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PROPERTIES OF WOOD RELATED TO DRYING

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PROPERTIES OF WOOD RELATED TO DRYING[1]

Information on the Seasoning Characteristics of Wood Helpful in Understanding Kiln-drying Problems

By

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There are more than 150 different species of wood in the United States, each having its own drying characteristics. About 72 of these are commercially important, and information is available on how they can best be kiln-dried. There are many irregularities in the normal wood of all species, and since their drying characteristics and irregularities are important in the kiln-drying of wood, the kiln operator should have some general knowledge about them.

Softwoods and Hardwoods

Trees are divided into two general classes, softwoods and hardwoods. The softwoods are needle-leaved trees such as the pines, Douglas-fir, the spruces, hemlock, true firs, and cypress. The hardwoods are broad, flat-leaved trees such as birch, elm, maple, the oaks, aspen, walnut, and the gums. The softwoods are usually easier to kiln-dry than the hardwoods. More severe drying conditions can be safely used, and the time required to dry woods such as southern yellow pine is considerably less than that required to kiln-dry oak to the same moisture content.

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[1]This chapter of a Dry-kiln Operator's Manual was prepared by Edmund F. Rasmussen with the assistance of other members of the Division of Timber Physics, Forest Products Laboratory. The information was obtained from various sources, including the results of research conducted by the Laboratory during the past 40 years.

[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Gross Structural Features

A cross section of an oak log is diagrammed in figure 1. The very outer portion of the tree is the bark, C. Just beneath the bark is a layer called the inner bark, B, and beneath it is the cambium, A. The bark, inner bark, and cambium have no effect on drying, except that where the bark is intact drying is slower.

Sapwood (fig. 1, D).--Sapwood plays an important part in the tree's growth activity because it contains active cells. In general, only the last few outside layers of the sapwood carry on any great amount of living activity. The balance of the sapwood functions in the moisture relationships and food-storage activities of the tree. Therefore, its moisture content is usually much higher than the moisture content of the heartwood. Sapwood, however, can be dried more easily and loses moisture more rapidly than heartwood.

Heartwood (fig. 1, E).--Certain structural and chemical changes occuring during the life of a tree change the sapwood to heartwood. Heartwood does not assist in the living activities of the tree. It does, however, support the tree. The structural and chemical changes do not all take place at the same time. One of the first changes to occur when sapwood changes to heartwood is a reduction in porosity. This retards moisture movement considerably, so that heartwood dries much more slowly than sapwood. Because it usually surface checks and honeycombs more readily than sapwood, it requires milder drying conditions. Other changes include the darkening of the wood and, in some woods, more resistance to decay. The decrease in the rate of moisture movement may take place several years before the wood changes color. Therefore a band of heartwood next to the sapwood may have the same color as the sapwood but not dry so easily.

Pith (fig. 1, F).--The pith of a tree is laid down by the growing tip. It is usually very small and of no practical importance in the drying of wood. The wood immediately around the pith, however, differs in some ways from most of the wood in the tree, and it is almost impossible to dry such wood without drying defects.

Annual rings.--Diameter growth of a tree in temperate climates is represented by rings that usually can be easily seen on an end section of a tree or log as concentric circles with the pith as the center. Each annual ring is composed of springwood and summerwood. The inner portion, which is formed first, is called the springwood, and the outer portion, which is formed last, is called the summerwood. When lumber is cut from a log, the annual rings are cut across in one direction or another and form a pattern on the broad faces of the boards. These patterns are shown in figure 2. They are called plain-sawed and quarter-sawed. A palin-sawed board shows the side of the rings on the broad face (fig. 2, B), and a quarter-sawed board shows the edge of the rings on the broad face (fig. 2, A). The closer the annual rings are to the pith, the greater their degree of curvature (fig. 1). Boards cut nearer the pith will tend to split and warp more than boards cut from the outer portions of the log.

Wood rays (fig. 1, G).--Wood rays as seen on the face of a quarter-sawed board, are ribbonlike strands of cells that run at right angles to the annual rings. They are weaker than most of the wood. Because of this weakness, surface checks end checks, and honeycombs usually start in or next to the rays. Woods such as oak and beech have particularly large rays and require special care during initial drying so as to minimize surface checking. Where rays are prominent, they form patterns or figures on the broad faces of quarter-sawed boards (fig. 2).

Grain and texture.--The physical characteristics of various woods, as determined by the growth structure, that have some bearing on drying characteristics are loosely termed "grain" and "texture." Several additional terms are used in describing grain. The terms "fine-grained" and "coarse-grained" refer to the ring pattern, either the prominence of the summerwood band or the width of the annual rings. When used in connection with the wood cells, grain refers only to the direction of the cells or "fibers." In straight-grained wood the fibers, in general, run parallel with the length of the board. In cross-grained wood they run at an angle to the length of the board. The terms "end grain" and "side grain" are also commonly used in discussing moisture loss and seasoning defects. A cross section of a log or board has an end-grain surface. Any other section, radial, tangential, or intermediate, has a side-grain surface. Water moves more rapidly from the end-grain than from the side-grain surfaces. Therefore the tendency to check is greater at the end of a board.

Texture usually refers to the diameter of individual cells. A fine-textured wood has small cells; a coarse-textured wood has large cells. If all the cells of a softwood, or all the pores of a hardwood, are approximately the same size, the wood is usually called "uniform-textured." If the weight of two samples of wood from the same species varies considerably, the heavy sample is often called "hard-textured" and the light sample "soft-textured." Coarse-texture woods usually dry faster than fine-texture woods. Uniform-texture woods, in general, are less subject to drying defects than are nonuniform-texture woods.

Irregularities in structure.--Trees commonly have a number of irregularities such as knots, spiral grain, tension wood, and compression wood. Irregularities in grain are also caused in lumber by the way in which the lumber is sawed from the log.

Cross grain may either be the result of the way in which the log is sawed or of spiral grain that occurs in the tree while it is growing. When the direction of the spiral grain alternately runs in one direction, then in another direction interlocked grain results. Lumber containing cross, spiral, and interlocked grain shrinks more in length than does straight-grained lumber. This causes bowing, crooking, and twisting.

Knots are grown-over parts of branches of the tree. Because of differences in shrinkage these knots sometimes drop out after drying. More often, however, they are loosened or checked during drying and drop out of the boards during planing.

Compression wood is abnormal wood that forms on the under side of leaning softwood trees and limbs. Because this wood shrinks more longitudinally than normal wood, bowing and crooking result. If this warping is restrained, the compression wood may fail and form cross breaks in the lumber.

Tension wood develops on the upper side of leaning hardwood trees. Lumber containing this wood will also shrink more longitudinally than will normal wood, and it will produce the same defects as compression wood.

Wood-moisture Relations

All wood in growing trees contains water, commonly called "sap." From the drying standpoint, the sap is considered to be plain water, although the materials dissolved in the sap may sometimes be of commercial importance; for example, the sugar of sugar maple. Most of the water in green wood must be removed in order to obtain satisfactory performance in use. Because all wood gains and loses moisture in an attempt to reach a state of balance with the conditions under which it is stored or used, it always contains some water. The amount of water it contains depends upon the relative humidity and temperature of the surrounding air. Therefore some knowledge of the relationships between wood and water is necessary in order to understand how wood will act, not only in drying, but also during fabrication and use.

Moisture in wood.--Water is held by wood in two ways; as "free water" in the cell cavities and as "hygroscopic water" in the cell walls. The free water does not affect the properties of wood other than weight. The hygroscopic water, however, does affect the properties of wood in many ways, and it is this moisture that is the most difficult to remove in drying.

Moisture-content determination.--The universally accepted method of determining the moisture content of wood is the oven-drying method, or oven test, in which the moisture content is calculated from weight values obtained before and after drying a sample of wood in an oven. The moisture content is expressed as a percentage of the oven-dry weight of the wood.

Proper selection of representative sample boards or pieces from which the moisture-content sections are cut is exceedingly important. Extreme accuracy in determining the moisture content of the sections is of little value if a wide variation of moisture content exists throughout the pile or load of lumber being tested and the selected pieces are not representative. If considerable variation of moisture content is suspected, several pieces should be selected in order to obtain a representative average value for the material being tested. When a carload or kiln charge contains lumber from different sources or lots, a separate representative sample should be obtained for each lot if the use involved requires that refinement, or the sample should be confined to the lot that is critical in determining kiln operation or any other operation involved.

Preparation of moisture sections involves cutting moisture sections from a piece selected for test as shown in figure 3. Wood dries much more rapidly from end-grain surfaces than from side-grain surfaces; and if a board has been allowed to dry without end coating for some time, the moisture content near the end of the board will be lower than in the center of the piece. The moisture-content sections should be cut, therefore, at some distance from the ends of the pieces. When it is known definitely that the ends of the pieces have not been exposed to drying conditions for more than a few days, a minimum distance of 6 inches is suggested. Otherwise a minimum distance of 24 inches is recommended.

The sections should be approximately 1 inch thick. In dimension stock that is 1 inch square or less in cross-sectional dimensions, the section should be 2 inches or more along the grain to yield a piece having a volume of 2 or more cubic inches. To speed up oven-drying, such long moisture sections may be partially crosscut at one-half inch intervals. Sections less than 1 inch in thickness may lead to errors in moisture determinations due to the very rapid drying from the end-grain surfaces during the sawing operation and handling prior to weighing. Since on thin sections the percentage of end-grain area is very high, the error can be great. There are some advantages in using sections thinner than 1 inch, particularly for getting quick results and for using some of the self-calculating moisture-content scales when operating a large battery of kilns. Whenever such thin sections are used, however, a special technique must be used in which the sections are cut rapidly on a sharp, cool-running band saw and are handled thereafter so that moisture loss has little chance to occur. An operator's technique in such operations should be checked frequently by making tests on sections of full thickness and applying proper correction factors to the values obtained from thin sections. The errors are likely to be greater, of course, with green or partially seasoned material. After the sections are cut, all loose splinters and sawdust should be removed, and the sections should be weighed immediately. If it is necessary to cut a number of sections at a time, they should be protected from drying by wrapping them in aluminum foil with paper backing. The aluminum side should be placed next to the section. If it is known that the sections are of approximately the same moisture content, they can be stacked end grain to end grain to protect each other from end drying; otherwise each section should be wrapped separately. A method of subdividing a section to check the distribution of the moisture between inner and outer zones of the boards is shown in figure 3.

Placement of saw, scales, and oven close together in a sheltered place or weighing room is helpful in obtaining accurate moisture content determinations. Occasionally, sample boards must be cut at some distance from the weighing room. When this is done the pieces to be used for kiln samples should be cut at least 4 inches longer than the desired length of the kiln sample. These can then be taken to the weighing room, where both ends of each piece should be trimmed back at least 1 inch to get away from the effects of end drying. Immediately following this operation, the moisture sections and kiln sample should be cut and weighed.

Moisture sections weighing more than 200 grams should be weighed to within 0.10 gram, sections weighing between 100 and 200 grams should be weighed to 0.05 gram, and those weighing less than 100 grams should be weighed to within 0.01 or 0.02 grams. An accurate scale is necessary in order to obtain this weighing accuracy. Weights obtained in grams, instead of grains, or ounces, simplify the calculations. A triple-beam balance is a convenient type of balance to use in kiln-drying work. The one shown in figure 4 is sensitive to 0.01 gram and has auxiliary weights making its capacity more than 1,000 grams. Any torsion balance sensitive to 0.02 gram should be suitable. A torsion balance with auxiliary weights and double rider sensitive to 0.01 gram is shown in figure 5. A type of balance (not illustrated) known as a trip scale, which is sensitive to 0.1 gram, is also suitable for weighing moisture sections above 200 grams in weight. The triple-beam balance and the trip scale have knife-edge balances that must be kept free of dirt and corrosion to remain accurate.

When sections are weighed, it is desirable to mark the weight on each section and also to give each section an identifying mark and to keep a separate record on tabulation paper or a form made specially for the purpose.

Oven-drying the sections is done by placing them in an oven maintained at a temperature of 212° to 221° F. (100° to 105° C.). Drying of each section should be continued until it reaches a constant weight. To test for constant weight, weigh a few sections and replace them in the oven for 4 hours of additional drying. If these sections have lost no further weight, the entire group of sections can be assumed to be at constant weight. An electric oven, such as the one shown in figure 6, equipped with a temperature-regulating device and a thermometer, is convenient for this operation. Where large numbers of sections must be dried at the same time, a large oven equipped for forced circulation of air is desirable. It is also possible to use a large oven heated with steam at low pressure, if it can be made to maintain satisfactorily the required temperature. The oven should have some vents to allow the evaporated moisture to escape. The sections should be open-piled in the oven to allow free access of air to each. Excessive temperatures or excessive periods of drying should be avoided since they cause distillation or oxidation of the wood and erroneous results may be obtained. Ordinarily, in the case of light woods, 12 hours of oven-drying may be sufficient, but heavy wood may require 48 hours of oven-drying or more. Newly cut sections should not be placed in the oven with sections that are dried and ready to be weighed, for the dry sections will temporarily absorb moisture from the fresh sections.

Calculating the moisture content is the next step. The weight of the water removed is divided by the oven-dry weight of the section and the quotient is multiplied by 100. The weight of the water equals the original weight minus the oven-dry weight of the section. Combining both statements into an algebraic expression:

$$\text{Moisture content (percent)} = \frac{\text{original weight} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100.$$

An example of a moisture-content calculation is as follows:

A 1-inch section of green black walnut lumber weighed 122.5 grams.

After oven-drying, the section weighed 67.6 grams.

$$\text{Moisture content} = \frac{122.5 - 67.6}{67.6} \times 100$$

$$= \frac{54.9}{67.6} \times 100$$

$$= 0.812 \times 100$$

$$= 81.2 \text{ percent.}$$

It is sometimes convenient for slide-rule calculation to use an equivalent method of calculation by the following formula:

$$\text{Moisture content (percent)} = \left(\frac{\text{original weight}}{\text{oven-dry weight}} - 1\right) \times 100$$

Following through with the values used in the foregoing example:

$$\text{Moisture content} = \left(\frac{122.5}{67.6} - 1\right) \times 100$$

$$= (1.812 - 1) \times 100$$

$$= 0.812 \times 100$$

$$= 81.2 \text{ percent}$$

The moisture content of green wood.--The amount of water in green wood varies widely. One wood may contain as little as 30 percent (based on its oven-dry weight), while another may contain 200 percent or more. Such variations may occur not only between species but also within the same species and even in the same tree. Sapwood usually contains more water than heartwood. In some species the butt logs of the tree contain much more water than the top logs. One example of this is redwood. The place where the tree grows influences the amount of moisture in the wood. Trees growing in swampy areas are likely to contain more moisture than those growing in dry areas. Certain species, however, contain large amounts of water even though growing under reasonably dry conditions. Contrary to popular belief, the amount of water in greenwood does not vary to any appreciable amount with the season of the year in which the trees are cut. There are, however, areas of lower and higher concentrations of water in trees, and these areas shift about from time to time. The fact that trees bleed more easily in the spring of the year is due to the sap being under greater pressure. Some species of wood contain zones of exceptionally high moisture content. These zones are called "water pockets." The water in water pockets dries out very slowly. Woods such as eastern white pine, noble fir, western hemlock, and sweetgum frequently contain water pockets. The green moisture contents of a number of commerically important woods are given in table 1.

The fiber saturation point of wood.--The point at which the cell wall is saturated, but no free water remains in the cell cavity, is defined as the "fiber saturation point." The moisture content, based on the oven-dry weight at the fiber saturation point is approximately the same for all woods, 30 percent. The fiber saturation point is important in the drying of wood for the following reasons: (1) More heat is required to move water from the cell wall than from the cavity; (2) a wood cell will not shrink until it reaches the fiber saturation point; and (3) large changes in the physical and mechanical properties of wood begin to take place at the fiber saturation point.

The equilibrium moisture content of wood.--Any piece of wood will give off to or take on moisture from the surrounding atmosphere until the moisture in the wood has come to a balance with that in the atmosphere. The moisture in the wood at the point of balance is called the equilibrium moisture content. Assuming constant temperature, the ultimate moisture content that a given piece of wood will attain depends entirely upon the relative humidity of the air surrounding it. This relationship is illustrated in figure 7, which shows, for example, that wood kept in air constantly at 141° F. and 65 percent relative humidity will eventually come to a moisture content of about 10 percent. The equilibrium moisture content condition of air at this temperature and relative humidity is said to be 10 percent. In dry-kiln work equilibrium moisture content is designated by the letters EMC.

The information in figure 7 is not handy enough for dry-kiln use where temperatures and relative humidities vary from low values to high. To meet this variance EMC values for various dry- and wet-bulb temperatures commonly used in kiln-drying are shown in table 2. This table has extensive use in kiln-drying.

How Wood Dries

The kiln operator should have an understanding of what causes moisture to move in wood and of the factors that influence the rate of moisture movement.

Movement of moisture in wood.--Water in wood normally moves from zones of higher to zones of lower moisture content. This fact supports the familiar statement that "wood dries from the outside in," which means that the surface of the wood must be drier than the inside if moisture is to be removed. In drying, the surface fibers of the heartwood of most species attain the EMC corresponding to the immediately surrounding atmosphere almost as soon as drying begins, and at this time a moisture gradient is said to be established. The surface fibers of sapwood also tend to reach a state of balance with the surrounding drying atmosphere early in the drying process, if the air circulation is fast enough to evaporate the water as rapidly as it comes to the surface of the wood. If the air circulation is too slow, however, a longer time is required for the surfaces of sapwood to attain EMC. To reduce drying time, the initial EMC condition in the kiln should be as low as possible without causing serious end checking or surface checking.

Moisture in wood moves through several kinds of passageways. Some of the passageways of certain species, such as the resin ducts in softwoods, are so large that they can be seen with the naked eye; others can be seen only under the highest-powered microscope.

Most of the moisture lost by wood during drying moves through cell cavities and small openings in the cell walls. Moisture moves in these passageways in any direction, longitudinally as well as laterally. Lighter, porous woods dry, in general, more rapidly than do the heavier, less porous woods. Exceptions to this rule are porous woods that have the passageways plugged with material such as resins and gums.

Forces that move water.--When wood is drying, several forces may be acting to reduce its moisture content, and they all may be acting at the same time. These forces are:

1. Capillary action that causes free water to flow mostly through cell cavities and small openings in the cell wall.

2. Differences in relative humidity that cause moisture that is in the vapor state to flow through various passageways. These differences are particularly effective at higher temperatures and lower moisture contents and in the more porous woods.

3. Differences in moisture content that move the hygroscopic water through passageways in the cell wall. These differences are very important in low-temperature drying.

Free water moves by capillary forces, but hygroscopic moisture moves by the process of diffusion.

Movement of water by capillary action is due to the attraction between water particles and the walls of the small openings in the cell walls and also to the attraction of water particles to each other. When green wood starts to dry, evaporation of water from the surface cells sets up forces that exert a pull on the free water in the zones or layers of wood beneath the surface and a flow results. This movement of water is similar to that of a wick. Much of the free water in sapwood moves in this manner.

Movement of moisture by diffusion results from relative-humidity and moisture content differences between the surface and the interior of the wood. The moisture evaporated from wood moves to the surfaces by two types of diffusion that act at the same time. At high temperatures, diffusion of water vapor through the larger passageways is the most important, while at low temperatures most of the moisture diffuses through the passageways within the cell walls.

Longitudinal diffusion toward the end-grain surface of a piece of wood depends mostly on the number of cell cavities located in the cross-sectional area. Therefore diffusion in this direction is slower in the heavy woods, since they have small cell cavities and thick cell walls. Diffusion toward the end-grain surface is about 10 to 15 times faster than diffusion toward the lateral surfaces of wood. Since the diffusion of water is only 10 to 15 times as great longitudinally as it is laterally, drying from end-grain surfaces is of practical importance only in relatively short items. For example: In a 1-inch board 15 inches long moisture from the exact center would require about the same length of time to reach the broad faces as the ends because the short distance of lateral travel, 1/2 inch, can be covered in the same time as the longer distance of longitudinal travel, 7-1/2 inches. It is evident, therefore, that coating the ends of a long board will have no practical effect on the drying time.

Lateral diffusion accounts for most of the moisture removed from wood during drying. The rate of lateral diffusion depends to a large extent upon the porosity or openness of the small openings in the cell walls and upon the thickness of the cell walls. Thus pervious woods dry faster than impervious woods. Generally, in softwoods, the rate of diffusion decreases rapidly as the specific gravity of the wood increases.

Diffusion in heartwood and sapwood differs considerably, with sapwood drying faster than heartwood under the same drying conditions. This is probably due to the fact that extractives plug the small cell-wall openings in the heartwood and thereby slow up the rate of moisture diffusion. The heartwood of some species may reach a lower moisture content in a shorter drying time than the sapwood. This is accounted for, however, by the fact that the heartwood has a much lower initial moisture content than the sapwood.

Factors that influence drying rate.--The rate at which wood dries is dependent upon the steepness of the moisture gradient and the temperature of the wood. Thus the drier the surfaces of the wood or the lower the relative humidity of the surrounding atmosphere, the greater will be the forces that exert moisture diffusion. That is why drying schedules call for a lowering of the relative humidity when danger of end checking and surface checking are past. The higher the temperature that can be safely used to dry the wood, the faster will be the rate at which the moisture will diffuse from the wet interior to the drier surfaces.

Drying time varies considerably. The approximate drying time for 1-inch lumber of most of the commercially important woods is given in table 3. The drying time for thicker stock is more than proportional to the increased thickness. A general rule is that 2-inch stock takes about four times longer to kiln-dry to the same moisture content as does 1-inch stock.

Specific Gravity and Weight of Wood

Specific gravity of wood is of interest to the kiln operator because it is one of the characteristics of wood that is a guide to the ease of drying. In general, the heavier the wood the more difficult it is to dry. Specific gravity is defined as "the ratio of the weight of a body to the weight of an equal volume of water." Usually the specific gravity of wood is based on the volume of green wood and its oven-dry weight; which means that if the specific gravity of a specimen is 0.50, the weight of the wood substance in a cubic foot of green wood is half that of the weight of a cubic foot of water. The higherthe specific gravity of wood, the greater is the amount of oven-dry wood found in a unit volume of green wood. Thus at the same moisture content the higher-specific-gravity woods hold more water and require longer to dry to a low moisture-content value. The specific gravity of a number of commercial woods is given in table 4.

Weight of wood depends on its specific gravity and its moisture content. Calculated values of weights are given in table 5. The values given for weight per thousand board feet at 15 percent moisture content apply to actual board feet and not to a thousand-board-feet lumber scale. Rough lumber is generally oversized, and dressed lumber is undersized with respect to nominal thickness. Therefore, the weight-per-thousand values will need to be adjusted upwards or downwards, depending upon whether the measurements are taken on rough or on dressed lumber.

Shrinkage of Wood

When wood is dried below the fiber saturation point it shrinks. When it has dried to 15 percent moisture content, about one-half of the total possible shrinkage has taken place; when dried to 8 percent moisture content, nearly three-fourths of the maximum possible amount has taken place. Figure 8 indicates how Douglas-fir shrinks with loss of moisture. While these curves are not straight, shrinkage is generally thought of as a straight-line curve.

Wood shrinks about one and one-half of two times more around the annual rings (tangentially) than it does across the rings (radially). The shrinkage along the grain (longitudinally) is very little in normal wood. The combined effects of radial and tangential shrinkage are shown in figure 9.

As a rule, the heavier woods shrink more radially and tangentially than do the lighter ones. Also, heavier pieces shrink more than do lighter pieces of the same species.

Shrinkage variability.--Shrinkage varies considerably. It not only differs along the three directions of grain, tangential, radial, and longitudinal, but also among species. It varies widely in material cut from the same species and even in material cut from the same tree. The higher the specific gravity of wood the greater the shrinkage. A change in the size of the cell cavities during the process of drying also affects shrinkage. Since the size of a cell cavity is affected by drying stresses, the over-all shrinkage of wood is influenced by the drying conditions. Generally, the higher the temperature and relative humidity in the initial stages of drying the greater the shrinkage.

Despite the variation in shrinkage, values have been collected over many years that may be considered approximate averages values for the various species. These values, based on the green dimension, are listed in table 6. Although these values are given in percentages of the green dimension, they can be converted very easily to useful units of measurement. Each 3 percent of shrinkage is roughly equivalent to 1/32 inch per inch of dimension.

On the average, hardwoods shrink more than softwoods. Although, in general, the woods of high specific gravity have the greater shrinkage, there are exceptions. Basswood, a light wood, has a high shrinkage, while black locust, a heavy wood, has a moderate shrinkage. The amount of shrinkage and the difference between radial and tangential shrinkage have a direct bearing on the seasoning defects that occur during drying. In other instances, they help to determine the use to which the dried lumber is put.

Effects of shrinkage.--If no shrinkage occurred during drying, most of the problems related to seasoning would not exist. Shrinkage is responsible for decrease in dimension, loss of footage, warping, end and surface checking, and splitting, honeycombing, and case-hardening. Shrinkage begins as soon as the tree is cut into logs. Drying from the freshly cut ends is likely to cause severe end checks because of drying and shrinking. If the logs remain in the woods or yard for a considerable period of time, especially in hot, dry weather, end checks may extend a considerable distance into the log. Green lumber exposed to severe drying conditions will also end check and surface check.

End and surface checks and end splits are caused by too severe drying conditions in the initial stages of drying. The wood in attempting to shrink is subjected to severe drying stresses that may cause the wood to fail along the wood rays, resin ducts, or other lines of weakness. End checks and surface checks may extend in depth to form honeycomb checks. If the surfaces are dried below the fiber saturation point and do not check, they stretch and become set in an expanded condition as drying continues. This is the first step in the development of case-hardening.

Changes in dimension result when a piece of wood has been dried to a low moisture content. The piece will be thinner, narrower, and also slightly shorter than it was when green. Allowance for shrinkage must be made in sawing lumber from logs. If the lumber is sawed too thick, unnecessary waste will occur during surfacing operations; if sawed too thin, it will fail to make the required dry thickness. Due to differences in shrinkage, it is impossible to saw the lumber to a green thickness that will make the desired dry, dressed thickness without some waste. The sawing allowance for shrinkage is influenced by species, type of lumber, and by warping. Some species shrink more than others; for example, one mill cutting southern yellow pine, cottonwood, yellow-poplar, and black tupelo on a gang saw experienced difficulty with respect to scanty thicknesses with the cottonwood and black tupelo, but not with the other two species.

Grain direction influences the final dimension of dry boards. Plain-sawed boards shrink less in thickness than quarter-sawed boards, but the outer edges of plain-sawed boards, particularly those cut from small trees, are often equivalent to quarter-sawed boards. Shrinkage in width is important, because it results in a footage loss. The loss of footage is affected by the species, type of lumber, and the width of the boards, and it is greater in the species having a large tangential shrinkage, in wide boards, and in plain-sawed lumber. Board footage losses in kiln-drying air-dried hardwood lumber from an average moisture content of 18 percent down to 5 percent have been calculated. These values are based on plain-sawed lumber of normal width. Wider than average boards will exceed the footage-loss figure. The estimated footage loss in percent of air-dried tally, based on the total tangential-shrinkage value is shown in figure 10.

Warping, which can be broken down into cupping, bowing, crooking, and twisting, is also the result of shrinkage. Cupping may result from different rates of drying from each face, or from more shrinkage on the outer face (face toward the bark side of the tree) of a flat-sawed board (fig. 9). The other three forms of warping usually result from grain irregularities or from the presence of bands of abnormal wood.

Electrical Resistance of Wood

The electrical resistance of wood is of interest to the kiln operator because electrical moisture meters are being extensively used to determine the moisture content of stock before and after kiln-drying. Although the accuracy of moisture meters can be ± 1 percent, they are not recommended as control instruments for kiln-drying schedules because inaccuracies due to a number of reasons can occur very easily. The value of a kiln charge of lumber warrants the greater time required for precision determination of moisture content by the oven-drying method. The average moisture content of the kiln charge, however, can be determined by moisture meters at the time of unloading, provided that several readings are taken from different boards. Moisture meters also provide a quick means for segregating lumber into moisture content groups before kiln-drying. The electrical resistance of wood varies greatly with changes in moisture content below the fiber saturation point, with the resistance increasing as the moisture content is lowered. Because the electrical resistance varies between species, meters must be provided with tables to convert meter readings to moisture contents for different species being tested The electrical resistance of different woods at various moisture-content values is given in table 7. This table can be used to convert meter readings to resistance and to reconvert to moisture content for other species. For example, if a resistance-type meter is calibrated for Douglas-fir and then reads 10 percent moisture content, the resistance is 630 megohms. If the measurement were taken on walnut, the moisture content would actually be more than 10 percent.

Temperature also influences the electrical resistance of wood. As the temperature of wood is increased, its resistance decreases. Most resistance-type meters are calibrated at 70° F. and require correction if used to test hot lumber. The correction is approximately 1/2 percent for every 10° F. that the wood is above or below 70° F. This approximation is shown in figure 11. A method of making corrections is described.

Color of Wood

The color of wood is influenced by the conditions under which it is dried. High temperature tends to darken the heartwood, and sometimes the color of sapwood is materially changed by chemical reactions. As a tree grows, the sapwood gradually changes to heartwood, and with this change there is a usually marked change in color. Holly, basswood, cottonwood, and magnolia, however, are examples of hardwoods in which there is little or no difference in color between the sapwood and the heartwood. White pine, spruces, and true firs are examples of softwoods that do not change color materially when the sapwood changes to heartwood. The color changes that might take place in the heartwood during drying are usually of little concern to the dry-kiln operator. Kiln-drying may darken the color somewhat, but for most purposes such changes are of no practical importance. The color changes with which the kiln operator is most concerned are those that are modified by methods of drying and handling of sapwood.

Sap stain is a discoloration caused by fungus and occurs principally in air-drying. Improved and different methods of piling and chemical treatments of the green wood are the remedial measures.

Chemical stain occurs in kiln-drying green sapwood, and in some instances the color change is beneficial and in other cases it is detrimental. Walnut, for example, is steamed in vats prior to drying to darken the sapwood. At one time "sapgum" was steamed in order to produce a salmon-colored wood that the using industries preferred and paid a premium to get. Orchard woods are also steamed when green to obtain a more uniform color through the heartwood, as well as to darken the sapwood so that it is more nearly the color of heartwood. European beech is often steamed prior to drying in order to improve its color appearance. The sapwood of hickory tends to turn pinkish when kiln-dried, and very low initial temperatures must be used if the whiteness of hickory sapwood is to be preserved. Paper birch sapwood turns a sort of brownish color when kiln-dried, and many plants prefer air-drying for that reason.

Perhaps one of the most troublesome color changes in wood is brown stain in pine. It is usually most conspicuous at or near the surface, but it may penetrate throughout the wood. The stain is more pronounced in areas where most evaporation occurs, as at the end surfaces and on the tangential surfaces.

The occurrence of brown stain is closely associated with the drying of wood. It appears in the zone where the water vaporizes and thus deposits the solutes or extractives. The stain appears beneath the surface if the porosity of the wood and the severity of the drying conditions promote rapid drying of the surface fibers. Under such conditions a steep moisture gradient is established with a moisture content of the surface fibers well below the fiber saturation point. When the water moves so freely through the wood that the surface fibers remain moist for some time after exposure to a drying atmosphere, the stain tends to develop at or near the surface of the lumber.

In pine, chemical brown stain develops in either sapwood or heartwood. Very commonly it occurs in the area of the heart-sap junction. Blue and brown stains due to fungi are generally confined to the sapwood only.

The exact nature of the chemical changes responsible for chemical brown stain is not fully understood. Experience has shown, however, that the stain occurs only as the wood dries, appearing during both air-drying and kiln-drying. The degree of staining is influenced by the temperature and relative humidity employed in drying, i.e., a high-temperature, high-humidity schedule will produce a greater amount of staining than when a low-temperature, low-humidity schedule is followed.

No completely successful way of preventing chemical brown stain is known. Certain means can, however, be recommended for limiting its occurrence. The substances responsible for the brown stain are insoluble or only moderately soluble in cold water; therefore mild temperatures during drying will decrease the concentration of the staining materials. Since the zone of extractive concentration should be kept well below the surface, as low a relative humidity as is possible without developing serious surface checking should be maintained. High air-velocities are essential to prevent excessive increases in relative humidity of the air moving across the kiln load. An important factor in the development of chemical brown stain is the length of storage of the logs and lumber. The most effective method of keeping stain to a minimum is to cut the logs into lumber soon after felling the trees and to avoid solid piling of the green lumber for more than a day.

Sticker stains in drying wood is sometimes a baffling problem. In some cases the wood underneath the sticker remains light-colored, and in other instances the wood underneath the sticker darkens more than the wood between the stickers. Unfortunately, sticker stains do not always surface off. Remedies for this problem include (1) use of dry stickers, and sometimes of the same species as the wood; (2) air-dry to below the fiber saturation point before kiln-drying; (3) kiln-drying immediately after piling, and (4) use of stickers as narrow as economically practicable.

Table 1.--Average moisture content of green wood

Species[1]	Moisture content[2]		
	Heartwood	Sapwood	Mixed heartwood and sapwood
SOFTWOODS	Percent	Percent	Percent
Baldcypress	121	171	
Cedar:			
Alaska yellow	32	166	
Eastern red	33		
California incense	40	213	
Northern white			55
Port Orford white	50	98	
Atlantic white			35
Western red	58	249	
Douglas-fir:			
Coast type	37	115	
Intermediate type	34	154	
Rocky Mountain type	30	112	
Fir:			
Alpine			47
Balsam			117
Grand (lowland white)	91	136	
Noble	34	115	
Pacific silver	55	164	
Red			108
White	98	160	
Hemlock:			
Eastern	97	119	
Western	85	170	
Larch, western	54	119	
Pine:			
Eastern white			68
Lodgepole	41	120	
Ponderosa	40	148	
Red	32	134	
Southern yellow:			
Loblolly	33	110	
Longleaf	31	106	
Shortleaf	32	122	

Table 1.--Average moisture content of green wood (Continued)

Species[1]	Moisture content[2]		
	Heartwood	Sapwood	Mixed heartwood and sapwood
SOFTWOODS	Percent	Percent	Percent
Sugar	98	219	
Western white (Idaho)	62	148	
Redwood:			
Second-growth			127
Old-growth	86	210	
Spruce:			
Eastern	34	128	
Englemann	51	173	
Sitka	41	142	
Tamarack (eastern larch)	49		
HARDWOODS			
Alder, red		97	
Apple			46
Ash:			
Black	95		
White	46	44	
Aspen (quaking and big tooth)	95	113	
Basswood	81	133	
Beech	55	72	
Birch:			
Paper	89	72	
Yellow	74	72	
Buckeye, yellow			141
Butternut			104
Cherry, black	58		

Table 1.--Average moisture content of green wood (Continued)

Species[1]	Moisture content[2] Heartwood	Sapwood	Mixed heartwood and sapwood
HARDWOODS	Percent	Percent	Percent
Chestnut	120		
Chinquapin			134
Cottonwood, black	162	146	
Dogwood			62
Elm:			
American	95	92	
Rock	44	57	
Hackberry	61	65	
Hickory	65	50	
Holly			82
Hophornbeam (ironwood)			52
Laurel, California (Oregon myrtle)			65
Locust, black			40
Madrone			81
Magnolia	80	104	
Maple:			
Silver (soft)	58	97	
Sugar (hard)	65	72	
Oak:			
California black	76	75	
Live			50
Northern red	80	69	
Southern red	83	75	
Southern swamp	79	66	
Tan			89
White	64	78	

Table 1.--Average moisture content of green wood (Continued)

Species[1]	Moisture content[2]		
	Heartwood	Sapwood	Mixed heartwood and sapwood
HARDWOODS	Percent	Percent	Percent
Osage-orange			31
Persimmon			58
Sweetgum	79	137	
Sycamore	114	130	
Tupelo:			
Black	87	115	
Water	158		
Walnut, black	90	73	
Willow, black			139
Yellow-poplar	83	106	

[1] Scientific names are listed in table 8 opposite accepted U. S. Forest Service common names for individual species.

[2] Based on oven-dried weight.

(Sheet 4 of 4)

TABLE 2.—*Relative-humidity* [1] *and equilibrium-moisture-content* [2] *table for use with dry-bulb temperatures and wet-bulb depressions*

Temperature dry-bulb (°F.)	Wet-bulb depression (°F.)																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50
30	89	78	67	57	46	36	27	17	6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	...	*15.9*	*12.9*	*10.8*	*9.0*	*7.4*	*5.7*	*3.9*	*1.6*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
35	90	81	72	63	54	45	37	28	19	11	3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	...	*16.8*	*13.9*	*11.0*	*10.3*	*8.8*	*7.4*	*6.0*	*4.5*	*2.9*	*0.8*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
40	92	83	75	68	60	52	45	37	29	22	15	8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	...	*17.6*	*14.8*	*12.9*	*11.2*	*9.9*	*8.6*	*7.4*	*6.2*	*5.0*	*3.5*	*1.9*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
45	93	85	78	72	64	58	51	44	37	31	25	19	12	6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	...	*18.3*	*15.6*	*13.7*	*12.0*	*10.7*	*9.5*	*8.5*	*7.5*	*6.5*	*5.3*	*4.2*	*2.9*	*1.5*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
50	93	86	80	74	68	62	56	50	44	38	32	27	21	16	10	5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	...	*19.0*	*16.3*	*14.4*	*12.7*	*11.5*	*10.3*	*9.4*	*8.5*	*7.6*	*6.7*	*5.7*	*4.8*	*3.9*	*2.8*	*1.5*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
55	94	88	82	76	70	65	60	54	49	44	39	34	28	24	19	14	9	5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	...	*19.5*	*16.9*	*15.1*	*13.4*	*12.2*	*11.0*	*10.1*	*9.3*	*8.4*	*7.6*	*6.8*	*6.0*	*5.3*	*4.5*	*3.6*	*2.5*	*1.3*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	...	*19.9*	*17.4*	*15.6*	*13.9*	*12.7*	*11.6*	*10.7*	*9.9*	*9.1*	*8.3*	*7.6*	*6.9*	*6.3*	*5.6*	*4.9*	*4.1*	*3.2*	*2.3*	*1.3*	*0.2*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20	16	13	8	6	2	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	...	*20.3*	*17.8*	*16.1*	*14.4*	*13.3*	*12.1*	*11.2*	*10.4*	*9.7*	*8.9*	*8.3*	*7.7*	*7.1*	*6.5*	*5.8*	*5.2*	*4.5*	*3.8*	*3.0*	*2.3*	*1.4*	*0.4*	---	---	---	---	---	---	---	---	---	---	---	---	---	---
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3	---	---	---	---	---	---	---	---	---	---	---	---
	...	*20.6*	*18.2*	*16.5*	*14.9*	*13.7*	*12.5*	*11.6*	*10.9*	*10.1*	*9.4*	*8.8*	*8.3*	*7.7*	*7.2*	*6.6*	*6.0*	*5.5*	*4.9*	*4.3*	*3.7*	*2.9*	*2.3*	*1.5*	*0.7*	---	---	---	---	---	---	---	---	---	---	---	---
75	96	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31	28	24	21	18	15	12	10	7	4	1	---	---	---	---	---	---	---	---	---
	...	*20.9*	*18.5*	*16.8*	*15.2*	*14.0*	*12.9*	*12.0*	*11.2*	*10.5*	*9.8*	*9.3*	*8.7*	*8.2*	*7.7*	*7.2*	*6.7*	*6.2*	*5.6*	*5.1*	*4.7*	*4.1*	*3.5*	*2.9*	*2.3*	*1.7*	*0.9*	*0.2*	---	---	---	---	---	---	---	---	---
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3	---	---	---	---	---	---	---
	...	*21.0*	*18.7*	*17.0*	*15.6*	*14.3*	*13.2*	*12.3*	*11.5*	*10.9*	*10.1*	*9.7*	*9.1*	*8.6*	*8.1*	*7.7*	*7.2*	*6.8*	*6.3*	*5.8*	*5.4*	*5.0*	*4.5*	*4.0*	*3.5*	*3.0*	*2.4*	*1.8*	*1.1*	*0.3*	---	---	---	---	---	---	---
85	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38	36	33	30	28	25	23	20	18	15	13	11	9	4	---	---	---	---	---	---
	...	*21.2*	*18.8*	*17.2*	*15.7*	*14.5*	*13.5*	*12.5*	*11.8*	*11.2*	*10.5*	*10.0*	*9.5*	*9.0*	*8.5*	*8.1*	*7.6*	*7.2*	*6.7*	*6.3*	*6.0*	*5.6*	*5.2*	*4.8*	*4.3*	*3.9*	*3.4*	*3.0*	*2.4*	*1.7*	*0.9*	---	---	---	---	---	---
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	9	5	1	---	---	---	---
	...	*21.3*	*18.9*	*17.3*	*15.9*	*14.7*	*13.7*	*12.8*	*12.0*	*11.4*	*10.7*	*10.2*	*9.7*	*9.3*	*8.8*	*8.4*	*8.0*	*7.6*	*7.2*	*6.8*	*6.5*	*6.1*	*5.7*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.3*	*2.8*	*2.1*	*1.3*	*0.4*	---	---	---	---
95	96	92	89	85	82	79	75	72	69	66	63	60	57	55	52	49	46	44	42	39	37	34	32	30	28	26	23	22	20	17	14	10	6	2	---	---	---
	...	*21.3*	*19.0*	*17.4*	*16.1*	*14.9*	*13.9*	*12.9*	*12.2*	*11.6*	*11.0*	*10.5*	*10.0*	*9.5*	*9.1*	*8.7*	*8.2*	*7.9*	*7.5*	*7.1*	*6.8*	*6.4*	*6.1*	*5.7*	*5.3*	*5.1*	*4.8*	*4.4*	*4.0*	*3.6*	*3.0*	*2.3*	*1.5*	*0.8*	---	---	---
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	17	13	10	7	4	---	---
	...	*21.3*	*19.0*	*17.5*	*16.1*	*15.0*	*13.9*	*13.1*	*12.4*	*11.8*	*11.2*	*10.6*	*10.1*	*9.6*	*9.2*	*8.9*	*8.5*	*8.1*	*7.8*	*7.4*	*7.0*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.9*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.6*	*0.7*	---	---
105	96	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	44	42	40	37	35	34	31	29	28	26	24	20	17	14	11	8	---	---
	...	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.0*	*13.2*	*12.6*	*11.9*	*11.3*	*10.8*	*10.3*	*9.8*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.6*	*7.3*	*6.9*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.8*	---	---
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	23	20	17	14	11	4	---
	...	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.3*	*12.6*	*12.0*	*11.4*	*10.8*	*10.4*	*9.9*	*9.5*	*9.2*	*8.8*	*8.4*	*8.1*	*7.7*	*7.5*	*7.2*	*6.8*	*6.6*	*6.3*	*6.0*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.0*	*3.5*	*3.0*	*2.5*	*1.1*	---
115	97	93	90	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	50	48	45	43	41	40	38	36	34	32	31	29	26	23	20	17	14	8	2
	...	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*10.9*	*10.4*	*10.0*	*9.6*	*9.3*	*8.9*	*8.6*	*8.2*	*7.8*	*7.6*	*7.3*	*7.0*	*6.7*	*6.5*	*6.2*	*5.9*	*5.6*	*5.4*	*5.2*	*4.7*	*4.3*	*3.9*	*3.4*	*2.9*	*1.7*	*0.4*
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	28	25	22	19	17	10	5
	...	*21.3*	*19.0*	*17.4*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.7*	*7.4*	*7.2*	*6.8*	*6.6*	*6.3*	*6.1*	*5.8*	*5.6*	*5.4*	*5.0*	*4.6*	*4.2*	*3.7*	*3.3*	*2.3*	*1.1*
125	97	94	91	88	86	83	80	77	75	73	70	68	65	63	61	59	57	55	53	51	48	47	45	43	41	39	38	36	35	33	30	27	24	22	19	13	8
	...	*21.2*	*18.9*	*17.3*	*16.1*	*15.0*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*8.0*	*7.7*	*7.5*	*7.2*	*7.0*	*6.7*	*6.5*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.8*	*4.4*	*4.0*	*3.6*	*2.7*	*1.6*
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35	32	29	26	24	21	15	10
	...	*21.0*	*18.8*	*17.2*	*16.0*	*14.9*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*8.0*	*7.8*	*7.6*	*7.3*	*7.0*	*6.8*	*6.6*	*6.4*	*6.1*	*5.9*	*5.6*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.0*	*2.0*
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	35	32	30	27	25	19	14
	...	*20.7*	*18.6*	*16.9*	*15.8*	*14.8*	*13.8*	*13.2*	*12.5*	*11.9*	*11.4*	*10.9*	*10.4*	*10.0*	*9.6*	*9.4*	*9.0*	*8.7*	*8.4*	*8.0*	*7.8*	*7.6*	*7.3*	*7.1*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.1*	*4.8*	*4.4*	*4.1*	*3.4*	*2.6*
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	55	53	51	49	48	46	45	43	42	41	38	36	33	30	28	23	18
	...	*20.2*	*18.4*	*16.6*	*15.4*	*14.5*	*13.7*	*13.0*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.9*	*9.5*	*9.2*	*8.9*	*8.6*	*8.3*	*8.0*	*7.8*	*7.5*	*7.3*	*7.1*	*6.9*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.2*	*4.9*	*4.5*	*4.2*	*3.6*	*2.9*
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	41	38	35	33	31	25	21
	...	*19.8*	*18.1*	*16.2*	*15.2*	*14.2*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.6*	*10.1*	*9.7*	*9.4*	*9.1*	*8.8*	*8.5*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.9*	*4.6*	*4.3*	*3.7*	*3.2*
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	43	40	38	35	33	28	24
	...	*19.4*	*17.7*	*15.8*	*14.8*	*13.9*	*13.2*	*12.4*	*11.8*	*11.3*	*10.8*	*10.4*	*9.9*	*9.6*	*9.2*	*9.0*	*8.6*	*8.4*	*8.0*	*7.8*	*7.6*	*7.3*	*7.2*	*6.9*	*6.7*	*6.6*	*6.4*	*6.2*	*6.0*	*5.7*	*5.5*	*5.3*	*4.9*	*4.6*	*4.4*	*3.7*	*3.2*
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	45	42	40	38	35	30	26
	...	*18.9*	*17.3*	*15.5*	*14.5*	*13.7*	*12.9*	*12.2*	*11.6*	*11.1*	*10.6*	*10.1*	*9.7*	*9.4*	*9.0*	*8.8*	*8.4*	*8.1*	*7.8*	*7.6*	*7.4*	*7.2*	*7.0*	*6.8*	*6.5*	*6.4*	*6.2*	*6.0*	*5.8*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.4*	*3.8*	*3.3*
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49	46	44	42	39	37	32	28
	...	*18.5*	*16.9*	*15.2*	*14.2*	*13.4*	*12.7*	*12.0*	*11.4*	*10.9*	*10.5*	*10.0*	*9.6*	*9.2*	*8.9*	*8.6*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.5*	*5.3*	*5.0*	*4.8*	*4.5*	*4.4*	*3.8*	*3.3*
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51	48	46	43	41	39	34	30
	...	*18.1*	*16.4*	*14.9*	*14.0*	*13.2*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.8*	*9.4*	*9.1*	*8.8*	*8.4*	*8.1*	*7.7*	*7.5*	*7.2*	*7.0*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.6*	*5.4*	*5.2*	*4.9*	*4.7*	*4.5*	*4.3*	*3.8*	*3.3*
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68	67	65	64	63	61	60	59	57	56	54	53	52	50	47	45	43	41	36	32
	...	*17.7*	*16.0*	*14.6*	*13.8*	*13.0*	*12.2*	*11.7*	*11.1*	*10.6*	*10.0*	*9.7*	*9.2*	*9.0*	*8.7*	*8.3*	*8.0*	*7.6*	*7.4*	*7.1*	*6.9*	*6.8*	*6.5*	*6.3*	*6.1*	*5.9*	*5.8*	*5.5*	*5.4*	*5.3*	*5.1*	*4.8*	*4.6*	*4.4*	*4.2*	*3.7*	*3.2*

[1] Relative-humidity values in roman type.
[2] Equilibrium-moisture-content values in italic type.

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Table 3.--Approximate drying periods for 1-inch lumber[1]

Species[2]	Time required to kiln-dry 1-inch stock from: 20 to 6 percent moisture content	Green to 6 percent[3] moisture content
SOFTWOODS	Days	Days
Baldcypress	4-8	10-20
Cedar:		
Alaska yellow		4-6
Eastern red	2-3	6-8
California incense		3-6
Northern white		8-10
Port Orford white		4-8
Atlantic white		8-10
Western red		10-15
Douglas-fir:		
Coast type		2-4
Intermediate type		4-7
Rocky Mountain type		4-7
Fir:		
Alpine		3-5
Balsam		3-5
Grand (lowland white)		3-5
Noble		3-5
Pacific silver		3-5
Red		3-5
White		3-5
Hemlock:		
Eastern		3-5
Western		3-5
Larch, western		3-5
Pine:		
Eastern white	2-3	4-6
Lodgepole		3-5
Ponderosa		3-6
Red		6-8
Southern yellow:		
Loblolly		3-5
Longleaf		3-5
Shortleaf		3-5

Table 3.--Approximate drying periods for 1-inch lumber[1] (Continued)

Species[2]	Time required to kiln-dry 1-inch stock from: 20 to 6 percent moisture content	Green to 6 percent[3] moisture content
SOFTWOODS	Days	Days
Pine:		
Sugar:		
Light	....	3-4
Sinker	....	5-10
Western white (Idaho)	....	3-5
Redwood:		
Light	3-5	10-14
Sinker	5-7	20-24
Spruce:		
Eastern	....	4-6
Engelmann	....	3-5
Sitka	....	4-7
Tamarack (eastern larch)	....	3-5
HARDWOODS		
Alder, red	3-5	6-10
Apple	4-7	10-15
Ash:		
Black	5-7	10-14
White	4-7	11-15
Aspen (quaking and bigtooth)	3-5	6-10
Basswood	3-5	6-10
Beech	5-8	12-15
Birch:		
Paper	....	3-5
Yellow	5-8	11-15
Buckeye, yellow	5-8	12-16

Table 3.--Approximate drying periods for 1-inch lumber[1] (Continued)

Species[2]	Time required to kiln-dry 1-inch stock from: 20 to 6 percent moisture content	Time required to kiln-dry 1-inch stock from: Green to 6 percent[3] moisture content
HARDWOODS	Days	Days
Butternut	5-8	10-15
Cherry, black	5-7	10-14
Chestnut	4-8	8-12
Chinquapin	7-12	22-28
Cottonwood, black	4-8	8-12
Dogwood	5-8	12-16
Elm:		
American	4-6	10-15
Rock	5-8	13-17
Hackberry	4-6	7-11
Hickory	4-12	7-15
Holly	5-8	12-16
Hophornbeam (ironwood)	5-8	12-16
Laurel, California (Oregon myrtle)	5-7	10-15
Locust, black	5-8	12-16
Madrone	8-11	15-20
Magnolia	4-6	10-15
Mahogany	4-7	12-15
Maple:		
Silver (soft)	4-6	7-13
Sugar (hard)	5-8	11-15

Table 3.--Approximate drying periods for 1-inch lumber[1] (Continued)

Species[2]	Time required to kiln-dry 1-inch stock from: 20 to 6 percent moisture content	Green to 6 percent[3] moisture content
HARDWOODS	Days	Days
Oak:		
California black	6-10	25-35
Live	....	30-40
Red	5-10	16-28
Tan	7-12	24-30
White	6-12	20-30
Osage-orange	5-8	12-16
Persimmon	5-8	12-16
Sweetgum:		
Heartwood	8-12	15-25
Sapwood	5-7	10-15
Sycamore	4-7	6-12
Tupelo:		
Black	4-6	6-10
Water	5-7	6-12
Walnut, black	5-8	10-16
Willow, black	5-8	12-16
Yellow-poplar	3-6	6-10

[1] Because of the many factors affecting drying rate and the lack of specific data covering each case, wide variation from these values must be expected. They are intended only as representing a general picture of average drying periods and should not be used as time schedules. Some of the drying times shown were obtained from commercial kiln operators.

[2] Scientific names are listed in table 8 opposite accepted U. S. Forest Service common names for individual species.

[3] Some softwoods are usually dried to about 10 percent moisture content, but the drying times shown will still apply.

Table 4.--Specific gravity of wood

Species[1]	Average specific gravity[2]	Species[1]	Average specific gravity[2]
SOFTWOODS		SOFTWOODS	
Baldcypress	0.42	Redwood:	
		Second-growth	0.30
Cedar:		Old-growth	.38
Alaska yellow	.42		
Eastern red	.44	Spruce:	
California incense	.35	Eastern	.38
Northern white	.29	Engelmann	.32
Port Orford white	.40	Sitka	.37
Atlantic white	.31		
Western red	.31	Tamarack (eastern larch)	.49
Douglas-fir:			
Coast type	.45	HARDWOODS	
Intermediate type	.41		
Rocky Mountain type	.40	Alder, red	.37
Fir:		Apple	.61
Alpine	.31		
Balsam	.34	Ash:	
Grand (lowland white)	.37	Black	.45
Noble	.35	White	.55
Pacific silver	.35		
Red	.37	Aspen (quaking and bigtooth)	.38
White	.35		
Hemlock:		Basswood	.32
Eastern	.38		
Western	.38	Beech	.56
Larch, western	.50	Birch:	
		Paper	.48
Pine:		Yellow	.55
Eastern white	.34		
Lodgepole	.38	Buckeye, yellow	.33
Ponderosa	.38		
Red	.41	Butternut	.36
Southern yellow:			
Loblolly	.47	Cherry, black	.47
Longleaf	.54		
Shortleaf	.46	Chestnut	.40
Sugar	.35		
Western white (Idaho)	.36	Chinquapin	.42

Table 4.--Specific gravity of wood (Continued)

Species[1]	Average specific gravity[2]	Species[1]	Average specific gravity[2]
HARDWOODS		HARDWOODS	
Cottonwood, black	0.39	Maple:	
		Silver (soft)	0.44
Dogwood	.64	Sugar (hard)	.56
Elm:		Oak:	
American	.46	California black	.51
Rock	.57	Live	.81
		Red[3]	.54
Hackberry	.49	Tan	.56
		White	.60
Hickory	.65	Osage-orange	.76
Holly	.50	Persimmon	.64
Hophornbeam (ironwood)	.63	Sweetgum	.44
Laurel, California (Oregon myrtle)	.51	Sycamore	.46
Lemonwood	.82	Tupelo:	
		Black	.46
Locust, black	.66	Water	.46
Madrone	.58	Walnut, black	.51
Magnolia	.45	Willow, black	.34
		Yellow-poplar	.38

[1]Scientific names are listed in table 8 opposite accepted U. S. Forest Service common names.

[2]Based on weight when oven-dry and volume when green.

[3]Average of northern and southern red oak.

(Sheet 2 of 2)

Table 5.--Calculated weights of wood

Species[1]	Weight in pounds per cubic foot: Based on weight and volume at a moisture content of 15 percent	Weight in pounds per cubic foot: Based on weight and volume at a moisture content of 8 percent	Weight per 1,000 board feet at a moisture content of 15 percent (actual board feet)
SOFTWOODS			
Baldcypress	32.0	31.1	2,670
Cedar:			
Alaska yellow	31.1	30.1	2,590
Eastern red	33.1	32.0	2,760
California incense	25.3	24.1	2,110
Northern white	21.6	20.7	1,800
Port Orford white	29.8	28.7	2,480
Atlantic white	23.4	22.7	1,950
Western red	23.1	22.3	1,920
Douglas-fir:			
Coast type	33.9	33.0	2,820
Intermediate type	31.2	30.5	2,600
Rocky Mountain type	30.1	29.0	2,510
Fir:			
Alpine	22.3	21.2	1,860
Balsam	25.9	25.0	2,160
Grand (lowland white)	28.0	27.0	2,330
Noble	26.6	25.9	2,220
Pacific silver	27.0	26.3	2,220
Red	27.9	27.0	2,320
White	27.0	26.3	2,250
Hemlock:			
Eastern	28.5	27.7	2,370
Western	29.1	28.4	2,420
Larch:			
Western	38.3	37.7	3,190
Pine:			
Eastern white	25.1	24.0	2,090
Lodgepole	28.7	27.3	2,390
Ponderosa	28.3	27.3	2,360
Red	30.9	30.2	2,570

Table 5.--Calculated weights of wood (Continued)

Species[1]	Weight in pounds per cubic foot		Weight per 1,000 board feet at a moisture content of 15 percent (actual board feet)
	Based on weight and volume at a moisture content of 15 percent	Based on weight and volume at a moisture content of 8 percent	
SOFTWOODS			
Pine:			
Southern yellow:			
Loblolly	35.6	34.8	2,970
Longleaf	40.8	39.8	3,990
Shortleaf	35.0	34.2	2,920
Sugar	25.8	24.8	2,150
Western white (Idaho)	27.5	26.8	2,290
Redwood:			
Second-growth	22.3	21.3	1,860
Old-growth	25.4	24.5	2,120
Spruce:			
Eastern	28.4	27.6	2,370
Engelmann	23.7	23.0	1,970
Sitka	27.8	27.0	2,320
Tamarack (eastern larch)	37.1	36.0	3,090
HARDWOODS			
Alder, red	28.2	27.7	2,350
Apple	47.2	46.8	3,930
Ash:			
Black	34.5	33.9	2,870
White	40.6	39.6	3,380
Aspen (quaking and bigtooth)	26.6	26.0	2,220
Basswood	25.3	25.1	2,110
Beech	43.3	42.6	3,610
Birch:			
Paper	37.9	37.7	3,160
Yellow	42.4	41.9	3,530

Table 5.--Calculated weights of wood (Continued)

Species[1]	Weight in pounds per cubic foot: Based on weight and volume at a moisture content of 15 percent	Weight in pounds per cubic foot: Based on weight and volume at a moisture content of 8 percent	Weight per 1,000 board feet at a moisture content of 15 percent (actual board feet)
HARDWOODS			
Buckeye, yellow	24.9	24.4	2,070
Butternut	27.0	26.2	2,250
Cherry, black	35.5	34.5	2,960
Chestnut	30.0	29.2	2,500
Chinquapin	31.7	31.0	2,640
Cottonwood, black	28.3	27.7	2,360
Dogwood	50.0	49.8	4,160
Elm:			
American	36.3	35.7	3,020
Rock	43.4	42.3	3,620
Hackberry	36.8	35.9	3,070
Hickory	50.3	50.2	4,190
Holly	38.9	38.4	3,240
Hophornbeam (ironwood)	48.9	48.3	4,070
Laurel, California (Oregon myrtle)	38.9	37.6	3,240
Lemonwood	56.2	54.3	4,680
Locust, black	48.6	46.5	4,050
Madrone	44.5	43.9	3,710
Magnolia	33.6	32.9	2,800

Table 5.--Calculated weights of wood (Continued)

Species[1]	Weight in pounds per cubic foot: Based on weight and volume at a moisture content of 15 percent	Weight in pounds per cubic foot: Based on weight and volume at a moisture content of 8 percent	Weight per 1,000 board feet at a moisture content of 15 percent (actual board feet)
HARDWOODS			
Maple:			
Silver (soft)	34.9	33.9	2,910
Sugar (hard)	41.7	41.1	3,470
Oak:			
California black	39.0	37.7	3,250
Live	62.7	61.2	5,220
Red	43.4	42.8	3,620
White	45.9	45.4	3,820
Osage-orange	56.7	54.7	4,720
Persimmon	49.5	49.0	4,120
Sweetgum	34.1	33.6	2,840
Sycamore	34.9	34.3	2,910
Tupelo:			
Black	35.0	34.3	2,920
Water	35.0	34.3	2,920
Walnut, black	38.1	36.7	3,170
Willow, black	26.1	25.8	2,170
Yellow-poplar	28.3	27.5	2,360

[1]Scientific names are listed in table 8 opposite accepted U. S. Forest Service common names for individual species.

(Sheet 4 of 4)

Table 6.--Shrinkage values of wood based upon its dimensions when green

Species[1]	Shrinkage					
	Dried to 20 percent moisture content			Dried to 6 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
SOFTWOODS	Percent	Percent	Percent	Percent	Percent	Percent
Baldcypress	1.3	2.1	3.5	3.0	5.0	8.4
Cedar:						
Alaska yellow	.9	2.0	3.1	2.2	4.8	7.4
Eastern red	1.0	1.6	2.6	2.5	3.8	6.2
California incense	1.1	1.7	2.5	2.6	4.2	6.1
Northern white	.7	1.6	2.3	1.8	3.9	5.8
Port Orford white	1.5	2.3	3.4	3.7	5.5	8.1
Atlantic white	.9	1.7	2.8	2.3	4.3	7.0
Western red	.8	1.7	2.6	1.9	4.0	6.2
Douglas-fir:						
Coast type	1.7	2.6	3.9	4.0	6.2	9.4
Intermediate type	1.4	2.5	3.6	3.3	6.1	8.7
Rocky Mountain type	1.2	2.1	3.5	2.9	5.0	8.5
Fir:						
Alpine	.8	2.4	3.0	2.1	5.9	7.5
Balsam	.9	2.2	3.6	2.3	5.5	9.0
Grand (lowland white)	1.1	2.4	3.5	2.7	6.0	8.8
Noble	1.5	2.8	4.2	3.6	6.6	10.0
Pacific silver	1.5	3.3	4.7	3.8	8.3	11.7
Red	1.3	2.3	3.9	3.2	5.8	9.8
White	1.1	2.4	3.3	2.6	5.7	7.8
Hemlock:						
Eastern	1.0	2.3	3.2	2.4	5.4	7.8
Western	1.4	2.6	4.0	3.4	6.3	9.5
Larch, western	1.4	2.7	4.4	3.4	6.5	10.6
Pine:						
Eastern white	.8	2.0	2.7	1.8	4.8	6.6
Lodgepole	1.5	2.2	3.8	3.6	5.4	9.2
Ponderosa	1.3	2.1	3.2	3.1	5.0	7.7
Red	1.5	2.4	3.8	3.7	5.8	9.2

(Sheet 1 of 4)

Table 6.--Shrinkage values of wood based upon its dimensions when green (Contd.)

Species[1]	Shrinkage					
	Dried to 20 percent moisture content			Dried to 6 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
SOFTWOODS	Percent	Percent	Percent	Percent	Percent	Percent
Pine:						
Southern yellow:						
Loblolly	1.6	2.5	4.1	3.8	5.9	9.8
Longleaf	1.7	2.5	4.1	4.1	6.0	9.8
Shortleaf	1.5	2.6	4.1	3.5	6.2	9.8
Sugar	1.0	1.9	2.6	2.3	4.5	6.3
Western white (Idaho)	1.4	2.5	3.9	3.3	5.9	9.4
Redwood:						
Second-growth	.7	1.6	2.3	1.8	3.9	5.7
Old-growth	.9	1.5	2.3	2.1	3.5	5.4
Spruce:						
Eastern	1.4	2.6	4.2	3.4	6.2	10.1
Engelmann	1.1	2.2	3.5	2.7	5.3	8.3
Sitka	1.4	2.5	3.8	3.4	6.0	9.2
Tamarack (eastern larch)	1.2	2.5	4.5	3.0	5.9	10.9
HARDWOODS						
Alder, red	1.5	2.4	4.2	3.5	5.8	10.1
Apple	1.9	3.4	5.9	4.7	8.4	14.7
Ash:						
Black	1.7	2.6	5.1	4.0	6.2	12.2
White	1.5	2.5	4.3	3.8	6.2	10.7
Aspen (quaking and bigtooth)	1.2	2.2	3.8	2.8	5.4	9.2
Basswood	2.2	3.1	5.3	5.3	7.4	12.6
Beech	1.7	3.7	5.4	4.1	8.8	13.0

(Sheet 2 of 4)

Table 6.--Shrinkage values of wood based upon its dimensions when green (Contd.)

Species[1]	Shrinkage					
	Dried to 20 percent moisture content			Dried to 6 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
HARDWOODS	Percent	Percent	Percent	Percent	Percent	Percent
Birch:						
Paper	2.1	2.9	5.4	5.0	6.9	13.0
Yellow	2.3	3.0	5.4	5.5	7.1	13.0
Buckeye, yellow	1.2	2.6	4.0	2.9	6.5	10.0
Butternut	1.1	2.0	3.4	2.7	5.1	8.5
Cherry, black	1.2	2.4	3.8	3.0	5.7	9.2
Chestnut	1.1	2.2	3.9	2.7	5.4	9.3
Chinquapin	1.5	2.5	4.4	3.8	6.2	11.0
Cottonwood, black	1.3	3.1	4.7	3.1	7.4	11.3
Dogwood	2.4	3.8	6.6	5.9	9.4	16.6
Elm:						
American	1.4	3.2	4.9	3.4	7.6	11.7
Rock	1.6	2.7	4.7	3.8	6.5	11.3
Hackberry	1.6	3.0	4.6	3.8	7.1	11.0
Hickory	2.4	3.8	6.0	5.8	9.1	14.3
Holly	1.5	3.2	5.4	3.8	7.9	13.5
Hophornbeam (ironwood)	2.7	3.2	6.2	6.8	8.0	15.5
Laurel, California (Oregon myrtle)	.9	2.7	4.0	2.3	6.8	9.9
Lemonwood	1.3	2.2	3.7	3.3	5.7	9.3
Locust, black	1.5	2.3	3.3	3.7	5.8	8.2

(Sheet 3 of 4)

Table 6.--Shrinkage values of wood based upon its dimension when green (Contd.)

Species[1]	Shrinkage					
	Dried to 20 percent moisture content			Dried to 6 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
HARDWOODS	Percent	Percent	Percent	Percent	Percent	Percent
Madrone	1.8	4.0	5.8	4.5	9.9	14.5
Magnolia	1.7	2.9	4.5	4.2	7.0	10.9
Mahogany	1.2	1.6	2.6	2.9	4.0	6.4
Maple:						
Silver (soft)	1.0	2.4	4.0	2.4	5.8	9.6
Sugar (hard)	1.6	3.2	5.0	3.9	7.6	11.9
Oak:						
California, black	1.2	2.2	4.0	3.0	5.5	10.1
Live	2.2	3.2	4.9	5.5	7.9	12.3
Red[2]	1.4	3.0	4.9	3.4	7.2	11.8
White[3]	1.8	3.1	5.3	4.3	7.4	12.8
Osage-orange	......	......	3.0	......	......	7.4
Persimmon	2.5	3.6	6.1	6.3	9.0	15.3
Sweetgum	1.7	3.3	5.0	4.2	7.9	12.0
Sycamore	1.7	2.5	4.7	4.1	5.3	11.4
Tupelo:						
Black	1.5	2.6	4.6	3.5	6.2	11.1
Water	1.4	2.5	4.2	3.4	6.1	10.0
Walnut, black	1.7	2.4	3.8	4.2	5.7	9.0
Willow, black	.8	2.6	4.6	2.1	6.5	11.5
Yellow-poplar	1.3	2.4	4.1	3.2	5.7	9.8

[1]Scientific names are listed in table 8 opposite accepted U. S. Forest Service common names.

[2]Average of black oak, laurel oak, pin oak, northern red oak, scarlet oak, southern red oak, swamp red oak, water oak, and willow oak.

[3]Average of bur oak, chestnut oak, post oak, swamp chestnut oak, swamp white oak, and white oak.

Table 7.--The average electrical resistance along the grain in megohms, measured at 80° F. between two pairs of needle electrodes 1-1/4 inches apart and driven to a depth of 5/16-inch, of several species of wood at different values of moisture content

Species of wood	Percentage of moisture content																		
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Conifers:																			
Cypress, southern	12,600	3,980	1,410	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	1.78	1.26	0.91	0.66	0.51	0.42
Douglas-fir (coast type)	22,400	4,780	1,660	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	2.14	1.51	1.10	.79	.60	.46
Fir, California red	31,600	6,760	2,000	725	315	150	83	48	28.8	18.2	11.8	7.6	5.01	3.31	2.29	1.58	1.15	.83	.63
Fir, white	57,600	15,850	3,980	1,120	415	180	83	46	26.9	16.6	11.0	6.6	4.47	3.02	2.14	1.55	1.12	.86	.62
Hemlock, western	22,900	5,620	2,040	850	400	185	98	51	28.2	16.2	10.0	6.0	3.89	2.52	1.58	1.05	.72	.51	.37
Larch, western	39,800	11,200	3,980	1,445	560	250	120	63	33.9	19.9	12.3	7.6	5.02	3.39	2.29	1.62	1.20	.87	.66
Pine, eastern white	20,900	5,620	2,090	850	405	200	102	58	33.1	19.9	12.3	7.9	5.01	3.31	2.19	1.51	1.05	.74	.52
Pine, longleaf	25,000	8,700	3,160	1,320	575	270	135	74	41.7	24.0	14.4	8.9	5.76	3.72	2.46	1.66	1.15	.79	.60
Pine, ponderosa	39,800	8,910	3,310	1,410	645	300	150	81	44.7	25.1	14.8	9.1	5.62	3.55	2.34	1.62	1.15	.87	.69
Pine, shortleaf	43,600	11,750	3,720	1,350	560	255	130	69	38.9	22.4	13.8	8.7	5.76	3.80	2.63	1.82	1.29	.93	.66
Pine, sugar	22,900	5,250	1,660	645	280	140	76	44	25.7	15.9	10.0	6.6	4.36	3.02	2.09	1.48	1.05	.75	.56
Redwood	22,400	4,680	1,550	615	250	100	45	22	12.6	7.2	4.7	3.2	2.29	1.74	1.32	1.05	.85	.71	.60
Spruce, Sitka	22,400	5,890	2,140	830	365	165	83	44	25.1	15.5	9.8	6.3	4.27	3.02	2.14	1.58	1.17	.91	.71
Hardwoods:																			
Ash, commercial white	12,000	2,190	690	250	105	55	28	14	8.3	5.0	3.2	2.0	1.32	.89	.63	.50	.44	.40	.40
Basswood	36,300	1,740	470	180	85	45	27	16	9.6	6.2	4.1	2.8	1.86	1.32	.93	.69	.51	.39	.31
Birch	87,000	19,950	4,470	1,290	470	200	96	53	30.2	18.2	11.5	7.6	5.13	3.55	2.51	1.78	1.32	.95	.70
Elm, American	18,200	2,000	350	110	45	20	12	7	3.9	2.3	1.5	1.0	.66	.48	.42	.40	.40	.40	.40
Hickory, true	......	31,600	2,190	340	115	50	21	11	6.3	3.7	2.3	1.5	1.00	.71	.52	.44	.40	.40	.40
Khaya[1]	44,600	16,200	6,310	2,750	1,260	630	340	180	105.0	60.2	35.5	21.9	14.10	9.33	6.16	4.17	2.82	1.99	1.44
Magnolia	43,700	12,600	5,010	2,040	910	435	205	105	56.2	29.5	16.2	9.1	5.25	3.09	1.86	1.17	.74	.50	.32
Mahogany, American	20,900	6,760	2,290	870	380	180	85	43	22.4	12.3	7.2	4.4	2.69	1.66	1.07	.72	.49	.35	.26
Maple, sugar	72,400	13,800	3,160	690	250	105	53	29	16.6	10.2	6.8	4.5	3.16	2.24	1.62	1.23	.98	.75	.60
Oak, commercial red[2]	14,400	4,790	1,590	630	265	125	63	32	18.2	11.3	7.3	4.6	3.02	2.09	1.45	.95	.80	.63	.50
Oak, commercial white	17,400	3,550	1,100	415	170	80	42	22	12.6	7.2	4.3	2.7	1.70	1.15	.79	.60	.49	.44	.41
Shorea[3]	2,890	690	220	80	35	15	9	5	2.8	1.7	1.1	.7	.45	.30	.21	.16	.12	.09	.07
Sweetgum	38,000	6,460	2,090	815	345	160	81	45	25.7	15.1	9.3	6.0	3.98	2.63	1.78	1.26	.87	.63	.46
Tupelo, black[2]	31,700	12,600	5,020	1,820	725	275	120	58	27.6	13.0	6.9	3.7	2.19	1.38	.95	.63	.46	.33	.25
Walnut, black	51,300	9,770	2,630	890	355	155	78	41	22.4	12.9	7.8	4.9	3.16	2.14	1.48	1.02	.72	.51	.38
Yellow-poplar[2]	24,000	8,320	3,170	1,260	525	250	140	76	43.7	25.2	14.5	8.7	5.76	3.81	2.64	1.91	1.39	1.10	.85

[1] Known in the trade as "African mahogany."

[2] The values for this species were calculated from measurements on veneer.

[3] A Philippine hardwood, identified as tanguile or some similar species.

Z M 87886 F

Table 8.--Accepted U. S. Forest Service common and scientific names for timber trees

Common name	Scientific name
HARDWOODS	
Alder, red	Alnus rubra
Apple	Malus sp.
Ash:	
Black	Fraxinus nigra
White	Fraxinus americana
Aspen[1]:	
Bigtooth	Populus grandidentata
Quaking	Populus tremuloides
Basswood, American	Tilia americana
Beech, American	Fagus grandifolia
Birch:	
Paper	Betula papyrifera
Yellow	Betula lutea
Buckeye, yellow	Aesculus octandra
Butternut	Juglans cinerea
Cherry, black	Prunus serotina
Chestnut, American	Castanea dentata
Chinquapin, golden	Castanopsis chrysophylla
Dogwood, flowering	Cornus florida
Elm:	
American	Ulmus americana
Rock	Ulmus thomasii
Hackberry	Celtis occidentalis
(sugarberry)	Celtis laevigata
Hickory:	
True hickory group	
Mockernut	Carya tomentosa
Pignut	Carya glabra

Table 8.--Accepted U. S. Forest Service common and scientific names for timber trees (Contd.)

Common name	Scientific name
HARDWOODS	
Hickory:	
True hickory group:	
Shagbark	Carya ovata
Shellbark	Carya laciniosa
Pecan hickory group:	
Bitternut	Carya cordiformis
Nutmeg	Carya myristicaeformis
Pecan	Carya illinoensis
Water hickory	Carya aquatica
Holly, American	Ilex opaca
Hophornbeam, eastern (ironwood)	Ostrya virginiana
Laurel, California (Oregon myrtle)	Umbellularia californica
Lemonwood	Calycophyllum candidissimum
Locust:	
Black	Robinia pseudoacacia
Madrone, Pacific	Arbutus menziesii
Magnolia:	
Southern	Magnolia grandiflora
Sweetbay	Magnolia virginiana
Cucumber magnolia	Magnolia acuminata
Mahogany:	
Central American	Swietenia macrophylla
West Indies	Swietenia mahagoni
Maple:	
Hard maple group:	
Sugar	Acer saccharum
Black	Acer nigrum
Soft maple group:	
Red	Acer rubrum
Silver	Acer saccharinum
Oak:	
California black	Quercus kelloggii
Live	Quercus virginiana

Table 8.--Accepted U. S. Forest Service common and scientific names for timber trees (Contd.)

Common name	Scientific name
HARDWOODS	
Oak:	
Northern red	Quercus borealis
Southern red	Quercus falcata
White oak group	Quercus sp.
Osage-orange	Maclura pomifera
Persimmon	Diospyros virginiana
Sweetgum	Liquidambar styraciflua
Sycamore, American	Platanus occidentalis
Tanoak	Lithocarpus densiflora
Tupelo:	
Black	Nyssa sylvatica
Water	Nyssa aquatica
Swamp	Nyssa sylvatica var. biflora
Walnut, black	Juglans nigra
Willow, black	Salix nigra
Yellow-poplar	Liriodendron tulipifera
SOFTWOODS	
Baldcypress	Taxodium distichum
Cedar:	
Alaska yellow	Chamaecyparis nootkatensis
Eastern red	Juniperus virginiana
California incense	Libocedrus decurrens
Northern white	Thuja occidentalis
Port-Orford white	Chamaecyparis lawsoniana
Atlantic white	Chamaecyparis thyoides
Western red	Thuja plicata
Douglas-fir (includes coast, intermediate, and Rocky Mountain types)	Pseudotsuga taxifolia

Table 8.--Accepted U. S. Forest Service common and scientific names for timber trees (Contd.)

Common name	Scientific name
SOFTWOODS	
Fir:	
Alpine	Abies lasiocarpa
Balsam	Abies balsamea
Grand (lowland white)	Abies grandis
Noble	Abies procera
Pacific silver	Abies amabilis
California red	Abies magnifica
White	Abies concolor
Hemlock:	
Eastern	Tsuga canadensis
Western	Tsuga heterophylla
Larch, western	Larix occidentalis
Pine:	
Eastern white	Pinus strobus
Lodgepole pine	Pinus contorta var. latifolia
Ponderosa	Pinus ponderosa
Red	Pinus resinosa
Southern yellow:	
Loblolly	Pinus taeda
Longleaf	Pinus palustris
Shortleaf	Pinus echinata
Sugar	Pinus lambertiana
Western white (Idaho)	Pinus monticola
Redwood	Sequoia sempervirens
Spruce:	
Eastern[1]:	
Black	Picea mariana
Red	Picea rubens
White	Picea glauca
Engelmann	Picea englemanni
Sitka	Picea sitchensis
Tamarack (eastern larch)	Larix laricina

[1]Lumber sold under this common name may contain one or more of the species listed. It is not possible to differentiate these species on the basis of the wood alone.

Figure 1.--Cross section of an oak tree showing:

A, cambium; B, innerbark; C, bark;

D, sapwood; E, heartwood; F, pith;

G, ray.

(ZM 22596 F)

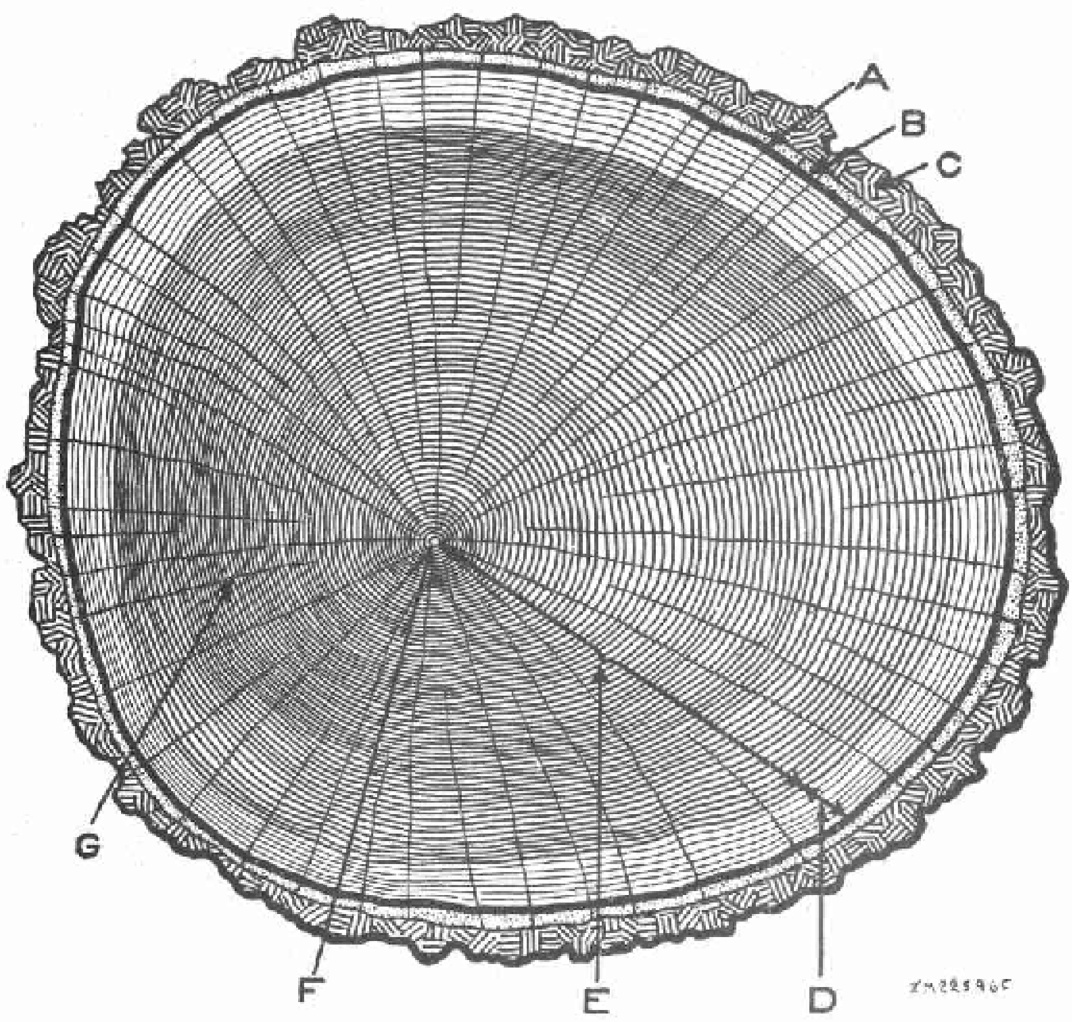
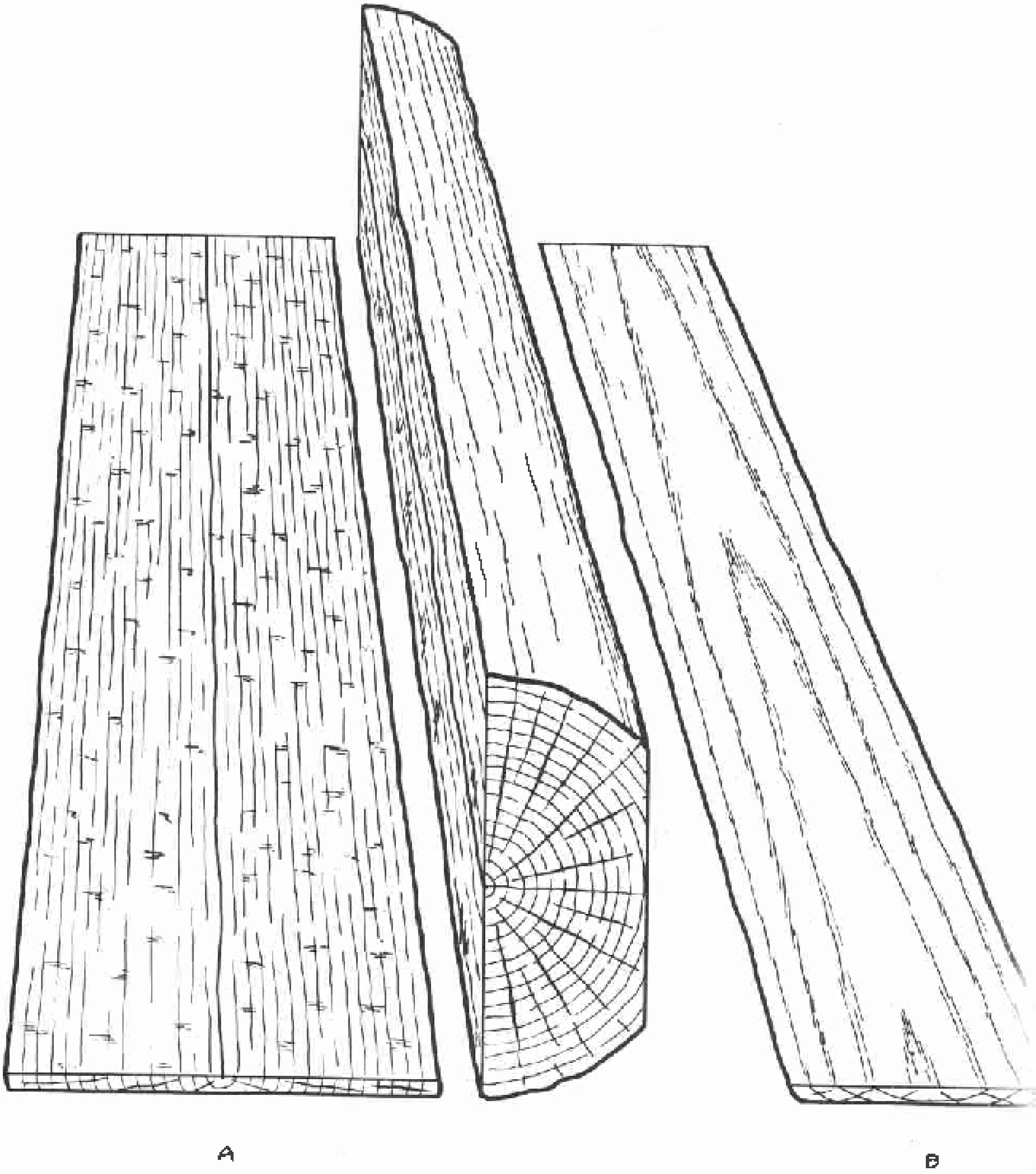

A
B
C
G
F
E
D
ZM22596F

Figure 2.--Quarter-sawed (A) and plain-sawed (B) boards cut from a log.

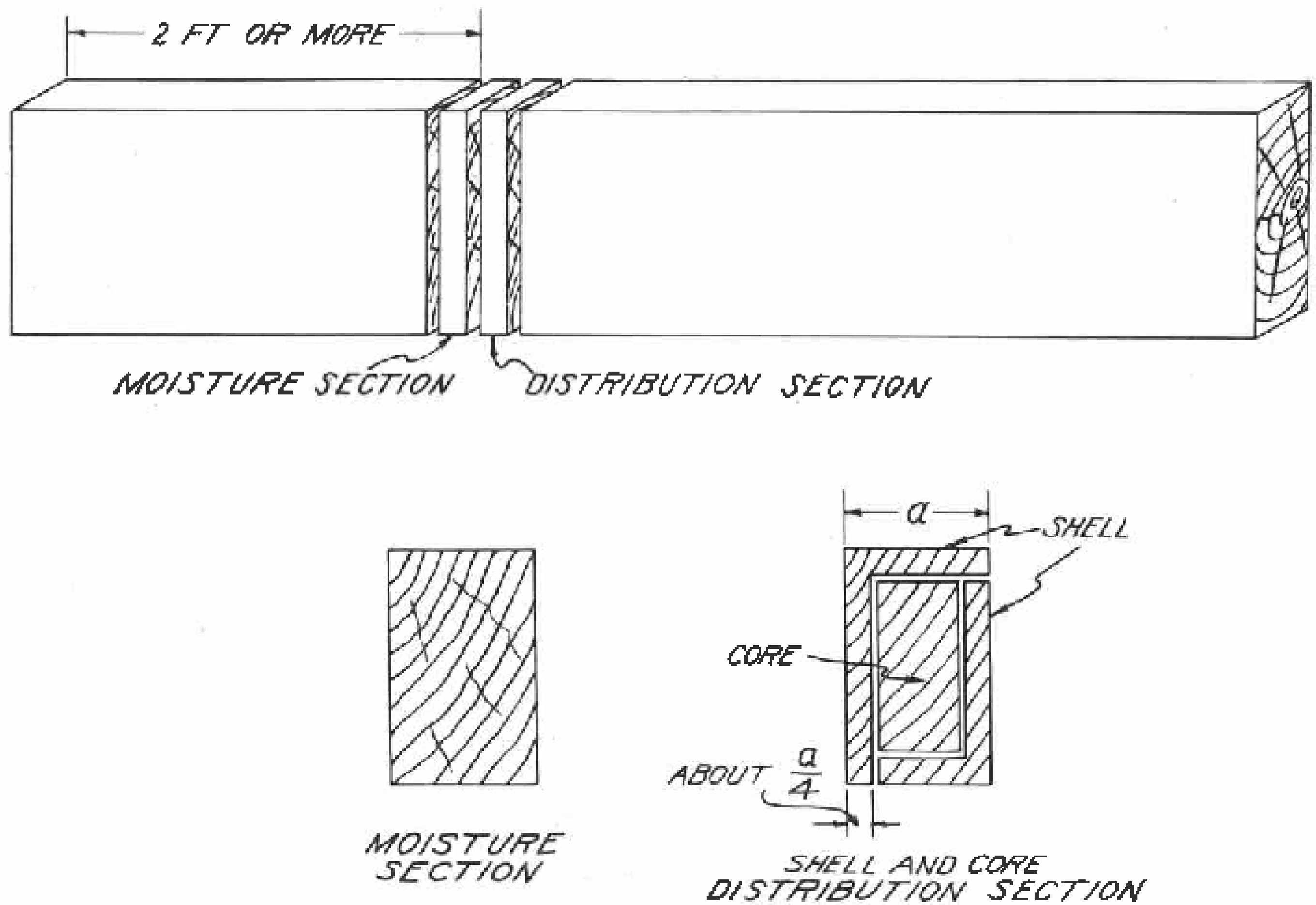
(ZM554F)



ZM 554 F

Figure 3.--Method of cutting sections from a piece of wood for moisture-content and moisture-distribution determinations.

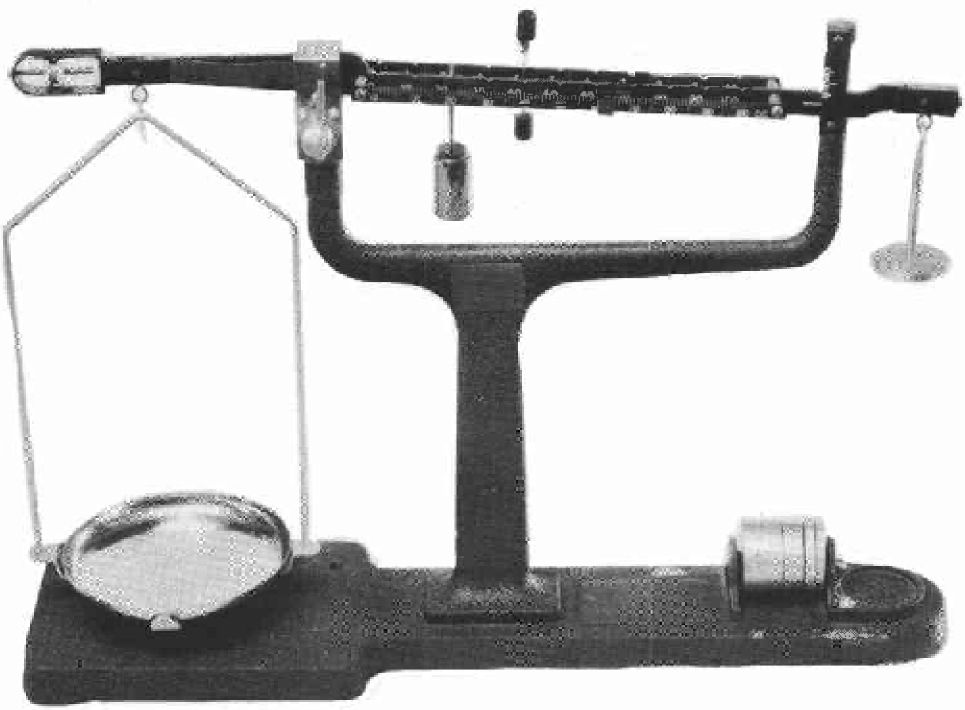
(ZM 12314 F)


2 FT OR MORE
MOISTURE SECTION
DISTRIBUTION SECTION
MOISTURE SECTION
a
SHELL
CORE
ABOUT a/4
SHELL AND CORE DISTRIBUTION SECTION

ZM 123 14 F

Figure 4.--Triple-beam type of balance with auxiliary weights.

(ZM 64322 F)



ZM 64322 F

Figure 5.--Pan-type of balance with double beam and auxiliary weights.

(ZM 64321 F)

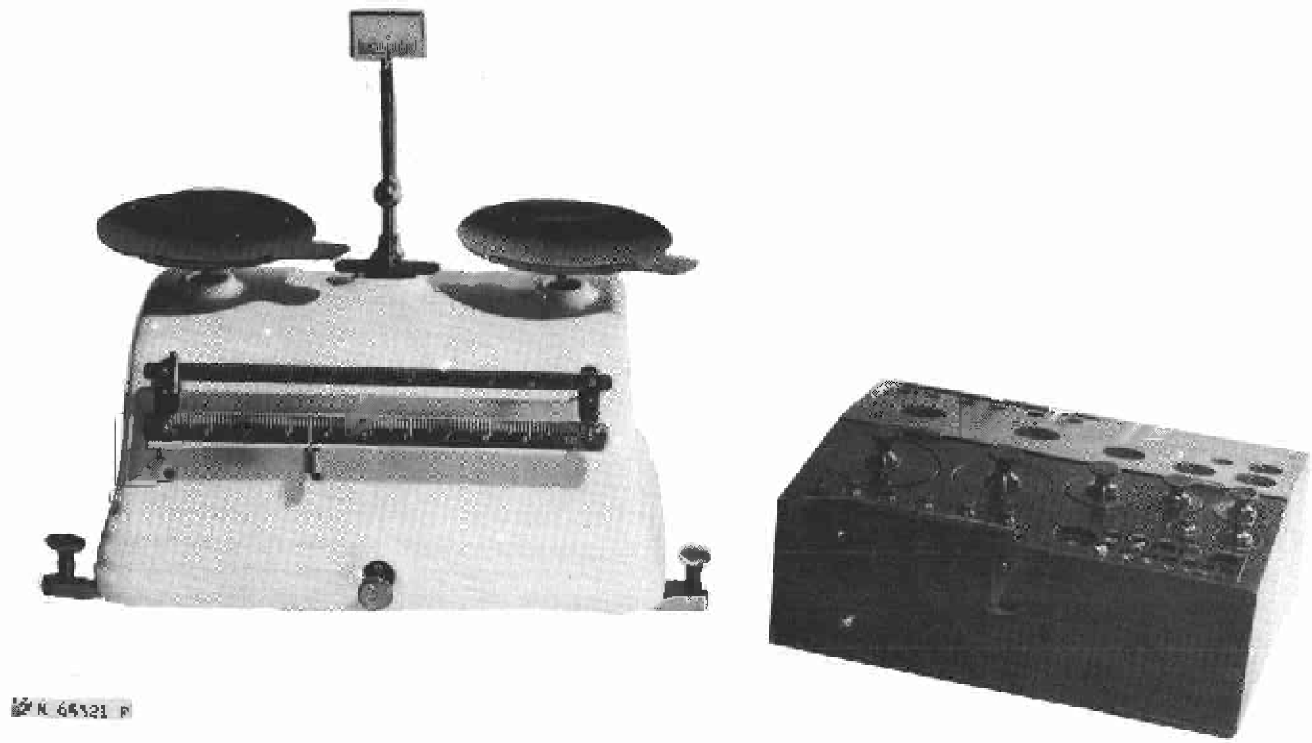

N 65321 F

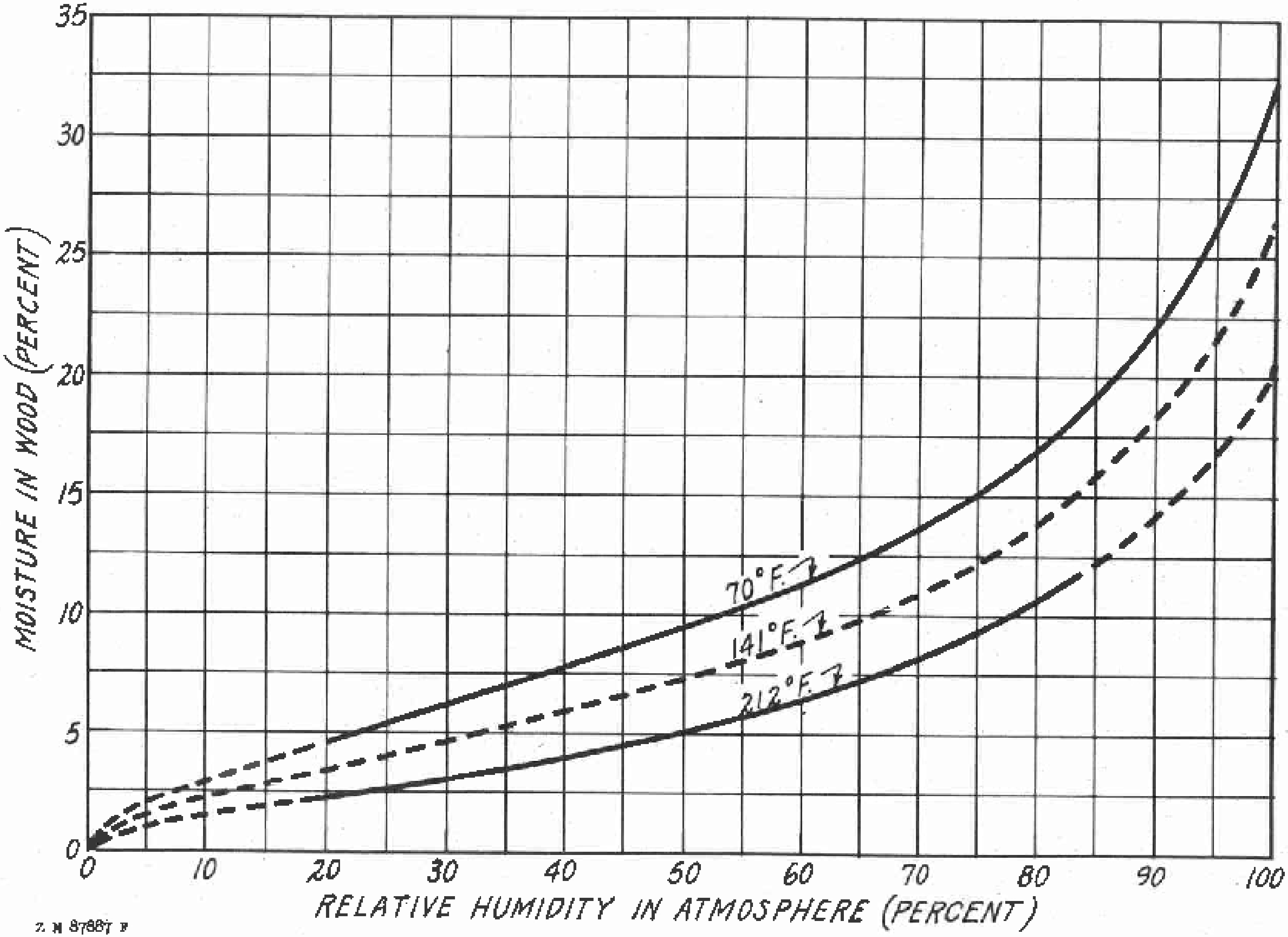
Figure 6.--Electrical oven with automatic
temperature control.

(ZM 8911 F)

ZM8911F

Figure 7.--Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere at three temperatures.

(ZM 87887 F)

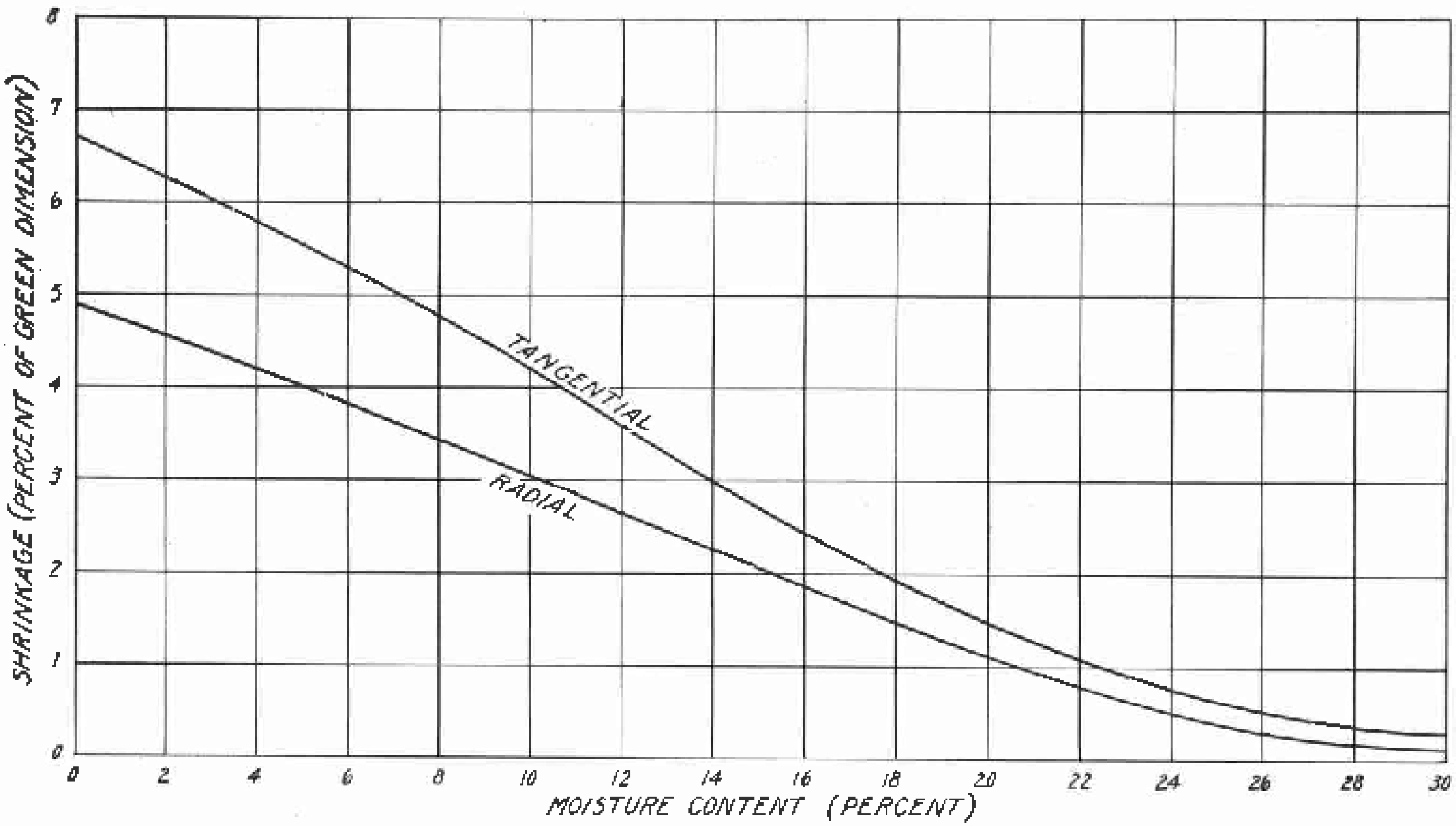


70°F.
141°F.
212°F.
MOISTURE IN WOOD (PERCENT)
RELATIVE HUMIDITY IN ATMOSPHERE (PERCENT)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100

Z M 87887 F

Figure 8.--Typical moisture-content, shrinkage curves for Douglas-fir. Although the curves are not straight lines, for practical shrinkage calculations they may be considered as such.

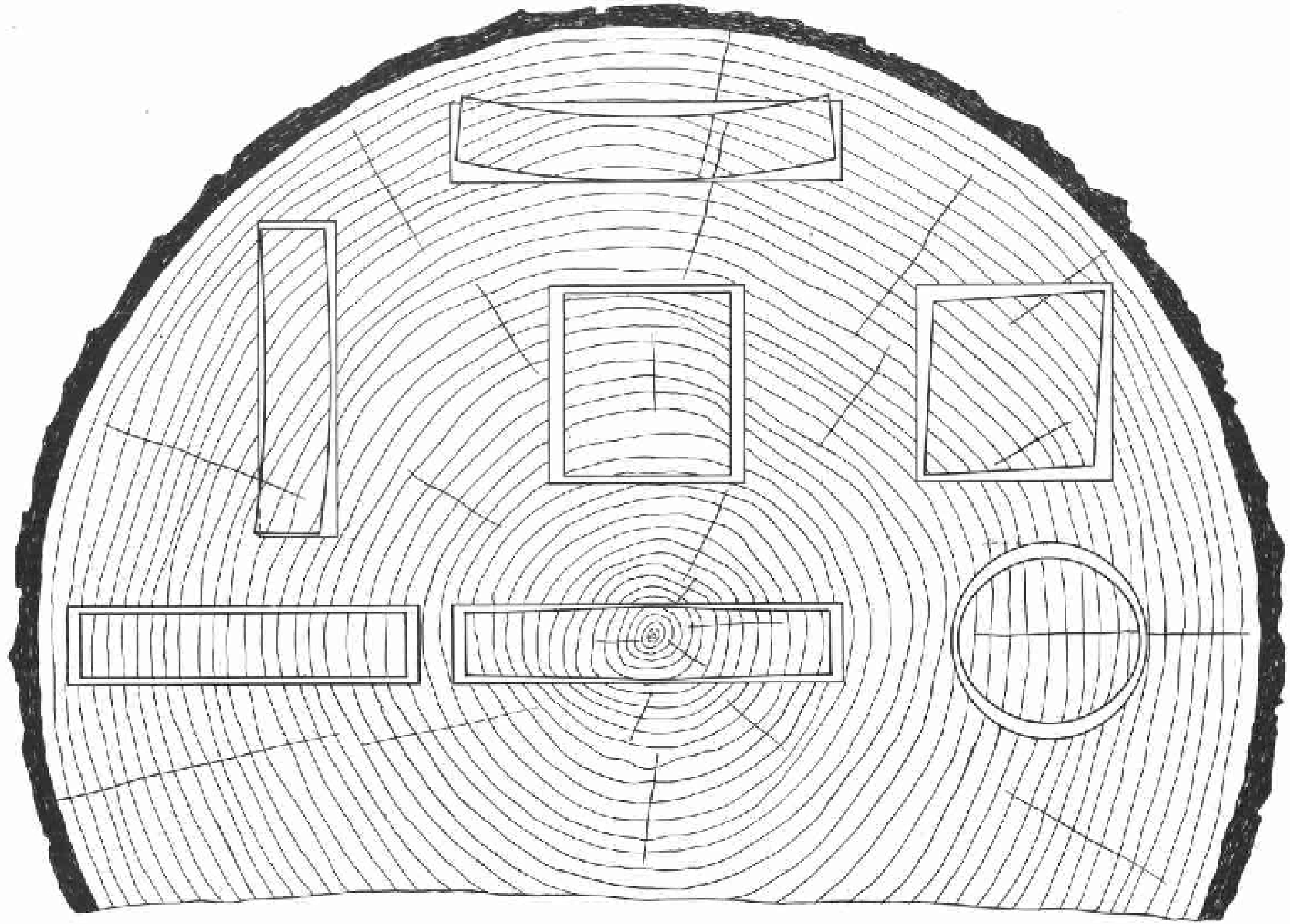
(ZM 61223 F)


SHRINKAGE (PERCENT OF GREEN DIMENSION)
MOISTURE CONTENT (PERCENT)
TANGENTIAL
RADIAL
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

Z M 61223 F

Figure 9.--Characteristic shrinkage and distortion of plain-sawed and of quarter-sawed boards, squares, and rounds as affected by the direction of the annual rings. The dimensional changes shown are somewhat exaggerated.

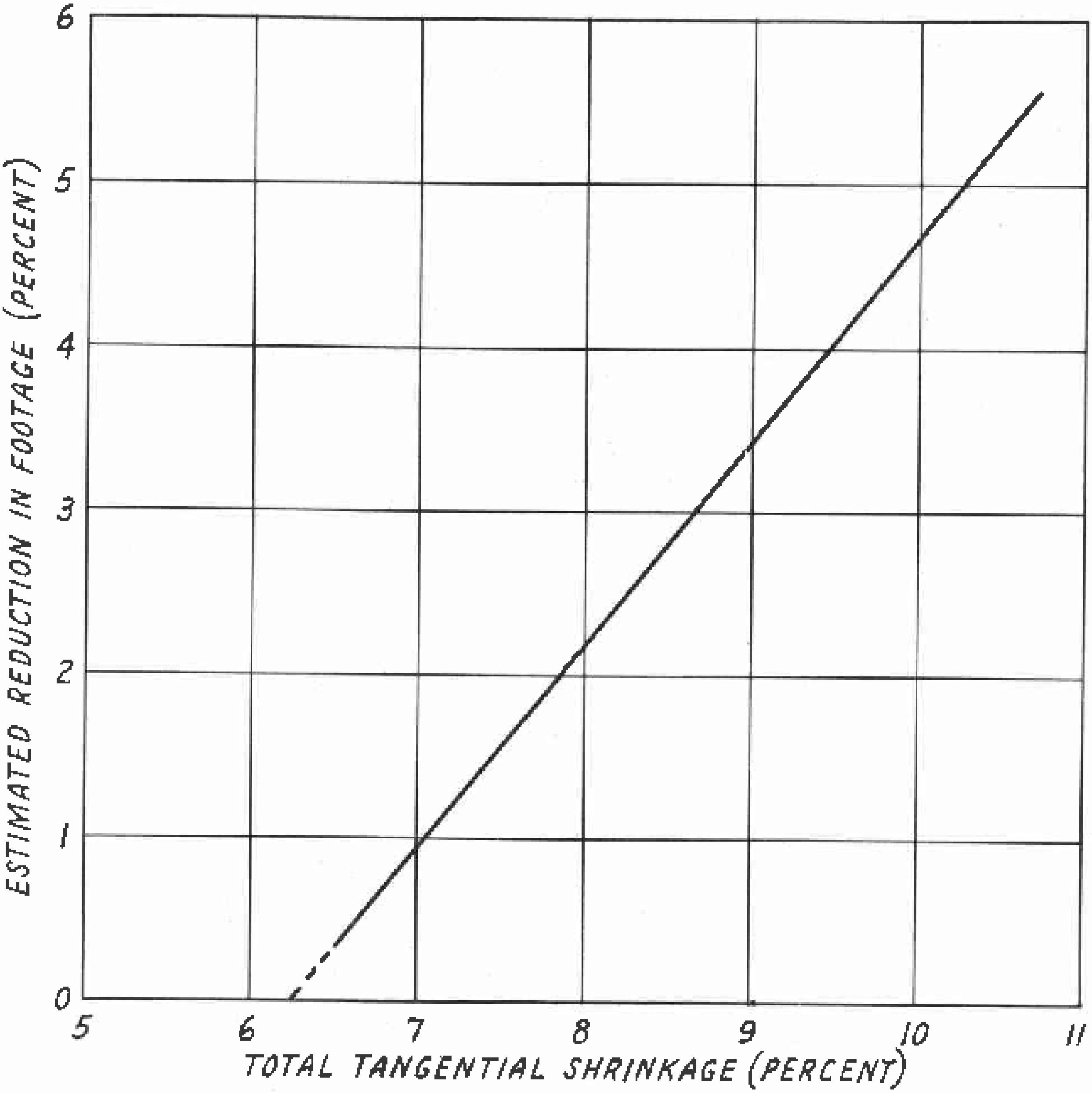
(ZM 12474 F)



ZM12494F

Figure 10.--Estimated reduction in footage (percent of air-dried tally) **vs.** tangential shrinkage (percent of dimension when green) for carload shipments of hardwoods when kiln-dried to a moisture content of 5 percent from an air-dried condition of 18 percent.

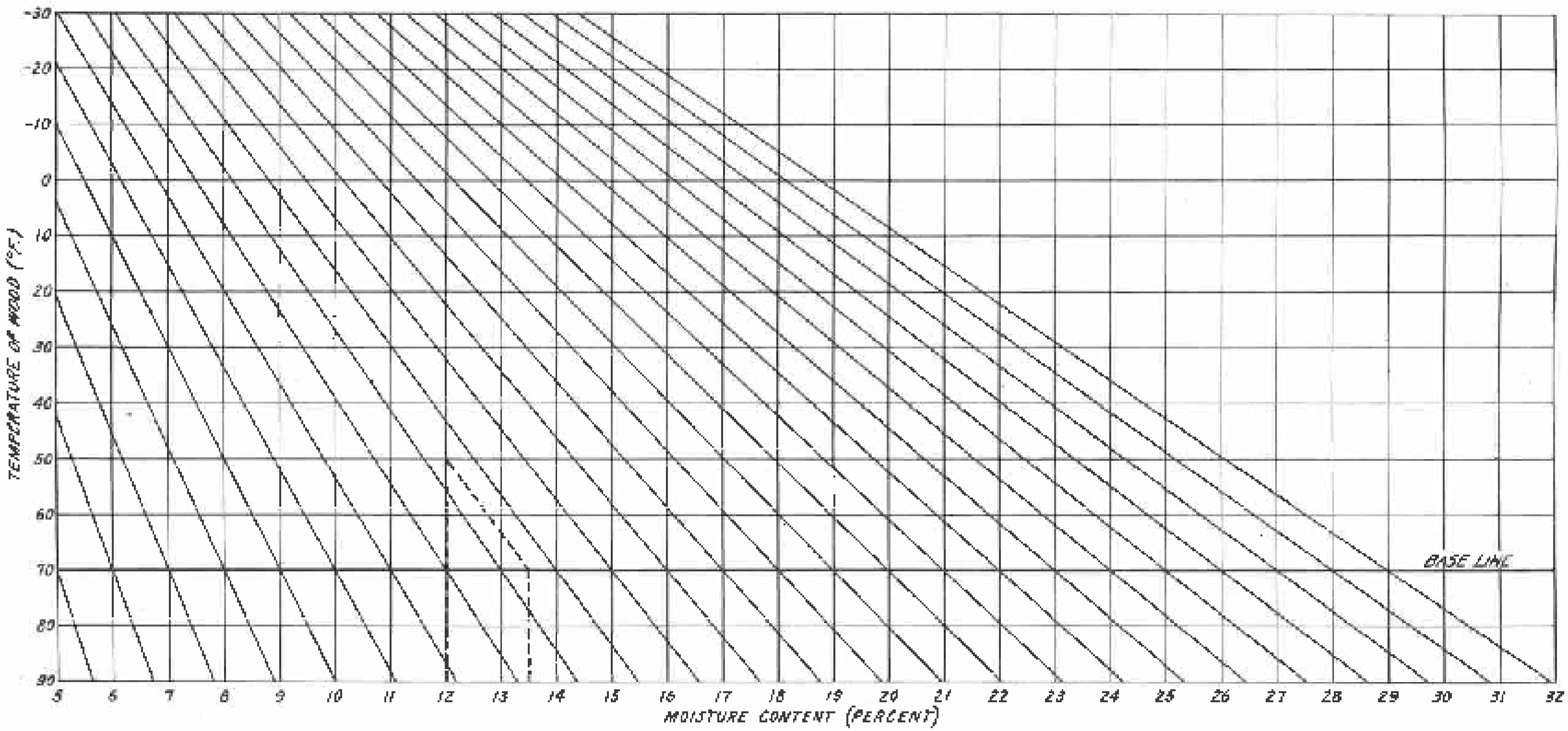
(ZM 38992 F)


6
5
4
3
2
1
0
ESTIMATED REDUCTION IN FOOTAGE (PERCENT)
5
6
7
8
9
10
11
TOTAL TANGENTIAL SHRINKAGE (PERCENT)

Z M 38992 F

Figure 11.--Temperature corrections applicable to moisture content determined with electric moisture meters. Find the moisture content measured by the moisture meter on the lower margin of the diagram, follow this line vertically to the horizontal temperature line approximating the temperature of the wood being tested, and then follow the sloping lines to the 70° F. base line and read the corrected moisture content vertically below. Example: measured moisture content, 12 percent; temperature of wood, 50° F.; corrected moisture content, 13.5 percent.

(ZM 76476 F)


TEMPERATURE OF WOOD (°F.)
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
BASE LINE
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
MOISTURE CONTENT (PERCENT)

Z M 76476 F