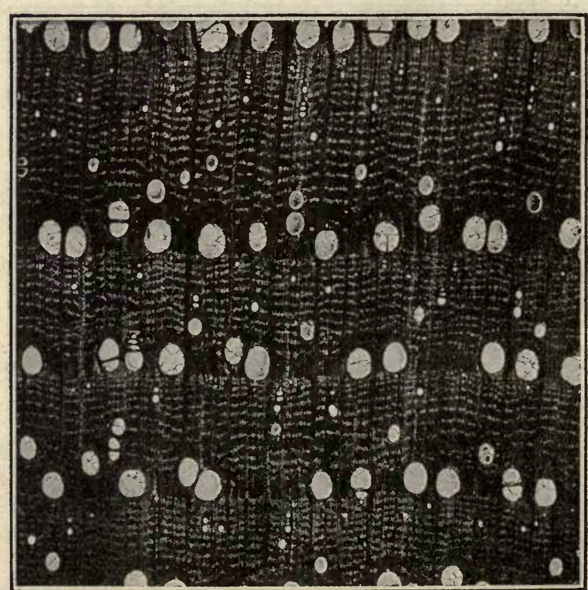

FIG. 31.—Shagbark (hickory). Cross section magnified 15 diameters.

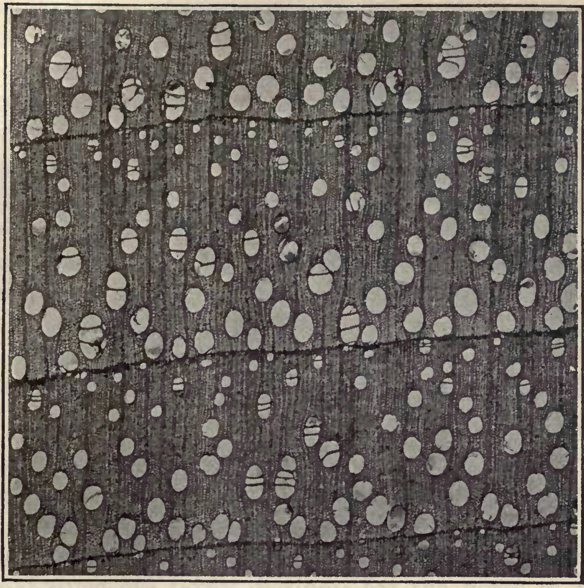

FIG. 32.—Black walnut. Cross section magnified 15 diameters.

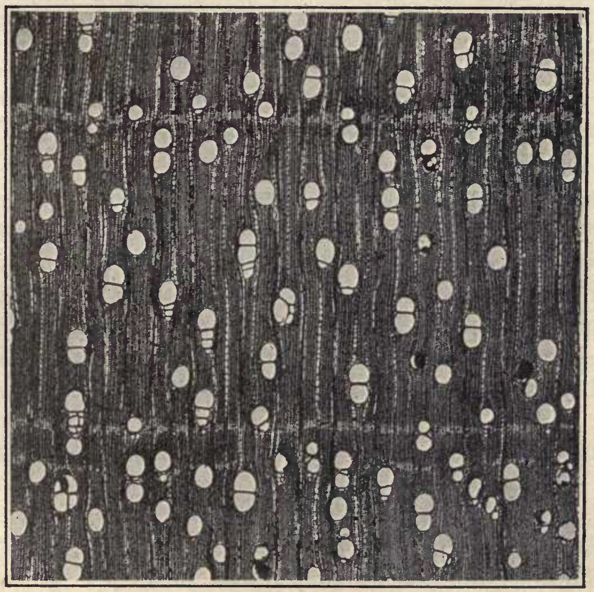

FIG. 33.—(True) mahogany. Cross section magnified 15 diameters.

The wood of the hickories is very heavy, hard, and tough as a rule, except water hickory, which usually is lighter in weight and not as strong. The sapwood is several inches wide. The heartwood is reddish-brown and is without characteristic odor or taste.

The annual rings are clearly defined by a zone of larger pores in the springwood, except in water hickory, in which the pores decrease in size only slightly in the summer wood thus making it diffuse-porous. The pores in the summer wood are few and isolated. The most characteristic feature of the hickories is the numerous fine, light-colored tangential lines (parenchyma) in each annual ring. A lens is necessary to see these lines distinctly. The rays are not visible without a lens. (See fig. 31.)

Hickory is not easily confused with other woods. The great hardness and fine lines of parenchyma distinguish it from other commercial woods.

BLACK WALNUT (*Juglans nigra*). (B, D, E.)

Black walnut is heavy, hard, and usually straight-grained. The heartwood has a rich chocolate-brown color. The sapwood is lighter colored but tinged with some of the color of the heartwood.

The annual rings are fairly distinct, for the pores in the springwood gradually decrease in size toward the outer limit of each annual ring. Most of the pores are visible without a lens, but the rays are very fine. (See fig. 32.)

The color and distinct pores are usually sufficient to distinguish black walnut from all other woods.

BUTTERNUT (*Juglans cinerea*), or white walnut. (A, B, D.)

Butternut resembles black walnut in structure but is lighter in weight, softer, and lighter colored, resembling black ash or chestnut in color.

(TRUE) MAHOGANY (*Swietenia mahogani*). (Native in southern Florida, southern Mexico, Central America, northern South America, and the West Indies.)

Mahogany has a lustrous reddish brown appearance turning darker on exposure to the air for a long time. It varies greatly in weight. The lighter pieces are often classed separately as "baywood." The wood is practically odorless and tasteless, which distinguishes it from Spanish cedar, or cigar-box cedar (*Cedrela odorata*), which has a characteristic odor.

The growth-rings (probably annual rings) are widely variable in width from one-thirty-second to one-half inch or more. They are defined by fine light-colored lines. (See fig. 33.) The pores are plainly visible without a lens and uniformly distributed throughout the growth-ring, appearing as grooves on the longitudinal surfaces. Numerous pores contain dark amber-colored gum. The rays are also distinct without a lens.

African mahogany resembles true mahogany more than any other species. It has about the same color and the pores are fully as distinct without a lens; but the fine light-colored lines which define the growth-rings are missing, thus affording an easy method of distinguishing the two species. (Compare figs. 33 and 34.)

Red gum and birch can be stained so as to imitate mahogany surprisingly well, but on close inspection it will be found that the pores of red gum and birch are not distinctly visible without a lens.

African Mahogany (*Khaya sp.*). (West coast of Africa.)

African mahogany is related to true mahogany in the same way that cigar-box cedar is; that is, it belongs to the same family but to a different genus. It resembles true mahogany in color, size of pores, medullary rays, and workability, but differs in having no well-defined growth-rings. (See fig. 34.) Occasionally narrow zones of less porous wood occur but these must not be confused with the sharply defined white lines found in true mahogany. The weight of the two species averages about the same.

Like true mahogany the African species has pores plainly visible without a lens, many of the pores containing a dark amber-colored gum.

Beech (*Fagus atropunicea*). (A, B, D, E, and eastern half of C.)

Beech is a heavy, hard wood, without characteristic odor or taste. The heartwood has a reddish tinge varying from light to moderately dark. The sapwood is usually several inches wide and passes gradually into the heartwood.

The pores are invisible without a lens and decrease in size, slightly and gradually, from the inner to the outer portion of each ring. (See fig. 35.)

Some of the rays are broad, being fully twice as wide as the largest pores and appearing on the radial surface as conspicuous reddish brown "flakes" about one-eighth inch wide with the grain. The other rays are very fine.

Maple resembles beech, except that in maple the widest rays are about the same width as the largest pores and not so conspicuous on the radial surface. Sycamore (*Platanus occidentalis*) resembles beech in structure; but the rays in sycamore are all broad and therefore appear more numerous, and the wood is considerably lighter in weight.

Black Cherry (*Prunus serotina*). (A, B, C, D, E.)

The wood of the black cherry is moderately heavy, fairly straight-grained, and without characteristic odor or taste. The sapwood is narrow. The heartwood has a lustrous reddish-brown color.

The annual rings are fairly well defined on account of the slightly larger pores of its springwood, which decrease in size gradually

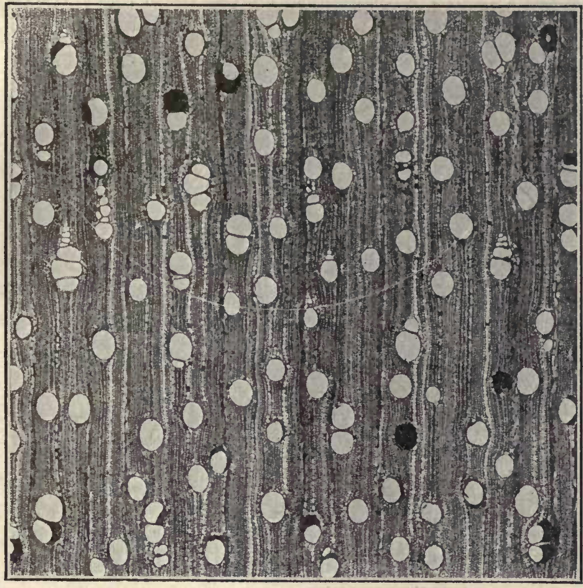

FIG. 34.—African mahogany. Cross section magnified 15 diameters.

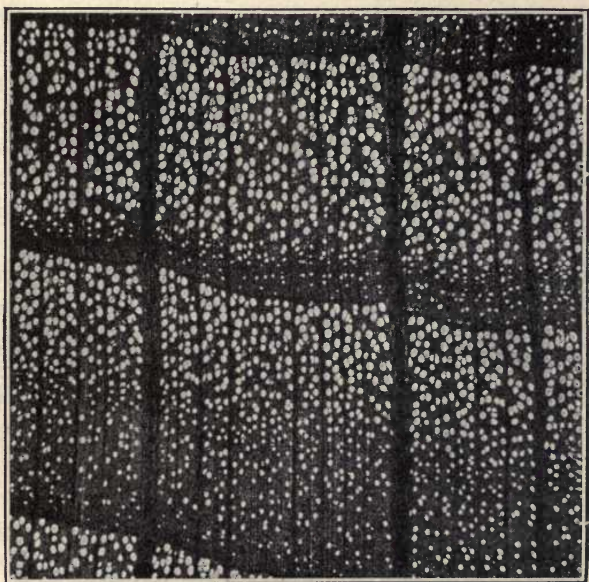

FIG. 35.—Beech. Cross section magnified 15 diameters.

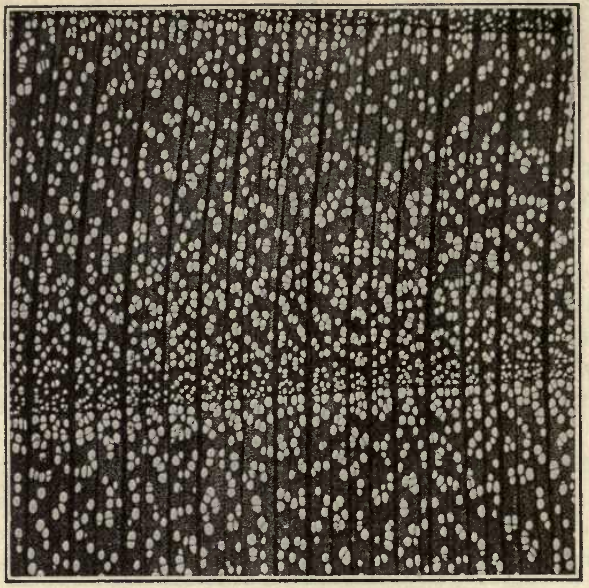

FIG. 36.—Black cherry. Cross section magnified 15 diameters.

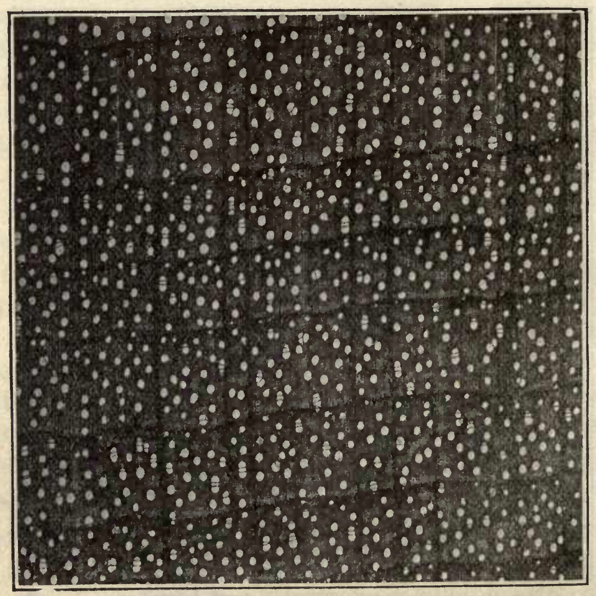

FIG. 37.—Sugar maple. Cross section magnified 15 diameters.

toward the outer limit of each annual ring. The pores are not visible without a lens.

The rays are very distinct on the end surface, the larger ones being as wide as the largest pores. (See fig. 36.)

Cherry is easily distinguished from most other woods by its color. Mahogany has a similar color, but the pores in mahogany are easily visible without a lens.

THE MAPLES.

Sugar maple (*Acer saccharum*) is heavy, hard, and difficult to cut across the grain, in which respects it differs from the soft maples, silver maple (*Acer saccharinum*—A, B, D, E), and red maple (*Acer rubrum*—A, B, D, E, and eastern half of C), which are not quite as heavy and hard. The sapwood is wide in all the maples, and is often sold separately as "white maple." The heartwood is light reddish brown, without characteristic odor or taste.

The annual rings are defined by a thin reddish layer usually more conspicuous on dressed longitudinal surfaces.

The pores are all very small and uniformly distributed throughout the annual rings. (See fig. 37.)

The rays are very distinct without a lens, and under a lens the largest ones appear fully as wide as the largest pores. On radial surfaces the rays are conspicuous as small reddish brown "flakes" about one-thirty-second to one-sixteenth inch wide with the grain. In sugar maple only part of the rays are as wide as the pores; the others are very fine, being barely visible with a lens. In both the soft maples all the rays are broad, although usually not quite so broad as the large ones of sugar maple. However, they give the appearance of being more numerous. This is a rather fine distinction and an inspector should have samples for comparison.

Birch and beech resemble maple somewhat, although a little experience with the woods will readily show the difference. Birch has larger pores, visible as fine grooves on dressed surfaces, and the rays on the end surface are not distinctly visible without a lens. In beech some of the rays are very conspicuous, being fully twice as wide as the largest pores, and the pores decrease in size and number toward the outer part of each annual ring.

THE BIRCHES.

YELLOW BIRCH (*Betula lutea*). Gray birch. (A, B, C.)
SWEET BIRCH (*Betula lenta*). Cherry birch. (A, B, D.)

The woods of the yellow birch and sweet birch are so much alike that as a rule no distinction is made between the two. The yellow birch is the more abundant of the two. The heartwood of both is marketed as "red birch" and the sapwood as "yellow birch." The wood is heavy, fairly straight-grained, and without characteristic odor or taste. The sapwood is wide and almost white. The heartwood is light to moderately deep reddish-brown.

The annual rings are rather indistinct. The pores are of almost uniform size throughout the annual rings and barely visible under a good light and on a very smoothly cut end surface. (See fig. 38.) On dressed longitudinal surfaces the pores appear as fine grooves. The rays are not distinct without a lens.

Maple is occasionally confused with birch; but the two are easily distinguished by the fact that in maple the pores are much smaller and the rays wider, being very distinct without a lens.

Red Gum (*Liquidambar styraciflua*). Sweet gum. (B, southern part of D, E.)

Red gum is moderately heavy, somewhat lock-grained, and without characteristic odor or taste. The sapwood (sold as "sap gum") is highly variable in width. It is white with a pinkish hue or often blued with sap stain. The heartwood is reddish brown, often with irregular darker streaks. The wood has a very uniform structure. The annual rings and pores are not distinct to the unaided eye, but the rays are fairly distinct without a lens. (See fig. 39.)

The uniform structure, interlocked grain, and reddish-brown color are usually sufficient to distinguish red gum from other woods.

Yellow Poplar (*Liriodendron tulipifera*). Whitewood, Tulip poplar. (B, D, E.)

Yellow poplar is moderately light, straight-grained, and without characteristic odor or taste. The sapwood is from 1 inch to several inches wide. The heartwood is light to moderately dark yellowish-brown with a greenish tinge.

The annual rings are limited by light-colored lines. The pores are evenly distributed throughout the annual ring, and are too small to be visible with the unaided eye. The rays are distinct without a lens. (See fig. 40.)

Cucumber (*Magnolia acuminata*) is easily confused with yellow poplar and is usually sold as such, although it averages slightly heavier in weight. It grows in the same region, except Florida and the South Atlantic coast.

Basswood (*Tilia americana*). Linden. (A, B, C, D, E.)

Basswood is a light, soft, straight-grained wood with a creamy brown color. The heartwood is not clearly defined from the sapwood. It is without taste, but has a slight characteristic odor even when dry.

The wood is diffuse-porous, the pores being invisible without a lens. The rays are fairly distinct on the end surface and often conspicuous on the radial surface. (See fig. 41).

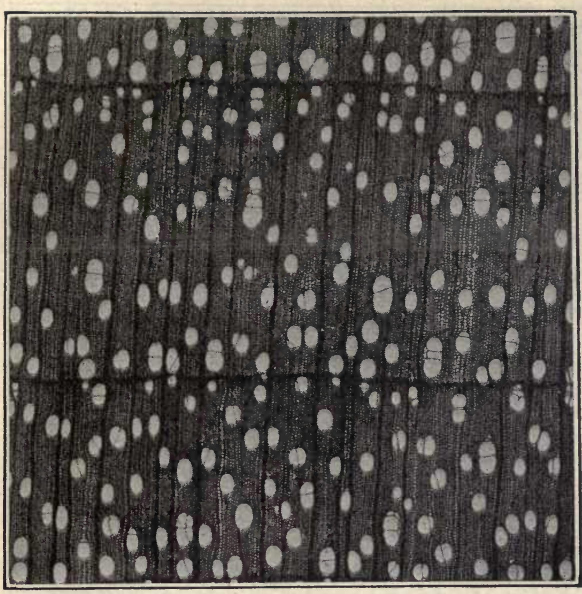

FIG. 38.—Yellow birch. Cross section magnified 15 diameters.

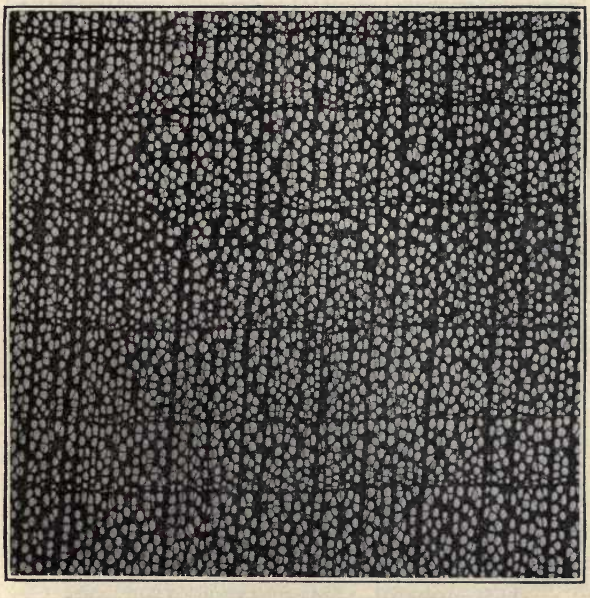

FIG. 39.—Red gum. Cross section magnified 15 diameters.

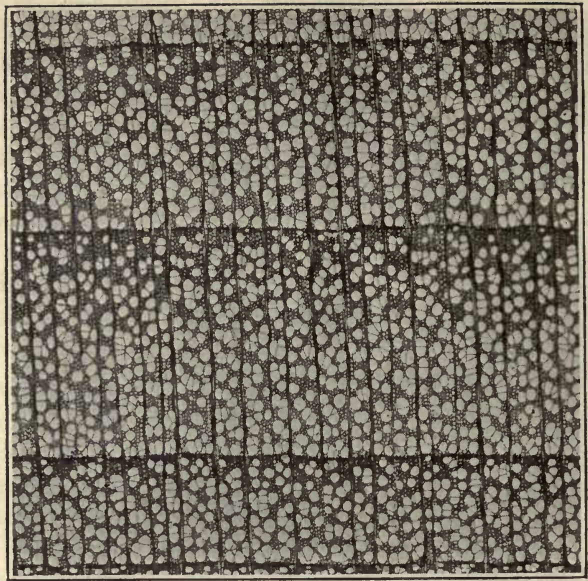

FIG. 40.—Yellow poplar. Cross section magnified 15 diameters.

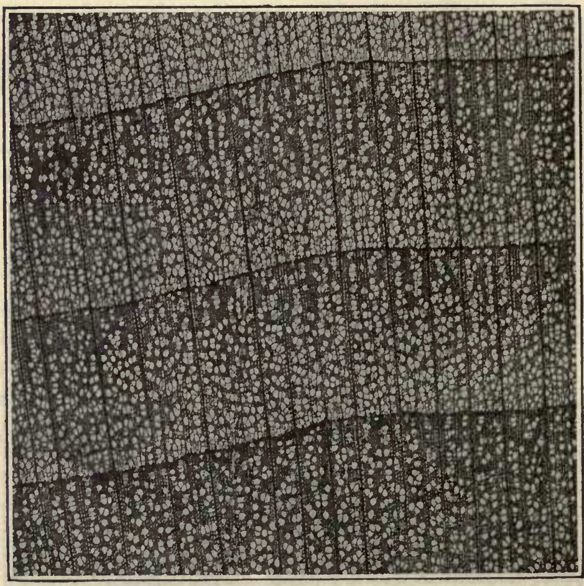

FIG. 41.—Basswood. Cross section magnified 15 diameters.

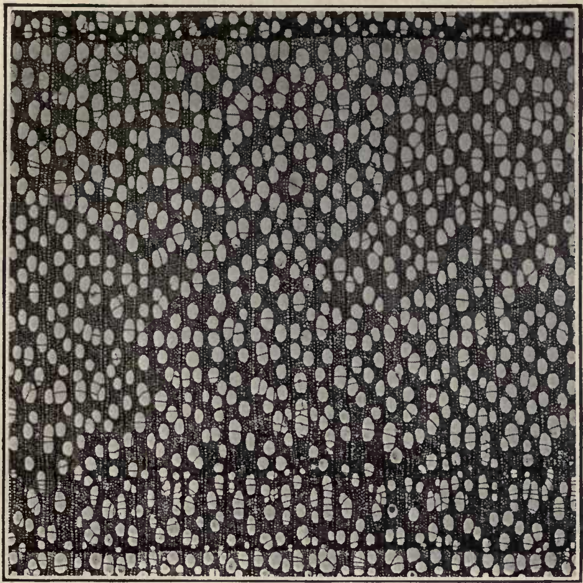

FIG. 42.—Cottonwood. Cross section magnified 15 diameters.

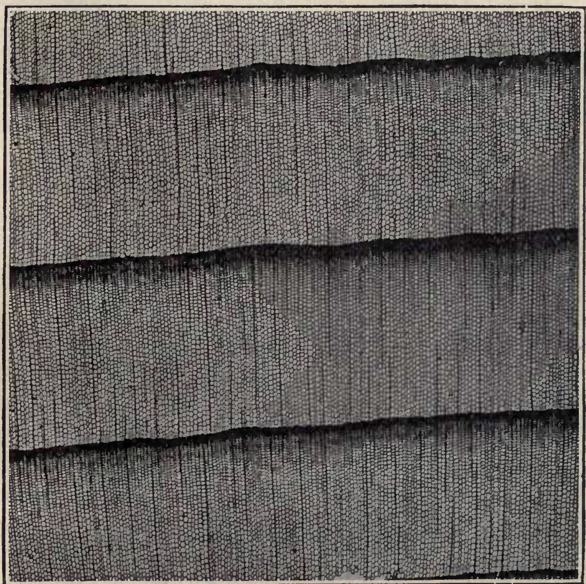

FIG. 43.—Western red cedar. Cross section magnified 15 diameters.

Cottonwood resembles basswood, but is more grayish in color, has larger pores, and very fine rays not visible without a lens. Buckeye (*Æsculus octandra*, B, D) resembles basswood in color and texture, except that the rays are much finer and are visible only with a good lens.

COTTONWOOD (*Populus deltoides*). Poplar. (B, C, D, E, F.)

Cottonwood is light and fairly straight-grained (occasionally somewhat cross-grained). The straight-grained lumber warps less, and is believed to come from old slow-growing trees known as "yellow cottonwood" in distinction from the "white cottonwood," which usually has wide annual rings and is more subject to warping. Cottonwood is without taste but has a slight characteristic odor. The heartwood is light grayish-brown not clearly defined from the sapwood.

The wood is diffuse-porous, the pores being very numerous and, under favorable conditions, barely visible without a lens, appearing as fine grooves on finished lumber. The rays are very fine, barely visible with a lens. (See fig. 42.)

Cotton gum, or tupelo (*Nyssa aquatica*, E), resembles cottonwood, but usually is heavier, and has smaller pores. Yellow poplar is similar in weight and hardness, but its greenish tinge usually distinguishes it. Basswood has more of a creamy white color, smaller pores, and more distinct rays.

The swamp cottonwood (*Populus heterophylla*) of the Southern States and the black cottonwood (*Populus trichocarpa*) found west of the Rocky Mountain region have the same appearance and properties as the common cottonwood (*Populus deltoides*).

CONIFERS.

THE CEDARS.

Western red cedar (*Thuja plicata*, H) is light and straight-grained. The sapwood is rarely over 1 inch wide. The heartwood is reddish-brown, with the characteristic odor of cedar shingles and a somewhat bitter taste when chewed. The wood is not "pitchy" and contains no resin ducts, although it contains a slight quantity of aromatic oils

The annual rings are distinct, moderate in width, with a thin, but well-defined band of summerwood. Pores are entirely absent, and the rays are very fine. (See fig. 43.)

Arbor-Vitæ (*Thuja occidentalis*), or northern white cedar (A, B, C), resembles the western red cedar in odor and taste, but usually it is without the reddish hue, has very narrow annual rings, and averages lighter in weight.

Incense Cedar (*Libocedrus decurrens*) (southern half of H and I), is also very similar to the western red cedar, although it has wider sapwood as a rule. Particles of amber-colored resin in the cells, as seen on the radial surface with a good hand lens, are abundant in incense cedar, but almost absent in the western red cedar. Incense cedar has more of the spicy odor and taste, and the wood is firmer than that of the western red cedar; but these distinctions are relative and can be applied only by comparing samples of the two species.

The wood of Port Orford Cedar (*Chamæcyparis lawsoniana*) (H), also known as Lawson cypress, is moderately light, straight-grained, and with a pronounced spicy odor and taste. The sapwood is not clearly defined from the heartwood because of the pale-brown color.

The summerwood is not dense and hard, as in many coniferous woods, and the springwood is a little firmer than in the western red cedar, thus making Port Orford cedar a wood very uniform in structure and less spongy than some of the other cedars. (See fig. 44.)

The odor and light-brown color are usually enough to identify Port Orford cedar.

Yellow Cedar (*Chamæcyparis nootkatensis*), or Alaska cypress (H), resembles Port Orford cedar in weight, structure, and odor, but is almost clear yellow in color.

THE WHITE PINES.

Eastern White Pine (*Pinus strobus*). (A, B, C.)
Western White Pine (*Pinus monticola*). Idaho white pine. (F, H, I.)

The above two species of the white-pine group are very similar in the character of the wood. They are moderately light, straight-grained, and practically tasteless, but have a slight, yet distinct, resinous odor. The sapwood varies from one to several inches in width. The heartwood is creamy-brown to light reddish-brown, especially reddish at knots.

The annual rings are distinct, but the summerwood is not a pronounced darker or appreciably harder layer. Through a lens the resin ducts appear on the end surface as specks, or minute openings (see fig. 45) and on the longitudinal surfaces often as yellowish-brown lines. Exudations of resin are common.

Since the eastern and western white pines are very similar in appearance and properties, it is not necessary to distinguish between the two commercially. The outer portion of western yellow-pine logs has narrow annual rings with a very thin layer of summerwood (see fig. 21), approximating the white pines in appearance, and is often sold as "white pine." However, it can be distinguished by its horny, glistening layer of summer wood, especially in the wider rings in which it is more conspicuous (compare figs. 45 and 47).

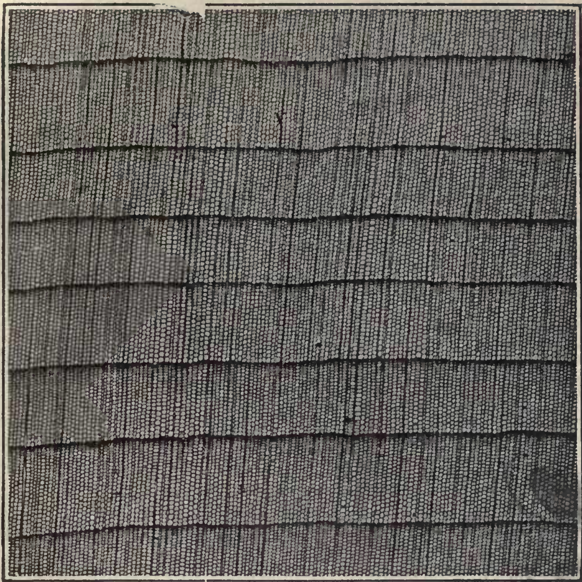

FIG. 44.—Port Orford cedar Cross section magnified 15 diameters

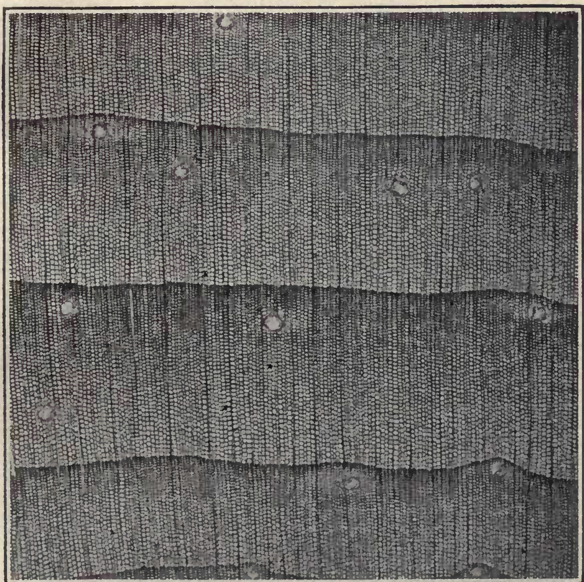

FIG. 45.—Western white pine. Cross section magnified 15 diameters.

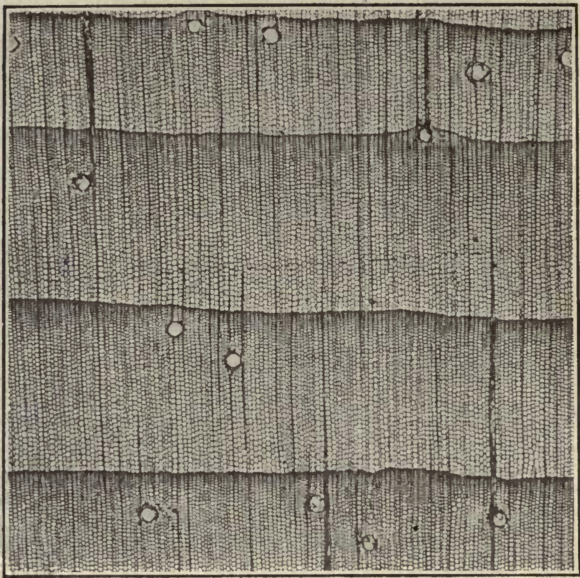

FIG. 46.—Sugar pine. Cross section magnified 15 diameters.

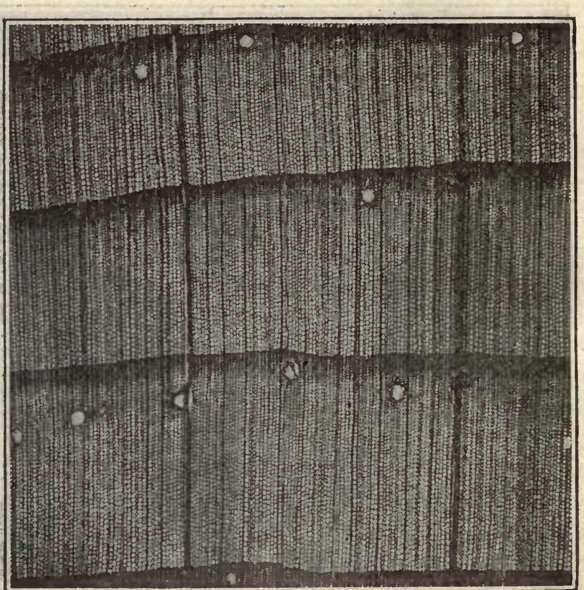

FIG 7 —Western yellow pine. Cross section magnified 15 diameters.

Often the summerwood is more distinct on the longitudinal surface; and in a shipment of western yellow-pine lumber numerous boards with conspicuous layers of summer wood may be found.

SUGAR PINE (*Pinus lambertiana*). (I.)

Sugar pine is very much like the white pines in structure and properties, and in fact belongs to the white-pine group botanically. The sapwood is from one to several inches wide. The heartwood is very light brown, only slightly darker than the sapwood and practically never reddish, as is the case quite often in the white pines. Brown stain is common, and is caused by drying the lumber under certain conditions. The summerwood never appears as a horny, glistening band as in the hard pines.

The wood of sugar pine has a slightly coarser texture than that of white pine; that is, the fibrous cells and also the resin ducts have a greater average diameter. The distinction is rather fine, however, to use without a compound microscope. (See fig. 46.) On a longitudinal surface the resin ducts are usually more conspicuous as brownish lines, but in some pieces no more so than in the white pines.

Resinous exudations, which become granular and have a sweetish taste, are quite common in sugar-pine lumber, and when present are the most reliable means of distinguishing it from other pines.

THE YELLOW OR HARD PINE GROUP.

WESTERN YELLOW PINE (*Pinus ponderosa*). "California white pine." (F, G, H, I.)
NORWAY PINE (*Pinus resinosa*). Red pine. (A, C, and northern half of B.)
SHORTLEAF PINE (*Pinus echinata*). (E.)
LOBLOLLY PINE (*Pinus tæda*). (E.)
LONGLEAF PINE (*Pinus palustris*). (E.)

The yellow pines are mostly heavier, harder, more resinous, and contain a wider and harder layer of summerwood than the white pines. However, exceptions occur, notably western yellow pine, which in the outer part of the mature trees is often as light in weight as the average white pine. The sapwood is variable in width in the different species and even in the same species, averaging narrowest in longleaf pine. The heartwood is orange-brown to reddish-brown in color.

The summerwood is usually defined as a conspicuously denser, harder, and darker band of rings of average width (see Shortleaf pine in Pl. II, opposite p. 50); but in very narrow rings, such as are found in the sapwood of old trees of western yellow pine, the summerwood layer is very narrow and inconspicuous. (See figs. 21 and 47.)

The resin ducts are plainly visible with a lens on a smoothly cut end surface, and often appear as brownish lines on the longitudinal surfaces. Exudations of resin are common in the yellow pines.

No reliable means of distinguishing all the yellow pines without a compound miscroscope is known. The order in which the above species are listed indicates on the average their relative weight, increasing from western yellow pine to longleaf pine. Exceptions occur, however; for instance, some shortleaf pine is heavier than the average longleaf.

Douglas fir is somewhat similar to yellow pine in appearance, but usually has a distinct reddish hue as contrasted with the orange-brown color of yellow pine (see also Douglas fir).

DOUGLAS FIR (*Pseudotsuga taxifolia*). Oregon pine. Douglas spruce. (F, G, H, I.)

Douglas fir differs from other firs (white fir, noble fir, grand fir, balsam fir, etc.) in being resinous, heavier, stronger, and in having a distinctly darker heartwood. The heartwood has a reddish hue, usually quite pronounced although in old coast firs the outer part of the heartwood is less reddish and is marketed as "yellow fir." The sapwood is from one to several inches wide.

The annual rings are made distinct by a conspicuous band of summerwood. Resin ducts are present but not so distinct as in the pines, usually appearing as whitish specks in the summerwood. Often several ducts are in short, tangential rows, a feature never found in the pines. (Compare figs. 47 and 48.) Exudations of resin are common or can usually be made to appear slightly by warming the wood.

The wood of western larch (*Larix occidentalis*) (F, H) resembles that of Douglas fir considerably, but has narrower sapwood (rarely over 1 inch) and lacks the reddish color of the fir. The resin ducts in the two species are of about the same character, although the fir is more resinous as a rule. With a compound miscroscope Douglas fir can easily be distinguished from all other commercial woods by the presence of fine spirals in the cells, similar to the thread in a nut. This can be seen on a longitudinally split surface without preparing a miscroscopic slide.

SPRUCE.

WHITE SPRUCE (*Picea canadensis*). (A, B, C.)
RED SPRUCE (*Picea rubens*). (A, B.)
SITKA SPRUCE (*Picea sitchensis*). Tideland spruce. (H.)

The spruces are moderately light, straight-grained woods. In the white spruce and red spruce the heartwood is as light colored as the sapwood, but in Sitka spruce the heartwood has a light reddish tinge, making it a little darker than the sapwood.

The annual rings are clearly defined by a distinct, but not horny, band of summerwood. Spruce resembles the white pines in texture, but the resin ducts are fewer and smaller in spruce (compare figs. 44 and 48), usually appearing as whitish specks in the summerwood.

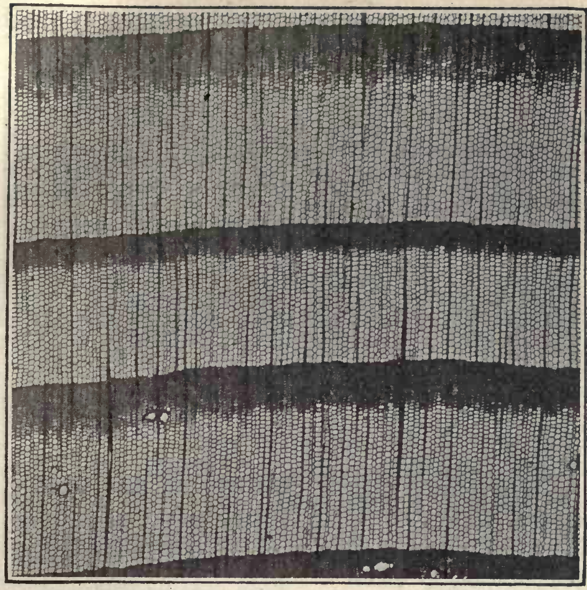

FIG. 48.—Douglas fir. Cross section magnified 15 diameters.

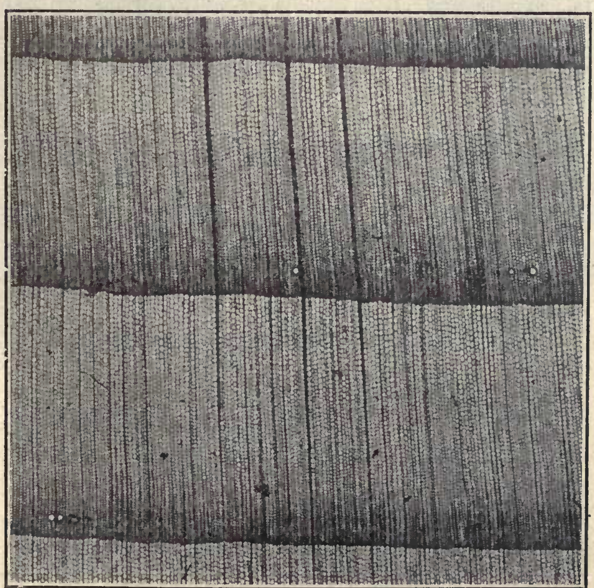

FIG. 49.—Sitka spruce. Cross section magnified 15 diameters.

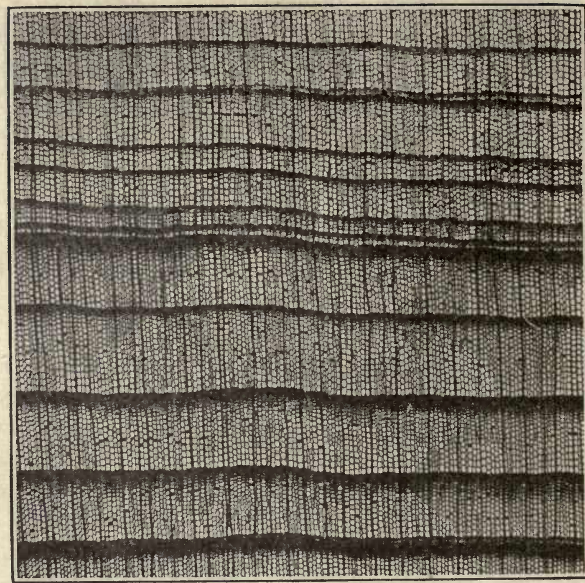

FIG. 50.—Bald cypress. Cross section magnified 15 diameters.

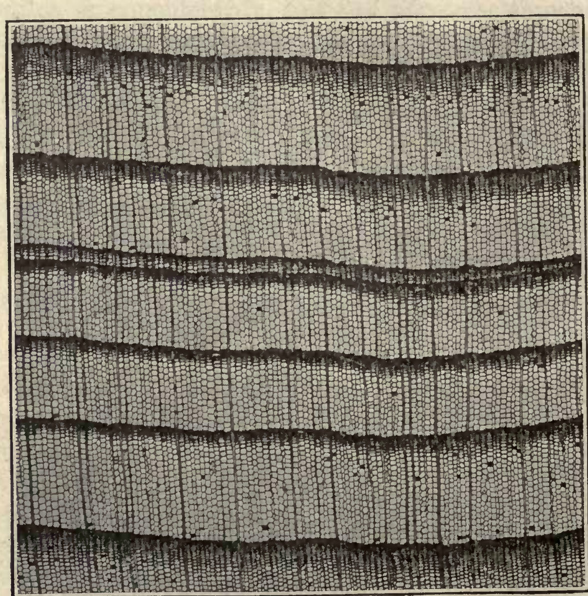

FIG. 51.—Redwood. Cross section magnified 15 diameters.

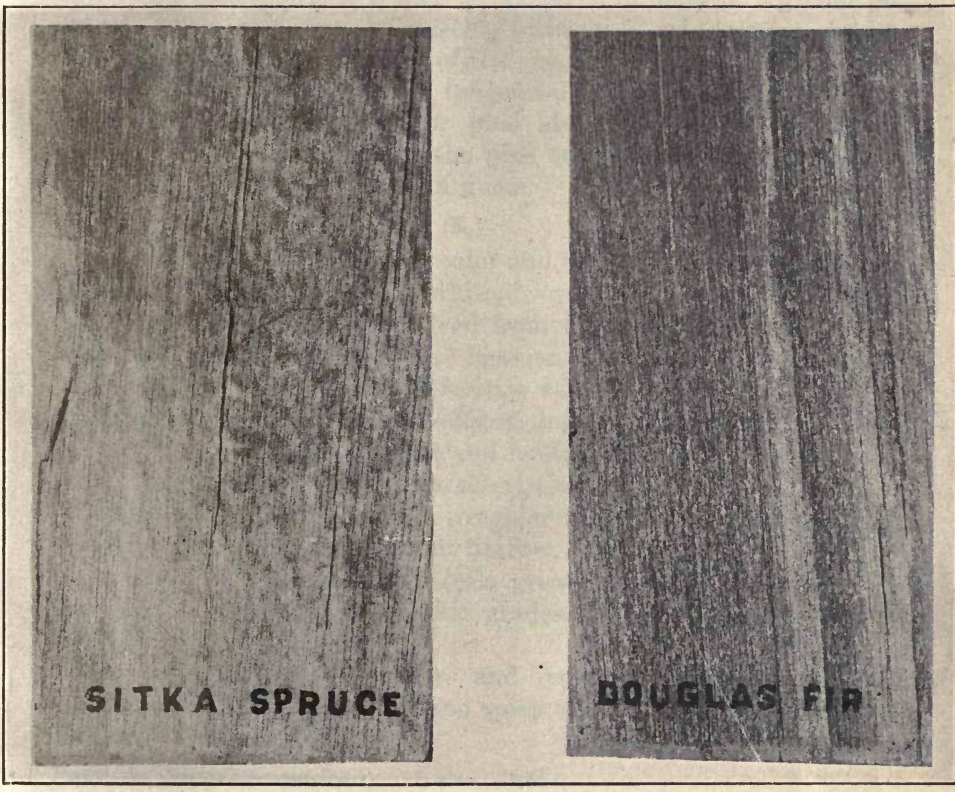

FIG. 52.—Split tangential surfaces of Sitka spruce and Douglas fir showing the "pocked" or dimpled appearance of the spruce not found in Douglas fir. This characteristic is most pronounced in Sitka spruce with narrow rings and is almost entirely absent in very wide-ringed material.

Pitch pockets are occasionally found in spruce, and slight exudations of resin occur on cuts made before seasoning the wood.

On account of its reddish tinge, Sitka spruce might be confused with light grades of Douglas fir. However, the fir has denser summerwood except in very narrow rings; therefore, rings of average width should be compared. Tangentially split surfaces of Sitka spruce usually have numerous slight indentations which give it a "pocked" or dimpled appearance never found in Douglas fir (see fig. 50). This characteristic is more pronounced in material with narrow annual rings, and may be missing entirely in wide-ringed spruce, especially that near the center of the tree. Occasionally, the eastern spruces also show this uneven tangential surface to a slight extent. Some trees of western yellow pine also develop this "pocked" appearance of the wood, but the pine can be distinguished by the larger and more numerous resin ducts.

Bald Cypress (*Taxodiun distichum*). (E.)

Cypress is highly variable in color and weight. Commercially, the wood is often classified as, "white," "yellow," "red," or "black" cypress, although it is all derived from the same botanical species. As a rule, the darker grades are heavier, but this is not always the case. The wood has a characteristic rancid odor when fresh. In dry wood the odor is less pronounced, but can be detected by whittling it or, better yet, sawing it and holding the sawdust to the nostrils. The wood is without characteristic taste.

The annual rings usually are irregular in width and outline. The summerwood is very distinct but narrow, although wider than in the cedars (see fig. 50). Cypress feels greasy or waxy to the touch, especially the heavier and darker grades. Resin ducts and exudations of resin are absent.

Cypress resembles the cedars and redwood somewhat; but the cedars have an aromatic odor and spicy taste, and redwood is tasteless and odorless.

Redwood (*Sequoia sempervirens*). (I, along coast.)

Redwood is moderately light, straight-grained, and obtainable in large clear pieces. The heartwood is deep reddish-brown in color as a rule. Occasionally, lighter colored pieces, resembling western red cedar, are found.

The wood contains no resin ducts. The annual rings are made very distinct by a narrow but dense band of summerwood alternating with soft, spongy springwood (see fig. 51). Redwood is without characteristic odor or taste. The lack of these distinguishes it from the cedars, which it resembles in appearance and properties.

Publications on the Nomenclature, Occurrence, and Structure of American Woods.

1. Government publications.

Check List of Forest Trees of the United States. Forest Service Bulletin 17. 1898. 15 cents.

Timber: An Elementary Discussion of the Characteristics and Properties of Wood. Forest Service Bulletin 10. 1895. 10 cents.

Guide Book for the Identification of Woods Used for Ties and Timbers. Special Forest Service Publication. 1917. 30 cents.

NOTE.—The above publications may be obtained at the prices indicated from the Superintendent of Documents, Government Printing Office, Washington, D. C.

2. Papers prepared by the Forest Products Laboratory and published in various journals:

A Visual Method of Distinguishing Longleaf Pine (for pieces containing the pith), by Arthur Koehler.
 American Lumberman, September 11, 1915.
 Engineering Record, September 11, 1915.

Pyloses: Their Occurrence and Practical Significance in Some American Woods, by Eloise Gerry.
 Journal of Agricultural Research, May 25, 1914.

A Plea for Closer Discrimination in the Use of the Words "Grain" and "Texture" with respect to Wood, by Arthur Koehler.
 Hardwood Record, February 25, 1917.

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