INTRODUCTION

A large number of tree species are pulped in the United States and Canada. Much information is available on certain of these species but, unfortunately, such data are scattered in a wide variety of publications. This book brings together this scattered information from silvics to pulping properties.

Several sections have been enlarged in this new edition, and information has been added on bark, including structure, physical properties, and chemical composition. As in the previous edition, the range of a species is shown on a map when feasible. Information on four exotic species that are planted in the United States has also been added; these are Eucalyptus spp., Ailanthus altissima (ailanthus), Alnus glutinosa (European black alder), and Populus alba (white poplar).

The author and revisers acknowledge with thanks the assistance received from members of The Institute of Paper Chemistry staff in assembling the data. Special thanks go to Dean W. Einspahr, John D. Litvay, Thomas J. McDonough, and the Editorial, Photography and Duplicating staff.

Five summary tables are located at the back of the book. These are Table I — Tracheid Dimensions and Decay Resistance, Table II — Wood and Bark Specific Gravity, Table III — Calorific Value of Wood and Bark, Table IV — Chemical Composition of Wood, and Table V — Chemical Composition of Bark.
EXPLANATION OF TERMS

Units of Measurement

Both English and metric units are given wherever possible.

Tree Name

The common name, scientific name and synonyms were largely taken from the USDA, Forest Service Agriculture Handbook no. 519, 1978 (Little, E. L., Jr. Important Forest Trees of the United States).

Range

The general area in which the species is indigenous is shown on a map when feasible. Altitudinal range is also given if limiting and available, as well as the acreage covered. It must be remembered that certain localities within the range may not contain the tree because of environmental conditions, natural enemies, or removal by man.

Dimensions

Average dimensions of mature trees are given.

Pathology

Major disease and insect enemies of each species are briefly mentioned. Much of this information concerns the trees and far less of it, the logs. Unfortunately, there is no direct relationship between the pathological resistance of a growing tree and the durability of the wood cut from it. Certain types of diseases do not interfere with the use of wood for chemical pulping; others cause so much decay that the tree is useless.

Gross Features of the Wood

The general characteristics and properties of the typical wood from the merchantable part of the tree are given. When the planes of section are described, x signifies cross, r signifies radial, and t signifies tangential.

Microscopic Structure of Wood and Bark

The minute anatomy of wood and bark is described with dimensions and characteristics normally present. Weight factor and fiber coarseness data have been added where possible. Photomicrographs illustrating wood and bark structure at higher magnification are scattered throughout the report. Additional information on the bark of 42 species may be obtained from the Institute of Paper Chemistry, including test results of simulated hammer-milling, bark toughness and strength, and wood/bark adhesion. This work was done under the Institute's Project 3212, “Bark and Wood Properties of Pulpwood Species as Related to Separation and Segregation of Chip/Bark Mixtures”.

Physical Properties of Wood

Several common values do not have to be determined by stress. Specific gravity is based on the oven-dry weight and the volume of the material when it was in a green, air-dry, or oven-dry condition. The density is given in pounds per cubic foot for various conditions of moisture and also as pounds of dry wood substance per cubic foot volume when green. Much information has also been added on specific gravity variation within the tree and changes in specific gravity due to fertilization, geographic location, etc.

The moisture content is the average for green wood. It is the custom in wood industries to relate the loss in moisture from the original to the oven-dry condition to the weight of the oven-dry piece, whereas in the pulp and paper industry moisture is expressed as a percentage of the original weight as it is with chemicals. Both values are given as well as relative sapwood and heartwood moisture content where available.

Most woods have their cell walls saturated and the cell cavities free from water (fiber saturation point) at a moisture content of 25 to 30% (based on the oven-dry weight). When the moisture content decreases below the fiber saturation point, shrinkage takes place. The shrinkage values for volume, radial direction and tangential direction are figured on the loss in size to the oven-dry condition based on the dimension when green; the shrinkage to the air-dry condition will be less.

Physical Properties of Bark

Information on the specific gravity and moisture content of bark has been added when available. In many cases, specific gravity is given for the inner and outer bark, as well as the total bark.
Chemical Composition of Wood and Bark

Much information is available in the literature, particularly on the composition of wood, and not all of this information can be included if the book is to be kept to a reasonable size. Representative information is given, and the reader may utilize the literature cited to obtain more information.

Pulping

Descriptions of pulping processes have been kept brief and, again, the reader is encouraged to read the articles cited for more information.
Scientific Name  *Populus tremuloides* Michx.

Synonyms  Trembling aspen, aspen, poplar, popple, golden aspen, mountain aspen

Family Name  Salicaceae

Range  The most widely distributed hardwood in North America, with a range extending from Newfoundland and Labrador west across Canada along the northern tree limit to northwestern Alaska. The southern boundary extends from New Jersey westward to Iowa and then northwestward to British Columbia. It is also found in the mountains of western United States, in northern Mexico and in scattered locations in western Virginia and northern Missouri. Aspen is the most widely distributed forest type in the Lake States, covering about 13 million acres (5.3 million ha) (1). The total acreage in the aspen-birch type in the northern forests of the United States is approximately 23.7 million acres (9.6 million ha) (2).

Silvics  Growth and development of aspen is strongly influenced by soil conditions and, on medium and better quality sites, aspen can reach 70-80 ft (21-24 m) in height by age 50. These soils are usually porous, loamy,
humic and rich in lime. However, aspen can also be found on rocky, shallow soils, sandy areas and heavy clay soils. The species is very intolerant and with competition a long, slender bole with a small, rounded crown is developed; the root system is superficial. Although aspen occurs as a scattered tree in unbroken woods or on stream banks, it occupies logged and burned areas in almost pure stands. In the northern forest on burns its common associates are pin cherry, bigtooth aspen, gray birch, willow, and an understory of maple, birch, and beech. In the Lake States on sandy soils jack pine, aspen and white birch mixtures are common. On better soils an understory of balsam fir or maple, birch, and beech. In the Lake States or on stream banks, it occupies logged and burned areas in almost pure stands. In the northern forest on burns its common associates are pin cherry, bigtooth aspen, gray birch, willow, and an understory of maple, birch, and beech.

Pathology  Resistance to decay: low

Because of its thin bark and shallow root system, aspen is subject to fire damage, to storm and ice breakage and windthrow. Small trees are frequently browsed by deer and moose and may be girdled by rabbits or mice. Hypoxylon canker (Hypoxylon mammatum) is considered to be the most serious disease of aspen in the Lake States and occurs widely with birches, alders, balsam poplar, and lodgepole or ponderosa pine with an understory of tolerant conifers. Reproduction by seed is very good and root sprouts are frequent.

Tree Dimensions  Small to medium-sized tree, 50-60 ft (15-18 m) tall and 1-2 ft (30-61 cm) in diameter.

Microscopic Structure of the Wood

**Vessels.** Early springwood vessels are solitary or in clusters of 6 or more. They are approximately 95-100 \( \mu m \) in diameter. These large vessels are immediately adjacent to the terminal band and are separated by 1-3 rows of fibers. The vessels in the latewood are smaller and average approximately 60-70 \( \mu m \) in diameter. They appear in smaller clusters and are separated by as many as 8-10 rows of fibers. There are between 85 and 180 vessels per sq mm. Perforation plates are simple; intervessel pits orbicular to angular. Volume occupied, approximately 34%.

**Fibers.** Average, 1.04 mm (0.4-1.9 mm) in length and 10-27 \( \mu m \) in diameter. Cell wall thickness 2-3 \( \mu m \). Weight factor 0.45; coarseness 8.59 mg/100 m. Volume occupied, approximately 55%. Gelatinous fibers, which have a cell wall thickness more than double that of normal fibers, are quite common in this wood species. Einspahr, et al. (5), in a study on 17-year-old trees growing in a natural sucker stand, found that fiber length in the outer portion of the tree is quite high near the base, increases moderately up to a height of 6.5 ft (2 m), and then decreases with increasing height. At all heights sampled, mean fiber length increased outwards from the pith to the cambium.

**Rays.** Unstoried, uniseriate, up to 25 cells (481 \( \mu m \)) in height, 27 per sq mm on the tangential surface, 9 per mm tangentially on the x-section, homogeneous, 3 to 13
roughly circular pits leading from ray crossing to vessel; volume occupied, approximately 11%.

**Longitudinal Parenchyma.** Terminal, forming a narrow, continuous or interrupted line; volume occupied, trace.

**Gross Features of the Bark.** Aspen bark is variable in appearance from smooth and light colored to rough and dark. The normal bark is smooth and gray, with a typically waxy feel. The rough, dark bark apparently results from mechanical injury or attack by fungi and lichens (6) or from a combination of both outside stimulation and natural formation (7). Rhytidome formation may appear in very old trees, principally at their bases. For pulpwood diameter trees (6-10 in or 15-25 cm dbh), the bark of the bole typically consists of about 80% inner bark and 20% outer bark. However, on rough-barked trees the percentage of outer bark may run as high as 40%. Bark volume averages about 18%. Covington (8) found that in New Mexico the bark of quaking aspen appears green at higher altitudes and chlorophyll concentrations are inversely correlated with altitude. At lower altitudes, higher chlorophyll content is masked by a white bloom of dead periderm cells. Altitudinal gradients in reflectance of bark could be adaptive. At high altitudes, more light would be available for cortical photosynthesis and for raising bark temperatures during winter. At low altitudes, trees would be protected from high bark temperatures and injury from sunscald.

**Microscopic Structure of the Bark**

**Young Bark.** The cell arrangement of the inner bark (secondary phloem) is the same for both mature and young bark except for the rather late development of fibers in young bark. Although the scattered fibers may appear early, the formation of tangential bands of sclerenchyma cells has occurred as late as 6-8 years of age in branches (7). The outer bark of young stems includes an epidermis which is one row of compact cells. The next layer, the periderm, includes several distinct layers. The widest area, the phellem, has uniform thin-walled rectangular cells, compactly arranged. This layer makes up about 2% by weight of the dry bark. The cortex occupies a greater portion of the bark in young stems than in the mature trunk. The outer part of the cortex has thick cell walls with large intercellular spaces. Cortical parenchyma forms the bulk of the cortex. In older branches, some cortical parenchyma become
lignified. Sclereid groups are absent in very young stems with scattered groups of fibers gradually appearing in older stems.

**Mature Bark.** The inner bark is made up of sieve tubes, companion cells, parenchyma cells, sclerenchyma (phloem fibers and sclereids), and ray cells. The sieve tubes are large diameter (40-50 \( \mu m \)), thin-walled cells whose individual sieve tube elements are approximately 800 \( \mu m \) in length. They are normally surrounded by small diameter, thin-walled companion cells and parenchyma cells. The inner bark of quaking aspen is characterized by tangential bands, 2-10 cells in width, of phloem fibers. The bands may be discontinuous near the cambium zone. The fibers are approximately 18-20 \( \mu m \) in diameter. They have a cell wall thickness of 8-10 \( \mu m \) and a narrow lumen of 2-4 \( \mu m \). These fibers have an average length of approximately 1 mm. The distribution of phloem fibers decreases from the cambial zone toward the periderm. Phloem fibers make up 25% of the total inner bark with only 6% at the outer limit. The sclereids range from none in the greater part of the inner bark to 28% at the outer part of the inner bark. The percentage of sclereids in the total inner bark averages 15%. Harder, et al. (9) found a fibrous yield of 8% when quaking aspen bark was pulped to a solids yield of 33.8%. The homogeneous, uniseriate phloem rays are distributed uniformly throughout the inner bark.

**Periderm.** Structurally, the last-formed periderm in the outer bark of mature trees, as in the young stem, consists of one layer of cork cambium (phellogen) and two to three layers of phelloderm and layers of cork (phellem). The periderm may be divided into three main types: (1) the thin-walled cells, which are rectangular to nearly square in shape and about 30 \( \mu m \) to 50 \( \mu m \) in diameter as shown on both cross and radial sections. This type of cell amounts to approximately 40% of the total periderm; (2) the thick-walled cells are about the same shape and size as the thin-walled cells with distinct simple pits and often containing a resinous substance; (3) the sclereids are often found in small groups more or less tangentially connected and scattered at the outer part of the phellem in the older trunk. These sclerified cells occupy the smallest percentage of the total periderm, usually less than 10%, but the numbers can be quite variable. These three kinds of cell types in mature periderm have no definite pattern of distribution, although the thin-walled layers generally alternate with the thick-walled layers and the sclerified cells are often associated with the thick-walled cells.

**Cortex.** The cortex in aspen retains its position from the young to the old trunk, and its cells have about the same contents as in the young stage, except for their size and abundance of contents. The cortex can occupy up to 7-9% of the total thickness of bark. The cortical region does not show distinct demarcation from the inner bark. These two parts are merged together by the loosely arranged cortical parenchyma, the dilated phloem rays and phloem parenchyma, together with scattered groups of sclerenchyma.

**Physical Properties of Wood**

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>Green volume</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Air-dry volume</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Oven-dry volume</td>
<td>0.40</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td>Green</td>
<td>43 (689)</td>
</tr>
<tr>
<td></td>
<td>Air-dry</td>
<td>27 (432)</td>
</tr>
<tr>
<td></td>
<td>Oven-dry</td>
<td>25 (400)</td>
</tr>
<tr>
<td>Density, lb/cu ft</td>
<td>Oven-dry weight per green volume</td>
<td>22 (352)</td>
</tr>
</tbody>
</table>
Einspahr, et al. (10) found that the specific gravity of a 6-year-old quaking aspen sucker stand which was fertilized and irrigated for 3 years was only moderately reduced even though volume growth was 140% greater than on the control plot.

Einspahr, et al. (77), in a study on 17-year-old trees growing in a natural sucker stand, found that specific gravity was highest in the butt, decreased with increasing height and leveled off at heights from 4.5-6.5 ft (1.4-2.0 m) for annual rings near the center of the tree. At most sampling heights, specific gravity was high near the pith, lower 3-5 rings out from the center and then increased from that point out toward the cambium.

Other publications relating to specific gravity include Maeglin (72), Besley (73), Pronin (14), Einspahr, et al. (15), Brown and Valentine (16), Valentine (17), and Einspahr and Benson (18).

Percent shrinkage, dried to 0% moisture content: r - 3.5, t - 6.7, v - 11.5.

Percent moisture content, when green

| Green basis | 48 |
| Oven-dry basis | 94 |

Percent moisture content

| oven-dry basis (19) |

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>19.3</td>
<td>19.2</td>
<td>17.3</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>78.5</td>
<td>78.9</td>
<td>79.5</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>-</td>
<td>-</td>
<td>63.5</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>48.8</td>
<td>50.1</td>
<td>51.0</td>
</tr>
<tr>
<td>Hemicellulose, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ash, %</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>18.8</td>
<td>18.7</td>
<td>22.5</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>-</td>
<td>-</td>
<td>5.1</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>-</td>
<td>-</td>
<td>5.3</td>
</tr>
<tr>
<td>Moisture content, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Solubility in Alcohol</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>2.9</td>
<td>2.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Ether, %</td>
<td>1.0</td>
<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>18.7</td>
<td>17.2</td>
<td>-</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>2.8</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Cold water, %</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>Water, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Uronic anhydride, %
In hemicelluloses
Pentosans, %
Uronic anhydride
Hexosans
(by difference)

|                | 4.97 | 69.1 | 16.5 | 14.4 |

Corrected for ash.
^Corrected for ash, lignin, and extractives.
Corrected for ash and lignin.

Musha and Goring (30) found the Klason lignin content to be 0.195 and 0.183 g/g and acid-soluble lignin to be 0.031 and 0.030 g/g (separate analyses). Bray and Paul (37) give analyses, and Van Beckum and Ritter (32) give data on holocellulose and C.&B. cellulose. Methoxyl content is 20.5% (33). Ether solubles are 1.0-2.7% of whole wood (34, 35). The wood contains 3.0% alcohol-benzene extractives (36).

**Summative Analysis**

Wise et al. (37)

| Total extractives, % | 4.3 |
| Lignin, % | 18.1 |
| Acetyl, % | 3.4 |
| Alpha-cellulose, % | 51.2 |
| Hemicelluloses, % | 21.2 |
| Summation, % | 98.2 |

**Carbohydrates.** Wise et al. (37), using a modified Hagglund-Bratt method, found 1.5% mannan.

**Extractives** The ether extract of whole wood is 2.28% (based on solids). The content of vanillin, syringaldehyde, p-hydroxybenzaldehyde, vanillic acid, syringic acid, p-hydroxybenzoic acid, p-coumaric, acid, and ferulic acid is given for whole wood, sapwood, heartwood, and rootwood by Pearl and Beyer (38). Browning and Bublitiz (39) found ether extractives to contain 2% resin acids, 72% free fatty acids, and 18% unsaponifiables, while Buchanan et al. (40) found them to contain 2% resin acids, 5% free fatty acids, 66% fats, and 19% unsaponifiables. For information on fatty acids and resin acids see Swan (41). Pearl and Harrocks (42) identified neutral materials from the benzene extractives. For information on hot water extractives see Pearl and Darling (43). For steam volatile components of extractives from heartwood see (44).

For general information on extractives see Pearl (45) and Rowe and Conner (46).

The ammonia-base acid sulfite spent liquor was ether-extracted and found to contain vanillin, syringaldehyde, hydroxybenzoic acid, benzoic acid, vanillic acid, and other unidentified compounds (47). Sawdust and spent liquor from NSSC pulping were analyzed for content of ether extractives and for vanillin, syringaldehyde, and hydroxybenzoic acid. Spent liquor from sodium-base acid sulfite pulping was analyzed for ether extractives and for vanillin, syringaldehyde, p-hydroxybenzaldehyde, vanillic acid, syringic acid, p-hydroxybenzaldehyde, vanillic acid, syringic acid, p-hydroxybenzoeic acid, and p-coumaric acid (48). Three isomeric lignans were isolated from spent sulfite liquor (49). Seven crystalline aromatic compounds were isolated from the ether-soluble portion of the hydrolysate liquors which were obtained from sawdust (50).

Other Information. For an analysis of elements see Young and Guinn (51) and Young et al. (52).

**Chemical Composition of Bark**

**Proximate Analyses**

Chang and Mitchell (53)

| Ash, % | 2.8 |
| Methoxyl, % | 4.75 |
| Solubility in Alcohol, % | 11.6 |
| Benzene, % | 4.0 |
| 1% NaOH, % | 22.0 |
| Hot water, % | 4.7 |

The bark contains 3.9% ash (54) and 5.2% ash (36).

**Carbohydrates.** Bark contains 4-O-methyl glucuronoxylan (55). It contains a galactoglucomannan that contains galactose, glucose, and mannose. Chang and Mitchell (53) have analyzed reducing sugars from extractive-free bark.

**Extractives.** Bark contains 9.23% ether extractives (38) and 15% alcohol-benzene extractives (37). Hot-water extractives fractionated with ethyl acetate contained salicin, trichocarpin, salireposide, salicyl alcohol, pyrocatechol, 2,6-dimethoxy-benzoquinone, and cinnamic
extractives in hark, see Pearl and Darling (57); for water extractives see Pearl (38), Pearl and Beyer and (58), extractives from bark, see Pearl (45). For information on acid Glycosides in aqueous extractives of diploids (43). and triploids were compared (56). For hot water extractives see Pearl (59).

The bark contains 1.9% calcium and 0.03% silica (as a grandidentatin, acids such as benzoic, p-coumaric, vanillic, syringic, ferulic, and p-hydroxybenzoic acids, phenols such as salicyl alcohol and pyrocatechol, and sugars such as glucose, fructose, and sucrose (59). Pearl (60) reports on other aromatic compounds from bark. The bark contains 1.9% calcium and 0.03% silica (as a percent of oven-dry weight of the bark) (36).

Pulping

Chemimechanical. The impregnation of chips with a mixture of sodium sulfite and sodium hydroxide prior to refining substantially improves brightness (61).

Holopulping. Alkaline pretreatment, sodium chlorite acidified with glacial acetic acid, and alkali extraction give pulps in higher yield than kraft pulp and pulps that are higher in burst strength, breaking length, and lower in tear factor. Pulp properties are given for ethanol-water pulps (62).

Kraft. The wood is pulped easily; it is easily bleached, requiring 5.65% total chlorine for 80 G.E. brightness at a permanganate number of 14.0 (63). The pulp hydrates quickly, is about 65% as strong as spruce except for folding endurance (64, 65, 66). The kraft pulp yield is 54-64% (67). Keays and Hatton (68) found a yield of 57.1% at a permanganate number of 12.5 and quality equivalent to commercial bleached and unbleached hardwood kraft pulps. For unscreened kraft pulp yields, see Bella and Hunt (69). A two-stage process of pretreatment with H₂S before kraft pulping gives unbleached pulps, similar in strength and beatability to polysulfide pulps; they are brighter than polysulfide pulps (70). The natural variation of pulp and papermaking properties between clones was studied by Van Buijtenen et al. (71). For kraft pulping information see Hunt et al. (72) and Horn (73). Quaking aspen is a principal ingredient with other hardwoods in bleached kraft pulp. Newsprint and fine papers are made from kraft pulps (74). The yield for bark is 33.8%.

Magnefite. A bleachable semichemical pulp has a somewhat lower bleached pulp burst and tear resistance than the normal bleachable NSSC pulp; a semichemical pulp suitable for corrugating medium is equivalent to NSSC pulp (75).

Mechanical. The wood is readily pulped to a yield of 90%; it requires about 25% more power than for white spruce and is from 50-65% lower in various strength properties than spruce or fir; its color is good and it is readily bleached. It is used in book papers, tissue papers, and heavy structural boards (76, 77, 78, 79, 80, 81, 82, 83, 65, 84, 85, 86, 87, 88). Groundwood is used for fiberboard.

Neutral Sulfite Semichemical. Pulps are particularly bright and strong. They are used in corrugating medium, board filler stock, and coarse wrapping paper. A bleached grade has been used in book papers and experimentally in glassine. It is readily bleached by chlorine or sodium peroxide (89, 90, 91, 92, 93, 94, 95, 96, 80, 97, 98).

Others. Water and/or steam (99).

Soda. Is fairly readily pulped, yield is normal, pulp is weak and bleaches easily, it imparts opacity, bulk, softness, and absorbency to the sheet. Its principal use is with bleached sulfite pulp in the manufacture of book paper, and some is used in tissues, particularly facial tissues (100, 101, 102, 80, 103, 82, 98, 104, 87, 105).

Sulfite. The wood is readily pulped, yield is good, the pulp hydrates quickly, is of excellent color, usually contains small black specks which disappear on bleaching, is easily bleached, has a strength 50% lower than spruce, and does not have the opacity or bulk characteristics of soda pulp. It is used in small amounts in newsprint, mimeo, tissue, writing, and book papers (106, 80, 107, 108, 82, 83, 87).

Utilization of Wood and Bark The wood is similar to that of Populus grandidentata. It is light in color, soft, generally straight grained, fine, and uniformly textured. It has a characteristic odor when wet and is odorless and tasteless when properly dried. It shrinks moderately and can be air dried or kiln dried satisfactorily. If wetwood or pockets of high moisture content are present, however, the affected zones may collapse, check, or remain high in moisture after the normal drying schedule. Tension wood may cause warpage. Because aspen wood is light, it has low strength. It is also moderately stiff and is moderately low in shock resistance. It seldom splits when nailed and has excellent nail-holding ability.
Calorific Value of Wood

$17.7 \times 10^6$ BTU per air-dry cord.
$5785$ BTU/lb air-dry
$3215$ kg cal/kg air-dry

Calorific Value of Bark

$8430$ BTU/lb
$4665$ kg cal/kg

$271,814$ BTU/ft$^3$
$1938$ kg cal/m$^3$

Chemical Uses of Bark. Salicin is used in pharmacy, chemistry, and biology (59).

Other Uses of Wood. The wood is used for boxes and crates, farm building construction, core stock material, furniture, novelties, woodenware, excelsior, matches, plywood, factory and dimension lumber, preservative-treated products, fiberboards, particle boards, and animal feeds. Wood has been fed to sheep (109). Sawdust can be treated with fungus and NaOH for improved digestibility for rumen organisms.

Bibliographies A bibliography on world literature relating to *Populus*, 1964-1974, has been compiled by Hart (110).

Literature Cited


34. McGovern, J. N.; McGregor, G. H. TAPPI Data Sheet No. 118 (Dec. 1944).


81. Munro, W. A. Paper Trade J. 77(20-60) (Nov. 15, 1933).


BIGTOOTH ASPEN

Scientific Name  Populus grandidentata Michx.

Pathology  Resistance to decay: low

Because of its thin bark, bigtooth aspen is susceptible to fire, particularly at a young age. The species is also subject to windthrow and tops break easily from ice and snow. Hypoxylon canker (Hypoxylon mammatum), which is so damaging to quaking aspen, is somewhat less so to bigtooth aspen. The heart rot, Phellinus igniarius, attacks bigtooth aspen to a lesser extent than it does quaking aspen but is still a serious problem. Several species of fungi that produce cankers on larger trees belong to the genus Nectria. Other fungi reported to frequently cause cankers on bigtooth aspen include Poria laevigata, Valsa sordida and V. nivea. Common leaf spots can be caused by Venturia tremulae. Bigtooth aspen and its hybrids also appear to be particularly susceptible to a leaf disease closely resembling Plagiodroma populifolia.

Defoliators that attack bigtooth aspen include the forest tent caterpillar (Malacosoma disstria), the large aspen tortrix (Archips conflictana), the satiny moth (Siltunodis salicis), and the gypsy moth (Lymantria dispar). The most important of these is the forest tent caterpillar and it occurs over most of the range of bigtooth aspen. The poplar borer (Saperda calcarata) attacks trees of all ages, with trees between 2-6 in (5-15 cm) in diameter most likely to be heavily infested. Another poplar-gall saperda which feeds on young trees, causing breakage, is Saperda concolor.

Gross Features of the Wood  Similar to quaking aspen. Sachs, et al. (7) found that wetwood derives primarily from bacterial infections. Invasion of sapwood vessels by bacteria probably proceeds from initial root infections.

Microscopic Structure of the Wood  Similar to quaking aspen. Einspahr, et al. (2) describe the variation in fiber length among bigtooth aspen and its hybrids.

Gross Features of the Bark  Olive green but often not readily separated from that of quaking aspen; later becomes brown and furrowed.

Microscopic Structure of the Bark  Similar to quaking aspen (3).

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>Green volume 0.35</td>
</tr>
<tr>
<td></td>
<td>Air-dry volume 0.39</td>
</tr>
<tr>
<td></td>
<td>Oven-dry volume 0.41</td>
</tr>
</tbody>
</table>

Silvics  Very similar to quaking aspen, with which it occurs mixed or in scattered groups in the forest. It is not, however, of such widespread distribution or of as frequent occurrence. Reproduction by seed is very good and root sprouts are frequent. This species seems to require a less fertile soil with a higher sand content for good growth than does quaking aspen. From its occurrence on knolls and drier sites, it appears to require the better-drained, better-aerated soils. Bigtooth aspen is rated as very intolerant.

Range  Northeastern United States and southern Canada.
### Density, lb/cu ft (kg/cu m)

- Green: 43 (689)
- Air-dry: 27 (432)
- Oven-dry: 26 (416)

### Density, lb/cu ft (kg/cu m) - Oven-dry weight per green volume
- 22 (352)

### Publications relating to specific gravity include Erickson (4), Maeglin (5), and Pronin (6).

Percent shrinkage, dried to 0% moisture content: r - 3.3, t - 7.9, v - 11.8.

Percent moisture content, when green
- Green basis: 50
- Oven-dry basis: 99

### Physical Properties of Bark

**Specific gravity oven-dry weight & volume:** 0.66

### Chemical Composition of Wood

**Proximate Analyses**

<table>
<thead>
<tr>
<th>Component</th>
<th>Freeman and Peterson (8)</th>
<th>Bloom et al. (9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sap</td>
<td>Heart</td>
</tr>
<tr>
<td>Lignin, %</td>
<td>16.3</td>
<td>16.9</td>
</tr>
<tr>
<td>Holocellulose</td>
<td>78.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>22.5</td>
<td>23.0</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>5.17</td>
<td>5.05</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>0.65</td>
<td>0.72</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>62.7</td>
<td>64.4</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.26</td>
<td>0.33</td>
</tr>
<tr>
<td>Pentosans Total, %</td>
<td>23.3</td>
<td>23.8</td>
</tr>
<tr>
<td>In cellulose, %</td>
<td>14.5</td>
<td>15.8</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>5.48</td>
<td>6.07</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>5.27</td>
<td>5.35</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>2.41</td>
<td>2.13</td>
</tr>
<tr>
<td>Ether, %</td>
<td>1.02</td>
<td>1.03</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>3.13</td>
<td>0.99</td>
</tr>
<tr>
<td>Cold water, %</td>
<td>2.70</td>
<td>1.36</td>
</tr>
</tbody>
</table>

Bloom et al. (9) also include data on ethanolamine cellulose and correlation between the number of chlorinations and lignin in Cross & Bevan cellulose. Isenberg et al. (10) found the wood to contain 2.1-2.4% alcohol-benzene solubles; whole wood contained 0.9-1.0% ether solubles, sapwood contained 1.0% ether solubles, and heartwood contained 1.0% ether solubles.

**Extractives.** For general information on extractives see Pearl (11). For information on aromatic compounds, see Pearl (12).

### Chemical Composition of Bark

**Extractives.** For information on water extractives see Pearl (11); for aromatic compounds see Pearl (12); for phenolic glycosides, see Rowe and Conner (13).

### Pulping

**Soda.** Wood is pulped readily and is fairly easily bleached.

**Sulfite.** The wood is readily pulped, is of excellent color, and is fairly easily bleached.

### Utilization of Wood and Bark

It is generally straight-grained, fine, and uniformly textured. It has a characteristic odor when wet and is odorless and tasteless when properly dried. It shrinks moderately and can be air dried or kiln dried satisfactorily. If wetwood or pockets of high moisture content are present, the affected zones may collapse, check, or remain high in moisture after the normal drying schedule. Tensionwood may cause warpage. Because aspen wood is light, it has low strength. It is also moderately stiff and is moderately low in shock resistance. It seldom splits when nailed and has excellent nail-holding ability.

### Calorific Value of Wood

18.2 x 10^6 BTU/air-dry cord

### Other Uses of Wood

Most aspen is used for pulp products such as book and specialty papers, newsprint, and insulation board. Most aspen lumber is remanufactured into boxes, crating, pallets, furniture parts, lumber core, and interior trim. A small volume is used for panel stock, match and core stock, excelsior, particleboard, paper roll plugs, and turned products.

Bibliographies A bibliography on world literature relating to *Populus*, 1964-1974, has been compiled by Hart (14).


Scientific Name  *Populus balsamifera* L.

Synonyms Balm, balm-of-Gilead, bam, tachahac, hackmatack, cottonwood

Family Name  Salicaceae


**Silvics**  The tree is medium sized with a long, cylindrical bole; a narrow, open, pyramidal crown, and a shallow root system. It adapts to a variety of soil textures but needs abundant moisture and a cool to cold climate. It is characteristic of alluvial bottomlands and river banks and is typical of northern Canada where it occurs in pure stands, or mixed with willows, alders, birches and black and white spruces. In the southern part of its range, it usually occurs in isolated patches. In the Lake States, its associates are aspen, balsam fir, white-cedar, and paper birch. Balsam poplar frequently reproduces by means of root suckers. It is rated as intolerant.

**Tree Dimensions**  60-80 ft (18-24 m) tall and 1-2 ft (30-61 cm) in diameter

**Pathology**  Resistance to decay: low

Young trees, because of their thin bark, are susceptible to fire, although mature trees are relatively fire resistant. The species is not as subject to loss from disease as the aspens. Heart rot caused by *Phellinus igniarius* and butt rot by *Armillariella mellea* are common decays in balsam poplar, although the loss from these rots is less than it is in the aspens. Leaf spots, rusts and blights are common but generally are not damaging.
The most serious insect pest of balsam poplar is the poplar-and-willow borer (Cryptorhynchus lapathi), an introduced species. Small trees may be completely girdled or seriously weakened. The poplar borer (Saperda calcarata) also attacks balsam poplar. The forest tent caterpillar (Malacosoma disstria) will feed on balsam poplar but it is not a preferred species.

Gross Features of the Wood
Similar to aspen, but coarser in texture, somewhat darker, and devoid of luster. Discoloration due to incipient decay is more prevalent.

Microscopic Structure of the Wood

Vessels. 30-145 per sq mm, the largest 75-150 μm in diameter; perforation plates simple; intervessel pits orbicular to oval or angular, 9-13 μm in diameter.

Fibers. Thin to medium walls, 23-40 μm in diameter. Length, about 1.2 mm.

Rays. Unstoried, uniseriate, essentially homogeneous.

Longitudinal Parenchyma. Terminal, forming a narrow, continuous, or interrupted line.

Gross Features of the Bark
On young stems the bark is greenish brown to reddish brown; on older trunks eventually becoming gray to grayish black and dividing into flat, scaly, or shaggy ridges separated by narrow fissures. Bark averages 17.5% of the rough volume of roundwood (7).

Microscopic Structure of the Bark
Rhytidome formation is distinct and is composed of alternate layers of secondary phloem and periderm in the outer bark. Periderms are thin and phloem fibers occupy most of the secondary phloem in the outer bark.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Value (specific gravity)</th>
<th>Value (density)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.30</td>
<td>40 (641)</td>
</tr>
<tr>
<td>Air-dry volume</td>
<td>0.33</td>
<td>23 (368)</td>
</tr>
<tr>
<td>Oven-dry volume</td>
<td>0.34</td>
<td>21 (336)</td>
</tr>
<tr>
<td>Density, lb/cu ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kg/cu m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>40 (641)</td>
<td></td>
</tr>
<tr>
<td>Air-dry</td>
<td>23 (368)</td>
<td></td>
</tr>
<tr>
<td>Oven-dry</td>
<td>21 (336)</td>
<td></td>
</tr>
<tr>
<td>Density, lb/cu ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kg/cu m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oven-dry weight per green volume</td>
<td>19 (304)</td>
<td></td>
</tr>
</tbody>
</table>

Chemical Composition of Wood

Extractives. For general information on extractives see Pearl (4).

Chemical Composition of Bark

Extractives. For information on hot-water extractives of bark see Pearl and Darling (5); on water extractives, Pearl (6); on extractives, Abramovitch et al. (7). Chloroform and ethyl acetate extracts of green bark contain 3 glucosides: salicin, trichocarpin, and salireposide; other glucosides were detected (8).

Other Information. For information on aromatic compounds see Pearl (9). Bark contains salicornin, trichocarposide, populoside, salicylosalicin, and dihydromyricetin (10).

Pulping

Groundwood. Newsprint of average strength and opacity is made from 90% groundwood of 105 freeness and 10% southern pine semibleached sulfate pulp of 530 freeness. Pulps of high strength and brightness (64-67%) and low opacity (85-88%) and freeness of 360-485, 630, and 500 were made from 60% cottonwood groundwood and 10% southern pine semibleached sulfate pulp mixed with 30% of either chemigroundwood or NSSC or cold soda pulps. Papers made of 75% groundwood and 25% other cottonwood pulp had a burst strength equal to that of commercial papers and lower tear strength. Willow groundwood as 30% of the furnish, although darker and much weaker than cottonwood groundwood, gave paper of good strength and sufficient brightness.
Groundwood can be bleached with $\text{H}_2\text{O}_2$. It can be used for fiberboard.

Kraft. Pulp mixed with *Alnus rubra* kraft pulp gave satisfactory duplicating and offset printing paper.

**Utilization of Wood and Bark**

**Literature Cited**


**Colorific Value of Wood**

\[ 17.2 \times 10^6 \text{ BTU/air-dry cord} \]

**Chemical Uses of Wood.** Balm-of-Gilead, used in cough medicine, is derived from the buds (12).

Bibliographies A bibliography on world literature relating to *Populus*, 1964-1974, has been compiled by Hart (73).
Eastern Cottonwood

Scientific Name  *Populus deltoides* Bartr. ex. Marsh.

Synonyms Southern cottonwood, eastern poplar, Carolina poplar, necklace poplar, alamo

Family Name  Salicaceae

Range  Eastern cottonwood grows throughout most of the eastern half of the United States with the exception of the higher Appalachian areas. Found along streams and bottomlands, its range extends from southern Quebec and Ontario west to southeastern North Dakota, south through western Kansas, Oklahoma and southern Texas, to northwestern Florida and Georgia. Its best commercial development occurs on the alluvial bottomlands of the lower Mississippi River and its tributaries. Cottonwood is seldom found at elevations of more than 15-20 ft (5-6 m) above the average level of nearby streams.

Silvics  In the forests this medium- to large-sized tree is tall, clear and cylindrical with a rather widespread crown and an extensive superficial root system. It grows principally along streams and water courses in mixture with various willows, sycamore, and some of the bottomland oaks. Abundant and continuous moisture throughout the growing season is as important to cottonwood as is the texture and fertility of the soil. Humid climate and moist, medium-textured soil with good internal drainage promotes the best growth of cottonwood.

Tree Dimensions  75-85 ft (23-26 m) tall and 2-3 ft (61-91 cm) in diameter. However, free-growing trees on good sites can exceed 120 ft (37 m) in height at age 30. Cottonwood is rated as very intolerant.

Pathology  Resistance to decay: low

Cottonwood is very susceptible to fire and a fire of moderate intensity will kill trees 6-10 in in diameter (7). Diseases appear to be of minor importance in cottonwood stands. Canker diseases are most severe on poor sites and under conditions of environmental stress (2). The pioneer organism in canker diseases is *Septoria musiva*. *Cytospora* spp. usually invade the *Septoria* cankers. *Septoria musiva* may also cause leaf spots and can reduce growth through premature defoliation. Cottonwood is also subject to the leaf rust (*Melampsora medusa*) above latitude 40°. This rust may cause defoliation, weakening the tree, and predisposing it to other pathogens.

One of the most serious insect pests of cottonwood plantations and natural stands is the cottonwood leaf beetle (*Chrysomela scripta*). The adults and larvae feed on foliage and young stems, reducing tree growth and vigor. Another destructive insect is the cottonwood twig borer (*Gypsonoma haimbachiana*). Larvae feed in terminal tissues on both the main stem and lateral branches. Heavily damaged trees develop crooks or a number of forks. Clearwing borers (*Paranthrene dolii* and *P. tricincta*) also cause serious losses in plantations, the first by damaging the tree base and the second by attacking the terminals. An additional borer of cottonwood is *Saperda calcarata*, attacking trunks of trees 3 years and older (2).

Gross Features of the Wood  The general structure of the wood of eastern cottonwood is similar to that of aspen but coarser in texture, somewhat darker, and devoid of luster. The wood is semiring to diffuse porous. The growth rings are distinct but inconspicuous and often very wide. The small xylem vessels are barely visible with the naked eye in the earlywood and decrease gradually in size throughout the latewood. The vessels are solitary or in radial rows of two or more. Parenchyma are terminal, the light-colored lines being more or less distinct. The rays are very fine, scarcely visible with a hand lens and are unstoried, uniseriate, and essentially homogeneous.
Microscopic Structure of the Wood  See the description for balsam poplar.

Vessels. Earlywood vessels are 100-150 µm in diameter while latewood vessels are about 1/2 this size. Vessel elements vary in number from 30-145 per sq mm. Isebrands (3) found that vessel percent increased at most heights with increasing age of the annual increment in two dominant 21-year-old trees. Within an annual increment, vessel percent increased with height.

Fibers. Average, 1.0 mm in length and 25-40 µm in diameter. Cell walls thin to medium thick. Weight factor 0.45. DeBell, et al. (4) found no significant changes in fiber length three years after treatment when N was applied to a 9-year-old plantation. Isebrands and Bensend (5) studied the incidence and structure of gelatinous fibers in rapid-growing cottonwood. They found that all samples removed from each pair of rings in disks cut at 8 heights in each of two trees contained some gelatinous fibers, although the incidence was particularly high in samples from the upper levels of the bole. The last few rows of cells in each growth ring were devoid of gelatinous fibers. Posey, et al. (6), in studying natural variation in fiber length of eastern Cottonwood, found that fiber length decreased from east to west. Bhagwat (7) found that the application of N, P, K and mulching significantly increased the fiber length and the double-wall thickness of fiber walls. It failed to produce any significant effects on the percent of cross-sectional area occupied by the lumens of fibers and the amount of gelatinous fibers in the wood. Other publications related to fiber dimensions include Jett and Zobel (8), Kaeiser (9), Einspahr, et al. (10), and Isebrands (11).

Gross Features of the Bark Thin, smooth and light yellowish-green in young stems, the bark of eastern cottonwood becomes ash-gray with age, dividing into thick, flattened or rounded ridges separated by deep fissures. In structure, the barks of species of Populus are alike, especially the secondary phloem.

Microscopic Structure of the Bark In general, eastern cottonwood bark is rather similar in structure to quaking aspen and bigtooth aspen except in the periderm.

Periderm. The last-formed periderm consists of a layer of phellogen, 2-3 layers of phelloderm and layers of thin- and thick-walled phellem or cork. The phellem is comparatively loose in arrangement. Small groups of sclerified cells are often associated with the thick-walled cells, or close to them.

Sieve Tube Elements. The thin-walled sieve tubes may be solitary but are mostly in small groups of 2-5. Together with companion cells and phloem parenchyma, they are bounded radially by uniseriate rays and tangentially by bands of sclerenchyma or phloem fibers. Sieve tubes are oval to polygonal in cross section and vary from 25 µm to 50 µm in diameter. Quite variable, sieve tube elements are usually 600 µm to 1 mm long.

Parenchyma. Parenchyma cells are distributed in a more or less reticulate formation among the sieve tubes. On cross section, these cells are round to oval and average approximately 20 µm in diameter.

Phloem Fibers. Narrow tangential bands of phloem fibers, closely and evenly spaced, are characteristic of the inner bark of eastern cottonwood. The bands of fibers average approximately 60 µm in radial dimension and consist of mostly 3-4 fibers in radial rows. Occasionally, a small portion of the band may be more than 200 µm in width and consist of 10-12 fibers in radial rows. On cross section, the phloem fibers are polygonal in shape and average approximately 20 µm in diameter at the broadest portion. The cell walls are very thick, about 10 µm, and the lumen is narrow, approximately 2-3 µm. The fibers average approximately 1.0 mm in length. Harder, et al. (12) found a fibrous yield of 9% when eastern cottonwood bark was pulped to a solids yield of 35.4%.
Sclereids. Small groups of thick-walled sclereids appear in the outer part of the inner bark.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green volume</td>
<td></td>
<td>0.37</td>
</tr>
<tr>
<td>Air-dry volume</td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>Oven-dry volume</td>
<td></td>
<td>0.43</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td></td>
<td>49 (785)</td>
</tr>
<tr>
<td>Air-dry</td>
<td></td>
<td>28 (448)</td>
</tr>
<tr>
<td>Oven-dry</td>
<td></td>
<td>26 (416)</td>
</tr>
</tbody>
</table>

Bhagwat (7) found that the application of N, P, K and mulching significantly increased the specific gravity of the wood. DeBell, et al. (4) found that specific gravity decreased by 3% three years after treatment when N was applied to a 9-year-old plantation. However, this slight reduction was far outweighed by increased volume growth. Posey, et al. (6), in studying natural variation in fiber length of eastern cottonwood, found that specific gravity increased from east to west. Farmer and Wilcox (13) determined that wood near the cambium was denser than that near the pith or middle of stems and that a relatively low correlation existed between density of juvenile and later-formed wood. A slight negative relationship was observed between specific gravity and mean annual diameter increment. Other publications relating to specific gravity include Isebrands (17), Einspahr, et al. (10), Jett and Zobel (8), Walters and Bruckmann (14), and Maeglin (15).

Percent shrinkage, dried to 0% moisture content: * r - 3.9, t - 9.2, v - 14.1.

Percent moisture content, when green *

<table>
<thead>
<tr>
<th>Basis</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green basis</td>
<td>53</td>
</tr>
<tr>
<td>Oven-dry basis</td>
<td>111</td>
</tr>
</tbody>
</table>

Physical Properties of Bark

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green volume</td>
<td></td>
<td>0.29</td>
</tr>
<tr>
<td>Outer bark</td>
<td></td>
<td>0.32</td>
</tr>
<tr>
<td>Total bark</td>
<td></td>
<td>0.31</td>
</tr>
<tr>
<td>Density (100% moisture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>content)</td>
<td></td>
<td>0.81</td>
</tr>
</tbody>
</table>

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th>Property</th>
<th>Bray and Paul (17)</th>
<th>McGovern and Keller (16)</th>
<th>Musha and Goring (18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>22.0</td>
<td>23.6</td>
<td>-</td>
</tr>
<tr>
<td>Klason lignin, %</td>
<td>-</td>
<td>-</td>
<td>0.234</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>65.2</td>
<td>63.2</td>
<td>-</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>47.5</td>
<td>46.5</td>
<td>-</td>
</tr>
<tr>
<td>Pentosans, total, %</td>
<td>18.0</td>
<td>19.0</td>
<td>-</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>-</td>
<td>-</td>
<td>1.20</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>0.9</td>
<td>1.8</td>
<td>-</td>
</tr>
<tr>
<td>Ether, %</td>
<td>-</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>14.8</td>
<td>15.4</td>
<td>-</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>-</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>Acid, %</td>
<td>-</td>
<td>-</td>
<td>0.028</td>
</tr>
</tbody>
</table>

Moore and Effland (19) report the proximate analysis of rings 2-20 of different trees. The alcohol-benzene extractives content is 1.4% (20), and the ether solubles is 0.3-0.4% (21, 22).

Other Information. For inorganic elements see Osterhaus et al. (23).

*These data are for southern cottonwood (Populus deltoides var. virginiana).
Chemical Composition of Bark. The ash content is 6.2%; alcohol-benzene extractives, 7.9%; calcium, 2.5%; silica, 0.18% (calculated as percentage of oven-dry weight of the bark) (20). For inorganic elements see Osterhaus et al. (23).

Extractives. The bark contains phenolic glycosides (24).

Pulping

Alkaline. is bleached with difficulty; the breaking length and burst strength are slightly higher than for gum, and tear strength is low (25).

Cold soda. corrugating boards were somewhat stronger than boards made from oak pulp, and they had a Concora value of 77.4 lb. (26).

Groundwood. The wood is suitable for groundwood pulping, particularly for use as a coarse grade in insulating board and as fine grades for groundwood book and specialty papers.

Kraft. The wood is readily pulped, and the yield is high (27). The yield for bark is 35.4%.

Mechanical. The wood is readily pulped and color is fair; pulps satisfactory for certain furnishes can be obtained on various stone surfaces with moderate energy consumption by adjusting the grinding pressures; pulps are suitable particularly for use as a coarse grade in insulating board and as fine grades for groundwood book and specialty papers (28, 29, 30, 31).

Neutral Sulfite Semichemical. Chidester (32) studied the influence of pretreatment with acid, neutral, and alkaline liquors and of bleaching on yield and properties; he describes the uses of pulps. See also Rue et al. (33).

Soda. The wood is readily pulped, yield is high, and it is fairly easily bleached (27, 34).

Sulfite. The wood is readily pulped, and the yield is normal (35, 36).

Other Information. The light color of the pulp requires little bleaching for most uses. The pulp is used in the manufacture of high grade book and magazine paper.

Utilization of Wood and Bark

Use Properties of Wood. The wood is comparatively uniform in texture, generally straight grained, moderately light in weight, moderately weak, moderately limber, moderately soft, difficult to season, is relatively easy to glue, is difficult to work without producing shipped or fuzzy grain, has moderate shrinkage, and is prone to warping. It has low nail-holding ability, does not split easily, and holds paint well. It is without characteristic odor or taste when dry.

Calorific Value of Wood

$16.8 \times 10^6$ BTU/air-dry cord

Calorific Value of Bark

$162,545$ BTU/ft$^3$  \[1160$ k$ cal/m$^3$\]

Other Uses of Wood. Cottonwood is used for lumber, veneer, plywood, short bolts, and food containers. Lumber and veneer go mainly into nailed and wirebound wood boxes and crates. Lumber and veneer are also used for interior parts of furniture, plywood, agricultural implements, woodenware, and matches. Bolts are used for small articles and prefabricated furniture parts.

Bibliographies A bibliography on world literature relating to *Populus*, 1964-1974, has been compiled by Hart (37). A selected bibliography on cottonwood has been compiled by Applequist (38).

Literature Cited


35. Carpenter, C.; McGall, F. Rayon Textile Mo. 19:538, 618(1938).


BLACK COTTONWOOD

Scientific Name: *Populus trichocarpa* Torr. & Gray

Synonyms: California poplar, balsam cottonwood, western balsam poplar

Family Name: Salicaceae

Range: Extends from Kodiak Island and southeastern Alaska southward along the Pacific Coast to mountain areas in Baja California, Mexico and eastward in a triangular area throughout most of British Columbia to south-central Montana.

Silvics: The tree has a long, clear bole and a narrow, cylindrical, round-topped crown. Within the range of black cottonwood, the climate varies from relatively arid to humid; and soils, from moist gravels and sands to rich humus and occasionally clay. In drier areas, this species is found usually on bottom land, along stream banks and pond edges, and at the foot of moist mountain slopes. It requires abundant moisture, nutrients, and oxygen aeration and a soil pH of 6.0-7.0 for optimum growth. Black cottonwood is found in mixture with Douglas-fir, grand fir, alders, maples, and willows. The species is rated as very intolerant.

Tree Dimensions: The tallest western broadleaf tree. Trees reach 45 ft (14 m) in height and 12-13 in (30-33 cm) in diameter at 82 years of age on Montana sites, and mature in 75 years in California with maximum diameters of 24 in (61 cm) and heights of 60 ft (18 m). Exceptional growth has been found in the Fraser Valley of British Columbia where individuals reached 32.5 in (83 cm) in diameter and 120 ft (37 m) in 27 years and studies have shown the species to grow well up to 200 years of age.

Pathology: Resistance to decay: low

Black cottonwood is frequently injured or killed by late spring frosts. Because of its thin bark, it is also highly susceptible to fire damage. The main diseases are a canker of young trees caused by *Valsa (Cytospora) sordida* and fungus decay in old or damaged trees (1). The occurrence of *Valsa sordida* is closely related to tree vigor. Black cottonwood is among the poplar species that develops a wetwood condition in which the wood is not only high in moisture but is darker than normal and has a pH on the alkaline side (1).

The satin moth, Leucoma (Stilphotia) salicis, feeds on black cottonwood although its damage has been restricted by the combination of introduced and native parasites. A sawfly attacking black cottonwood is the poplar leaffolding sawfly (Phyllocolpa bazemani). A cambium borer found in Montana and Alberta is Laspeyresia populana.

Gross Features of the Wood: The wood of black cottonwood is medium textured and moderately light to light. The whitish sapwood frequently merges into the grayish white to light grayish brown heartwood. Inconspicuous growth rings are narrow to wide with numerous, small pores gradually decreasing in size through the latewood. The wood is semiring to diffuse porous. Parenchyma are terminal, appearing more or less distinct as a narrow, light-colored line.

Microscopic Structure of the Wood: See the description for balsam poplar.

Fibers: Average, 1.38 mm in length and 23-40 μm in diameter (2). Thin to medium-thick cell walls. Weight factor 0.45.

Vessels: 30-145 per sq mm, averaging 0.58 mm in length and up to 75-150 μm in diameter.
Rays. Scarcely visible with a hand lens, unstoried, uniseriate and essentially homogeneous.

Gross Features of the Bark  The bark is tawny yellow to gray and smooth on young stems. It later becomes dark gray to grayish brown and is separated by furrows into narrow, flat-topped ridges. Double bark thickness averaged 9.6% as a percentage of the diameter outside bark for all sections (3).

Microscopic Structure of the Bark  The mature bark of P. trichocarpa is similar to that of P. balsamifera and P. heterophylla and differs from the bark structure of other species of Populus by the distinct formation of a rhytidome which is composed of alternate layers of secondary phloem and periderm in the outer bark. The inner bark is composed of thin-walled sieve tube elements which may be solitary but are mostly in small groups of 2-5 together with companion cells and phloem parenchyma. These cells are bounded radially by uniseriate phloem rays which are essentially homogeneous and tangentially by bands of phloem sclerenchyma, composed principally of typical phloem fibers. The cross section of the fibers is polygonal and they are approximately 20-25 μm in diameter. The fiber cell walls are thick, about 10 μm. Harder, et al. (4) found a fibrous yield of 12% when black cottonwood bark was pulped to a solids yield of 26%.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Green volume</th>
<th>Air-dry volume</th>
<th>Oven-dry volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.32</td>
<td>0.35</td>
<td>0.37</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td>46 (737)</td>
<td>24 (384)</td>
<td>23 (368)</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td>Oven-dry weight per green volume</td>
<td>20 (320)</td>
<td></td>
</tr>
</tbody>
</table>

Okkonen, et al. (5) determined that specific gravity increased with increasing height in the tree.

An additional publication relating to specific gravity has been issued by the U.S. Forest Service (6).

Percent shrinkage, dried to 0% moisture content: r - 3.6, t - 8.6, v - 12.4.

Percent moisture content, when green

| Basis            | 57  | 132 |

Percent moisture content oven-dry basis (7)

| Heartwood | 162   | Sapwood | 146 |

Physical Properties of Bark

<table>
<thead>
<tr>
<th>Property</th>
<th>Inner bark</th>
<th>Outer bark</th>
<th>Total bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity green volume</td>
<td>0.38</td>
<td>0.42</td>
<td>0.40</td>
</tr>
<tr>
<td>Density (100% moisture content)</td>
<td>Green weight/green volume</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>Specific gravity oven-dry weight &amp; volume (8)</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th>Component</th>
<th>Fahey and Martin (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>21.4</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>75.0</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>49.1</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.5</td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>19.2</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>2.7</td>
</tr>
<tr>
<td>Ether, %</td>
<td>0.7</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>18.0</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>2.6</td>
</tr>
</tbody>
</table>

An ash content of 0.3% was reported by Rapson et al. (11), and alcohol-benzene extractives of 2.3% by I.P.C. (12).

Carbohydrates. For information on cell wall polysaccharides see Shafizadeh and McGinns (13).

Other Information. The wood contains 1.8% tannins (14).

Chemical Composition of Bark

Proximate Analyses

<table>
<thead>
<tr>
<th>Component</th>
<th>I.P.C. (12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, %</td>
<td>5.0</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>20.0</td>
</tr>
<tr>
<td>Calcium, %</td>
<td>1.1</td>
</tr>
<tr>
<td>Silica, %</td>
<td>0.08</td>
</tr>
</tbody>
</table>

<sup>a</sup>As a percent of oven-dry weight of the bark.
Extractives. Trichoside is a hot-water extractive that is soluble in ethyl acetate (75); for hot water extractives of green bark see Estes and Pearl (18); for extractives see Pearl (17); Pearl and Darling (18) and Rowe and Conner (19).

Other Information. The tannin content is 4.7% (14).

Pulping

Kraft. The wood is easily pulped, yield is high, strength of pulp is low, and the pulp easily beaten. Kraft pulps required 16.0 and 11.5% active alkali for a permanganate number of 10.4 and 15.6, respectively; the corresponding pulp yields were 53.2 and 56.2%; cottonwood pulp with a permanganate number of 15 had higher strength retention than the pulp with permanganate number 10; pulp with a permanganate number above 15 retained 93% of its strength; bleached cottonwood pulp retained 79-93% of its strength. Bleached pulps could be used with other pulps to make duplicating paper (10).

Mechanical. The wood is fairly readily pulped, color of pulp is excellent, and strength is about that of western hemlock. Groundwood can be bleached with ZnS₂O₄ or H₂O₂; two-stage bleaching with H₂O₂ followed by ZnS₂O₄ gives brightness of 75.0.

Soda. The wood is readily pulped.

Sulfite. The wood is readily pulped, yield is high, and strength is low (20).

Other Information. The light color of the pulp requires little bleaching for most purposes.

Utilization of Wood and Bark

Use Properties of Wood. The wood is comparatively uniform in texture, generally straight grained, moderately soft, moderately weak, and moderately light in weight. It is weaker than eastern cottonwood. It has moderate shrinkage and is prone to warping. It is glued satisfactorily, has low nail-holding ability, does not split easily, and holds paint well. It has a sour odor when moist and is odorless and tasteless after it is seasoned. The gelatinous fibers known as tension wood cause fuzzy grain when the logs are sawed into lumber or cut into veneer; this tension wood causes buckling of veneer as soon as it is cut and often shrinks abnormally during drying.

Calorific Value of Wood

\[ 15.5 \times 10^6 \text{ BTU/air-dry cord} \]

Calorific Value of Bark

\[ 219,125 \text{ BTU/gf}^3 \]
\[ 1560 \text{ kcal/m}^3 \]

Other Uses of Wood. Cottonwood is used for lumber, veneer, plywood, short bolts, and excelsior. Lumber and veneer go mainly into nailed and wire bound wood boxes and crates. It is used for food containers. Lumber and veneer are also used for interior parts of furniture, plywood, agricultural implements, woodenware, and matches. Bolts are used for small articles and prefabricated furniture parts. Pulp is used in the manufacture of high-grade book and magazine paper.

Bibliographies A bibliography on world literature relating to Populus, 1964-1974, has been compiled by Hart (27).

Literature Cited

7. U.S. Forest Products lab. USDA, Forest Serv. Agriculture Handbook no. 72, 1974.
Black Willow

Scientific Name: *Salix nigra* Marsh.

Synonyms: Swamp willow, western black willow

Family Name: *Salicaceae*

Range: Eastern United States

Silvics: This small tree has a broad, irregular crown and a superficial root system. The trunk has a tendency to branch not far above the ground, but the form and size of the tree are much better in the lower Mississippi Valley. It will grow on almost any soil but its shallow, wide-spreading roots need an abundant and continuous supply of moisture and it is usually found along streams or lakes or in swamps. Best growth is achieved where the average yearly rainfall is 51 in (130 cm). It occurs in pure stands or in mixture with southern cottonwood, swamp privet, water locust, river birch, sycamore, and red maple. It is rated as very intolerant.

Tree Dimensions: 30-40 ft (9-12 m) tall and 12-18 in (30-46 cm) in diameter. On the best sites in the Mississippi Valley, the tree will reach 140 ft (43 m) in height and 4 ft (122 cm) in diameter.

Pathology: Resistance to decay: low

More than 80% of the rot in black willow is caused by top and branch rots and many trees are hollow (?). The most important trunk rot of willow in the north is *Trametes suaveolens*. Willow blight is the most important disease of black willow and it results from the combined effects of two pathogens, *Fusciadium (Pollacciya) salicinoleum* and *Physalospora miyabeana*. In severe cases, defoliation is almost complete and, after several years, trees can be killed. Black willow is also susceptible to Texas root rot (*Phymatotrichum omnivorum*) and bacterial wetwood.

The cottonwood leaf beetle (*Chrysolomela scripta*) feeds on black willow and severe infestations can cause considerable damage. The willow sawfly, *Nematus (Pteronidia) ventralis* and *N. salicisodoratus* also attack willow, occasionally causing heavy defoliation. Willow is also subject to attack from the poplar borer (*Saperda calcarata*) and oyster shell scale (*Lepidosaphes ulmi*).

Gross Features of the Wood: The sapwood is whitish and the heartwood light brown to pale reddish brown or grayish brown, frequently with darker streaks. The wood is moderately soft and moderately light without characteristic odor or taste. The wood is usually straight grained and the growth rings are inconspicuous. The pores are numerous and small, the largest barely visible with the naked eye in the springwood, decreasing gradually in size through the summerwood, sometimes as diffuse-porous, arranged solitary or in short radial groups of 2 or more. Parenchyma are terminal, generally invisible at low magnifications. The rays are very fine, scarcely visible with a hand lens.

Microscopic Structure of the Wood:

Vessels: 30-120 per sq mm, the largest 90-160 μm in diameter; perforation plates simple; intervessel pits orbicular to oval to angular, 6-10 μm in diameter; volume occupied, approximately 38%. Wooten and Taylor (2) found that vessel volume generally increased with distance from the pith and with increasing height and that slow growth zones had a high proportion of vessel tissue.

Fibers: Thin walled to moderately thick walled (2.4-3.9 μm); average, 16-32 μm in diameter and 1.1 mm (0.5-2.3 mm) in length; volume occupied, approximately 54%. Wooten and Taylor (2) found that long fibers are thicker-walled than short fibers and that fiber length, fiber wall thickness and fiber diameter increased with
distance from the pith at all heights. According to Taylor and Wooten (3), there was a decrease in average fiber length from 1.21 mm at the 5-foot (1.5 m) level to 1.00 mm at the 75-foot (23 m) level.

Rays. Unstoried, uniseriate, heterogeneous with upright cells in 1 or more (usually 1) marginal rows and frequently also in the body of the ray; pits leading to vessels restricted to the upright cells, fairly numerous, and forming a more or less reticulate pattern; volume occupied, approximately 7%.

Longitudinal Parenchyma. Marginal, forming a narrow, continuous or interrupted line, 1-2-seriate; volume, trace.

Gross Features of the Bark. Brown to nearly black, the bark is divided into deep fissures, separating thick, interlacing ridges. The total thickness of bark on old trees varies from 1-2 in. The outer bark is soft and rather fibrous while the inner bark is light creamy yellow, turning darker after exposure. Bark thickness is significantly correlated with cubic volume of each log (4).

Microscopic Structure of the Bark

Inner Bark. The inner bark is characterized by a very abundant supply of lignified phloem fibers. They occur in somewhat oblique tangential lines of varying lengths. These lines begin immediately outside the cambial zone and are separated radially by similarly oriented bands of tissue, composed of sieve tube elements, companion cells, and longitudinal parenchyma. These phloem cell types are only somewhat distorted and are not really crushed, even at the outer bark. Phloem rays are uniseriate, and they maintain almost perfect radial alignment. The alternating tangential bands of fibers and other phloem cells are spaced relatively close, but between groups of every seven or so bands of fibers, there appears a phloem band about twice the normal width of similar adjacent bands and containing no fiber. It is conceivable that these nonfiber-containing regions serve as growth markers for the periodic (perhaps annual) addition of secondary phloem. The secondary phloem amounts to approximately 81% of the tissues in the total bark (5).

Outer Bark. The outer bark of black willow consists of relatively concentric periderms. As the periderms are manufactured, regions of secondary phloem are cut off to the outside, including fibers. Parenchyma here seem to dilate somewhat and many sieve tube elements are still uncrushed, giving a somewhat expanded appearance to the rhytidome in comparison to the inner bark.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Green Volume</th>
<th>Air-Dry Volume</th>
<th>Oven-Dry Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (lb/cu ft)</td>
<td>51 (817)</td>
<td>26 (416)</td>
<td>25 (400)</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>0.34</td>
<td>0.37</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Taylor and Wooten (3) found that specific gravity increased linearly with tree height. According to Taylor (5), there was no significant relationship between growth rate and specific gravity. Specific gravity was positively related to fiber wall thickness. Wooten and Taylor (2) found that high specific gravity was associated with low vessel volume.

Percent shrinkage, dried to 0% moisture content: r - 4.4, t - 7.7, v - 14.4.

Percent moisture content, when green

<table>
<thead>
<tr>
<th>Basis</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green basis</td>
<td>58</td>
</tr>
<tr>
<td>Oven-dry basis</td>
<td>139</td>
</tr>
</tbody>
</table>

Physical Properties of Bark

<table>
<thead>
<tr>
<th>Property</th>
<th>Inner Bark</th>
<th>Outer Bark</th>
<th>Total Bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity (green volume)</td>
<td>0.40</td>
<td>0.28</td>
<td>0.34</td>
</tr>
<tr>
<td>Density (100% moisture content)</td>
<td>Green weight/green volume</td>
<td>0.67</td>
<td></td>
</tr>
</tbody>
</table>

Specific gravity oven-dry weight & volume (7) 0.37

Choong and Cassens (4) found a moisture content of 111.2% with a standard deviation of 25.2% in willow species growing in Louisiana.
Chemical Composition of Wood

**Extractives.** Isenberg et al. (8) found the whole wood to contain 0.3% ether solubles, and The Institute of Paper Chemistry (9) found alcohol-benzene extractives to be 2.6%. For information on extractives see Rowe and Conner (10).

Chemical Composition of Bark

**Proximate Analyses**

<table>
<thead>
<tr>
<th></th>
<th>I.P.C.</th>
<th>Chang and Mitchell (11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, %</td>
<td>6.3</td>
<td>6.0</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>-</td>
<td>3.74</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene, %</td>
<td>-</td>
<td>1.6</td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>6.9</td>
<td>-</td>
</tr>
<tr>
<td>Alcohol, %</td>
<td>-</td>
<td>3.8</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>-</td>
<td>23.8</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>-</td>
<td>4.8</td>
</tr>
</tbody>
</table>

I.P.C. (9) found bark to contain 1.8% calcium and 0.08% silica (as a percent of oven-dry weight of the bark).

**Carbohydrates.** For reducing sugars from extractive-free bark, see Chang and Mitchell (11).

**Extractives.** Tannin could be extracted from the bark.

**Pulping**

**Kraft.** The wood is readily pulped, and the yield is high (12).

**Mechanical.** The wood is readily pulped, and the dark color limits its use (13, 14).

**Neutral Sulfite Semichemical.** Chidester (15) studied the influence of acid, neutral, and alkaline pretreatment and bleaching on yield and mechanical properties; he reports the uses of pulps.

**Soda.** The wood is pulped readily to yields of 45-50% and is fairly easy to bleach (12, 16).

**Sulfite.** The wood is readily pulped, yield is 50-55%, pulp is of excellent color, and it is fairly easily bleached (17, 16).

Utilization of Wood and Bark. The wood is soft and very weak in bending stress and crushing strength. It is moderately light, and uniform in texture. Its nail-holding ability is low and, due to a somewhat interlocked grain does not split readily. Shrinkage during seasoning is moderately large, and care must be exercised during the drying process to prevent warping. It has excellent ability to stay in place once properly seasoned. The wood is not durable under conditions favorable to decay. It is used for millwork and household furniture, shipping containers, doors, veneer, cabinetwork, toys, cutting boards, picture frames, stack cooperage, excelsior, charcoal, pulp and paper, woodenware, wooden shoes, polo balls, and artificial limbs. It is desirable for carving.

**Calorific Value of Bark**

- 7170 BTU/lb
- 3985 k cal/kg
- 151,960 BTU/ft³
- 1080 kcal/m³

**Chemical Uses of Bark.** Bark is a source of salicin, used medicinally as an algesic (10).

**Other Uses of Bark.** Bark tea is used as a folk remedy for colds accompanied by fever (10).

**Literature Cited**


YELLOW BIRCH

Scientific Name  *Betula alleghaniensis* Britton

Synonyms  Gray birch, silver birch, swamp birch

Family Name  Betulaceae

Range  Newfoundland to Minnesota, south in the Appalachians. Much of the yellow birch is found in the maple-beech-birch type and this type covers 32 million acres (13 million ha) or about 9% of all the forest land in the eastern United States (1).

Gross Features of the Wood  The sapwood is light yellow and the heartwood a distinctive reddish brown. The wood is moderately hard to hard, moderately heavy to heavy, without characteristic odor or taste. Flat grain boards show a faint growth ring. The growth ring is indistinct to the unaided eye, delineated by a fine line of denser, fibrous tissue at the outer margin and usually by smaller pores in the summerwood portion of the ring. The wood is diffuse-porous, with pores appearing as whitish dots to the unaided eye; nearly uniform in size and evenly distributed throughout the growth ring.

Silvics  This medium-sized tree has a long, well-formed bole, a small, irregularly rounded crown, and a shallow, widespread root system. One of the most typical of the northern hardwoods, this species occurs in mixture on sandy loam soils with sugar maple, beech, hemlock, red spruce, balsam fir, and white pine. Yellow birch is a prolific seeder, usually producing some seed annually, and very large crops at irregular intervals. The species is rated as intermediate in tolerance.

Tree Dimensions  60-70 ft (18-21 m) tall and 1-2 ft (30-61 cm) in diameter.

Pathology  Resistance to decay: low+

See paper birch, as the same diseases and insects attack both species. Yellow birch is also a favored species for attack by the gypsy moth (*Lymantria dispar*).

Microscopic Structure of the Wood

Vessels  50-100 per sq mm, the largest 60-160 μm in diameter; perforation plates scalariform; intervessel pits orbicularr to broad oval to angular, minute (2-4 μm in diameter); volume occupied, approximately 21%.

Fibers  Thin to moderately thick walled, 20-36 μm in diameter and 1.5 mm (0.8-2.7 mm) long; weight factor (unbleached kraft) of 0.60; volume occupied, approximately 66%.

Rays  Unstoried, 1-5-seriate, homogeneous; volume occupied, approximately 11%.
Longitudinal Parenchyma. Apotracheal-diffuse and in aggregates, paratracheal and marginal; volume occupied, approximately 2%.

Periderm. The first periderm on the main trunk is developed continuously for at least 30 years. Phellem cells are rectangular in shape on both cross and radial sections, and hexagonal on tangential section. Phellem cells are about 10-25 \( \mu m \) high. Cell walls are even in thickness and suberized. Under regular growth conditions, the phellem of yellow birch is developed generally uniformly. Only at the peeled portion or connected with lenticels are there, some very loosely arranged phellem cells. Their shape tends to be oval rather than rectangular as shown on cross section. The periderm accounts for 20.1% of the tissues in the total bark.

Cortical Region. Persistent up to the middle age of the tree. Cells at this region remaining in the mature bark are the cortex cells and sclereid band. Cortex cells are still parenchymatous and contain abundant tanniferous substance and occasionally crystals. Among the cortex cells, there are abundant intercellular spaces and cavities formed. The sporadic sclereids are also increased.

Sieve Tube Elements. Sieve tubes in the secondary phloem are arranged in small groups interrupted by the phloem: parenchyma and rays. Sieve tubes within the space confined by the contiguous rays and parenchyma cells are often aligned in 1-3 layers. A tangential layer of sieve tubes between two rays usually has 2-5 sieve tubes. They are polygonal in shape, tending to be oval and tangentially elongated. The length of sieve tube elements is variable, from 480-1025 \( \mu m \) with a mean length of 827 \( \mu m \). The ends of sieve tube elements are gradually pointed. Sieve tubes amount to 30.6% of the tissue elements of the secondary phloem.

Parenchyma. Phloem parenchyma cells in the secondary phloem are reticulately distributed, and occasionally sporadic. They are mostly in single layers but sometimes, locally, 2-3 in a short radial row. A parenchyma strand is usually composed of 8-10 cells. Cells contain tanniferous substances and sometimes solitary crystals.

Sclerenchyma. Sclerenchyma cells in the secondary phloem are mainly sclereids which are transformed from parenchyma strands and some ray cells. A sclereid group is usually initiated from a few sclerotic parenchyma cells and gradually more surrounding cells are involved. A large group often consists of 20-30 cells. They are irregular in shape and size but not much branched. Their cell walls are very thick with distinct lamellate layers and simple pits. Cells often contain single crystals. Sclereids account for 22.1% of the tissue elements of the secondary phloem.
Rays. Phloem rays in the secondary phloem are mostly 3-seriate and up to 4-seriate. Rays close to the cambial region are mostly about 20 cells and 300 μm in height and about 50 μm wide as shown on tangential section. They become dilated towards the outer bark. The rays are homogeneous. Cells contain tanniferous substances and some ray cells may become sclerified.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Green volume</th>
<th>Air-dry volume</th>
<th>Oven-dry volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.55</td>
<td>0.62</td>
<td>0.66</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td>Green 57 (913)</td>
<td>Air-dry 43 (689)</td>
<td>Oven-dry 41 (657)</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m) per green volume</td>
<td>34 (545)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An additional publication on specific gravity is Maeglin (5).

Percent shrinkage, dried to 0% moisture content: \( r = 7.2 \), \( t = 9.2 \), \( v = 16.7 \).

Percent moisture content, when green

<table>
<thead>
<tr>
<th>Moisture content basis</th>
<th>Heartwood</th>
<th>Sapwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green basis</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Oven-dry basis</td>
<td>67</td>
<td></td>
</tr>
</tbody>
</table>

Besley (7) obtained average moisture contents of 42% for winter, 45% for spring, 37% for summer and 40% for fall.

Physical Properties of Bark

Specific gravity oven-dry weight & volume (8) 0.74

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th>Component</th>
<th>Clermont and Schwartz (9)</th>
<th>F.P.L. (10)</th>
<th>Freeman and Peterson (11)</th>
<th>Aung (12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>18.81&lt;sup&gt;a&lt;/sup&gt;</td>
<td>22.7</td>
<td>18.6</td>
<td>20.2</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>78.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>72.5</td>
<td>79.5</td>
<td>76.5</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>-</td>
<td>-</td>
<td>59.4</td>
<td>58.4</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>42.55&lt;sup&gt;c&lt;/sup&gt;</td>
<td>51.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hemicelluloses, %</td>
<td>26.57&lt;sup&gt;d&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.26</td>
<td>0.8</td>
<td>0.11</td>
<td>0.5</td>
</tr>
<tr>
<td>Pentosans</td>
<td>20.2</td>
<td>22.6</td>
<td>26.9</td>
<td>26.9</td>
</tr>
<tr>
<td>In holocellulose, %</td>
<td>-</td>
<td>-</td>
<td>26.5</td>
<td>24.9</td>
</tr>
<tr>
<td>In C. &amp; B. cellulose, %</td>
<td>-</td>
<td>-</td>
<td>19.3</td>
<td>17.0</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>5.45</td>
<td>-</td>
<td>8.79</td>
<td>6.11</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>5.80</td>
<td>-</td>
<td>6.01</td>
<td>6.04</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>-</td>
<td>2.6</td>
<td>0.97</td>
<td>1.89</td>
</tr>
<tr>
<td>Alcohol, %</td>
<td>-</td>
<td>-</td>
<td>0.86</td>
<td>-</td>
</tr>
<tr>
<td>Ether, %</td>
<td>1.43</td>
<td>0.8</td>
<td>0.36</td>
<td>0.30</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>19.55</td>
<td>15.4</td>
<td>1.30</td>
<td>1.29</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>2.85</td>
<td>2.7</td>
<td>1.20</td>
<td>0.93</td>
</tr>
<tr>
<td>Cold water, %</td>
<td>1.59</td>
<td>-</td>
<td>1.59</td>
<td>-</td>
</tr>
<tr>
<td>Water, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Uronic anhydride, %</td>
<td>4.58</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In hemicelluloses</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>67.0&lt;sup&gt;d&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Uronic anhydride, %</td>
<td>13.7&lt;sup&gt;d&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hexosans (by difference), %</td>
<td>19.3&lt;sup&gt;d&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<sup>a</sup>Corrected for ash.
<sup>b</sup>Corrected for extractives, ash, and lignin.
<sup>c</sup>Corrected for lignin and ash.
<sup>d</sup>As % of moisture-free hemicellulose.
Ritter and Fleck (13) report sap- and heartwood analyses from two trees. Richter (14) gives analyses of sap- and heartwood of two trees felled at different times of the year. Musha and Goring (15) report a klason lignin content of 0.207 g/g, acid-soluble lignin, 0.027, and methoxyl, 1.50. Young (16) found the xylan content of unextracted stem wood to be 16.26% of oven-dry wood.

**Extractives.** Heartwood was extracted with light petroleum ether, acetone, and ethanol, and extractives were identified (17). For information on extractives see Rowe and Conner (18).

**Other Information.** For the distribution of gum see Koran and Yang (19). For information on free fatty acids see Hemingway (20).

### Chemical Composition of Bark

#### Proximate Analyses

<table>
<thead>
<tr>
<th>Component</th>
<th>Richter (27)</th>
<th>Chang and Mitchell (22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>41.7</td>
<td>36.5</td>
</tr>
<tr>
<td>Ash, %</td>
<td>—</td>
<td>1.7</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>—</td>
<td>3.46</td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>17.48</td>
<td>16.6</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene, %</td>
<td>—</td>
<td>4.3</td>
</tr>
<tr>
<td>95% Alcohol, %</td>
<td>—</td>
<td>10.8</td>
</tr>
<tr>
<td>Ether, %</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Acid-alcohol, %</td>
<td>—</td>
<td>12.3</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>—</td>
<td>5.9</td>
</tr>
<tr>
<td>1% NaOH</td>
<td>—</td>
<td>28.4</td>
</tr>
</tbody>
</table>

Chang and Mitchell (22) found that the content of volatiles in oven-dry bark was 76.5%, fixed carbon was 21.0%, and ash was 2.5%; they also report an ash content of 2.3% in the ultimatic analysis.

**Carbohydrates.** Reducing sugars from extractive-free bark are reported by Chang and Mitchell (22).

**Extractives.** The bark was extracted with light petroleum ether, acetone, and ethanol, and extractives were identified (17). For information on extractives see Rowe and Conner (18).

**Pulping**

**Acid Sulfite.** The yield is 44.8%, and chlorine requirement is 5%; for mechanical properties see Richter (27).

**Chemigroundwood.** The treated wood is ground with 50-65% of the power required by and double the production rate of spruce; the pulp is 3-4 times as strong as ordinary spruce groundwood. The yield is 85-90% (23).

**Kraft.** The wood is pulped easily; 14% chemical is consumed for a yield of 56.9%; it is easily bleached, requiring 6.2% total chlorine for 80 G.E. brightness at a permanganate number of 14.0 (12). For other pulping information see Hatton (24).

**Mechanical.** Pulps are short fibered. Energy consumption is reasonable, and strength is low (25, 23, 26, 27, 28). Refiner groundwood is improved by treatment with NaOH and Na₂SO₃ (29).

**NSSC.** The pulp is particularly bright and strong. It has potential use as a partial substitute for chemical pulps in paper products, including newsprint and other groundwood-sulfite papers, in addition to being used in corrugating medium and coarse wrapping paper (30, 26, 31). A bleached grade prepared by conventional chlorine-hypochlorite bleaching has been used to advantage experimentally in glassine and in groundwood and other book papers.

**Soda.** Is pulped with some difficulty; yield is normal, and the pulp is fairly easy to bleach (32, 33, 27, 34, 35, 36, 37).

**Sulfite.** The wood is readily pulped, yield is normal, and color is dark yet readily bleached to give soft bright pulps of high opacity. Burst strength is about 80% that of spruce, and tear strength is low. When pulped green the wood contains waxes which may cause trouble similar to that of pitch (38, 33, 39, 27, 34, 36). The screened yield of unbleached pulp is 45%. The wood has been pulped experimentally with a sodium sulfite liquor buffered with sodium sulfate to produce a pulp with a burst strength near that of softwood sulfate pulp.

**Other Information.** See sweet birch.

### Utilization of Wood and Bark

**Use Properties of Wood.** The wood is hard, heavy, stiff, strong, easily veneered, takes a good polish, shrinks moderately, dries easily, and wears well. The wood is difficult to glue and is glued more easily with synthetic-resin glues than with natural glues. It must be dried carefully to prevent checking and warping. The lumber has a tendency to split during nailing; once it has been
nailed, the nail-holding ability is excellent. The wood is
difficult to work with hand tools and can be readily
shaped by machine.

**Calorific Value of Wood**

\[
26.2 \times 10^6 \text{ BTU/air-dry cord} \\
5790 \text{ BTU/lb air-dry} \\
3215 \text{ kcal/kg air-dry}
\]

**Calorific Value of Bark**

\[
9200 \text{ BTU/o.d. lb} \\
5110 \text{ kcal/kg oven-dry}
\]

**Chemical Uses of Wood.** The wood is used for alcohol
production: 37 gallons of 95% alcohol per ton by the
Madison process. It is also used to produce acetate of
time, charcoal, tar, and oils.

**Chemical Uses of Bark.** The bark of twigs yields oil of
wintergreen. With the advent of synthetic products, the
use for this purpose is decreasing.

**Other Uses of Wood.** The wood is used for veneer, ties,
cooperage, fuel, furniture, boxes, baskets and crates,
woodenware, handles, shuttles, spools, bobbins, looms,
laundry appliances, sash, doors, general millwork. See
also sweet birch.

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1043(1940-1941).


PAPER BIRCH

Scientific Name  *Betula papyrifera* Marsh.

Synonyms  White birch, canoe birch, silver birch

Family Name  Betulaceae

Range  Paper birch, with its varieties, has a transcontinental range extending from northeastern United States through most of Canada to Alaska, reaching northward almost to the limit of tree growth. In the United States, although paper birch is most abundant in the northern New England area, it is common in the Lake States and New York and is also found in scattered localities of other northern states and on a few high mountains in West Virginia and North Carolina. Growing stock volume of paper birch in the United States is approximately 7 billion ft³ (.20 m³). Of this, 43% is in Alaska, 29% is in the Northeastern States, 27% is in the Lake States, and 1% in the Pacific Northwest (7).

Silvics  This medium-sized tree has a long, cylindrical bole, an irregularly rounded crown, and a shallow root system. It occurs as a scattered tree in the mixed coniferous-hardwood forests of the north, mixed with white pine, red spruce, white spruce, balsam fir, maple, beech, yellow birch, and black ash. In some areas, with white spruce and balsam fir, it comprises a large part of the permanent forest. On burned areas very commonly a mixture of paper birch and aspen is found, especially if the site is moist. Growth and development of paper birch are dependent on climate and soil conditions. There is a wide tolerance in pattern and amount of precipitation, but, in general, paper birch grows best with short, cool summers where the average July temperature does not exceed 70° F (21° C) and where there are cold winters with ground snow cover for long periods. Well-drained sandy loam soils encourage the best development, although shallow, stony soils and even bog and peat soils are common. Podzol soils, a result of relatively cool climate, high rainfall, and good drainage, are the usual sites of paper birch. It is rated as intolerant.

Tree Dimensions  50-70 ft (15-21 m) tall and 1-2 ft (30-61 cm) in diameter. An occasional tree on the best sites may exceed 100 ft (30 m) in height and 30 in (76 cm) in diameter.

Pathology  Resistance to decay: low+

Paper birch is susceptible to a condition known as logging decadence where vigor is lowered as a result of opening stands. To prevent this, no more than a third of the basal area of a stand should be removed. A similar condition is birch dieback and the cause of this condition is still unknown, although it is probably related to stress factors. The cause of most cankers on paper birch is *Hectria galligena* and these cankers are common on low-vigor trees. The most common root rot is caused by *Armillariella mellea*, while important heart rots include *Phellinus igniarius*, *Porina obliqua*, *Daedalea unicolor*, and *Stereum murrayi*.

The most important borer attacking paper birch is the bronze birch borer, *Agrilus anxius*, and control depends upon removal of weakened and mature trees. It is frequently associated with both dieback and logging decadence, although it is not considered a cause of those.
two problems. The forest tent caterpillar (*Malacosoma disstria*) can be a serious enemy at times, although the most spectacular outbreaks are generally associated with other hardwoods. Other defoliators include the birch skeletonizer (*Bucculatrix canadensis*), leaf mining sawflies (*Fenusa pusilla*, *Heterarthrus nemoratus*, and *Profenusa thomsonii*).

Gross Features of the Wood Similar to yellow birch, but usually somewhat lighter in color. The wood of paper birch varies in color from a whitish-yellow or light reddish-brown sapwood to dark or reddish-brown heartwood. Growth rings are frequently indistinct and pores appear as whitish dots to the unaided eye. Paper birch is straight grained and classified as a diffuse porous wood.

Microscopic Structure of the Wood See yellow birch.

Fibers. Average 1.8 mm in length. Cell wall thickness of unbeaten, unbleached pulp fibers was 3.75 μm (2). Weight factor (unbleached kraft) of 0.60 and coarseness of 13.08 mg/100 m (2).

Gross Features of the Bark Dark brown at first, the bark of paper birch becomes chalky to creamy white, separating into thin, papery layers. It is generally smooth along most of the trunk with local areas of peeling, and especially in older trees, it becomes nearly black and deeply fissured at the basal end of the trunk. The regular layers of the periderm are easily discernible in cross section and the inner bark (secondary phloem) and cortical regions are light yellowish-brown in color with conspicuous scleroid groups. Bark volume averages about 13%. According to Smith and Kozak (3), double bark thickness averaged 8.2% as a percentage of the diameter outside bark for all sections. Other publications on thickness and volume of bark include Hale (4) and Millikin (5).

Microscopic Structure of the Bark

Young Bark. The periderm in the outer bark consists of continuously developed and compactly arranged phellem or cork cells of rather uniform size, shape and cell wall thickness and large cell cavities. One to two layers of phelloderm usually occur on the inner side of the phellogen. Lenticel openings may extend through the periderm deep into the cortical region. Abundant sclerotic cortical cells appear in the cortex, which consists of a few layers of collenchymalike cells and ordinary cortex cells aligned more or less in tangential rows. The cortex cells are of a parenchymatous nature and contain plastids, tanniferous substances and often crystals. Except for the lack of scleroids, the secondary phloem appears in young bark as in the mature.

Mature Bark.

Periderm. The periderm is made up of two different forms of phellem cells. The radial dimensions of one form show distinct striations. Although the tangential diameter and height of both cell types are about the same, the radial diameter of the narrow cell form is about 5 μm and the broad form, 12 μm and up. The seasonal growth of the trunk corresponds more or less to the alternate growth of the phellem cells, and the boundary between the two types can account for the “peeling” of the bark of periderm. According to Chang (6), the periderm accounts for 32.5% of the tissues in the total bark.

Cortical Region. Persists up to middle age. With abundant intercellular spaces and increased sporadic scleroids, the parenchymatous cortex cells are like those of the young trees.

Inner Bark. The inner bark of mature paper birch is composed of sieve tube elements, parenchyma and ray cells and thick-walled sclerenchyma cells or scleroids arranged in large groups. There are no fibers in the inner bark. Sieve tubes, aligned in 1-3 tangential layers, are polygonal in shape and vary in diameter from 20-60 μm, depending on direction of measurement (radial or tangential) and in length from 520-1250 μm. Patterns of sieve tube groups are formed by the distribution of the phloem ray cells. Phloem parenchyma cells are more or less circular in cross section with an average diameter of 20 μm and heights of 100-150 μm. These reticular cells are distributed throughout the secondary phloem and some are transformed to form large groups of scleroids with adjacent sclerified ray cells. Phloem rays are homogeneous and generally 3-seriate. Conspicuously broader than in the xylem, the rays average 15-20 cells and approximately 300 μm in height near the cambium. Some ray cells become sclerified, having developed a lignified secondary wall. These transformed ray and parenchyma cells form the sclerenchyma cells or scleroid groups. Very thick walled and irregular in size and shape, 20-30 cells form a large scleroid group. The groups of scleroid cells generally are separated from the cambium by 5-6 rows of sieve tubes.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (Green volume)</td>
<td>0.48</td>
</tr>
<tr>
<td>Specific gravity (Air-dry volume)</td>
<td>0.55</td>
</tr>
<tr>
<td>Specific gravity (Oven-dry volume)</td>
<td>0.57</td>
</tr>
</tbody>
</table>
Density, lb/cu ft (kg/cu m)  Green       50 (801)  Air-dry  38 (609)  Oven-dry  36 (577)

Density, lb/cu ft (kg/cu m) Oven-dry weight per green volume  30 (481)

Additional publications on density include Besley (7) and Maeglin (8).

Percent shrinkage, dried to 0% moisture content:  r- 6.3, t-8.6, v-16.2.

Percent moisture content, when green

- Green basis  39
- Oven-dry basis  65

Percent moisture content oven-dry basis (9)

Additional information on bark specific gravity can be found in Lamb and Marden (17).

Physical Properties of Bark

Specific gravity
- Inner bark  0.57
- Outer bark  0.54
- Total bark  0.56

Density (100% moisture content) Green weight/green volume  1.16

Specific gravity oven-dry weight & volume (10)  0.69

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sap</td>
<td>Heart</td>
<td>Sap</td>
<td>Heart</td>
<td>Sap</td>
<td>Heart</td>
</tr>
<tr>
<td>Lignin, %</td>
<td>19.4</td>
<td>17.2</td>
<td>19.6</td>
<td>18.48a</td>
<td>19.4</td>
<td>17.1</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>77.1</td>
<td>76.6</td>
<td>70.9</td>
<td>79.3b</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>–</td>
<td>55.6</td>
<td>51.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>44.7</td>
<td>–</td>
<td>–</td>
<td>40.97c</td>
<td>44.8</td>
<td>41.2</td>
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<tr>
<td>Hemicellulose, %</td>
<td>–</td>
<td>0.24</td>
<td>0.21</td>
<td>27.25a</td>
<td>0.29</td>
<td>0.24</td>
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<tr>
<td>Ash, %</td>
<td>–</td>
<td>0.24</td>
<td>0.21</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pentosans Total, %</td>
<td>23.3</td>
<td>28.8</td>
<td>28.6</td>
<td>22.0</td>
<td>23.9</td>
<td>22.6</td>
</tr>
<tr>
<td>In holocellulose, %</td>
<td>–</td>
<td>28.5</td>
<td>25.7</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>In C. &amp; B. cellulose, %</td>
<td>–</td>
<td>18.0</td>
<td>14.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Mannan, %</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>–</td>
<td>7.12</td>
<td>7.6</td>
<td>4.94</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>–</td>
<td>6.10</td>
<td>5.75</td>
<td>5.93</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Xylan, %</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Moisture content, %</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>5.58</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>2.8</td>
<td>3.31</td>
<td>6.44</td>
<td>–</td>
<td>–</td>
<td>0.09</td>
</tr>
<tr>
<td>Ether, %</td>
<td>1.3</td>
<td>0.79</td>
<td>2.39</td>
<td>2.36</td>
<td>–</td>
<td>0.16</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>14.1</td>
<td>–</td>
<td>–</td>
<td>20.1</td>
<td>14.9</td>
<td>17.1</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>1.5</td>
<td>2.39</td>
<td>2.15</td>
<td>2.71</td>
<td>1.7</td>
<td>–</td>
</tr>
<tr>
<td>Cold water, %</td>
<td>–</td>
<td>1.28</td>
<td>1.12</td>
<td>2.02</td>
<td>1.1</td>
<td>–</td>
</tr>
<tr>
<td>Alcohol, %</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1.35</td>
</tr>
<tr>
<td>Water, %</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.96</td>
</tr>
<tr>
<td>Acid-alcohol, %</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>4.86</td>
<td>4.63</td>
<td>–</td>
</tr>
<tr>
<td>Uronic anhydride, %</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>45.5</td>
</tr>
<tr>
<td>Cellulose, %</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>75.9d</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>In hemicelluloses</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>13.8d</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
Hexosans (by difference)  10.3d

\[ ^a \text{Corrected for ash.} \]
\[ ^b \text{Corrected for ash, lignin, and extractives.} \]
\[ ^c \text{Corrected for ash and lignin.} \]
\[ ^d \text{As \% of the moisture-free hemicelluloses.} \]
\[ ^e \text{Based on extractive-free wood.} \]

Young (18) found the xylan content of stemwood to be 21.85\% of the oven-dry unextracted wood. Richter (19) gives analyses for several samples. Musha and Goring (20) found the Klasson lignin content to be 0.212 and 0.199 g/g, acid-soluble lignin, 0.048 and 0.048, and MeO to be 1.52 and 1.55.

Carbohydrates. Young (17) found the galactan content of wood to be 0.6\%, glucan, 44.7\%, and arabinan, 0.5\% (based on extractive-free wood).

Extractives

Chemical Composition of Bark

<table>
<thead>
<tr>
<th>Proximate Analyses</th>
<th>Chang and Mitchell (31)</th>
<th>I.P.C. (25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, %</td>
<td>1.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>4.04</td>
<td>-</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol-Benzene, %</td>
<td>-</td>
<td>17.0</td>
</tr>
<tr>
<td>Benzene, %</td>
<td>9.4</td>
<td>-</td>
</tr>
<tr>
<td>95% alcohol, %</td>
<td>10.5</td>
<td>-</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>25.1</td>
<td>-</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>2.5</td>
<td>-</td>
</tr>
</tbody>
</table>

Other ash contents are 1.7\% and 1.8\% (32).

Extractives. This is a rich source of betulin (26); other extractives soluble in light petroleum ether, acetone, and ethanol have been analyzed. For information on extractives see Rowe and Conner (28).

Other Information. The bark contains 80.3\% volatile matter, 18.0\% fixed carbon, 57.4\% carbon, 6.7\% hydrogen, 0.3\% nitrogen, 33.8\% oxygen, no sulfur (32), 0.7\% calcium, and 0.06\% silica (as a percent of oven-dry weight of the bark) (25).

For an analysis of elements in bark see Young (33) and Young et al. (29).

Pulping. Birches may be pulped by practically all of the commercial pulping processes. Mechanical pulp is not well suited for most uses because of the short fiber length and low pulp strength. Although sulfite, sulfate, and soda pulping can be used, the best yields and strength properties result from the sulfate method. Various types of papers can be made.

Alcohol and SO\(_2\). This has been used at high pressure; the wood has also been pulped with acetic acid and SO\(_2\) (34).

Chemigroundwood. This is moderately low in strength and is usually blended with softwood groundwood and sulfite pulps to make newsprint. The yield varies from 80-95\% (35).
Kraft. The wood is pulped easily; the pulp is easily bleached, requiring 4.70% total chlorine for 80 G.E. brightness at a permanganate number of 13.1 (36). The strength is about 75% that of spruce except for folding endurance (37). For information on kraft pulping see Legg and Hart (38) and Horn (39). Burst strength is 77%, tear, 62%, fold, 41%, and tensile strength 86% of that of spruce at S-R 550-600. Kraft pulp seems to have the best overall strength properties of any hardwoods. The pulp is equivalent to 75% that of spruce (35).

Groundwood. The pulp is short fibered and low in strength. Although it is light colored, it has a pinkish tinge; energy consumption is relatively low. It is suitable for use in newsprint at up to 30% of the furnish; 50% of this furnish is P.B. neutral sulfite semichemical pulp and the rest is softwood groundwood pulp. The content of birch groundwood was gradually increased in papers of different weights and grades; the energy per cord was no higher than that required for softwood. The pulp strength was lowered when more than 10% of the groundwood furnish was birch; printing papers were satisfactory with up to 20% of birch groundwood. Birch groundwood has also been substituted for about 1/2 of the spruce groundwood in a groundwood-sulfite toweling paper. The absorbency was tripled while wet strength was lowered and dry strength was not lowered. It can be used as filler stock in the manufacture of book and magazine papers and newsprint (40, 41, 37, 42, 43, 44, 45). Refiner groundwood is improved by treatment with NaOH and Na₂SO₃ (46).

Sulfite. The wood is easily reduced, yield is normal, and color is poor but fairly easy to bleach. The pulp is considered to be nearly the equal of hemlock sulfite pulp in strength. The use of green wood may cause troubles because of excessive wax; seasoning usually eliminates this difficulty (47, 37, 48, 24, 45). Birch sulfite pulp approaches the softwood sulfite pulps in strength, having 75% of the burst and 90% of the tear strength of spruce at S.R. 550-600. Except for the highest strength papers, birch sulfite pulps can be used in the same papers as softwood sulfite pulps. Sodium bisulfite pulps are not weaker than NSSC pulps prepared with much larger proportions of chemicals (49). Ten percent of sodium sulfite was used to make semichemical pulp with improved strength characteristics; the properties were further improved by bleaching in three stages with 16% chlorine (50). The chlorine requirement for acid sulfite pulps is 5%; for mechanical properties see Richter (24).

Semichecmical. The wood can be pulped with sodium sulfite and sodium bisulfite (51). The pulp is comparatively low in strength (36).

NSSC. This pulp is particularly bright and strong (52, 38, 53, 54). Herbst and Marshall (55) report on bleached pulp properties. NSSC pulp is used in corrugating and coarse wrapping paper, and it makes lithographic paper of good quality. It is used as a substitute for chemical pulps in newsprint and other groundwood sulfite papers. Newsprint has been made with 20-60% birch sulfite semichemical pulp with varying amounts of spruce and birch groundwood (36).

Oxygen-Sodium Bicarbonate. This has been used in a 2-stage process.

Soda. The wood is reduced with some difficulty; the yield is normal; the pulp is fairly easy to bleach (56, 57, 45, 58). Bleach requirement is 15-20%. High-yield cold soda pulps are colored brown (59). The color is resistant to the action of strong bleach.

Utilization of Wood and Bark

Use Properties of Wood. The wood is easily worked with tools and, although not as strong, heavy, or hard as yellow birch, it is quite a strong, tough, serviceable wood. It has a fine, uniform texture, and the surface has a smooth, white appearance. It is relatively easy to dry and shrinks considerably during drying. The lumber has a tendency to split during nailing; once it has been nailed, the nail-holding ability is excellent.

Calorific Value of Wood

23.4 x 10⁶ BTU/air-dry cord

Calorific Value of Bark

360,590 BTU/ft³
2570 k cal/m³
10,310 BTU/o.d. lb
5730 kcal/kg oven-dry

Other Uses of Wood. The wood has been used for cooperage, crossties, and hardwood distillation equipment. It is used principally for lumber, veneer, pulpwood, fuelwood, and small turned products. The veneer products include ice cream sticks, picnic spoons, tongue depressors, and toothpicks. Turned products are bobbins, clothespins, spoons, broom handles, dowels, shoe shanks, shoe pegs, and toys.
Literature Cited


12. Forest Products Laboratory, Unpublished data.


17. Young, H. E. Personal communication.

18. Young, H. E. Progress Rept. No. 15, Complete Tree Institute, Univ. of Maine, Orono.


SWEET BIRCH

Scientific Name  Betula lenta L.

Synonyms  Black birch, cherry birch, mahogany birch

Family Name  Betulaceae

Range  Northeastern United States; southern Maine southward to northern Alabama and Georgia.

Silvics  This medium-sized tree has a graceful, spherical crown, a long, clear bole, and a deep, widespread root system. Deep, rich, moist, well-drained soils are preferred although the tree is also found on rocky sites. Sweet birch occurs as a scattered tree with maples, basswood, beech, oaks, and yellow-poplar. Best development is reached in Kentucky and Tennessee. The species is rated as intermediate in tolerance.

Tree Dimensions  50-60 ft (15-18 m) tall and 1-2 ft (30-61 cm) in diameter.

Pathology  Sweet birch is relatively free of disease. The most damaging disease is the Nectria canker (Nectria galligena). Grant and Spaulding (7) consider that the bending of twigs from ice and snow create cracks through which this canker can enter. Chief heart rotters of sweet birch are Phellinus igniarius and Poria obliqua. Because of its thin bark, sweet birch is easily damaged by fire.

Sweet birch is occasionally attacked by several leaf-feeding insects. These include the birch tube maker (Acrobasis betulella), the birch skeletonizer (Bucculatrix canadensisella), the oriental moth (Cnidocampa flavescens), the gypsy moth (Lymantria dispar), and the dusky birch sawfly (Croesus latitarsus).

Gross Features of the Wood  Similar to yellow birch.

Microscopic Structure of the Wood  See yellow birch.

Fibers  Average, 1.52 mm in length.

Vessels  Average, 0.91 mm in length.

Gross Features of the Bark  The bark is reddish brown to nearly black on young trees, with prominent, horizontal lenticels; on mature trees it is brownish black and breaks up into large, thin, irregular, scaly plates. Wintergreen oil is present in the inner bark of stems and roots.

Microscopic Structure of the Bark

Periderm  Phellem cells basically the same as described for yellow birch (2).

Physical Properties of Wood

Specific gravity

<table>
<thead>
<tr>
<th></th>
<th>Green volume</th>
<th>0.60</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air-dry volume</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>Oven-dry volume</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Density, lb/cu ft  (kg/cu m)

<table>
<thead>
<tr>
<th></th>
<th>Green</th>
<th>57 (913)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air-dry</td>
<td>46 (737)</td>
</tr>
<tr>
<td></td>
<td>Oven-dry</td>
<td>44 (705)</td>
</tr>
</tbody>
</table>

Density, lb/cu ft  (kg/cu m)

|          | Oven-dry weight per green volume | 37 (593) |

Percent shrinkage, dried to 0% moisture content:  r - 6.5, t - 8.5, v - 15.6.

Percent moisture content, when green

<table>
<thead>
<tr>
<th></th>
<th>Green basis</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oven-dry basis</td>
<td>53</td>
</tr>
</tbody>
</table>

Percent moisture content oven-dry basis (3)

<table>
<thead>
<tr>
<th></th>
<th>Heartwood</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sapwood</td>
<td>70</td>
</tr>
</tbody>
</table>

Chemical Composition of Wood

Extractives  Heartwood was extracted with light petroleum ether, acetone, and ethanol; extractives are lupeol, betulin, methyl salicylate, beta-sitosterol, beta-sitos-
terol-beta-D-glucoside, acetyl methyl betulinate, and procyanidin (in low yield) (4). For information on extractives see Rowe and Conner (5).

**Chemical Composition of Bark**

*Extractives.* Bark was extracted with light petroleum ether, acetone, and ethanol; extractives are lupeol (0.15%), betulin (0.05%), methyl salicylate, beta-sitosterol, lupenone, and procyanidin (in low yield) (4). For information on extractives see Rowe and Conner (5).

**Pulping** Birches may be pulped by practically all of the commercial processes. Mechanical pulp is not well suited for most uses because of the short fiber length and low pulp strength. Although sulfite, kraft and soda pulping can be used, the best yields and strength properties result from the kraft process.

**Utilization of Wood and Bark**

*Use Properties of Wood.* The wood is hard, heavy, stiff, strong, easily veneered, takes a beautiful polish, is easily glued, shrinks moderately, dries easily, and wears well. It is a little higher in strength than yellow birch and also has darker heartwood. All of the birches shrink considerably in drying. Birch lumber has a tendency to split during nailing; once it has been nailed, the wood has excellent nail-holding ability.

*Chemical Uses of Wood.* Twigs are used for birch oil. Birch beer is made from sap.

*Other Uses of Wood.* Birch is used principally for lumber, veneer, pulpwood, fuel, small turned products, cooperage, crossties, and hardwood distillation equipment.

**Literature Cited**


RIVER BIRCH

Scientific Name  *Betula nigra* L.

Synonyms Red birch, black birch, water birch

Family Name Betulaceae

Range Eastern United States. The only birch at low altitudes in the Southeast.

Silvics This medium-sized tree has a trunk which often divides 15 or 20 ft (5-6 m) from the ground into several arching branches. River birch, the only low elevation birch in the South, is most common along stream banks throughout its range and occurs mixed with sycamore, elms, soft maples, cottonwoods, and willows.

Tree Dimensions 30-60 ft (9-18 m) tall and 1-2 ft (30-61 cm) in diameter.

Pathology Resistance to decay: low+

The principal leaf disease of river birch is anthracnose (*Gloeosporium betulaceum*). There is no practical control for this disease under forest conditions, except possibly to allow better air movement and sunshine around the trees. River birch is susceptible to the common *Nectria* canker, (*Nectria galligena*), but is of less importance on this species than on other birches. It is also attacked by the eastern mistletoe (*Phoradendron serotinum*). The trunk rot (*Fomes robustus*) is common on river birch.

River birch is an important host for the borer, *Agrilus betulae*. It is also attacked by the cambium borer (*Phytobia pruinosa*), causing defects known as pith-ray flecks. Leaf feeders on river birch include *Acleris logiana*, dusky birch sawfly (*Croesus latitarsus*), birch leaf-mining sawfly (*Heterarthrus nemoratus*) and the gypsy moth (*Lymantria dispar*).

Gross Features of the Wood  Similar to yellow birch.

Microscopic Structure of the Wood  See yellow birch.

Gross Features of the Bark  Salmon pink, papery, later becoming coarsely scaly and gray to gray brown.

Microscopic Structure of the Bark  See yellow birch.

Periderm Phellem cells are basically the same as described for yellow birch (7).

Physical Properties of Wood Maeglin (2) obtained a mean core specific gravity, based on 8 trees, of 0.52 (green volume, oven-dry weight).

Hicks, et al. (3) found a stronger linear relationship between stump diameter and specific gravity than between stump diameter and dbh growth rate or age.

Physical Properties of Bark

Specific gravity oven-dry weight & volume (4)

0.70

Pulping See sweet birch.

Utilization of Wood and Bark

Use Properties of Wood. Probably similar to yellow birch.

Other Uses of Wood. Only a small amount of wood is used for lumber. It is used for turned items, woodenware, and shoe lasts.

Literature Cited


GRAY BIRCH

Scientific Name  *Betula populifolia* Marsh.
Synonyms White birch, wire birch, oldfield birch
Family Name Betulaceae
Range Northeast and Maritime provinces.

Silvics This small tree has a poorly formed, limby bole, an irregular, open, pyramidal crown, and a shallow root system. It will grow on the poorest soils and has seeded in large areas, where it is associated with pitch pine and scrub oak. On better soils it occurs with oaks and white pine. It also associates with red maple. Gray birch is rated as very intolerant.

Tree Dimensions 20-30 ft (6-9 m) tall and 15 in (38 cm) in diameter.

Pathology Resistance to decay: low

Leaf diseases are of little importance in gray birch. Gray birch is subject to the same stem diseases as the other birches but none of them develop as conspicuously in gray birch, probably due to the shorter life of the species. A large number of fungi rot the central cylinder of mature or damaged trees, including *Inonotus obliquus*, *Daedalea unicolor*, and *Phellinus igniarius*.

The bronze birch borer (Agrius anxius) will attack gray birch, although it is not a preferred species. Gray birch is subject to many leaf feeders, including the Japanese beetle (*Popillia japonica*), the birch leaf-mining sawfly (*Heterarthrus nemoratus*), the elm sawfly (*Cimbex americana*), and the gypsy moth (*Lymantria dispar*).

Gross Features of the Wood Similar to yellow birch but usually softer, lighter, and weaker. Abundant pith flecks in evidence.

Microscopic Structure of the Wood See yellow birch.

Average fiber length 1.26 mm.

Gross Features of the Bark The bark is at first brownish, soon grayish white, exfoliating very little in comparison with that of paper birch; black triangular patches are usually present on the trunk below the branch insertions. Besley (7) found the bark to amount to 12% of the rough tree weight.

Microscopic Structure of the Bark The bark of gray birch shows the same fundamental structure as that of paper birch (2).

Physical Properties of Wood
Specific gravity

<table>
<thead>
<tr>
<th></th>
<th>Green volume</th>
<th>0.45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-dry volume</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>Oven-dry volume</td>
<td>0.53</td>
<td></td>
</tr>
</tbody>
</table>

Density, lb/cu ft

<table>
<thead>
<tr>
<th></th>
<th>Green</th>
<th>46 (737)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kg/cu m)</td>
<td>Air-dry</td>
<td>36 (577)</td>
</tr>
<tr>
<td></td>
<td>Oven-dry</td>
<td>33 (529)</td>
</tr>
</tbody>
</table>

Density, lb/cu ft

<table>
<thead>
<tr>
<th></th>
<th>Green</th>
<th>28 (448)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kg/cu m)</td>
<td>Oven-dry weight</td>
<td>per green volume</td>
</tr>
</tbody>
</table>

Percent shrinkage, dried to 0% moisture content: \( r = 5.2 \), \( \nu = 14.7 \).

Percent moisture content, when green

<table>
<thead>
<tr>
<th></th>
<th>Green basis</th>
<th>39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven-dry basis</td>
<td>63</td>
<td></td>
</tr>
</tbody>
</table>

Besley (7) discusses the moisture content of gray birch.

Pulping

*Kraft*. Stems pulped without bark had a kappa no. of 22.1 and yield of 45.6%; strength properties are reported for bleached and unbleached pulps; process variables were studied (3). In another study Chase (4) found a yield from barked stems of 46% at a permanganate no. of 16.

NSSC. The whole tree above the stump except for foliage gave pulps with good strength properties (5).

Utilization of Wood and Bark

Use Properties of Wood. These are probably similar to the properties of paper birch.

Other Uses of Wood. A limited volume of wood finds its way into the trade as a substitute for paper birch; it is used for clothes pins, spoons, shoe pegs, toothpicks, and fuel.
Literature Cited


RED ALDER

Scientific Name  *Alnus rubra* Bong.

Synonyms Oregon alder, western alder, Pacific coast alder

Family Name  Betulaceae

Range  Confined to the Pacific coast region from southeastern Alaska southward to latitude 34° in southern California. It is generally found no further inland than 100 miles (160 km) and at elevations no higher than 2500 ft (762 m).

Silvics  The forest tree has a clear, symmetrical, slightly tapered bole, a narrow, domelike crown, and a shallow, spreading root system. Best growth is made on moist, rich bottomlands, slopes, and benches, although many trees are found on dry gravelly soils. The coastal region supplies the high humidity or annual rainfall in excess of 25 in that is required for good development. Temperature extremes vary greatly in the long north-south span with minimum temperatures below zero, or near zero for extended periods of time, limiting its range. Soils are not a serious limiting factor except as they affect soil moisture. Alder plantings contribute to the physical and chemical improvement of soil as its nitrogen-rich foliage decomposes rapidly and soil fertility increases through symbiotic fixation of nitrogen by organisms contained in the root nodules. This species occurs in pure stands or in mixture with Douglas-fir, Sitka spruce, western hemlock, western red-cedar, black cottonwood, and bigleaf maple. Red alder is a prolific seeder and is one of the first species to appear on burned and logged areas.

Tree Dimensions  80-130 ft (24-40 m) tall and 1-3 ft (30-91 cm) in diameter. Maximum volume in red alder stands obtained in 50-70 years.

Pathology  Resistance to decay: low

Red alder is exceptionally free of disease. The only noteworthy disease is white heart rot (*Phellinus igniarius*), which is particularly prevalent on injured trees and in overmature stands.

The forest tent caterpillar (*Malacosoma disstria*), the most widely distributed and destructive tent caterpillar in North America, will attack red alder. Another tent caterpillar found on red alder is the western tent caterpillar (*M. californicum*). Two sawflies attack red alder; the alder woolly sawfly (*Eriocampa ovata*) and the striped alder sawfly (*Hemichroa crocea*). These defoliators may slow growth but generally do not cause mortality.

Gross Features of the Wood  The wood is flesh colored to light brown with a reddish tinge; the heartwood is not distinguishable from the sapwood. It is straight grained, without characteristic odor or taste, diffuse-porous, and with distinct growth rings because of the whitish or brownish line at the outer margin. The pores are small, indistinct without a hand lens, solitary and in short radial groups of 2 or more. The longitudinal parenchyma are indistinct. The rays are of two types, narrow and broad (aggregate). The narrow rays are closely spaced and not visible with the naked eye. The broad rays are at irregular intervals (often at wide intervals), not sharply delimited and relatively inconspicuous to the naked eye in the x-section, and as much as an inch along the grain on the t-surface.

Microscopic Structure of the Wood

Vessels.  70-110 per sq mm, the largest 70-100 μm in diameter, 0.85 mm (0.70-1.01 mm) long; perforation plates scalariform with 15+ thin bars; intervessel pits orbicular to oval, quite widely spaced, fairly small (4-8 μm in diameter).

Fibers.  Thin to moderately thick walled, 16-40 μm in diameter and 1.2 mm long.
Rays. Unstoried; the narrow rays uniseriate or rarely in part biseriate; the aggregate rays consist of units similar to the narrow rays, and of included fibers and vessels.

Longitudinal Parenchyma. Paratracheal, apotracheal-diffuse, and in aggregates; the paratracheal parenchyma sparse, restricted to occasional cells, the apotracheal-diffuse parenchyma sparse to fairly abundant, the cells solitary or in short tangential rows of 2 or more.

Longitudinal Parenchyma. Paratracheal, apotracheal-diffuse, and in aggregates; the paratracheal parenchyma sparse, restricted to occasional cells, the apotracheal-diffuse parenchyma sparse to fairly abundant, the cells solitary or in short tangential rows of 2 or more.

Gross Features of the Bark. Red alder bark is thin, smooth and ashy-gray with frequent warty excrescences on the surface and yellowish to reddish-brown in areas where the inner bark is exposed. On old trees and the basal part of the trunk, the bark becomes rougher and tends to break into long shallow plates. On 35-year-old trees, approximately 10 in in diameter, bark thickness averages about 0.2 in. On cross section, there is a narrow layer of periderm, a narrow line of light yellow cortical sclerenchyma and a broad portion of reddish-brown secondary phloem with conspicuous light yellow sclereid groups more or less tangentially aligned, and aggregate phloem rays associated with those in the wood. According to Chang (7), rhytidome formation was not found in the bark. Double bark thickness averaged 7.0% as a percentage of the diameter outside bark for all sections (2).

Microscopic Structure of the Bark

Young Trees or Branches. The bark is composed of a periderm, thin-walled, suberized phellem cells, phellogen and approximately two layers of phelloderm. It also contains a cortical region with some sclereids bounded by a few layers of collenchyma cells, primary phloem tissues crushed within a band of sclerenchyma, and newly formed secondary phloem tissues in the arrangement of the mature bark. The cortical cells are parenchymatous and often contain tanniferous substances and occasionally solitary crystals. Lignified cortex cells and sclereids form the sclerenchyma band, and sporadic sclereids are found in the secondary phloem tissues.

Mature Bark. The mature bark consists of a periderm, a persistent cortical region and the secondary phloem.

Periderm. Only one band of periderm, composed mainly of thin-walled phellem cells, appears in middle-aged trees. Decomposed phellem cells, containing abundant large granules of unknown substances at the outer surface of the bark, may explain the spotted warty excrescences. The cells in the continuously developing layers of phellem are rectangular in cross and radial sections with a rather narrow radial diameter, often only 5 μm wide. The periderm band is completed by one layer of phellogen and 2-3 layers of thin-walled, regularly aligned parenchymatous phelloderm cells that join with the cortex.

Cortical Region. In mature trees, the cortical region is persistent with a zone of sclerenchyma as in the young stem.

Secondary Phloem. The secondary phloem consists of sieve tubes, parenchyma, sclerenchyma and phloem rays. It amounts to 86% of the tissues in the total bark (7).

Sieve Tube Elements. Sieve tubes, in 2-3 layers, are arranged in regular groups of 10-20, alternating with parenchyma bands and interrupted by sclereid-groups in the areas confined by the phloem rays. Retaining their original size and shape throughout most of the inner bark, they are long and cylindrical with sloping ends. Their tangential diameter varies from 30-60 μm and their total length, from 0.71-1.29 mm, with an average length of 1.03 mm. Companion cells, in a strand of 6-8 cells, are often associated with the sieve tube elements at the narrow dimension. The older, functionless sieve tubes often become lignified. Sieve tubes amount to 35% of the tissue elements of the secondary phloem (7).

Parenchyma. Often containing tanniferous substances, phloem parenchyma are variable on cross section, from 10-20 μm in their radial dimension and 20-30 μm in tangential dimension; and usually 150 μm high in a strand. These cells may become lignified, retaining their original shape and cavity size, and sometimes become sclerotic, initiating the formation of sclereid groups.
Sclerenchyma. Sclerenchyma in red alder bark is confined to three types of sclereids classified according to their origin. One group, initiated from transformed parenchyma and contiguous ray cells, usually form a few seasons' growth away from the cambium and increase in size by adding newly transformed cells to it. The second group, similar in composition and cell types, originate from transformed aggregate phloem rays. The cells in the entire ray become fully sclerified almost immediately away from the cambium and continuously develop as ordinary phloem rays in mature bark. Cortical sclereids, the third group, composed mainly of lignified cortex, are rather regular and uniform with evenly thick walls. Red alder sclerenchyma does not contain any typical phloem fibers. Sclerenchyma amounts to 26% of the tissue elements of the secondary phloem (7).

Rays. Phloem rays in mature bark are both uniseriate and aggregate. The homogeneous uniseriate rays, often partially biseriate, are rather closely spaced and about 30 cells, 400 μm high. The aggregate rays, corresponding in size and position to the xylem aggregate rays, are composed of uniseriate rays, parenchyma and some deformed sieve tubes.

Physical Properties of Bark

<table>
<thead>
<tr>
<th>Specific gravity</th>
<th>Inner bark</th>
<th>Outer bark</th>
<th>Total bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green volume</td>
<td>0.55</td>
<td>0.62</td>
<td>0.58</td>
</tr>
<tr>
<td>Air-dry volume</td>
<td>0.56</td>
<td>0.60</td>
<td>0.57</td>
</tr>
<tr>
<td>Oven-dry volume</td>
<td>0.58</td>
<td>0.61</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Density (100% moisture content)

| Green weight/ green volume | 1.15 |

Chemical Composition of Wood

<table>
<thead>
<tr>
<th>Lignin, %</th>
<th>24.1</th>
<th>23.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holocellulose, %</td>
<td>76.4</td>
<td>-</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.23</td>
<td>-</td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>22.8</td>
<td>-</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>3.15</td>
<td>-</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>5.51</td>
<td>-</td>
</tr>
</tbody>
</table>

Solubility in

<table>
<thead>
<tr>
<th>Ether, %</th>
<th>0.32</th>
<th>1.15</th>
<th>0.62</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol, %</td>
<td>2.44</td>
<td>3.81</td>
<td>2.68</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>1.56</td>
<td>3.64</td>
<td>2.02</td>
</tr>
</tbody>
</table>

Ritter and Fleck (9) have compared the springwood and summerwood in the heartwood. Rapson, et al. (10) found an ash percentage of 0.32.

Carbohydrates. The chemistry of polysaccharides in 2-stage sulfite pulps was examined by Schroeder and Hansen (77). The mannan content, by a modified Hagglund-Bratt method, was 0.8% (12).

Extractives. Tannin is 0.74% of oven-dry whole wood (7). For information on fatty acids and resin acids, see Swan (13). The alcohol-benzene extractive content is 2.1% (74).

Other Information. An extract of chlorite holocellulose with hot water gave 13.4% yield of hemicellulose (based on extractive-free wood) (75).
Chemical Composition of Bark

**Proximate Analyses**

<table>
<thead>
<tr>
<th></th>
<th>I.P.C. (14)</th>
<th>Corder (16)</th>
<th>Chang and Mitchell (17)</th>
<th>Kurth and Becker (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, %</td>
<td>5.9</td>
<td>3.1</td>
<td>3.1</td>
<td>—</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>—</td>
<td>—</td>
<td>3.85</td>
<td>—</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>6.0</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Benzene, %</td>
<td>2.3</td>
<td>—</td>
<td>—</td>
<td>0.75</td>
</tr>
<tr>
<td>Alcohol, %</td>
<td>3.9</td>
<td>—</td>
<td>—</td>
<td>11.21</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>27.5</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>3.7</td>
<td>—</td>
<td>—</td>
<td>8.55</td>
</tr>
<tr>
<td>Ether, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.22</td>
</tr>
<tr>
<td>Hexane, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>3.28</td>
</tr>
</tbody>
</table>

**Carbohydrates.** For contents of reducing sugars in extractive-free bark see Kurth and Becker (7) and Chang and Mitchell (17).

**Extractives.** Tannin is 4.20% of oven-dry bark. The chief white coloring matters in bark are the triterpene alcohol alnulin and its corresponding triterpene ketone protalnulin. Red coloring matters are a phenolic xyloside, phlobatannin, a tannin-carbohydrate complex, and phlobaphene. (7).

**Other Information.** Bark contains 0.05% silica and 1.4% calcium (as a percent of oven dry weight of the bark) (14).

**Pulping**

**Ammonia-Base Sulfite.** Process can be used for 70% alder and 30% other woods (18).

**Groundwood.** Can be bleached with SO2 followed by dithionite or peroxide; a two-stage process of H2O2 followed by ZnS2O4 gives a brightness of 63. Groundwood from chips can be bleached by a 2-stage process with hypochlorite and peroxide (19).

**Kraft.** The wood is readily pulped, yield is fairly high, strength is low, the pulp is easily beaten, and it is bleachable with some difficulty because of dirt specks and red shives (20). For kraft pulp properties see Fahey and Martin (27); for kraft pulping information see Hatton (22) and Horn (23). Kraft pulp mixed with *Populus balsamifera* kraft pulp gives satisfactory duplicating and offset printing paper.

NSSC. Pulp is excellent for container boards and bleached paper products; the bleached yield is 55%, and the pulp is strong (24); mixed with Douglas-fir 3:1 it is used for corrugating medium (25), and mixed with Douglas-fir it is also used for insulating boards. Chidester (26) studied the effect of variations in NSSC pulping on pulp properties and yield, and he describes uses of pulps.

Soda. The wood is pulped readily, yield is normal, it is fairly easy to bleach, and some wood gives considerable dirt specks which are not removed in bleaching (20).

**Sodium Bisulfite.** For physical and mechanical properties of pulp see Glennie and Mothershead (8). The wood is readily reduced, has poor color, and is bleachable. Two-stage sulfite pulping (bisulfite followed by alkali) gives a high-yield pulp of better strength than NSSC or kraft pulps (27).

**Other Information.** Pulp is used largely for tissues, label paper, and corrugating medium; for these it is mixed with softwood (28).

**Utilization of Wood and Bark**

**Use Properties of Wood.** The wood is straight grained, close and uniformly textured, and easy to work. It is moderately light in weight, moderately strong in bending and compression, moderately stiff and soft, and moderately low in ability to resist shock. It has little tendency to split in nailing and has moderate nail-holding ability. The wood can be glued satisfactorily, provided moderate care is used. It takes and holds paint
and enamel satisfactorily. It shrinks moderately and can be kiln dried. Proper drying prevents large losses from warping, cupping, and checking. Red alder has excellent dimensional stability. Most of the wood is used for furniture. In small quantities it is used for fixtures, general millwork, and handles. It has recently become important as pulpwood. It is also used for wooden parts of shoes. Pulpwood is the principal use, and lumber for furniture comes next in importance. The wood is also used for the cores of veneer, for firewood, paper roll plugs, charcoal, and matches.

Calorific Value of Wood
17.4 x 10^6 BTU/air-dry cord
8,000 BTU/oven-dry lb
4,445 k cal/kg oven-dry

Calorific Value of Bark
305,383 BTU/ft^3
2180 k cal/m^3
7945 BTU/lb
4415 k cal/kg

Literature Cited


The hickories of the genus *Carya* belong to the Juglandaceae, or walnut family. Eleven species are native in the eastern United States, with eight considered of commercial importance. Four are true hickories and four are classified as pecan hickories.

### True Hickories

- **Shellbark hickory** *C. laciniosa*
- **Pignut hickory** *C. glabra*
- **Shagbark hickory** *C. ovata*
- **Mockernut hickory** *C. tomentosa*

### Pecan Hickories

- **Pecan** *C. illinoensis*
- **Water hickory** *C. aquatica*
- **Nutmeg hickory** *C. myristicaeformis*
- **Bitternut hickory** *C. cordiformis*

---

**Range** The oak-hickory forest is the most extensive timber type in the United States (1). It covers 116 million acres (47 million ha), nearly one-quarter of the total forest area in the country (2) and extends from the prairie borders in Oklahoma, Kansas, and Minnesota through the Appalachian Mountains into the Piedmont and southern New England. Oak-hickory stands cover much of the uplands in the South, with hickories third in abundance, averaging 8.5% of the total hardwood volume on pine sites (3). The most abundant supply of hickory is found in Kentucky, West Virginia and Louisiana.

**Silvics** True hickories are medium-sized trees and are seldom found in pure stands. The hickories are relatively slow growing, even in comparison with oak. Preferred sites for the true hickories vary within their range, with drier sites generally occupied in the north. Oak-hickory stands cover much of the uplands in the South. Pecan hickories occupy much the same climate as the true hickories. Hickories have good seed crops at 2- to 5-year intervals, with light crops in intervening years. Both true and pecan hickories sprout prolifically from the stump. In addition, pecan hickories sprout from the root collar and roots. True hickories tend to be rather tolerant and are usually a climax species in their timber types. Pecan hickories tend to be much less tolerant.

**Pathology** Resistance to heartwood decay: slight

More than 100 fungi attack the hickories and pecans (4), including those that cause leaf diseases, bark cankers and wood and root rots. Among the most common leaf diseases are leaf blotch (*Mycosphaerella dendroides*), anthracnose (*Gnomonia caryae*), witches'-broom (*Microstroma juglandis*), and scab (*Cladosporium effusum*). However, they cause little damage other than varying degrees of defoliation. A bark canker (*Nectria galligena*) probably occurs on most species. One of the most common diseases from Pennsylvania southward is a trunk rot caused by *Poria spiculosa* (5). The most common root rot of hickory is probably *Clitocybe parasitica*.

The hickory bark beetle (*Scolytus quadrispinosus*) attacks most of the hickory species, feeding in the cambium. Trees are frequently seriously weakened or killed by these attacks. Other borers of hickory include the flat-headed borer (*Smodicum cucujiforme*), the pecan carpenterworm (*Cossetia magnificata*) and the living hickory borer (*Goes pulcher*). twig girdlers include the hickory twig girdler (*Oncideres cingulata cingulata*) and two other species, *O. cingulata texanus* and *O. postulatus*. The hickory spiral borer also attacks young hickory and is among the worst enemies of mockernut (6). A defoliator of hickories is the sycamore lacebug (*Corythucha ciliata*).

**Hickory is susceptible to fire at all ages.**

**Gross Features of the Wood of the True Hickories** A ring-porous species. The sapwood is white, and the heartwood is reddish brown. Young hickory contains more sapwood than heartwood. Sapwood is generally from 2-4 in (5-10 cm) in diameter in trees approximately 12 in (30 cm) in diameter. Growth rings are distinct. Longitudinal parenchyma are conspicuous as parallel white lines forming a ladder arrangement with the rays in the latewood. The wood is very heavy, very strong and stiff, high shock resistance and hard. Shrinkage is very large and care must be taken when drying the wood to avoid checking.
Gross Features of the Wood of the Pecan Hickories A
semiring-porous species. The sapwood is white, som­
times tinged with brown, and the heartwood is pale
brown to reddish brown, sometimes containing reddish
streaks of a slightly darker hue. The wood possesses a
moderate and highly pleasing grain pattern. The sap­
wood makes up a considerable portion of the cross
section of young trees, decreasing proportionally as the
trees grow older. Apotracheal parenchyma are con­
spicuous as parallel white lines, forming a ladderlike
arrangement with rays in the latewood, usually
extending into the earlywood zone. Rays are barely
visible to the unaided eye. Tyloses are visible in the
earlywood. The wood is rated as heavy, strong, stiff,
hard, and high in shock resistance. The wood is less
strong than that of the true hickories but somewhat
higher in strength than white oak, sugar maple and white
ash. Shrinkage is large but less than that of the true
hickories.

Microscopic Structure of the Wood (7)

Vessels. Very few, largest latewood vessels large to very
large, perforation plates simple, intervessel pits orbicular
to oval or angular through crowding, 6-8 μm in diameter.

Fibers. Average, 1.4 mm in length (mockernut
hickory), 1.3 mm in length (shagbark hickory unbeaten,
unbleached pulp: fiber length). Weight factor
(unbleached kraft) 0.35. Taylor (8) found, in shagbark
and mockernut hickory, that fiber length was at a
maximum near the middle of the growth increments and
decreased in the last-formed latewood. Last-formed
fibers in the growth rings were approximately the same
length as the first-formed fibers. However, fibers near
the center of the growth ring were approximately
one-third longer than first-formed earlywood fibers.
Other publications on fiber length include Taylor (9,
10).

Parenchyma. Apotracheal-diffuse and in aggregates, and
marginal; lines of banded parenchyma 1-4-seriate.

Rays. 1-5-seriate, homocellular to heterocellular; ray­
vessel pitting similar to intervessel type.

Microscopic Structure of the Bark of Shagbark Hickory

Sieve Tube Elements. Conspicuous, usually solitary
(sometimes in groups of 2 to 5) and fairly uniformly
distributed throughout the alternate tangential bands of
phloem fibers and parenchyma cells. They are oval to
polygonal in cross section and those cells located near
the cambium zone averages 75 μm in diameter. Sieve
tube elements become more or less crushed in the outer
regions of the secondary phloem.

Phloem Fibers. The large numbers of phloem fibers are
aligned in narrow, wavy, tangential bands, 3 to 4 fibers
in width. The cross section of the fibers is polygonal in
shape and averages approximately 20 μm in diameter.
walls of the fiber cross sections appear to be separated
into two distinct layers. Harder, et al. (11) found a
fibrous yield of 15% when shagbark hickory bark was
pulped to a solids yield of 28.3%.
Rays. Fairly numerous, 1-5-seriate, up to 25 or more cells high and evenly distributed throughout the inner bark.

Parenchyma Cell. Arranged in tangential bands, one to three cells in width, are round to oval in cross section and average approximately 30 μm in diameter. Parenchyma cells in a strand often contain solitary crystals.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Mockernut hickory</th>
<th>Shagbark hickory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.66</td>
<td>0.65</td>
</tr>
<tr>
<td>(green volume)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density, lb/cu ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kg/cu m) (12)</td>
<td>Green</td>
<td>64 (1025)</td>
</tr>
<tr>
<td></td>
<td>Oven-dry</td>
<td>39 (625)</td>
</tr>
</tbody>
</table>

Taylor (13) found that the specific gravity of mockernut hickory increased slightly as the distance from the pith increased at the 5-foot (1.5 m) level. The specific gravity of shagbark hickory increased in the early rings and then decreased in the later rings.

Keller, et al. (14) found that high density coincided with the most rapid growth.

According to Phillips (15), understory trees from the Piedmont of Georgia had slightly higher density, moisture content, and percent bark than trees from the mountains of North Carolina.

Additional publications relating to specific gravity include Maeglin (16), Pronin (17), Manwiller (18), and Taylor (9, 10).

Percent shrinkage, dried to 0% moisture content (19):

Pecan hickory, r = 4.9, t = 8.9, v = 13.6; Mockernut hickory, r = 7.7, t = 11.0, v = 17.8; Pignut hickory, r = 7.2, t = 11.5, v = 17.9; Shagbark hickory, r = 7.0, t = 10.5, v = 16.7.

Percent moisture content oven-dry basis (19)

<table>
<thead>
<tr>
<th></th>
<th>Heartwood</th>
<th>Sapwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitternut hickory</td>
<td>80</td>
<td>54</td>
</tr>
<tr>
<td>Water hickory</td>
<td>97</td>
<td>62</td>
</tr>
<tr>
<td>Mockernut hickory</td>
<td>70</td>
<td>52</td>
</tr>
<tr>
<td>Pignut hickory</td>
<td>71</td>
<td>49</td>
</tr>
</tbody>
</table>

Manwiller (20) found branchwood moisture content to be lower than that of the stemwood (51.5% vs. 48.4%) in 6-inch (15 cm) trees growing on southern pine sites.

Physical Properties of Bark

<table>
<thead>
<tr>
<th>Property</th>
<th>Inner bark</th>
<th>Outer bark</th>
<th>Total bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td></td>
<td></td>
<td>0.69</td>
</tr>
<tr>
<td>green volume</td>
<td></td>
<td></td>
<td>0.81</td>
</tr>
<tr>
<td>Shagbark hickory</td>
<td></td>
<td></td>
<td>0.72</td>
</tr>
</tbody>
</table>

Specific gravity oven-dry weight & volume (27)

| Mockernut hickory | 0.98 |

Density (100% moisture content)

| Shagbark hickory | 1.23 |

Chemical Composition of Wood

Proximate Analyses

| Lignin, % | Cellulose, % | Hemicellulose, % | Ash, % | Extractives, % | Mockernut Hickory | Mockernut (?}\n|-----------|--------------|------------------|--------|----------------|--------------------|------------------|
| 23.6      | 43.5         | 27.7             | 0.4    | 5.0            | 23.0               | 37.7             | 29.2 | 1.1 | 9.0 | 23.2 | 37.7 | 29.2 | 1.1 | 9.0 | 46.2 | 26.7 | 0.6 | 3.4 |
Shagbark hickory, alcohol-benzene extractives 3.2\% (22); mockernut hickory, alcohol-benzene extractives 5.3\% (23).

Chemical Composition of Bark

Proximate Analyses

<table>
<thead>
<tr>
<th></th>
<th>Chang and Mitchell (24)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pecan Hickory</td>
</tr>
<tr>
<td>Ash, %</td>
<td>7.5</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>2.69</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
</tr>
<tr>
<td>Benzene, %</td>
<td>0.8</td>
</tr>
<tr>
<td>95% alcohol, %</td>
<td>18.4</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>5.4</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>25.3</td>
</tr>
</tbody>
</table>

Shagbark hickory contains 7.3\% ash and 14.6\% alcohol-benzene extractives. Mockernut hickory bark contains 18.0\% alcohol-benzene extractives (23).

Carbohydrates

<table>
<thead>
<tr>
<th></th>
<th>Chang and Mitchell (24)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pecan Hickory</td>
</tr>
<tr>
<td>Reducing sugars from extractive-free bark</td>
<td></td>
</tr>
<tr>
<td>Glucose, %</td>
<td>69</td>
</tr>
<tr>
<td>Unknown substances, %</td>
<td>4</td>
</tr>
<tr>
<td>Galactose, %</td>
<td>4</td>
</tr>
<tr>
<td>Mannose, %</td>
<td>1</td>
</tr>
<tr>
<td>Arabinose, %</td>
<td>11</td>
</tr>
<tr>
<td>Xylose, %</td>
<td>11</td>
</tr>
</tbody>
</table>

Extractives. The bark contains azaleatin, caryatin, and juglone; for other information see Rowe and Conner (25).

Other Information. The bark of shagbark hickory contains 2.5\% calcium and 0.08\% silica (as a percent of oven-dry weight of the bark) (22).

Pulping

Kraft. For kraft pulping information see Horn (26).

NSSC. Four species of hickory, mockernut, pignut, sand, and shagbark, were pulped. The wood reacted to digestion in a manner normal for North American hardwoods. The pulps were dark in color and varied appreciably in strength between species. Shagbark hickory pulps generally approached aspen pulps in quality. Pulps of fair to medium quality were obtained from mockernut, pignut, and sand hickory.

A mixture containing 19\% bark was cooked to several yields. Although it produced more pulp per cord of rough wood, some strength was lost, and the chemical costs per ton of pulp were higher than when bark-free chips were cooked. The pulps were converted to a corrugated board of adequate strength and to a bond paper that was satisfactory except for low opacity.

A shagbark hickory linerboard had satisfactory burst strength and stiffness but did not match southern kraft liner in other properties. Glassine and greaseproof papers showed low permeability and satisfactory strength. A bond paper had excellent strength and good formation but had the low opacity inherent in bleached NSSC pulps (14).

Soda. Mockernut hickory is readily pulped; the pulp is very difficult to bleach.

Sulfite. Mockernut hickory is readily pulped; the pulp is pecky and rather difficult to bleach.

Utilization of Wood and Bark

Use Properties of Wood. Hickory is very high in combined strength, toughness, hardness, and stiffness, and it is extremely shock-resistant. It shrinks a great deal during drying, which often results in checking, warping, and other seasoning defects. It is difficult to machine and glue, and it is difficult to pressure treat with preservatives. The nail-holding ability is good, although there is a tendency for the wood to split when nailed. Red, white, and mixed red and white hickory have the same strength characteristics.

Calorific Value of Wood

<table>
<thead>
<tr>
<th></th>
<th>30.6 BTU/air-dry cord</th>
</tr>
</thead>
<tbody>
<tr>
<td>8180 BTU/oven-dry lb</td>
<td>4545 k cal/kg oven-dry</td>
</tr>
<tr>
<td>5800 BTU/lb air-dry</td>
<td>3222 k cal/kg air-dry</td>
</tr>
</tbody>
</table>

Calorific Value of Bark

<table>
<thead>
<tr>
<th></th>
<th>8420 BTU/oven-dry lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>4680 k cal/kg oven-dry</td>
<td>378,190 BTU/ft³</td>
</tr>
<tr>
<td>2695 k cal/m³</td>
<td></td>
</tr>
</tbody>
</table>

Chemical Uses of Bark. The bark has been used for pharmaceutical purposes (25).
Other Uses of Wood. The most important use is for tool handles. It is also used for furniture, ladder rungs, dowels, skis, archery equipment, baseball bats, and musical instruments. It is used to a limited extent in flooring, veneer, plywood, railroad crossties, fuelwood, and charcoal.

Literature Cited

**Scientific Name**  *Juglans cinerea* L.

**Synonyms** White walnut, oilnut

**Family Name** Juglandaceae

**Range** North and central regions of eastern United States and adjacent Canada.

***Silvics*** This tree is medium sized. When forest grown, it has a comparatively long trunk but very often it is short and divides into a few stout, ascending limbs which form a broad, irregular crown. The root system comprises a taproot and a number of deep, widespread laterals. Butternut prefers a rich, deep loamy soil with plenty of moisture but will grow under a wide range of soil and climatic conditions, if sufficient light is available. This species occurs in mixture, sparsely usually, with oaks, hickories, basswood, elms, black cherry, beech, yellow-poplar and farther north with hard maple and yellow birch. Butternut is rated as intolerant.

**Tree Dimensions** 40-60 ft (12-18 m) tall and 1-2 ft (30-61 cm) in diameter.

**Pathology** Resistance to decay: durable

Most trees appear to be affected to some extent. Many rot fungi attack butternut, with one of the main heart rot fungi being *Phellinus igniarius*. It is also a host for *Nectria* cankers. Butternut is susceptible to fire damage.

The most serious insect pest of butternut is probably the walnut caterpillar (*Datana integerrima*). Trees that are heavily defoliated several years in succession are frequently killed. Butternut is also attacked by the European fruit lecanium (*Lecanium corni*), also known as the brown elm scale.

**Gross Features of the Wood** The sapwood is white to light grayish brown and narrow. The lustrous heartwood is light chestnut brown, frequently variegated with pigment figure. The wood is moderately soft, moderately light, without characteristic odor or taste. Wood is semiering- or semidiffuse-porous and shows a conspicuous growth ring. It is straight grained. Parenchyma are visible with a hand lens arranged in fine, numerous, more or less continuous, tangential lines. The rays in x-section are fine and indistinct to the naked eye.

**Microscopic Structure of the Wood**

**Vessels.** 6-12 per sq mm, the largest 160-260 μm in diameter; perforation plates simple; intervessel pits orbicular to oval to angular, 10-16 μm in diameter.

**Fibers.** Average, 1.26 mm (0.6-2.0 mm) in length and 20-45 μm in diameter; thin walled.

**Rays.** Unstoried, 1-4-seriate, homogeneous to heterogeneous.

**Longitudinal Parenchyma.** Metatracheal and metatracheal-diffuse; lines of zonate parenchyma usually uniseriate.

**Gross Features of the Bark** The light gray bark is divided by shallow to moderately deep fissures into broad, flat ridges and is later more closely furrowed with a roughly diamond-shaped pattern.

**Physical Properties of Wood**

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>Green</td>
</tr>
<tr>
<td></td>
<td>Air-dry</td>
</tr>
<tr>
<td></td>
<td>Oven-dry</td>
</tr>
</tbody>
</table>
Density, lb/cu ft (kg/cu m)
Green 46 (737)
Air-dry 27 (432)
Oven-dry 25 (400)

Density, lb/cu ft (kg/cu m)
Oven-dry weight per green volume 22 (352)

Percent shrinkage, dried to 0% moisture content: r - 3.3, t - 6.1, v - 10.2.

Percent moisture content, when green
Green basis 51
Oven-dry basis 104

Physical Properties of Bark

Specific gravity
oven-dry weight & volume (7) 0.45

Chemical Composition of Wood

Proximate Analysis

I.P.C. (2)

Lignin, % 19.4
Alpha-cellulose (on chlorite holocellulose, %) 43.1

Acetyl, % 1.16
Methoxyl, % 5.47
Uronic acids, % 1.36
Solubility in, by successive extractions
Ethanol, % 0.5
50% Methanol, % 9.3
Hot water, % 1.0
Total, % 10.8

Pulping

Soda. The wood is readily pulped, yield is high, and the pulp is very difficult to bleach (3).

Sulfite. The wood is readily pulped, yield is normal, color is poor, and the pulp is fairly easily bleached (3).

Utilization of Wood and Bark

Use Properties of Wood. The wood is moderately soft, moderately light, has moderately small shrinkage, is straight grained, and is easily worked. The heartwood is frequently variegated with pigment figure, is lustrous, is moderately weak, and takes stain well.

Other Uses of Wood. The wood is used for furniture.

Literature Cited

2. Institute of Paper Chemistry. Unpublished data.
Scientific Name  *Celtis occidentalis* L.

Synonyms  Sugarberry, nettletree, false-elm, beaver-wood, common hackberry

Family Name  Ulmaceae

Range  Eastern half of the United States, except the southern border. Hackberry spp. amount to 0.1% of the hardwood volume on pine sites in 12 southern states (7).

Silvics  Hackberry is a medium-sized tree which grows on many types of soils, although it prefers rich, moist, alluvial soils. It is commonly found on slopes and bluffs and on soils rich in lime. It is a drought-resistant species and is a minor component of the following upland forest types: sugar maple-basswood, post oak-black oak, bur oak, eastern redcedar-hardwood, ashe juniper and Mohrs oak. Hackberry is rated as intermediate in tolerance.

Tree Dimensions  30-50 ft (9-15 m) tall and 18-24 in (46-61 cm) in diameter. On the best sites, it may reach 130 ft (40 m) in height and 3-4 ft (91-122 cm) in diameter (2).

Pathology  Hackberry is a relatively healthy species and is attacked by few wood-rotting fungi. The most important disease is witches'-broom, which causes a proliferation of the branch tips. Powdery mildew (*Sphaerotheca phytophila*) and several leaf-spot fungi are common. Hackberry is very susceptible to fire because of its thin bark.

Hackberry is the host of four gall-producing insects (*Pachypsylla celtidisgemma, P. celtidismamma, P. celtidisvesicula, and P. venusta*). However, their damage is not serious. Leaf feeders include the spiny elm caterpillar (*Euvanessa antiopa*) and the caterpillar of the hackberry butterfly (*Chlorippe celtis*). These leaf feeders are capable of defoliation when present in large numbers.

Gross Features of the Wood  The wood is straight-grained, sometimes interlocked-grained, dense, hard and strong. The sapwood is wide and varies in color from pale yellow to greenish yellow. The heartwood, when present, varies from yellowish gray to light brown, streaked with yellow (3). It is a ring-porous species with large vessels. Growth rings and rays are distinctly visible. The wood is free of gum, odor or taste.

Microscopic Structure of the Wood (3)

Vessels. Moderately to very numerous in the latewood. Largest earlywood vessels very large to extremely large, in several rows; perforation plates simple; spiral thickening present in the smaller vessels; intervessel pits orbicular or angular through crowding, 8-12 µm in diameter.

Parenchyma. Paratracheal-scanty to vasicentric and apotracheal-diffuse.

Rays. Unstoried, 1-13 (mostly 5-8)-seriate, heterocellular for the most part.

Fibers. Average, 1.13 mm in length.

Manwiller (4) obtained a mean stem wood fiber length of 1.12 and a mean branch wood fiber length of 0.86 for 6-inch (15 cm) trees growing on southern pine sites.

Gross Features of the Bark  Smooth, dark brown to gray, and quite thickly covered with warty protuberances.

Microscopic Structure of the Bark (5)

Periderm. In most of the bark, periderm formation is quite limited and persistent. It consists of 1-2 layers of phelloderm, a layer of phellogen and rather thin phellem. Periderm formation appears to occur more frequently in the area of corky warts or ridges.

Sieve Tube Elements. Tend to be arranged in tangential bands, 1-3 cells thick with some parenchyma strands dispersed within the band. Sieve elements are expanded greatly in the conducting phloem. In the nonconducting phloem, sieve elements are collapsed completely.

Parenchyma. Strands form tangential bands, 2-4 cells thick.

Fibers. Appear sporadically or in small groups in the tangential bands of parenchyma strands. They are very difficult to detect because they are small in diameter. Cell walls are un lignified and quite thick. Average length is 2.0 mm.

Scleides. Differentiated from parenchyma strands and some ray cells. They sometimes retain their original shape and size but mostly are expanded.
Rays. Heterogeneous and 5-8 (mostly 7-8)-seriate.

Physical Properties of Wood

Specific gravity Green volume 0.52

Manwiller (6) obtained a branch wood specific gravity of 0.55 for Celtis spp. growing on pine sites.

Moisture content oven-dry basis (7)

<table>
<thead>
<tr>
<th></th>
<th>Heartwood</th>
<th>Sapwood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>61</td>
<td>65</td>
</tr>
</tbody>
</table>

A stemwood moisture content of 72.6% (dry weight basis) was obtained by Manwiller (8).

Physical Properties of Bark

Specific gravity oven-dry weight & volume (9) 0.65

Pulping

Sulfite: Wood is readily pulped, exceptionally light colored, easily bleached.

Soda. Wood is readily pulped, rather difficult to bleach.

Utilization of Wood and Bark (10) The wood is moderately strong in bending, moderately weak in compression parallel to the grain, and high in shock resistance, but lacks stiffness. It has moderately large to large shrinkage but keeps its shape well during seasoning. The wood has top-rated gluing properties. It is intermediate in nail- and screw-holding ability, and it resists splitting from screws better than from nails.

Calorific Value of Wood

7880 BTU/oven-dry lb
4380 k cal/kg oven-dry

Calorific Value of Bark

7150 BTU/oven-dry lb
3970 k cal/kg oven-dry

Other Uses of Wood. The wood has been used for furniture, millwork, sporting and athletic goods. The veneer products include containers and interior plywood faces. Low-grade lumber is often made into boxes and crates.

Literature Cited

AMERICAN BEECH

Scientific Name  *Fagus grandifolia* Ehrh.

Synonyms Beech, red beech

Family Name  Fagaceae

Range The only species of this genus in the United States, American beech is found from Nova Scotia to northern Michigan and eastern Wisconsin in the north, to northwestern Florida and eastern Texas in the south.

Silvics The forest tree has a clear, straight, massive trunk with a small, narrow crown and a shallow, widespread root system. Within the range of this species, the growing season varies from 100-280 days and annual precipitation from 30-50 in (76-127 cm). As a mesophytic species, beech prefers loamy-textured soils and those with a high humus content over lighter soils, and will grow on poorly drained sites not subjected to prolonged flooding. The largest trees are found in the alluvial bottom lands of the Ohio and the lower Mississippi River valleys and along the western slopes of the southern Appalachian Mountains in mixture with basswood, yellow-poplar, black cherry, ash, sycamore, and bottomland oaks. In the north, it is usually associated with maple, birch and hemlock. Beech trees begin seed production at about 40 years of age but large crops are produced only at irregular intervals. The species also sprouts well from stumps less than 4 in (10 cm) in diameter, and may develop root suckers. However, in forest stands with associated hardwood species, heavy cutting tends to reduce beech reproduction and repeated clearcutting on short rotations may nearly eliminate the species. American beech is rated as very tolerant.

Tree Dimensions 60-80 ft (18-24 m) tall and up to 120 ft (36 m) under optimum conditions; 2-3 ft (61-91 cm) in diameter.

Pathology  Resistance to decay: low+

Because of its thin bark, American beech is susceptible to fire and sunscald injury. The species is subject to many diseases. Chief among them is the beech bark disease (*Nectria coccinea* var. *faginata*). The disease gains entrance after attack by the beech scale (*Cryptococcus fagi*) and causes extensive mortality. Beech suffers little damage from root or foliage diseases but few species are subject to decay by more species of fungi (7). The most common heart rot fungus of beech is *Phellinus igniarius* which is capable of rotting the entire central cylinder of the tree (2).

The most important insect pest of beech is the beech scale (*Cryptococcus fagi*), an introduced species. Large quantities of beech have been killed through the infestation by a combination of the beech scale and the beech bark disease. Control is obtained by removing diseased trees, with some degree of natural control provided by the twice-stabbed lady beetle and low winter temperatures. The most damaging defoliator is the saddled prominent (*Heterocampa guttivitta*), with beech being a preferred species. Other defoliators include the gypsy moth (*Lymantria dispar*), the forest tent caterpillar (*Malacosoma disstria*), and the Bruce spanworm (*Opereoptera bruceata*).

Gross Features of the Wood The sapwood is whitish and the heartwood whitish with a reddish tinge to reddish brown. The wood is hard, and heavy, without characteristic taste or odor. The wood is diffuse-porous with distinct growth rings delineated by a dark line or band of denser summerwood. Flat grain boards exhibit a faint growth ring figure. Pores are small, indistinct without a hand lens, usually crowded and largest in the springwood, decreasing in number and size through the central portion of the growth rings, scattered and very small in the late summerwood. The rays are of two types, compound and simple, the broad ones plainly visible with the naked eye, and the narrow rays, fine, not visible without magnification.
Microscopic Structure of the Wood

Vessels. 50-200 per sq mm, the largest 60-90 μm in diameter; tyloses present in the heartwood; perforation plates simple or those in the smaller vessels occasionally scalariform; intervessel pits oval-to long-elliptical, 6-20 μm in diameter.

Fibers. Average, 1.2 mm (0.6-1.9 mm) in length and 16-22 μm in diameter. Cell walls thick. Weight factor 0.52.

Rays. Unstoried, homogeneous or with marginal upright cells; compound rays 15 to 25+ seriate, 1 to several mm high; narrow rays much more numerous, 1-5-seriate, up to 500+ μm high; volume occupied 20.4%.

Longitudinal Parenchyma. Abundant, metatracheal and metatracheal-diffuse, the lines of the latter more evident toward the outer margin of the ring. Parenchyma cells occupy 20% of the volume of structural elements in the wood.

Gross Features of the Bark. The bark of American beech is similar in appearance on both young and old trunks. It is thin, close, smooth, light blue-gray and often mottled. Volume averages about 7%. Millikin (3) found that oven-dry bark weight per 100 ft³ (2.8 m³) of solid wood (peeled) averaged 242 lbs.

Microscopic Structure of the Bark

Inner Bark. Near the cambial zone, the inner bark consists of alternating tangential bands of longitudinal parenchyma and sieve tube elements. The small phloem rays are apparently not lignified and are distorted somewhat as they project outwardly into the older phloem. The larger multiseriate rays are not distorted, apparently are lignified, and show sclerosis just outside the cambium zone. These ray cells are also crystalliferous. The longitudinal parenchyma also tend to become more crystalliferous in older phloem. An interesting feature of the large multiseriate rays in beech is that the cambium zones of the rays themselves project inwardly from what would be considered their normal position. The latter would normally be expected to consist of a circumferential zone of cells in line with the cambium zone of the nonray tissue. It is apparent, however, that in hardwoods with "oak-type" rays, the cambium zone of these large rays is displaced inward toward the pith in a V-shaped wedge.

Outer Bark. The outer bark appears to consist of only one periderm but with concentric, alternating layers of thin and thick-walled phellem cells, except in lenticel regions. Just beneath the phellogen area, there appears to be only few, if any, distinguishable phelloderm cells, and cortical parenchyma (colenchyma) are persistent in many locations. No true sclereids or fibers were observed in the outer bark.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Green Volume</th>
<th>Air-Dry Volume</th>
<th>Oven-Dry Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>0.56</td>
<td>0.64</td>
<td>0.67</td>
</tr>
<tr>
<td>Density, lb/ft³ (kg/m³)</td>
<td>Green</td>
<td>Air-Dry</td>
<td>Oven-Dry</td>
</tr>
<tr>
<td></td>
<td>54 (865)</td>
<td>45 (721)</td>
<td>42 (673)</td>
</tr>
<tr>
<td>Density, lb/ft³ (kg/m³)</td>
<td>Oven-Dry Weight per Green Volume</td>
<td>39 (625)</td>
<td></td>
</tr>
</tbody>
</table>

Taylor (4) found that rays were compact tissues with a mean specific gravity considerably higher than that of sample blocks containing rays. He felt that possible selection for high specific gravity may result in increased ray volume.
Other publications containing information on specific gravity of beech are Jett and Zobel (5), Maeglin (6), and Murphey, et al. (7).

Percent shrinkage, dried to 0% moisture content: r - 5.1, t - 11.0, v - 16.3.

Percent moisture content, when green

<table>
<thead>
<tr>
<th></th>
<th>Green basis</th>
<th>Oven-dry basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>35</td>
<td>54</td>
</tr>
</tbody>
</table>

Percent moisture content oven-dry basis (8)

<table>
<thead>
<tr>
<th></th>
<th>Heartwood</th>
<th>Sapwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>55</td>
<td>72</td>
</tr>
</tbody>
</table>

Physical Properties of Bark

<table>
<thead>
<tr>
<th></th>
<th>Inner bark</th>
<th>Outer bark</th>
<th>Total bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.67</td>
<td>—</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Specific gravity green volume

Density (100% moisture content)

<table>
<thead>
<tr>
<th></th>
<th>Green weight/ green volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.74 (Fagus grandifolia var. caroliniana)</td>
</tr>
</tbody>
</table>

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th></th>
<th>Clermont and Schwartz (10)</th>
<th>F.P.L. (17)</th>
<th>Freeman and Peterson (12)</th>
<th>Aung (13)</th>
<th>Young (14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>22.25^a</td>
<td>21.0</td>
<td>20.6</td>
<td>22.3</td>
<td>21.1</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>77.5^b</td>
<td>75.7</td>
<td>76.2</td>
<td>76.9</td>
<td>72.7</td>
</tr>
<tr>
<td>Cellulose, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>C. &amp; B. Cellulose, %</td>
<td>—</td>
<td>—</td>
<td>60.8</td>
<td>60.7</td>
<td>—</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>43.65^c</td>
<td>51.2</td>
<td>—</td>
<td>—</td>
<td>43.4</td>
</tr>
<tr>
<td>Hemicelluloses, %</td>
<td>23.50^d</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.36</td>
<td>0.5</td>
<td>0.31</td>
<td>0.57</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Pentosans

<table>
<thead>
<tr>
<th></th>
<th>Total, %</th>
<th>In holocellulose, %</th>
<th>In C. &amp; B. cellulose, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total, %</td>
<td>19.5</td>
<td>20.2</td>
<td>25.6</td>
</tr>
<tr>
<td>Mannan, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>5.33</td>
<td>7.13</td>
<td>6.05</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>6.47</td>
<td>6.28</td>
<td>6.44</td>
</tr>
<tr>
<td>Xylan, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Solubility in

<table>
<thead>
<tr>
<th></th>
<th>Alcohol-benzène, %</th>
<th>Ether, %</th>
<th>1% NaOH, %</th>
<th>Hot water, %</th>
<th>Cold water, %</th>
<th>Water, %</th>
<th>Alcohol, %</th>
<th>Uronic anhydride, %</th>
<th>In hemicelluloses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol-benzène, %</td>
<td>—</td>
<td>1.8</td>
<td>1.37</td>
<td>0.91</td>
<td>0.14</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ether, %</td>
<td>0.86</td>
<td>0.7</td>
<td>0.20</td>
<td>0.57</td>
<td>0.22</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>16.43</td>
<td>14.7</td>
<td>—</td>
<td>2.17</td>
<td>2.33</td>
<td>0.23</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>2.31</td>
<td>1.5</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cold water, %</td>
<td>1.04</td>
<td>—</td>
<td>—</td>
<td>2.33</td>
<td>0.23</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Water, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1.63</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Alcohol, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.91</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Uronic anhydride, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>4.8</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

In hemicelluloses

<table>
<thead>
<tr>
<th></th>
<th>Pentosans</th>
<th>Uronic Anhydride</th>
<th>Hexosans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pentosans</td>
<td>67.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Uronic Anhydride</td>
<td>16.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>By difference</td>
<td>17.0</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

^aCorrected for ash.
^bCorrected for extractives, ash, and lignin.
^cCorrected for lignin and ash.
^dCorrected for ash.
Musha and Goring (75) found the lignin content was 0.240 g/g and the methoxyl content was 1.51 g/g. Jayme et al. (76) reported 38.1-42.8% cellulose by the chlorite method. Richter (77) gives analyses of sapwood and heartwood in two trees.

**Carbohydrates.** Young (74) reports a galactan content of 1.2%, glucan, 47.5%, and arabinan, 0.5%.

**Extractives.** Tannins are absent (18). The alcohol-benzene extractive content is 1.5% (19).

**Other Information.** The distribution of lignin and contents of cellulose, galactan, lignin, xylan, and glucosmannan were studied in tension wood and normal wood by Kuo (20).

### Chemical Composition of Bark

**Proximate Analyses**

<table>
<thead>
<tr>
<th>Component</th>
<th>Richter (21)</th>
<th>I.P.C. (19)</th>
<th>Milliken (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>41.82</td>
<td>37.0</td>
<td>–</td>
</tr>
<tr>
<td>Ash, %</td>
<td>–</td>
<td>8.3</td>
<td>10.5</td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>14.16</td>
<td>13.7</td>
<td>7.9</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>–</td>
<td>–</td>
<td>10.6</td>
</tr>
<tr>
<td>Ether, %</td>
<td>–</td>
<td>1.2</td>
<td>–</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>–</td>
<td>4.0</td>
<td>–</td>
</tr>
<tr>
<td>Acid-alcohol, %</td>
<td>–</td>
<td>13.2</td>
<td>–</td>
</tr>
</tbody>
</table>

**Other Information.** The bark contains 3.4% calcium and 1.1% silica (as a percent of oven-dry weight of the bark) (19), 75.2% volatiles, and 16.9% carbon (3). For an ultimate analysis see Millikin (3).

**Pulping**

**Acid Sulfite.** Yield is 43.5%, and chlorine requirement is 5.5%; burst strength and tear resistance are reported by Richter (21).

**Alkaline.** Yield is good, and freeness and burst strength are almost identical to gum, while breaking length, tear strength, and sheet density are slightly lower (22).

**Chemigroundwood.** The treated wood is ground with 1/2 to 2/3 the power and double the production rate of spruce. It is 3 to 4 times as strong as ordinary spruce groundwood. Yield is 85-90% (23, 24).

**Kraft.** It is about 50% as strong as spruce (25). The wood is pulped easily; it is easily bleached, requiring 4.85% total chlorine for 80 G.E. brightness at a permanganate number of 13.0 (13). For kraft pulp information see Hatton (26).

**Mechanical.** Pulp short fibered and strength low. For grinding experiments see Corbin (27).

**Neutral Sulfite Semichemical.** For information on the acid, neutral, and alkaline pretreatment and bleaching on yield and properties, and for uses of pulps, see Chidester (25).

**Soda.** Is slightly more difficult to pulp than aspen; yield is normal, is readily bleached, and strength is low (25, 29, 30, 31).

**Soda-Oxygen.** This method can be used.

**Sulfite.** The yield is slightly low, strength is about 60% of that of spruce, color is quite dark, yet the pulp is readily bleached to give soft bright pulps of high opacity (25, 21, 32). The pulp can be used for dissolving pulps.

**Utilization of Wood and Bark**

**Use Properties of Wood.** The wood is hard, dense, and light in color. It is hard between sycamore and hard maple.

**Calorific Value of Wood**

- 27.8 x 10^6 BTU/air-dry cord
- 6000 BTU/lb air-dry
- 3335 k cal/kg air-dry
Calorific Value of Bark

334,906 BTU/ft³
2390 k cal/m³

7640 BTU/oz. lb
4245 k cal/kg oven-dry

Alcohol production: 34 gallons of 95% alcohol per ton by the Madison process.

Other Uses of Wood. It is the preferred hardwood for handles and is used for commercial and industrial flooring, furniture, woodenware, and novelties. Chips are used in the brewing industry. The wood is also used for lumber, ties, veneer, and fuel. Fruits could be used for hog feed and vegetable oil.

Literature Cited

11. Forest Products Laboratory. Unpublished data.
14. Young, H. E. Personal communication.


The oaks of the genus *Quercus* belong to the Fagaceae, or beech family. There are 75 to 80 species of oaks in the United States. The important species are listed below in either the white, red or live oak group.

### WHITE OAKS

<table>
<thead>
<tr>
<th>White Oak</th>
<th>Genus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bur oak</td>
<td><em>Q. macrocarpa</em></td>
</tr>
<tr>
<td>Post oak</td>
<td><em>Q. stellata</em></td>
</tr>
<tr>
<td>Overcup oak</td>
<td><em>Q. lyrata</em></td>
</tr>
<tr>
<td>Gambel oak</td>
<td><em>Q. gambelli</em></td>
</tr>
<tr>
<td>Valley oak</td>
<td><em>Q. lobata</em></td>
</tr>
<tr>
<td>Oregon white oak</td>
<td><em>Q. garryana</em></td>
</tr>
<tr>
<td>Blue oak</td>
<td><em>Q. douglasii</em></td>
</tr>
<tr>
<td>Swamp white oak</td>
<td><em>Q. bicolor</em></td>
</tr>
<tr>
<td>Swamp chestnut oak</td>
<td><em>Q. michauxii</em></td>
</tr>
<tr>
<td>Chestnut oak</td>
<td><em>Q. prinus</em></td>
</tr>
<tr>
<td>Chinkapin oak</td>
<td><em>Q. muehlenbergii</em></td>
</tr>
</tbody>
</table>

### RED OAKS

<table>
<thead>
<tr>
<th>Red Oak</th>
<th>Genus</th>
</tr>
</thead>
<tbody>
<tr>
<td>California black oak</td>
<td><em>Q. kelloggii</em></td>
</tr>
<tr>
<td>Southern red oak</td>
<td><em>Q. falcata</em> (Q. rubra)</td>
</tr>
<tr>
<td>Northern red oak</td>
<td><em>Q. borealis</em> (Q. rubra)</td>
</tr>
<tr>
<td>Shumard oak</td>
<td><em>Q. shumardii</em></td>
</tr>
<tr>
<td>Pin oak</td>
<td><em>Q. velutina</em></td>
</tr>
<tr>
<td>Black oak</td>
<td><em>Q. laevis</em> (Q. catesbaei)</td>
</tr>
<tr>
<td>Turkey oak</td>
<td><em>Q. coccinea</em></td>
</tr>
<tr>
<td>Scarlet oak</td>
<td><em>Q. ellipsoidalis</em></td>
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<tr>
<td>Northern pin oak</td>
<td><em>Q. nuttallii</em></td>
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<tr>
<td>Nuttall oak</td>
<td><em>Q. marilandica</em></td>
</tr>
<tr>
<td>Blackjack oak</td>
<td><em>Q. nigra</em></td>
</tr>
<tr>
<td>Water oak</td>
<td><em>Q. phellos</em></td>
</tr>
<tr>
<td>Willow oak</td>
<td><em>Q. imbricaria</em></td>
</tr>
<tr>
<td>Shingle oak</td>
<td><em>Q. laurifolia</em></td>
</tr>
</tbody>
</table>

### LIVE OAKS

<table>
<thead>
<tr>
<th>Live Oak</th>
<th>Genus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live oak</td>
<td><em>Q. virginiana</em></td>
</tr>
<tr>
<td>Coast live oak</td>
<td><em>Q. agrifolia</em></td>
</tr>
<tr>
<td>Canyon live oak</td>
<td><em>Q. chrysolepis</em></td>
</tr>
<tr>
<td>Emory oak</td>
<td><em>Q. emoryi</em></td>
</tr>
</tbody>
</table>

Silvics: White oak (*Q. alba*) is the most important commercial species of oak in the United States. It grows best on northern lower slopes and in coves, but is found on wet bottom lands and on any upland aspect except extremely dry, shallow-soil ridges (1). Other species of oak encompass a wide variety of sites. Members of the white oak group can be distinguished from the red oaks through leaf characteristics. Red oaks have leaves with apex and bristle-tipped lobes while the white oaks have leaves with apex and the lobes not bristle-tipped. Red oak acorns require two years to mature whereas white oak acorns mature in one season. The oaks tend to be intermediate in tolerance.

Pathology: Resistance to decay: Red oak heartwood is not particularly durable under conditions favoring decay. White oak heartwood quite durable under conditions favoring decay. Of the white oaks, *Q. prinus* is the most resistant to decay, followed by *Q. garryana*, *Q. alba* then *Q. bicolor*.

Oak wilt, a vascular disease caused by the fungus, *Ceratocystis fagacearum*, is serious and widespread in 21 states. The leaves of infected trees wilt and fall. Some trees refooliate normally the next spring and again develop the symptoms while other trees die over winter. The red oaks are more susceptible than the white oak group. Anthracnose can be very damaging to the white oaks, whereas leaf blister (*Taphrina caerulescens*) is more severe on the red oaks (4). The oaks are subject to many canker diseases, with Nectria and Strumella cankers common in the North and canker rots common in the South (*Irpex mollis*, *Inonotus hispidus*, *Poria spiculosa*). Warty exsiccences, common on oaks, are caused by a species of *Phomopsis*. Hepting (4) felt that it was doubtful that any of the root-rot fungi attacking the oaks could be termed a primary pathogen.

The oaks are highly favored for attack by the gypsy moth (*Lymantria dispar*), together with gray birch and poplar. Silvicultural practices designed to promote the vigor of trees are helpful in increasing tree resistance to damage. Other defoliators include the forest tent caterpillar (*Malacosoma disstria*), brown tail moth (*Nygmia phaeorrhoea*), white-marked tussock moth (*Hemerocampa leucostigma*), spring cankerworm.
(Paleacrita vernata), fall cankerworm (Alsophila pometaria) and orange-striped oakworm (Anisota senatoria). The following borers work in various parts of the tree: two-lined chestnut borer (Agrilus bilineatus), Columbian timber beetle (Corythius columbianus), carpenter worm (Prionoxystus robiniae), broad-necked prionus (Prionus laticollis), and leopard moth (Zeuzera pyrina).

Gross Features of the Wood of White Oak The sapwood is whitish to light brown, and the heartwood is dark brown. The wood is hard, heavy to very heavy, without characteristic odor or taste. This ring-porous wood has a distinct, conspicuous growth ring and a high ray fleck. The springwood pores are large, distinctly visible with the naked eye; forming a conspicuous band 1 to 3 pores in width; tyloses are present and often occlude the pores in the heartwood. The transition from springwood to summerwood is abrupt or somewhat gradual; the summerwood pores are numerous, small; not distinct with a hand lens, scattered in radially aligned, flame-shaped tracts of light-colored tissue, thin walled. Parenchyma are visible with a hand lens, forming part of the conjunctive tissue between the springwood pores and the rays, composing most of the tissue in the flame-shaped areas, usually zonate in fine, more or less regular, tangential lines in the outer portion of the ring. The rays are of two types, broad and narrow. The broad compound rays are very conspicuous to the naked eye, separated by several to many narrow rays, appearing on the tangential surface as rather widely spaced, staggered lines of varying length which frequently extend an inch or more along the grain, forming a handsome, high fleck on the radial surface. The narrow simple rays are much more numerous than the broad rays, indistinct without magnification. Young (5) studied the effects of sewage effluent irrigation on anatomical characteristics of red oak. He found a 26% increase in summerwood and a 44% decrease in springwood in trees irrigated for 5 years.

The following table lists how the woods of the red oak group differ from the white oaks. Point #5 is the most dependable.

### White Oaks

1. Heartwood rich light brown to dark brown, without flesh-colored cast.

2. Annual rings usually compact, resulting in finer textured woods.

3. Transition from springwood to summerwood generally abrupt.

4. Springwood pores in the heartwood usually occluded with tyloses.

5. Summerwood pores barely distinct with a hand lens, thin walled, more or less angular.

6. Large rays average 0.5-1.25 in (1.3-3.2 cm) high and frequently more than 1.5 in (3.8 cm).

### Red Oaks

1. Heartwood pinkish or pale reddish brown.

2. Annual rings usually broader, resulting in stronger textured woods.

3. Transition from springwood to summerwood gradual to more or less abrupt.

4. Springwood pores in the heartwood usually open.

5. Summerwood pores plainly visible with a hand lens, thick walled, rounded.

6. Large rays average 0.25-0.5 in (0.6-1.3 cm) high and rarely more than 1.5 in (3.8 cm).

Microscopic Structure of the Wood

### White Oak Group

**Vessels.** Summerwood vessels 20-120 per sq. mm; largest springwood vessels 180-380 μm in diameter; perforation plates simple; intervessel pits orbicular to oval, 6-10 μm in diameter.

**Tracheids.** Vasicentric, intermingled with parenchyma, forming most of the conjunctive tissue between the springwood vessels and the rays and composing part of the flame-shaped areas in which the summerwood vessels are embedded.

**Fibers.** Average, 1.4 mm in length and 14-22 μm in diameter. Cell wall thickness 5.8 μm. Weight factor 0.45;
fiber coarseness 14.08 mg/100 m. Fibers frequently gelatinous. Branchwood fibers are significantly shorter than stemwood fibers (6). Taylor (7) found no significant differences in fiber length among geographic locations for post oak. Young (5) studied the effects of sewage effluent irrigation on anatomical characteristics of red oak. He found that fiber cell wall thickness was unaffected. Cano-Capri and Burkart (8) discuss the distribution of gelatinous fibers in southern red oak. Tyloses development in white oak is covered by Meyer (9).

Rays. Unstoried, homogeneous; broad rays 12-30+ seriate and 150-400+ μm wide in middle, many cells (into hundreds) in height; narrow rays, very numerous, uniseriate or occasionally in part biseriate, very variable in height (1-20+ cells).

**Longitudinal Parenchyma.** Abundant; paratracheal, metatracheal-diffuse, and usually metatracheal; the paratracheal intermingled with tracheids and distributed as described above, metatracheal-diffuse restricted to the fibrous areas and toward the outer portion of the ring, exhibiting more or less of a tendency toward aggregation into concentric lines of metatracheal.

Red Oak Group Similar to that previously described except for the density of summerwood vessels, which are only 10-30 per sq mm, and the size of the largest springwood vessels, which are 200-430 μm in diameter.
Gross Features of the Bark

White Oak Group  On the outer surface, white oak bark is ash-grey and characterized by long fissures formed by flatly overlapping ridges of rather thin scales. The outer bark is composed of many layers of rhytidome formed by the yellowish-brown periderm or cork, alternating with the isolated brown phloem tissues. Rhytidome of the white oaks is usually soft, rather loose, and on cross section, often wider than the creamy, light-colored inner bark, usually about 1 in (2.5 cm) wide. Broad rays and sclereid groups are visible. Phillips (70) found that the bark percent by weight averaged 23% of the total tree, including stem and branches. Bark percent was 21% for the stem and 32% for the branches.

Northern Red Oak  The outer bark of the mature northern red oak forms shallow and broad fissures with wide and flat-topped ridges and is firm, rather hard and dark brown. The inner bark (secondary phloem) is light yellowish-red and is as wide or wider than the total thickness of the rhytidome. Broad phloem rays and more or less curved sclerenchyma lines are visible to the naked eye. Trunks of young trees are smooth and grayish-brown.

Southern Red Oak  Bark of the southern red oak is dark brown to nearly black with thick rough ridges separated by deep, narrow fissures. The rhytidome is usually hard and firm and about the same width or narrower than the slightly yellow inner bark (secondary phloem). Broad phloem rays, often dilated early in the inner bark and spreading widely at the terminal regions, and more or less curved sclerenchyma lines are visible to the naked eye. Trunks of young trees are smooth and grayish-brown.

Microscopic Structure of the Bark

White Oak Group

Periderm. Periderm layers are conspicuously aligned in tangential bands, but broken regularly along the radius of the extending phloem rays. The last-formed periderm is composed of 1-2 layers of phelloderm, a layer of phellogen and 2-5 layers of phellem. Zones of the regular thin-walled phellem cells often alternate with 1-2 layers of thick-walled cells. Regularly aligned, peridermal cells are rectangular on cross and radial sections with radial diameters from 8-15 μm, tangential diameters from 20-35 μm, and heights, about 30 μm.

Sieve Tube Elements. Usually in groups of 4-10. Except in the last-formed bands next to the cambium, sieve tubes are crushed to varying degrees. Sieve tube elements vary from 220-590 μm in length. Often, short companion cells, about 50 μm high and in strands of up to 6 cells, are associated with them at their narrow dimension.

Parenchyma Cells. Frequently aligned in tangential bands of 3-5 layers and more or less rectangular in cross section, about 20-30 μm in tangential diameter and 50-100 μm in height. Forming strands about the same length as phloem fibers, crystalliferous parenchyma strands (probably containing calcium oxalate) are found at the margin of phloem fiber bands.

Phloem Fibers. In mostly 2-3 layers, phloem fibers are aligned in discontinuous tangential bands. The fibers are polygonal on cross section with diameters of 15-20 μm and a very narrow lumen. Cell walls are about 6 μm thick with the secondary walls sometimes separated into 2 layers. Tapering gradually to pointed ends, phloem fibers vary from 0.53-1.39 mm in length. Maturation often starting at the current season's growth, phloem fibers usually form pure bands with the crystalliferous parenchyma strands. At an old growth region, fiber bands may connect with a sclereid band.

Sclereids. Sclereids are transformed parenchyma and ray cells with irregularly expanded, thick walls. Sclereids form small groups that are initiated and often mature very near to the cambial region. The groups may be tangentially elongated and form short bands, or scattered within the broad phloem rays.

Rays. Phloem rays are of two types. The narrow, homocellular, usually uniseriate rays are usually about 22 cells or 150-200 μm high. The homocellular broad rays may be nearly 30 seriate. Cells within the broad rays often become lignified, beginning in the middle portion of the ray. Cells become very thick, usually retaining their original shape and size, but at times expanded and irregular in shape, and often contain crystals.
Rhytidome. The transformed secondary phloem tissues in the rhytidome outside of the last-formed periderm are mostly lignified and expanded cells mixed with sclereid groups. Sieve tubes are usually crushed and phloem fibers are not as abundant as in the inner bark.

Red Oak Group Red oak bark has the basic pattern of the subgenus Erythrobalanus Spach. (red oak group). Bark of young trees is basically similar in cell type and tissue arrangement to young white oak. In mature bark, the composition, cell size and shape of the periderm are also fundamentally alike. However, the periderm formation is less frequent and irregularly spaced, and, as the phloem rays seldom extend through the periderm, it is tangentially longer. As a result, the rhytidome is compact and comparatively narrower with fewer periderm layers. In red oaks, the well-developed, suberized phellem cells are often twice as thick as those of the white oak.

Physical Properties of Wood Information is available for many species of oak but, because of space limitations, only average values are given in many instances.

Specific gravity

| Commercial white oak | Green volume | 0.59 |
|                      | Air-dry volume | 0.67 |
|                      | Oven-dry volume | 0.70 |
| Commercial red oak  | Green volume | 0.57 |
|                      | Air-dry volume | 0.63 |
|                      | Oven-dry volume | 0.67 |
| Live oak             | Green volume | 0.81 |
|                      | Air-dry volume | 0.89 |
|                      | Oven-dry volume | 0.95 |

Density, lb/cu ft (kg/cu m)

| Commercial white oak | Green | 63 (1009) |
|                      | Air-dry | 47 (753) |
|                      | Oven-dry | 44 (705) |
| Commercial red oak  | Green | 64 (1025) |
|                      | Air-dry | 44 (705) |
|                      | Oven-dry | 42 (673) |
| Live oak             | Green | 76 (1217) |
|                      | Air-dry | 62 (993) |
|                      | Oven-dry | 59 (945) |

Density, lb/cu ft (kg/cu m) per green volume

| Commercial white oak | 37 (593) |
| Commercial red oak   | 36 (577) |
| Live oak             | 51 (817) |

Taylor (7) found no significant differences among geographic locations in specific gravity for post oak. He did find statistically significant differences between stemwood and branchwood specific gravity in red oak, with higher specific gravity in branches than in stems (6).

An additional publication on increment core specific gravity of several oaks is Maeglin (74).

Percent shrinkage, dried to 0% moisture content; Commercial white oak, r - 5.4, t - 9.3, v - 16.0; Commercial red oak, r - 4.3, t - 9.0, v - 14.8.

Percent moisture content, when green

| Commercial white oak | 41 | 70 |
| Commercial red oak   | 44 | 80 |
| Live oak             | 33 | 50 |

Percent moisture content oven-dry basis (75)

<table>
<thead>
<tr>
<th>Heartwood</th>
<th>Sapwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>White oak</td>
<td>64</td>
</tr>
<tr>
<td>Northern red oak</td>
<td>80</td>
</tr>
<tr>
<td>Southern red oak</td>
<td>83</td>
</tr>
</tbody>
</table>

Manwiller (76) found branchwood moisture content to be lower than that of the stemwood in 11 oaks studied.

An additional publication on moisture content is Phillips (10).

Physical Properties of Bark

| Commercial white oak | Inner bark | 0.67 |
|                      | Outer bark | 0.50 |
|                      | Total bark | 0.56 |
| Commercial red oak   | Inner bark | 0.62 |
|                      | Outer bark | 0.71 |
|                      | Total bark | 0.68 |
According to Koch (72), specific gravity of whole bark and outer bark of red oak increased significantly with height. Specific gravity of the inner bark increased progressively with height. Specific gravity of the outer bark was significantly greater than that of inner bark at all heights above the stump.

### Chemical Composition of Wood

#### Proximate Analyses

<table>
<thead>
<tr>
<th></th>
<th>Ritter and Fleck (18)</th>
<th>Bird and Ritter (19)</th>
<th>Chestnut Oak F.P.L. (20)</th>
<th>Red Oak Aung (21)</th>
<th>Southern Red Oak Wise and Ratliff (22)</th>
<th>Overcup Oak Wise and Ratliff (22)</th>
<th>Post Oak IPC. (23)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lignin, %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total, %</td>
<td>31.7</td>
<td>32.0</td>
<td>23.4</td>
<td>24.3</td>
<td>20.6</td>
<td>25.2</td>
<td>27.6</td>
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<tr>
<td>In holocellulose, %</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>C. &amp; B. cellulose, %</td>
<td>51.4</td>
<td>50.4</td>
<td>46.8</td>
<td>44.2</td>
<td>45.7</td>
<td>42.4</td>
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</tr>
<tr>
<td>Ash, %</td>
<td>0.47</td>
<td>0.42</td>
<td>0.44</td>
<td>0.16</td>
<td>0.41</td>
<td>0.94</td>
<td></td>
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<tr>
<td><strong>Pentosans</strong></td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Total, %</td>
<td>22.5</td>
<td>22.0</td>
<td>18.7</td>
<td>19.2</td>
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<td>In holocellulose, %</td>
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<tr>
<td>C. &amp; B. cellulose, %</td>
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<td>24.4</td>
<td>25.5</td>
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<tr>
<td>Acetic acid, %</td>
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<td>2.78</td>
<td>2.37</td>
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<tr>
<td>Methoxy, %</td>
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<td>5.91</td>
<td>6.44</td>
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<tr>
<td>Methoxy in lignin, %</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Solubility in</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.1</td>
</tr>
<tr>
<td>Ether, %</td>
<td>0.56</td>
<td>0.66</td>
<td>0.6</td>
<td>0.33</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1% NaOH, %</td>
<td>21.4</td>
<td>24.2</td>
<td>21.1</td>
<td>18.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot water, %</td>
<td>4.92</td>
<td>8.4</td>
<td>7.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold water, %</td>
<td>3.41</td>
<td>6.04</td>
<td>1.73</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetyl, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemicellulose, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemicellulose A, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemicellulose B, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xylan, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Uronic anhydride, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH₃, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a On extractive-free wood, after alcohol-benzene.
b Corrected for uronic anhydride.
c From MeO not in lignin.
### Extractives

#### I.P.C. Project 3212, Manwiller Rept. 9 (24)

<table>
<thead>
<tr>
<th>Extractives</th>
<th>Alcohol-benzene, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pin oak</td>
<td>4.4</td>
</tr>
<tr>
<td>Black oak</td>
<td>5.0</td>
</tr>
<tr>
<td>Post oak</td>
<td>4.3</td>
</tr>
<tr>
<td>Northern red oak</td>
<td>4.5</td>
</tr>
<tr>
<td>Southern red oak</td>
<td>4.8</td>
</tr>
<tr>
<td>Northern white oak</td>
<td>2.4</td>
</tr>
<tr>
<td>Southern white oak</td>
<td>4.6</td>
</tr>
<tr>
<td>White oak</td>
<td>—</td>
</tr>
<tr>
<td>Overcup oak</td>
<td>—</td>
</tr>
</tbody>
</table>

#### Solubility in Alcohol-benzene, %

<table>
<thead>
<tr>
<th>Species</th>
<th>% Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pin oak</td>
<td>4.4</td>
</tr>
<tr>
<td>Black oak</td>
<td>5.0</td>
</tr>
<tr>
<td>Post oak</td>
<td>4.3</td>
</tr>
<tr>
<td>Northern red oak</td>
<td>4.5</td>
</tr>
<tr>
<td>Southern red oak</td>
<td>4.8</td>
</tr>
<tr>
<td>Northern white oak</td>
<td>2.4</td>
</tr>
<tr>
<td>Southern white oak</td>
<td>4.6</td>
</tr>
<tr>
<td>White oak</td>
<td>—</td>
</tr>
<tr>
<td>Overcup oak</td>
<td>—</td>
</tr>
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</table>

#### Solubility in other solvents

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Species</th>
<th>% Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol</td>
<td>Pin oak</td>
<td>5.0</td>
</tr>
<tr>
<td>Benzene</td>
<td>Black oak</td>
<td>5.8</td>
</tr>
<tr>
<td>Ethanol</td>
<td>Post oak</td>
<td>6.1</td>
</tr>
<tr>
<td>Acetone</td>
<td>Northern red oak</td>
<td>6.0</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Southern red oak</td>
<td>6.0</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Northern white oak</td>
<td>5.0</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Southern white oak</td>
<td>—</td>
</tr>
<tr>
<td>Alcohol</td>
<td>White oak</td>
<td>—</td>
</tr>
</tbody>
</table>

#### Tannin content, %

<table>
<thead>
<tr>
<th>Tannin content</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black oak</td>
<td>slight</td>
</tr>
<tr>
<td>Blackjack oak</td>
<td>slight</td>
</tr>
<tr>
<td>Chestnut oak</td>
<td>3.3</td>
</tr>
<tr>
<td>Dwarf post oak</td>
<td>5.4</td>
</tr>
<tr>
<td>Laurel oak</td>
<td>none</td>
</tr>
<tr>
<td>Live oak</td>
<td>6.9</td>
</tr>
<tr>
<td>Northern red oak</td>
<td>2.5</td>
</tr>
<tr>
<td>Overcup oak</td>
<td>slight</td>
</tr>
<tr>
<td>Pin oak</td>
<td>none</td>
</tr>
<tr>
<td>Post oak</td>
<td>2.9</td>
</tr>
<tr>
<td>Scarlet oak</td>
<td>none</td>
</tr>
<tr>
<td>Shumard red oak</td>
<td>none</td>
</tr>
</tbody>
</table>

#### Chemical Composition of Bark

### Proximate Analyses

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>White Oak</th>
<th>Northern Red Oak</th>
<th>White Oak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, %</td>
<td>10.7</td>
<td>5.4</td>
<td>—</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>3.28</td>
<td>4.32</td>
<td>—</td>
</tr>
</tbody>
</table>

#### Solubility in other solvents

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Chemical Composition</th>
<th>White Oak</th>
<th>Northern Red Oak</th>
<th>White Oak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol</td>
<td>Ash, %</td>
<td>4.4</td>
<td>7.9</td>
<td>—</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Methoxyl, %</td>
<td>4.4</td>
<td>7.9</td>
<td>—</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Alcohol-benzene, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Ethanol, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Acetone, %</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Alcohol</td>
<td>1% NaOH, %</td>
<td>26.5</td>
<td>22.3</td>
<td>14.5</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Hot water, %</td>
<td>5.8</td>
<td>3.6</td>
<td>15.4</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Cold water, %</td>
<td>—</td>
<td>—</td>
<td>8.2</td>
</tr>
</tbody>
</table>

### Other Information

For information on phenolics of *Quercus rubra* see Seikel et al. (27). For chloroform and acetone-water extractives of *Quercus alba* see Chen (28); triglycerides, steroids, and a ferulic acid ester mixture were found in heartwood of white oak (28). For information on extractives see Rowe and Conner (29).

### Other Information

For an analysis of elements in red oak sapwood see Choong et al. (30).
Solubility in Alcohol-benzene, %

<table>
<thead>
<tr>
<th>Species</th>
<th>Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black oak</td>
<td>17.5</td>
</tr>
<tr>
<td>Post oak</td>
<td>12.9</td>
</tr>
<tr>
<td>Northern red oak</td>
<td>13.4</td>
</tr>
<tr>
<td>Southern red oak</td>
<td>14.7</td>
</tr>
<tr>
<td>White oak</td>
<td>12.9</td>
</tr>
</tbody>
</table>

The inner bark of red oak contains 11.1% ash, while the outer bark contains 8.9% (30).

Carbohydrates. For reducing sugars from extractive-free bark of red and white oak see Chang and Mitchell (37).

Extractives. For information on extractives see Rowe and Conner (29).

Other Information. For an analysis of elements in inner and outer bark of red oak see Choong et al. (30).

Pulping

Alkaline. This pulp from white, red, or scrub oak is generally of low quality; burst strength and breaking length are low (33). Continuous pulping can be used to produce a dissolving pulp from turkey oak (34).

Asplund. This pulp is used for hardboard.

Green Liquor. Pulp is made from 45% red oak, 45% white oak, and 10% other hardwoods; it is used for corrugating medium (35).

Groundwood. White oak is best bleached by a two-stage process with peroxide-hydrosulfite (36). Pulp made from 80% water oak and 20% willow oak contained 43% fines and had an opacity of 92.7% (37).

Holopulping. Optimum conditions for laboratory-scale process are alkaline pretreatment, lignin modification with sodium chlorite acidified with glacial acetic acid with a wetting agent present, and alkaline extraction; the yield was higher than with unbleached kraft pulp, and it was higher in burst strength and breaking length and lower in tear strength than kraft pulp (38).

Kraft. Red oak is pulped readily; the yield is low, the pulp is rather difficult to bleach, requiring 15-25% bleach. Southern red oak is pulped readily; the yield is normal and it is easily bleached. Small post oak is pulped readily; the yield is low, and it is fairly easily bleached.

White oak is pulped readily; the yield is low, and the pulp is very difficult to bleach, requiring 22-25% bleach. Overcup oak is difficult to pulp; the yield is low, and it is difficult to bleach. Some oaks are used in mixture with other native hardwoods as the short fiber component in book and magazine grades (39, 40, 41, 42). A sulfidity of 30-40% produces easily bleached pulp that requires 7-8% available chlorine to produce a GE brightness of 75 in a single stage (43). The pulp is easily bleached, requiring 3.86% total chlorine for GE brightness of 80 at a permanganate number of 12.4 (21). Linerboard is made from high-yield kraft pulps; for physical and chemical properties see Setterholm and Benson, (44). Polysulfide added to kraft liquor increases the yield from red oak (45). For physical properties of white oak kraft pulp see Horn (46). For pulp strengths of water oak before and after bleaching, see Perkins (47). Bark at a concentration of 16% by weight did not reduce the strength or brightness of pulps made from a mixture of northern red oak and white oak (37). For properties of kraft pulps bleached to GE brightness of 80, see Jett and Zobel (48).

NSSC: The pulp is used for corrugating medium.

Nitrocell. This process gives a relatively high yield of nitric acid pulp which is about as strong as sulfite pulp and not as strong as kraft (49).

Semichemical. The pulp is used for newsprint.

Semikraft. Corrugating medium has a flat crush value of 45 p.s.i.; the bleached pulp has low strength (50). Southern red oak pulps are suitable for corrugating medium (51). Pulps containing bark were too weak for use (52).

Soda. White oak wood is readily pulped; the yield is low, and it is very difficult to bleach (42); it requires 35-40% bleach. Quinone additives used for pulping red oak significantly increase the delignification rate and pulp yield and reduce rejects without significant losses in strength (53).

Cold Soda. Continuous pulping trials, mechanical properties, and physical properties of pulps made from 80% water oak and 20% willow oak are reported by Brown (37); the pulp strength is slightly above that of softwood groundwood; corrugating boards have Concora values somewhat below the commercial range of 70-80 lb. Boards made from 1 part red oak and 2 parts white oak had a Concora value of 51.3 lb. Both pulps had standard ring compression resistance; pulps can be
bleached with calcium hypochlorite to about 60-70% brightness with 6 and 10% available chlorine; opacity was 82-86%.

**Sulfite.** Red oak is pulped readily; the yield is normal, color is fair, the pulp is rather difficult to bleach. White oak is pulped with some difficulty; the yield is normal; the pulp is specky and difficult to bleach and requires 30-35% bleach, (42). Neutral sulfite pulps produced in high yield were stronger and lighter colored than the semikraft pulps made from southern red oak, and the pulp is suitable for corrugating medium (57).

**Utilization of Wood and Bark**

**Use Properties of Wood.** The oaks are relatively heavy woods. Large pores give them their coarse texture. White oaks usually have plugged pores, which make the wood impermeable. Oak is usually straight-grained, hard, quite strong, very stiff, tough, and bendable. Oak takes well to machining and gluing, and it holds fasteners exceptionally well; it tends to split when nailed. It takes a good finish. Oaks tend to shrink considerably, and they must be dried more slowly than many other hardwoods. Drying too quickly in a kiln can cause end and surface checking, honeycombing, and collapse, particularly in 2-inch or thicker lumber. Red oaks are easily penetrated with preservatives. There is a beautiful ray fleck on the quarter surface. White oaks are durable, while red oaks are not durable. Rapid-growing, second-growth oak is generally stronger, harder, and tougher than old-growth timber which is finer grained, softer, more easily worked, and takes a finer finish.

**Calorific Value of Wood**

**White oak**

30.6 x 10^6 BTU/air-dry cord

5791 BTU/lb air-dry

3215 k cal/kg air-dry

7780 BTU/oven-dry lb

4325 k cal/kg oven-dry

**Red Oak**

27.3 x 10^6 BTU/air-dry cord

5810 BTU/lb air-dry

3230 k cal/kg air-dry

7800 BTU/oven-dry lb

4335 k cal/kg oven-dry

**Calorific value of cellulose from extracted wood:**

7,320 BTU/lb

**Calorific value of hemicellulose from extracted wood:**

7,165 BTU/lb

**Calorific value of lignin from extracted wood:**

9,105 BTU/lb

**Calorific value of extractive-free wood:**

8,575 BTU/lb

**Calorific Value of Bark**

**White oak**

272,800 BTU/ft³

1945 k cal/m³

7260 BTU/oven-dry lb

4035 k cal/kg oven-dry

**Red oak**

353,615 BTU/ft³

2520 k cal/m³

7890 BTU/oven-dry lb

4385 k cal/kg oven-dry

**Chemical Uses of Wood.** Alcohol production from southern red oak is 36 gallons of 95% alcohol per ton by the Madison process.

**Destructive distillation:**

<table>
<thead>
<tr>
<th></th>
<th>Chestnut Oak</th>
<th>White Oak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol, %</td>
<td>1.22</td>
<td>1.34</td>
</tr>
<tr>
<td>Acetic acid, %</td>
<td>4.88</td>
<td>4.60</td>
</tr>
<tr>
<td>Tar, %</td>
<td>10.2</td>
<td>7.8</td>
</tr>
<tr>
<td>Charcoal, %</td>
<td>39.6</td>
<td>45.8</td>
</tr>
</tbody>
</table>

**Chemical Uses of Bark.** The bark is used for tannins and for internal and external pharmaceutical purposes (29).

**Other Uses of Wood.** Oak, principally white oak, is used for shipbuilding and boatbuilding. Oak is used for railroad ties. It is also used for hardwood dimension and flooring, for furniture, as veneer, particle boards, charcoal, pulp, chemical extractives, and plywood in millwork and furniture. White oak is used for tight barrels, kegs, and casks for the storage and curing of whiskey and wine. It is used for truck and trailer beds, mining timbers, containers, pallets, caskets, boxes, paneling, jigs, piling, cross arms, insulator pins, poles, fence posts, and fuel. Saw dust is fed to cattle and sheep.
Other Uses of Bark. Oak bark is used for phenol-bonded barkboard. Methods for improving wet- and dry-formed phenolic-bonded high-density hardboards are reported by Steinmetz (54).

Literature Cited


20. Forest Products Laboratory. Unpublished data.


AMERICAN BASSWOOD

Scientific Name *Tilia americana* L.

Synonyms: American linden, linden, linn, beetree, limetree, basswood

Family Name: Tiliaceae

Range: North central and northeastern states and adjacent Canada.

Silvics: The medium-sized tree has a long, clear, cylindrical, sometimes buttressed bole, and a deep but widespread root system. Best growth is in the Ohio valley where it occurs on deep, moist soils with yellow-poplar, sugar maple, white ash, beech, and black cherry. In the north, it grows on drier, more rocky sites in mixture with sugar maple, yellow birch, American elm, and beech. Basswood is a prolific sprouter. The species is rated as tolerant.

Tree Dimensions: 70-80 ft (21-24 m) tall and 2-3 ft (61-91 cm) in diameter. On good sites American basswood reaches 120-140 ft (37-43 m) in height and 4-4 1/2 ft (122-137 cm) in diameter.

Pathology: Resistance to decay: low

Basswood suffers little from disease. However, wood rot affects a large percentage of the larger trees and is caused by *Oxyporus populinus*, *Hydnum septentrionale*, *Pholiota adiposa*, *Hypox mollis*, and others. The most widespread leaf-spot disease is anthracnose (*Gnomonia tiliae*) but it seldom causes much damage. *Nectria galligena* can cause abundant cankerering on basswood (7). However, in a study in New York, cankered trees had grown faster than uncankered trees at the end of ten years (2).

Principal defoliators of basswood are the spring cankerworm (*Paleacrita vernata*), the fall cankerworm (*Alsophila pometaria*), the gypsy moth (*Lymantria dispar*), the variable oak leaf caterpillar (*Heterocampa mantuo*), the white-marked tussock moth (*Hemerocampa leucostigma*), and the walkingstick (*Diapherorhina femorata*). Basswood is a preferred host for the latter two species. The linden borer (*Saperda vestita*) occurs in the northeastern states and weakened trees are most susceptible to attack.

Gross Features of the Wood: The sapwood is whitish to creamy white or pale brown, merging more or less gradually into the darker heartwood which is pale brown, sometimes with a reddish tinge. It is soft, light, straight grained, fine, even textured, with a faint characteristic odor on a fresh-cut surface, and tasteless. Growth rings are fairly distinct, pores numerous, small, distinctly visible with a hand lens, quite evenly distributed, solitary and in radial or tangential groups of 2 or more. Parenchyma are not visible with a hand lens, zonate. The rays are variable in width, the broader not distinct in the cross section without a hand lens, forming high, scattered ray flecks on the quarter surface.

Microscopic Structure of the Wood

Vessels: 100-160 per sq. mm, the largest 60-160 μm in diameter, av. length 0.43 mm; perforation plates simple; spiral thickening present; intervessel pits orbicular to angular, 5-8 μm in diameter; volume occupied, approx. 56%.

Fibers: Average, 1.1 mm (0.4-1.9 mm) in length, 24-36 μm in diameter, thin walled; volume occupied, approx. 36%.

Rays: Unstoried, of two widths; broad rays 1-6-seriate, up to 1.2+ mm in height, essentially homogeneous; narrow rays uniseriate, for the most part, much lower than the broad rays (mostly less than 300 μm high), the cells nearly uniform in size but higher than those in the broad rays. Volume occupied, approx. 6%.

Longitudinal Parenchyma: Abundant, terminal and metatracheal, the lines are numerous and uniseriate; volume occupied, approx. 2%.

Publications in this area include Evert and Deshpande (3, 4).
SEM Micrograph Showing Intervessel Spiral Thickening of Basswood. Magnification — 1000X

Gross Features of the Bark. Green or grayish green on young trees, later breaking up into narrow ridges, somewhat scaly on the surface.

Microscopic Structure of the Bark (5)

Periderm. Superficial, continuous; phellem many layered, thin walled; cells regularly oriented; phelloderm variable, narrow to well developed.

Sieve Tube Elements. 400-500 μm long; end walls slightly oblique to oblique; side wall thick; starch grains abundant; sieve plates oblique to slightly oblique to almost transverse, simple or compound; when com-pound, composed of 5-10 large, equally spaced sieve areas; pores wide.

Parenchyma. Abundant, grouped, and banded; bands lying in between the fiber and sieve tube bands; cells as wide as or somewhat narrower than the sieve tubes.

Phloem Rays. Heterogeneous, not sclerified.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green volume</td>
<td></td>
<td>0.32</td>
</tr>
<tr>
<td>Air-dry volume</td>
<td></td>
<td>0.36</td>
</tr>
<tr>
<td>Oven-dry volume</td>
<td></td>
<td>0.38</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td>Green</td>
<td>41 (657)</td>
</tr>
<tr>
<td></td>
<td>Air-dry</td>
<td>26 (416)</td>
</tr>
<tr>
<td></td>
<td>Oven-dry</td>
<td>24 (384)</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td>Oven-dry weight per green volume</td>
<td>20 (320)</td>
</tr>
</tbody>
</table>

An additional publication related to specific gravity is Maeglin (6).

Percent shrinkage, dried to 0% moisture content: r - 6.6, t - 9.3, v - 15.8.

Percent moisture content, when green

Green basis | 51
Oven-dry basis | 105

Percent moisture content, oven-dry basis (7)

Heartwood | 81
Sapwood | 133

Physical Properties of Bark

Specific gravity oven-dry weight & volume (8) | 0.54

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th>Component</th>
<th>Clermont and Schwartz (9)</th>
<th>F.P.L. (10)</th>
<th>F.P.L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>17.21^a</td>
<td>20.0</td>
<td>-</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>78.6^b</td>
<td>76.7</td>
<td>-</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>-</td>
<td>-</td>
<td>61.2</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>44.98^c</td>
<td>48.2</td>
<td>-</td>
</tr>
</tbody>
</table>
Hemicelluloses; %
Ash, %
Pentosans, %
Acetyl, %
Methoxyl, %
Solubility in
  Alcohol-benzene, %
  Ether, %
  1% NaOH, %
  Hot water, %
  Cold water, %
  Uronic anhydride, %
In hemicelluloses
  Pentosans
  Uronic anhydride
  Hexosans (by difference)

Corrected for ash.
Corrected for extractives, ash, and lignin.
Corrected for lignin and ash.
Expressed as a percent of the moisture-free hemicelluloses.

McMillen et al. (77) give analysis using modified F.P.L. methods.

Extractives. Ether solubles are 0.9-13.2% of whole wood (72). See “Chemical Uses of Wood” following.

Pulping

Kraft. The wood is readily pulped, yield is normal, and the pulp is fairly easy to bleach (73).

Semichemical. The organic acids maleic acid, citric acid, and phthalic acid promote strength development in semichemical pulping (74).

Soda. The wood is readily pulped to a high yield; the pulp is fairly easy to bleach (73).

Sulfite. The pulp is very shivy and cannot be bleached satisfactorily (73).

Utilization of Wood and Bark

Use Properties of Wood. The wood is soft, light, straight-grained, and easily worked. The sapwood has a clean white appearance. It seasons without difficulty, has a smooth finish, takes and holds paints excellently, is not durable, and it has good gluing and nail-holding properties.

Calorific Value of Wood

17.0 x 10^6 BTU/air-dry cord

Chemical Uses of Wood. The wood is a source of useful pharmaceuticals; extractives include tannins, flavonoids, coumarins, triterpenes, and sterols. Fraxin is in twigs, and fatty acids are in the heartwood and sapwood (75).

Other Uses of Wood. It is used for lumber, veneer, and bolts, cooperage, and excelsior. Only a minor amount is used in mixture with other hardwood species for pulp and other fiber products. The light color of the wood, the freedom from warping, and good gluing qualities make it especially desirable for concealed furniture parts. The veneer is used in plywood, furniture, fixtures, baskets, crates, luggage, millwork, musical equipment, and sporting goods.

Other Uses of Bark. The inner bark is used for weaving chair seats and baskets.

Literature Cited


10. Forest Products Laboratory. Unpublished data.


WHITE ASH

Scientific Name: *Fraxinus americana* L.

Synonyms: American ash, Biltmore ash, Biltmore white ash

Family Name: Oleaceae

Range: Eastern half of the United States and adjacent Canada, from Nova Scotia west to eastern Minnesota and south to eastern Texas and northern Florida. Karchesky and Koch (7) estimated that ash spp. amounted to 0.9% of the hardwood volume on pine sites in 12 southern states.

Silvics: This large tree has an open, pyramidal crown of long, slender, lateral branches. Within its wide range, white ash grows under highly variable climatic factors. Local distribution is limited by requirements in regard to soil moisture and fertility. It reaches its best development on moderately well-drained soils and grows most commonly on fertile soils with a high nitrogen content and moderate to high calcium content with pH tolerance from 5.0-7.5. White ash is easily propagated by conventional methods of budding and grafting, and sprouts readily from freshly cut stumps of seedlings and saplings. Young ash trees have a strong apical dominance that causes them to grow vertically and comparatively branch free, and open-grown trees commonly remain single stemmed with only fine branches until they are 30-40 years old. Common associates include eastern white pine, northern red oak, white oak, sugar maple, red maple, yellow birch, American beech, black cherry, American basswood, eastern hemlock, and yellow-poplar. The species is rated as intermediate in tolerance, although it becomes less tolerant as it grows older.

Tree Dimensions: In mature forests, heights of 70-80 ft (21-24 m) are common and some trees in the Ohio River bottomlands attain heights of 120 ft (37 m) and 6 ft (183 cm) dbh.

Pathology: The leaf spot, *Mycosphaerella effigurata*, is common, as is *M. fraxincola*. Defoliation may occur on young trees. There are no noteworthy stem diseases of white ash. *Nectria galligena* cankers occur on branches but are rarely found on the main stem. Heart rot fungi causing cull in white ash include *Fomes fraxinophilus*, *Phellinus igniarius*, *Pleurotus ostreatus*, *Polyporus spraguei*, and *P. sulphureus* (2). Ash dieback, the cause of which is unknown, has affected large numbers of trees in the East and westward to Michigan.

The most serious insect pest of white ash is the oystershell scale (*Lepidosaphes ulmi*) with severe infestations capable of killing trees. A less troublesome scale is the San Jose scale (*Quadraspidiotus perniciosus*). Seasoned ash is a favored species for attack by powder-post beetles (*Lyctus spp.*), all of which feed on sapwood. Leaf feeders include the brown-headed ash sawfly (*Tomostethus multicinctus*) the forest tent caterpillar (*Malacosoma disstria*), the fall cankerworm (*Alsophila pometaria*), the elm spanworm (*Ennomos subsignarius*), and the cecropia moth (*Hyalophora cecropia*).

Gross Features of the Wood: White ash has a nearly white sapwood and a heartwood that is grayish brown, light brown or pale yellow, streaked with brown. The wood is straight grained, heavy and hard with distinct growth rings (ring porous), firm and lustrous, without characteristic odor or taste. Earlywood pores are large, distinctly visible to the naked eye while latewood pores are small and barely visible. Parenchyma are visible with a hand lens while rays are not distinct or barely visible to the naked eye.

Microscopic Structure of the Wood

Vessels: Average, 0.29 mm in length and 3.5 μm in diameter. Vessels very few in number; largest earlywood vessels large to very large; perforation plates simple; intervessel pits orbicular to short-oval or occasionally somewhat angular through crowding (3).

Parenchyma: Paratracheal-vasicentric, paratracheal-aliform to confluent in the outer latewood and marginal.

Rays: Unstoried, 1-3-seriate and homocellular.

Tracheids: Vasicentric tracheids present, confined to the immediate vicinity of the earlywood vessels.

Fibers: Average, 1.2 mm in length. Libriform fibers are thin-to-medium thick-walled, fine-to-medium. McElwee, et al. (4) obtained the following fiber lengths at b.h.: 1st ring - 0.79 mm, 3rd - 0.90 mm, 10th - 1.18 mm, and 25th ring - 1.14. Cell diameters at the 25th ring averaged 22.73 μm. Hiller (5) found no indications of any relationship between fibril angle and ring width or fiber length when trends of variation were compared, but a significant negative correlation was found between fiber length and fibril angle measured on the same fiber. Manwiller (6) obtained a mean fiber length for branch wood of 0.87.
Gross Features of the Bark  The bark of white ash is ashy gray although young stems may have an orange tinge. Later, the bark becomes finely furrowed into close, diamond-shaped areas separated by narrow, interlacing ridges. On very old trees the bark is slightly scaly along the ridges. Choong and Cassens (7) reported that bark thickness ranged from 0.38-0.54 in (.97-1.37 cm) and that bark thickness was not significantly correlated with cubic volume of the log.

Microscopic Structure of the Bark

Outer Bark. The outer bark or rhytidome consists of many regularly spaced layers of periderm and dead secondary phloem tissue. A periderm is composed of 2-3 layers of phelloderm, a layer of phellogen and several, usually 3-5, layers of thin-walled phellem cells. The walls of most cells in the outer bark are lignified.

Inner Bark. The inner bark or secondary phloem is composed of phloem rays, alternate bands of sieve tubes, phloem parenchyma and sclerenchyma (restricted to phloem fibers). The general arrangement is (a) sieve tubes, 1-2 cells in width, alternating with (b) phloem parenchyma, 1-2 cells in width, bordered by (c) discontinuous tangential layers or bands of thick-walled phloem fibers. The sieve tubes and phloem parenchyma retain, more or less, their original shape and size throughout most of the inner bark after they become functionless. The phloem fibers are more or less round in cross section, averaging approximately 1.12 mm in length and 20-25 μm in diameter. The last-formed tangential band of fibers is located approximately 0.25 mm from the cambium zone. These types of cells are bordered radially by homogeneous phloem rays which are generally 1-3-seriate. Harder, et al. (8) found a fibrous yield of 16% when white ash bark was pulped to a solids yield of 35.7%.

Physical Properties of Wood

Specific gravity Green volume 0.57

McElwee, et al. (4) obtained a density (lb/ft³) at b.h. of 33.7.

Mitchell (9) found that a trend toward increased specific gravity with increased growth rate was discernable.

Manwiller (10) obtained a stem wood specific gravity of 0.58 and a branch wood specific gravity of 0.56 for 6-inch trees growing on pine sites.

Physical Properties of Bark

Specific gravity Inner bark 0.52
Green volume Outer bark 0.43
Total bark 0.50

Density (100% moisture content) Green weight/ green volume 0.95

Specific gravity oven-dry weight & volume (15) 0.52

Manwiller (10) obtained a stem bark specific gravity of 0.41 and a branch bark specific gravity of 0.45 for 6-inch (15 cm) trees growing on pine sites.

Murphey, et al. (16) obtained a bark specific gravity of 0.48 on an oven-dry basis and 0.33 on a swollen basis.

Manwiller (14) obtained a stem bark moisture content of 47.5% and a branch bark moisture content of 46.1% (dry weight basis) for 6-inch trees growing on southern pine sites.

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th>Karchesy and Koch (7)</th>
<th>Georgia</th>
<th>Tennessee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>23.3</td>
<td>24.8</td>
</tr>
<tr>
<td>Cellulose, %</td>
<td>48.7</td>
<td>39.5</td>
</tr>
<tr>
<td>Hemicellulose, %</td>
<td>23.5</td>
<td>29.1</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Extractives, %</td>
<td>5.4</td>
<td>6.3</td>
</tr>
</tbody>
</table>

The wood contains 6.0% (17) and 4.0% (18) alcohol-benzene extractives.
Extractives. Ether solubles are 0.9-1.2% of the sapwood and 0.4-0.5% of the heartwood (19). For flavonoids see Fitzgerald and Reines, (20). For information on extractives see Rowe and Conner, (21).

Chemical Composition of Bark

Proximate Analyses. The bark contains 4.4% ash and 12.6% (18) and 17.0% (17) alcohol-benzene extractives.

Extractives

Murphey et al. (22)

Solubility in

Acetone, %
12.2
Ethanot, %
10.7
Ethanol-benzene, %
13.2
1% NaOH, %
15.0
Hot water, %
12.9
Cold water, %
11.2

For information on bark extractives see Rowe and Conner (21).

Pulping

Groundwood. The pulp is low in strength and of fairly good color. It is used in limited amounts in book and magazine papers (23).

Soda. The wood is readily pulped; the pulp is rather difficult to bleach.

Sulfite. The wood is fairly readily pulped; the pulp is of poor color and is specky and rather difficult to bleach.

Utilization of Wood and Bark

Use Properties of Wood. The wood is generally straight-grained and shrinks moderately; it holds its shape well and can be kiln-dried rapidly and satisfactorily. It is heavy, hard, strong, stiff, high in shock resistance, and wears smooth with use. The wood can be machined well, it is better than average in nail- and screw-holding strength, and it is intermediate for gluability.

Calorific Value of Wood

25 x 10^6 BTU/air-dry cord

8035 BTU/oven-dry lb
4465 k cal/kg oven-dry

Calorific Value of Bark

7695 BTU/oven-dry lb
4275 k cal/kg oven-dry
263,730 BTU/ft^3
1880 k cal/m^3

Chemical Uses of Bark. It has been used in folk medicine (27).

Other Uses of Wood. It is used for handles, especially for farm implements. It is also used for furniture, hardwood dimension and flooring, millwork, sporting and athletic goods, and wirebound boxes and crates.

Literature Cited


17. Manwiller, F. G. Personal communication. (letter of April 8, 1975 to D. Einspahr)


**BLACK ASH**

Scientific Name  *Fraxinus nigra* Marsh.

Synonyms Swamp ash, basket ash, brown ash, hoop ash, water ash

Family Name  Oleaceae

Range Northeastern and North Central Regions and adjacent Canada.

Silvics  This small to medium-sized tree has a rather poorly shaped bole, a small, open crown, and a very shallow, fibrous root system. It occurs along stream banks or swamp borders in association with white-cedar, balsam fir, red maple, yellow birch, and black tupelo. It reaches best development in northern Michigan and northern Wisconsin on peat soils. It typically occurs in bogs, along streams or in other poorly drained areas where there is a high water table. Black ash is rated as intermediate in tolerance.

Tree Dimensions  40-50 ft (12-15 m) tall and 18 in (46 cm) in diameter.

Pathology  Resistance to decay: low+

Black ash is subject to many of the same diseases as white and green ash, including the leaf spot, *Mycosphaerella effigurata* and the canker, *Nectria galligena*. The spongy white heartwood rot, *Inonotus hispidus*, is usually found in the upper tree trunk, where it gains entrance through wounds and can occasionally be serious (7).

The main insect pest of black ash is the oystershell scale (*Lepidosaphes ulmi*). Damage has been severe, with entire stands killed. Leaf feeders include the cecropia moth (*Hyalophora cecropia*), the forest tent caterpillar (*Malacosoma disstria*), the fall cankerworm (*Alsophila pometaria*), and the elm spanworm (*Ennomos subsignarius*).

Gross Features of the Wood  The very narrow sapwood of black ash is whitish to light brown, and the heartwood is dull grayish brown to brown (darker than in white ash). The wood is medium hard, moderately strong, medium heavy, straight grained, without characteristic odor or taste. The wood is ring porous with distinct growth rings which are frequently narrow. The springwood pores are large, distinct to the naked eye, and form a band 2-4 pores in width; the summerwood pores are small, barely visible to the naked eye, solitary and in radial groups of 2 or 3, rarely joined laterally by parenchyma in the late summerwood. The transition from springwood to summerwood is abrupt. The longitudinal parenchyma are visible with a hand lens, forming a narrow sheath around the pores in the summerwood, and rarely uniting them laterally. The rays are indistinct or barely visible to the naked eye on x-section.

Microscopic Structure of the Wood

Vessels.  In the summerwood 8-30 per sq mm; largest springwood vessels 160-260 μm in diameter; average length 0.27 mm; perforation plates simple; intervessel pits orbicular to short-oval or occasionally somewhat angular through crowding, 3-6 μm in diameter. Volume occupied, approx. 12%.

Tracheids.  Vasicentric, confined to the vicinity of the springwood vessels.

Fibers.  Thin to fairly thick walled, 12-22 μm in diameter and 1.3 mm long. Volume occupied, approx. 69%.

Rays.  Unstoried, 1-3-seriate, homogeneous. Volume occupied, approx. 12%.

Longitudinal Parenchyma.  Paratracheal, rarely paratracheal-confluent in the late summerwood, and terminal; sheath of paratracheal parenchyma around the summerwood vessels uniseriate for the most part; terminal parenchyma fairly abundant, grading into the tissue of the succeeding growth ring, not forming a distinct line. Volume occupied, approx. 7%.
**Gross Features of the Bark** Thin, gray to gray black, relatively smooth, later shallowly fissured into interlacing, scaly ridges.

**Physical Properties of Wood**

<table>
<thead>
<tr>
<th></th>
<th>Green volume</th>
<th>Air-dry volume</th>
<th>Oven-dry volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.45</td>
<td>0.49</td>
<td>0.53</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m) Green</td>
<td>52 (833)</td>
<td>34 (545)</td>
<td>33 (529)</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m) Oven-dry weight per green volume</td>
<td>28 (448)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A corrected publication related to specific gravity is Maeglin (2).

Percent shrinkage, dried to 0% moisture content: r - 5.0, t - 7.8, v - 15.2.

Percent moisture content, when green

<table>
<thead>
<tr>
<th></th>
<th>Green basis</th>
<th>Oven-dry basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>46</td>
<td>85</td>
</tr>
</tbody>
</table>

Percent moisture content oven-dry basis (g)

<table>
<thead>
<tr>
<th></th>
<th>Heartwood</th>
<th>Sapwood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95</td>
<td>-</td>
</tr>
</tbody>
</table>

**Physical Properties of Bark**

Specific gravity

<table>
<thead>
<tr>
<th></th>
<th>0.55</th>
</tr>
</thead>
</table>

**Chemical Composition of Wood**

**Proximate Analyses**

<table>
<thead>
<tr>
<th></th>
<th>Clermont and Schwartz (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>18.60^a</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>77.5^b</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>47.36^c</td>
</tr>
</tbody>
</table>

Hemicelluloses, % 21.18^a

Ash, % 0.66

Pentosans, % 16.66

Acetyl, % 5.34

Methoxy, % 5.96

Solubility in

- Ether, % 0.70
- 1% NaOH, % 20.78
- Hot water, % 3.63
- Cold water, % 3.11

Uronic anhydride, % 5.23

In hemicelluloses

- Pentosans, % 64.0^d
- Uronic anhydride 19.1^d
- Hexosans (by difference) 16.9^d

^aCorrected for ash.
^bCorrected for extractives, ash, and lignin.
^cCorrected for ash and lignin.
^dAs % of moisture-free hemicelluloses.

**Extractives.** For information on extractives see Rowe and Conner (6).

**Chemical Composition of Bark**

**Extractives.** See Rowe and Conner (6).

**Utilization of Wood and Bark**

**Use Properties of Wood.** The wood is not as strong as white ash but is moderately strong, hard, and stiff. It splits easier, shrinks more, is average in workability, and performs somewhat less favorably in service, especially when exposed to extreme cycles of moisture from wet to dry. The heartwood is dark; it has a fine grain, pleasing figure, seasons well, holds its shape well, has excellent bending qualities, and is medium in hardness.

**Calorific Value of Wood**

22.6 x 10^6 BTU/air-dry cord

Chemical Uses of Wood. Destructive distillation: pyrogallous acid, 34.6%; tar, 10.2%; charcoal, 39.3%.

Other Uses of Wood. Lumber, planing mill products, interior trim, cabinet work, veneer.
Literature Cited

**GREEN ASH**

**Scientific Name** *Fraxinus pennsylvanica* Marsh.

**Synonyms** Red ash, Darlington ash, white ash, swamp ash, water ash

**Family Name** Ulmaceae

**Range** The most widely distributed ash in North America. Its range extends from Nova Scotia to southeastern Alberta and Montña south to central Texas and northern Florida. Karchesky and Koch (7) estimate that ash spp. occupy 0.9% of the hardwood volume on pine sites in 12 southern states. There are roughly 6 billion board ft (.02 billion m³) of ash saw timber in the South (2).

**Silvics** This medium-sized tree has stout, upright branches, forming a compact, irregular crown. Although natural stands are confined to bottomlands, it grows well when planted on moist, upland sites. Green ash has thrived when planted on medium to coarse-textured upland sands and loams with good moisture relations and with neutral to alkaline reactions (3). Green ash is easily propagated by cuttings or grafting and it sprouts readily from the stumps of young trees. Young ash trees have strong apical dominance and a single straight stem until they are 15 ft (4.6 m) or more in height. Common associates include boxelder, red maple, pecan, sugarberry, sweetgum, American sycamore, eastern cottonwood, plains cottonwood, quaking aspen, black willow, and willow oak. The species is rated as intermediate in tolerance.

**Tree Dimensions** 50-60 ft (15-18 m) tall and 1 1/2-2 ft (46-61 cm) in diameter.

**Pathology** Pathology of green ash is similar to that of white ash. The heart rot fungus, *Fomes fraxinophilus* is of greater importance in green ash because both green ash and the fungus are prevalent in the Central and Lake States (4). Green ash is the only species of *Fraxinus* reported to be susceptible to Verticillium wilt (*V. albo-atrum*). Ash dieback has taken its toll of green ash although numbers of trees affected has not been as great as in white ash.

As with white ash, the most serious insect pest of green ash is the oystershell scale (*Lepidosaphes ulmi*), which can cause mortality among small trees and seedlings. Green ash also suffers from the same defoliators as white ash, including the brown-headed ash sawfly (*Tomostethus multicinctus*), the forest tent caterpillar (*Malacosoma disstria*), the fall cankerworm (*Alsophila pometaria*), the elm spanworm (*Ennomos subsignarius*), and the cecropia moth (*Hyalophora cecropia*).

**Gross Features of the Wood** The heartwood varies from brown to grayish brown while the sapwood is light-colored or nearly white. Growth rings are distinct and the wood has no characteristic odor or taste. Summerwood pores are barely visible to the naked eye. The wood is heavy, hard, strong, brittle, and coarse-grained. Second-growth trees contain a large proportion of sapwood while old-growth trees, which are scarce, characteristically have little sapwood.

**Microscopic Structure of the Wood** Similar to white ash.

Average fiber length of 1.27 mm. Manwiller (5) obtained a stem wood fiber length of 1.16 mm and a branch wood fiber length of 0.84 mm for 6-in (15 cm) diameter trees growing on southern pine sites. Saucier and Hamilton (6) found that the greatest variability in fiber length, cell wall thickness, and cell diameter was associated with horizontal position from the pith. Variation with height or radial location within trees was of much less importance. The greatest changes in cell dimension occurred in a core of wood surrounding the pith which contained approximately 5 annual rings and extended the length of the tree.

**Gross Features of the Bark** Usually gray and, on mature, trees it is finely furrowed into diamond-shaped areas, separated by narrow, interlacing ridges. On young stems, it may have an orange tinge.

**Microscopic Structure of the Bark**

**Inner Bark.** The inner bark of an examined specimen was quite thick, about 5 mm, and was composed of neatly arranged tissue containing sieve tube elements, companion cells, and longitudinal parenchyma. It was crossed in the radial direction by rays 1-3 cells wide and tangentially by interrupted lines of lignified fibers. Among the fibers were found only a few sclereids. Harder, et al. (7) found a fibrous yield of 13% when green ash bark was pulped to a solids yield of 38.0%.

**Outer Bark.** The outer bark or rhytidome was very similar in morphology to the inner bark except for the presence of numerous, thin-walled periderms. The latter
were almost concentric, were not very obvious (3-6 cells wide), but did appear to be lignified along with all other cells in the rhytidome.

Physical Properties of Wood

Specific gravity  Green volume  0.56

Manwiller (8) obtained a stem wood specific gravity of 0.56 and a branch wood specific gravity of 0.56 for 6-in (15 cm) trees growing on pine sites.

An additional publication related to specific gravity is Maeblin (9).

Percent moisture content, oven-dry basis (70)

Heartwood  Sapwood  58

Manwiller (77) obtained a stem wood moisture content of 47.4% and a branch wood moisture content of 46.9% (dry weight basis) for 6-in (15 cm) trees growing on southern pine sites.

Chemical Composition of Bark

Proximate Analyses. The ash content is 6.5% (14); Alcohol-benzene extractives comprise 12.6% (14), and 17.5% (73).

Extractives. For information on extractives see Rowe and Conner (16).

Physical Properties of Bark

Specific gravity  Inner bark  0.51  Green volume

Density (100% Moisture content)  Outer bark  0.43  Green weight/ green volume  0.91

Specific gravity oven-dry weight & volume (12)  0.94 (F. pensylvanica lanceolata)

Manwiller (8) obtained a stem bark specific gravity of 0.41 and a branch bark specific gravity of 0.45 for 6-in (15 cm) trees growing on southern pine sites.

Manwiller (77) obtained a stem bark moisture content of 77.2% and a branch bark moisture content of 86.0% (dry weight basis) for 6-in (15 cm) trees growing on southern pine sites.

Chemical Composition of Wood

Proximate Analyses. Alcohol-benzene extractives are 6.2% (13); and 4.0% (14).

Extractives. For information on flavonoids see Fitzgerald and Reines (15). For information on extractives see Rowe and Conner (16).

Chemical Composition of Wood

Proximate Analyses. Alcohol-benzene extractives comprise 12.6% (14), and 17.5% (73).

Extractives. For information on extractives see Rowe and Conner (16).

Other Information. The calcium content is 1.8%, and silica content is 0.12% (as a percent of oven-dry weight of the bark) (14).

Pulping

Alkaline. This pulp is of acceptable quality; it has a lower breaking length than gum and higher burst strength and tear strength (17).

Kraft. For properties of kraft pulps bleached to GE brightness of 80 see Jett and Zobel (18).

Utilization of Wood and Bark

Use Properties of Wood. The wood is not as strong as white ash but is moderately strong, hard, and stiff. It splits easier, shrinks more, is average in workability, and performs somewhat less favorably in service, especially when exposed to extreme cycles of moisture from wet to dry.

Calorific Value of Wood

7695 BTU/oven-dry lb
4275 k cal/kg oven-dry

Calorific Value of Bark

7470 BTU/oven-dry lb
4150 k cal/kg oven-dry

235,110 BTU/ft³
1675 k cal/m³
Literature Cited


SUGAR MAPLE

Scientific Name  Acer saccharum Marsh.

Synonyms  Hard maple, rock maple

Family Name  Aceraceae

Range  Eastern half of the United States, excluding the South Atlantic and Gulf Coastal plains and into southeastern Canada. The Lakes States, Ohio, Pennsylvania, New York, New England, the southern Appalachians and Canada contain most of the important stands.

hickories, ash, and yellow-poplar. The species is rated as tolerant.

Tree Dimensions  60-80 ft (18-24 m) tall and 2 ft (61 cm) in diameter.

Pathology  Resistance to decay: low+

Sugar maple is subject to a number of foliage diseases, including anthracnose, tar spots, septoria spot, gray-mold spot and powdery mildews. Nectria canker

Silvics  Under forest conditions, this medium-sized tree develops a clear, straight, full bole with a small, shallow, rounded crown and a shallow, wide-spreading root system. Best growth occurs on moist, fertile, welldrained soils but the species will persist on more sterile sites. Yield and quality of stands increase as soil fertility and moisture conditions improve. Height growth ceases or becomes negligible after 150 years, although sugar maple can reach 300-400 years of age. In the northern hardwood forest, yellow birch, beech, hemlock, white pine, red spruce, white ash, and basswood are common associates; farther south, sugar maple is found mixed with the central hardwoods such as basswood, oaks, (Nectria galligena) is common on sugar maple in the North, appearing to enter mainly through cracks in the top of a branch axil. Sunscald is common in the Northeast and Canada, particularly when an understory of maple is exposed following logging. A common killing disease is Verticillium wilt (V. albo-atrum), although this disease is less damaging to sugar maple than to Norway maple. Sugar maple is also subject to a number of trunk rots and stains.

Sugar maple is not highly susceptible to insect injury and serious outbreaks seldom occur (7). Defoliators are usually the most common insects attacking sugar maple,
including the forest tent caterpillar (*Malacosoma disstria*), the fall cankerworm (*Alsophila pometaria*), the saddled prominent (*Heterocampa guttivitta*), and the leaf roller moth (*Sparganothis acervorana*). Borers include the sugar maple borer (*Glycobius speciosus*), which is probably the most serious insect pest of sugar maple, the maple callus borer (*Sylvora acerna*), and the carpenterworm (*Prionoxystus robiniae*). The maple phenacoccus (*Phenacoccus acericola*) is the most important scale insect.

**Gross Features of the Wood**

The sapwood, which is reddish-brown, is clearly visible in mature trees, with occasional samples showing a slight reddish tinge; the heartwood is light reddish brown, the color becoming darker as the tree ages. The wood is hard, heavy, uniformly textured, with no distinct wavy grain. The wood is diffuse-porous with small pores, densely fibrous tissue, which gives a faint growth ring figure. Occasional samples show bird's-eye, curly, or wavy grain. The wood is diffuse-porous with small pores, indistinct without a hand lens, quite uniform in size, evenly distributed throughout the growth ring, solitary or in short radial groups of 2 or more. Parenchyma are not visible. The rays are of two widths; the broad rays are visible with the naked eye, fully as wide as the largest pores, forming a pronounced close ray fleck on the quarter surface, appearing on the tangential surface as short, crowded lines which are visible to the naked eye; the narrow rays are scarcely visible with a hand lens.

**Microscopic Structure of the Wood**

**Vessels.** 40-80 per sq mm; the largest 70-90 μm in diameter; perforation plates simple; spiral thickening present; intervessel pits orbicular to hexagonal, 6-10 μm in diameter; volume occupied, approx. 21%.

**Fibers.** Average, 0.8 mm (0.3-1.3 mm) in length and 16-30 μm in diameter. Thin to moderately thick walled. Coarseness range of 7.86 mg/100 m to 12.5 mg/100 m (2, 3). Volume occupied, approx. 61%.

**Rays.** Unstoried, essentially homogeneous; the broader rays 3-8 (mostly 5-7)-seriate, up to 800+ μm in height; the narrow rays 1-3 (mostly 1)-seriate, usually less than 200 μm in height; volume occupied, approx. 18%.

**Longitudinal Parenchyma.** Sparse, terminal paratracheal and metatracheal-diffuse.

**Gross Features of the Bark**

The bark on young trees is relatively smooth, firm and gray colored and becomes rougher and darker as the tree ages. The older, dark grayish-brown bark, generally hard and firm, develops deep furrows and tends to form long, shaggy strips. Comparatively narrow, the total thickness of the bark of a young tree of approximately 6-10 in (15-25 cm) diameter, is about 0.2-0.3 in (0.5-0.8 cm), half of which is inner bark, while an old tree has a bark thickness of up to 1 in (2.5 cm) (4). Besley (5) estimated bark to make up 13% of the rough tree weight in sugar maple. Smith (6) found that bark thickness was related to tree diameter by measuring 209 trees on medium sites. The regression was highly significant. An additional publication on bark volume is Millikin (7).

**Microscopic Structure of the Bark**

**Young Bark.** At the outer surface, the bark of young sugar maple is composed of a layer of epithelial cells, a periderm zone consisting of 4-5 layers of thin-walled phellem (cork), a phellogen layer, and a few layers of phelloidem. The cortex cells next to the periderm are small, collenchymalike and regularly aligned. Closer to the primary phloem, these cells increase in size, become more parenchymatous and loose in arrangement and often intermingle with the phloem tissues. Aligned in a circle around the axis, the primary phloem fibers appear in isolated groups. Between these groups, sclereids form until a complete cylinder of sclerenchyma tissue is formed as the tree grows older. Except for the lack of sclerenchyma cells in very young bark, the inner bark (secondary phloem) has the same tissue arrangement of broad phloem rays, sieve tube elements and tangential layers of parenchyma as that of the mature bark.

**Mature Bark.**

**Periderm.** Broad and continuously developing, the periderm of the mature bark is composed of alternate layers of thin-walled, suberized phellem and thick-walled peridermal (transformed phelloderm) cells, a layer of phellogen and 2-4 layers of phelloidem. As the first band of periderm retains its position outside the cortical region until middle age, the shaggy appearance of the outer bark or rhytidome appears quite late.

**Cortical Region.** Persisting until middle age, the cortical region represents a proportionally narrow zone of the entire bark. This region usually consists of somewhat "lignified" cortex cells with abundant cell contents, cortical sclerenchyma, remains of primary phloem fibers and some mingling of secondary phloem tissues.

**Phloem Rays.** Homogeneous and principally 3-6-seriate, phloem rays are variable in width, dilating toward the outer part of the inner bark and averaging more than 0.5 mm in height. Small rays prominent in the xylem are
only evident in the cambium zone or in the inner bark (secondary phloem) immediately adjacent to the cambium. Rays are rather uniform in shape and size and ray cells generally retain their original shape and nature, although some may become sclerified and merge into sclereid groups.

Sieve Tubes. Bounded by the phloem rays and usually banded above and below by parenchyma cells, sieve tubes, in 2-3 tangential layers, retain their regular shape and size only in a zone close to the cambial area. Quite uniform in shape, sieve tube elements average 35-40 µm in tangential diameter but vary greatly in length from 120-560 µm with ends varying from nearly horizontal to oblique. Beyond this zone, the thin-walled sieve tubes developed in previous years tend to collapse or become crushed.

Parenchyma. Aligned in tangential rows 2-4 layers wide throughout the inner bark. These cells average about 20-25 µm in tangential diameter and 200 µm in length. They may retain their original size and shape, expand, differentiate into fibers or be transformed into sclerotic cells.

Sclerechyma. Generally separated by 3-4 rows of parenchyma cells and crushed sieve tubes, tangential bands of sclerechyma are characteristic of the inner bark of sugar maple. These thick-walled sclerechyma bands are composed principally of sclerified ray and parenchyma cells and parenchyma that have elongated and developed lignified cell walls. Discontinuous tangential bands of fiber sclerechyma cells appear at the middle portion of the inner bark (secondary phloem). These thick-walled fibers, polygonal in shape, have an average diameter of 14 µm and a length of approximately 0.7 mm. Harder, et al. (8) found a fibrous yield of 3% when sugar maple bark was pulped to a solids yield of 33.9%.

Lamb and Marden (9) found a drop in basic density of about 5% for sapwood and about 7% for heartwood from heights of 1-17 ft (0.3-5.0 m), with little difference over the next 16 ft (5 m) up the stem for 90 trees with an av. dbh of 18 in (46 cm) and 190 years in age.

Shetron (10) measured specific gravity in 89 trees with a dbh > 10 in (25 cm) from old-growth stands on 11 soil types. There were significant differences in wood specific gravity between some of the soils. Within trees, specific gravity generally declined with increasing height, but increased at the base of the crown and decreased in younger portions of the crown.

Sajdak (11) found that growth rate and specific gravity were not related to a significant degree.

An additional publication related to specific gravity is Maeglin (12).

Percent shrinkage, dried to 0% moisture content: 1 - 4.9, t - 9.5, v - 14.9.

Percent moisture content, when green

<table>
<thead>
<tr>
<th></th>
<th>Green basis</th>
<th>Oven-dry basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heartwood</td>
<td>37</td>
<td>58</td>
</tr>
<tr>
<td>Sapwood</td>
<td>65</td>
<td>72</td>
</tr>
</tbody>
</table>

Physical Properties of Bark

<table>
<thead>
<tr>
<th></th>
<th>Inner bark</th>
<th>Outer bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.69</td>
<td>0.49</td>
</tr>
<tr>
<td>Green volume</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (100% moisture content)</td>
<td>Green weight/ green volume</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1.08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven-dry weight &amp; volume (14)</td>
<td>0.69</td>
</tr>
</tbody>
</table>

An additional publication related to bark specific gravity is Lamb and Marden (75).
### Chemical Composition of Wood

**Proximate Analyses**

<table>
<thead>
<tr>
<th></th>
<th>F.P.L.</th>
<th>F.P.L.</th>
<th>F.P.L.</th>
<th>Clermont and Schwartz (77)</th>
<th>Freeman and Peterson (76)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lignin, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20.3</td>
<td>21.3</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>72.3</td>
<td>76.0</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.12</td>
<td>4.05</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.83</td>
<td>0.97</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>60.8</td>
<td>56.8</td>
<td>60.4</td>
<td>60.3</td>
<td>21.10^a</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>21.0^a</td>
</tr>
<tr>
<td>Hemicelluloses, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>21.10^a</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.44</td>
<td>-</td>
<td>0.32</td>
<td>0.84</td>
<td>21.10^a</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.31</td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.31</td>
</tr>
<tr>
<td>Ether, %</td>
<td>0.25</td>
<td>2.3</td>
<td>0.1</td>
<td>0.89</td>
<td>0.24</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>17.6</td>
<td>19.7</td>
<td>-</td>
<td>2.08</td>
<td>2.98</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>4.36</td>
<td>3.4</td>
<td>2.08</td>
<td>1.20</td>
<td>2.98</td>
</tr>
<tr>
<td>Cold water, %</td>
<td>2.65</td>
<td>-</td>
<td>0.81</td>
<td>0.52</td>
<td>1.37</td>
</tr>
<tr>
<td>Water, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.78</td>
</tr>
<tr>
<td>Uronic anhydride, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.57</td>
</tr>
<tr>
<td>In hemicelluloses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>63.5^d</td>
</tr>
<tr>
<td>Uronic anhydride, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>63.5^d</td>
</tr>
<tr>
<td>Hexosans (by difference)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>63.5^d</td>
</tr>
</tbody>
</table>

---

^aCorrected for ash.
^bCorrected for extractives, ash, and lignin.
^cCorrected for ash and lignin.
^dAs % of moisture-free hemicelluloses.

Richter (79) gives analyses of sapwood and heartwood on trees felled at different times.

### Extractives

<table>
<thead>
<tr>
<th></th>
<th>Murphey &lt;i&gt;et al.&lt;/i&gt; (20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone, %</td>
<td>5.7</td>
</tr>
<tr>
<td>Ethanol, %</td>
<td>7.1</td>
</tr>
<tr>
<td>Ethanol-benzene, %</td>
<td>5.2</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>7.1</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>6.5</td>
</tr>
<tr>
<td>Cold water, %</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Alcohol-benzene extractives are 1.0% (21), ether solubles are 0.2-0.9% of whole wood, 0.1-0.2% of sapwood, 0.3-0.9% of heartwood (22). For information on fatty acids and resin acids see Swan (23).

**Other Information.** Mia (24) studied the crystalline inclusions dispersed among phenolic substances.

Solvent extractions and alkali treatments did not remove the darker color in the cell walls (25). For an analysis of the sap, see Rowe and Conner (26). The wood and bark contain β-sitosterol and a small amount of leucoanthocyanidins; the wood contains coniferaldehyde and sinapaldehyde.
Chemical Composition of Bark

Proximate Analyses

Chang and Mitchell (27)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, %</td>
<td>6.3</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>5.05</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
</tr>
<tr>
<td>Benzenes, %</td>
<td>1.2</td>
</tr>
<tr>
<td>95% alcohol, %</td>
<td>3.9</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>19.2</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>2.4</td>
</tr>
</tbody>
</table>

The bark contains 5.0% ash (28) and 6.0% alcohol-benzene extractives (27).

Carbohydrates

Reducing sugars from extractive-free barks:

Chang and Mitchell (27)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose, %</td>
<td>63</td>
</tr>
<tr>
<td>Unknown substances, %</td>
<td>2</td>
</tr>
<tr>
<td>Galactose, %</td>
<td>3</td>
</tr>
<tr>
<td>Mannose, %</td>
<td>1</td>
</tr>
<tr>
<td>Arabinose, %</td>
<td>6</td>
</tr>
<tr>
<td>Xylose, %</td>
<td>25</td>
</tr>
</tbody>
</table>

Other Information. The bark contains 3.0% calcium and 0.19% silica (as percent of oven-dry weight of the bark) (27).

Pulping

Acid sulfite. See Richter (19).

Chemigroundwood. The treated wood is ground with 1/2 to 2/3 the power and at double the production rate of spruce groundwood. The pulp is 3 to 4 times as strong as ordinary spruce groundwood (29, 30).

Kraft. The wood is pulped easily and the yield is normal. The pulp is rather difficult to bleach; it is weaker than spruce sulfite and is softer, bulkier, and more opaque (31, 32, 33). It is easily bleached, requiring 4.72% total chlorine for G.E. brightness of 80 at a permanganate number of 13.0 (34). For kraft pulping information see Hatton (35) and Horn (36).

Mechanical. The pulp is about equal in burst and tensile strength to the average of a number of commercial newsmprint grade pulps and it lower in tear strength; it requires about 100 HP day/ton. The pulp is dark (37, 38, 39).

NSSC. The pulp is good (40, 41).

Soda. The wood is pulped with some difficulty; the yield is normal, and the pulp is rather difficult to bleach. It is weaker than spruce sulfite pulp and is softer, bulkier, and more opaque (42, 37, 43, 44).

Sulfite. The wood is very easily pulped, the yield is normal, and the pulp has excellent color and strength about 2/3 that of spruce. It is easily bleached and the pulps are soft and flexible. It is suitable for absorbent, tissue, book, and specialty papers and dissolving pulp (45, 46, 31, 43, 44).

Utilization of Wood and Bark

Use Properties of Wood. The wood is hard, has splendid resonance, and is easily worked, taking a fine smooth surface and a high polish. It is easy to finish. It is easily glued. It is difficult to nail yet holds nails and screws well. It is very strong and stiff and is slow to season. It has good resistance to wear. Shrinkage is fairly high. The heartwood is moderately difficult to penetrate with a preservative.

Calorific Value of Wood

5790 BTU/lb air-dry
3215 k cal/kg air-dry

Calorific Value of Bark

7300 BTU/lb
4055 k cal/kg
283,960 BTU/ft³
2025 k cal/m³

Chemical Uses of Wood. Destructive distillation: methanol, 1.94%; acetic acid, 5.42%; tar, 12.4%; charcoal, 39.8%. Alcohol production: 38 gallons of 95% alcohol per ton by the Madison process.

Other Uses of Wood. See bigleaf maple. The sap of sugar maple is boiled down for syrup. Sugar maple is especially suitable for flooring, especially bowling alleys, dance floors, and factory floors. It is also used for musical instruments, especially piano frames.


**RED MAPLE**

**Scientific Name** Acer rubrum L.

**Synonyms** Scarlet maple, swamp maple, Carolina red maple, soft maple, water maple, white maple

**Family Name** Aceraceae

**Range** Red maple is found almost everywhere east of the 100th meridian where precipitation is adequate. The range includes southern Florida to Canada and the Atlantic Ocean to the prairies. However, the tree reaches its best development in Kentucky, Tennessee and nearby states. Standing soft maple sawtimber volume in the South is over 4 billion board feet (.01 billion m$^3$) (7). Red maple amounts to 3.6% of the hardwood volume on pine sites in 12 southern states (2).

**Tree Dimensions** Although it may reach 120 ft (37 m) in height and five ft (152 cm) in diameter under ideal conditions, the average height is 75-90 ft (23-27 m) and 1-1/2 to 2-1/2 ft (46-76 cm) in diameter.

**Pathology** Resistance to decay: low+

Most of the cankers attacking sugar maple also affect red maple. Nectria canker (N. galligena) is the most common in the Northeast. The eastern mistletoe (Phoradendron serotinum) commonly develops on red maple in the warmer and moister parts of its range (3). Much of the trunk rot in the Northeast is caused by Inonotus glomeratus (formerly Polyporus glomeratus). Phellinus igniarius (formerly Fomes igniarius) is another leading trunk rot of red maple. Root diseases are not of serious importance in red maple.

**Silvics** This medium-sized tree has a long, fairly clear bole, an irregular or rounded crown, and a shallow root system. Characteristically found on swampy sites, it is associated with black ash, black tupelo, cottonwood, American elm, and the bottomland oaks. But in the north it is also found on drier locations with the northern hardwoods. The species is rated as tolerant.
(Pulvinaria innumerabilis), the maple leaf scale (P. acericolora), and the oystershell scale (Lepidosaphes ulmi) are common scale insects on red maple. Leaf feeders include the elm spanworm (Ennomos subsignarius) which is capable of defoliating large areas of mixed hardwoods, the linden looper (Erannis tiliae), and the gypsy moth (Lymantria dispar).

Gross Features of the Wood  The wide sapwood is white and the heartwood is light brown, sometimes with a grayish or a faint purplish cast. The wood is soft to moderately hard, moderately heavy, without characteristic odor or taste. The growth rings are not very distinct, delineated by a narrow, darker line of denser fibrous tissue. The wood is diffuse-porous with small pores, indistinct without a hand lens, evenly distributed throughout the growth ring, mostly solitary or in short radial groups of 2 or more. Parenchyma are not visible. The rays are visible with the naked eye, intergrading in width, the broadest about as wide as the largest pores, forming a pronounced close ray fleck on the radial face, appearing on the tangential surface as short, crowded lines which are visible without magnification.

Microscopic Structure of the Wood

Vessels. 30-80 per sq. mm, av. length 0.42 mm, the largest 60-80 μm in diameter; perforation plates simple; spiral thickening present; intervessel pits orbicular to broad oval to angular, 5-10 μm in diameter. Volume occupied, approx. 18%.

Fibers. Thin to moderately thick walled, 16-30 μm in diameter and 0.82 mm (0.3-1.1) long; volume occupied, approx. 69%. Manville (5) found that for 10 trees with a diameter b.h. of 6 in, the fiber length in the stem averaged 0.83 mm and in the branches 0.66 mm. According to Saucier and Taras (6), fiber length was significantly correlated with sprout height, length of internode and diameter of internode in one-year-old seedlings.

Rays. Unstoried, essentially homogeneous; 1-5-seriate, uniseriate common. Volume occupied, approx. 13%.

Longitudinal Parenchyma. Trace.

Gross Features of the Bark On young trees, the bark is smooth and light gray, while on old trunks the bark is thick, dark gray and separated by vertical ridges into large, platelike scales. The percentage of red maple bark in the stem and branches was estimated at 16.1% on a dry weight basis (2). Additional publications on bark volume include Millikin (8) and Koch (9).

Microscopic Structure of the Bark

Inner Bark. Near the cambium zone, sieve tube elements and companion cells are aggregated into tangential bands which alternate with almost uniseriate lines of parenchyma and irregular groupings of relatively few phloem fibers. Progressing outward, one immediately encounters a greater frequency and crowding of fibers and sclereids, crushing of the sieve tube structure, and a general lack of cell patterns. One exception is the greater tendency for interrupted but wider tangential lines of parenchyma. Near the outer bark, the only recognizable cell types are fibers, sclereids, and parenchyma. Ray structure terminates as such about half-way through the inner bark, the cells becoming sclerotic and/or intergrading with other parenchyma.

Common Bark Characteristics of the Maples. According to Chang (10), the barks of the maples he studied, including red maple, have the following characteristics in common: (1) the presence of thin-walled, suberized phellem and thick-walled peridermal cells, which are often repeated in alternate layers, (2) the development of rather advanced types of sieve tube elements, (3) the presence of sclerotic cells with solitary crystals, (4) the development of typical phloem fibers which are variable in amount and in time of maturation in different species, (5) the homogeneous broad phloem rays, and (6) the persistence of the cortical region. Harder, et al. (17) found a fibrous yield of 12% when red maple bark was pulped to a solids yield of 32.0%.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Green volume</th>
<th>Air-dry volume</th>
<th>Oven-dry volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td>35 (561)</td>
<td>38 (609)</td>
<td>50 (801)</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td>31 (497)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td>31 (497)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent shrinkage, dried to 0%</td>
<td>r - 4.0</td>
<td>t - 8.2</td>
<td>v - 13.1</td>
</tr>
</tbody>
</table>

Phillips (72) obtained a stem specific gravity of 0.51 and a branch specific gravity of 0.50 for intermediate and suppressed trees in North Carolina.

Additional publications relating to specific gravity include Jett and Zobel (73) and Maeglin (74).
Percent moisture content, when green

Green basis 39
Oven-dry basis 63

Manwiller (15) obtained a stemwood moisture content of 69.9% and a branch wood moisture content of 75.1% for 6-in (15 cm) hardwoods growing on southern pine sites.

An additional publication related to moisture content is Phillips (72).

Physical Properties of Bark

<table>
<thead>
<tr>
<th>Specific gravity</th>
<th>Inner bark</th>
<th>0.59</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outer bark</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>Total bark</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Density (100% moisture content)

Green weight/green volume 1.22

Specific gravity, oven-dry weight & volume (76)

Koch (17) found that variation in bark specific gravity with height in the stem was greater within d.b.h. classes than between classes at any given height. Specific gravity was always less at the stump than at d.b.h. B.H. samples gave an adequate mean value for the tree.

Chemical Composition of Bark

Solubility in

| Alcohol-benzene, % | 2.5 |
| Ether, %           | 0.8 |
| 1% NaOH, %         | 17.9 |
| Hot water, %       | 4.4 |
| Alcohol, %         | ~   |
| Water, %           | ~   |

Koch (17) obtained a stem bark moisture content of 74.4% and a branch bark moisture content of 89.4% for 6-in (15 cm) hardwoods growing on southern pine sites.

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th></th>
<th>F.P.L. (18)</th>
<th>Aung (19)</th>
<th>Karchesy and Koch (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>22.8</td>
<td>22.4</td>
<td>23.0</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>71.0</td>
<td>75.0</td>
<td>23.3</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>44.5</td>
<td>49.8</td>
<td>30.4</td>
</tr>
<tr>
<td>Hemicellulose, %</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.7</td>
<td>0.38</td>
<td>0.3</td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>17.1</td>
<td>23.8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Extracellular

<table>
<thead>
<tr>
<th>Solubility in</th>
<th>F.P.L. (18)</th>
<th>Aung (19)</th>
<th>Karchesy and Koch (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol-benzene, %</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Ether, %</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>2.5</td>
<td>0.22</td>
<td>~</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>1.13</td>
<td>1.70</td>
<td>~</td>
</tr>
<tr>
<td>Extractives</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
</tbody>
</table>

Richter (20) gives analyses of sapwood and heartwood of two trees felled at different times.

Levitin (22) found the sapwood to contain 0.16-0.51 ether solubles and heartwood, 0.21-0.31%.

The alcohol-benzene extractives are 1.0% (23) and 3.8% (24).

Richter (20) found the alcohol-benzene solubles of wood to be 2.5%, ether solubles are 0.3-0.8% of whole wood, 0.2-0.5% of sapwood, and 0.2-0.3% of heartwood.

For information on fatty acids and resin acids see Swan (25). Tannins are absent (26).

For carbohydrates and extractives in sap see Rowe and Conner (27). Wood and bark contain glucose, ß-sitosterol, ß-catechin, and a pro- cyanidin.

For elements in wood and the complete tree see Young et al. (28) and Young and Guinn (29).

Chemical Composition of Bark

Extractives

<table>
<thead>
<tr>
<th>Solubility in</th>
<th>F.P.L. (18)</th>
<th>Aung (19)</th>
<th>Karchesy and Koch (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol-benzene, %</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Ether, %</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>2.5</td>
<td>0.22</td>
<td>~</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>1.13</td>
<td>1.70</td>
<td>~</td>
</tr>
<tr>
<td>Alcohol, %</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Water, %</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Extractives</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
</tbody>
</table>

Murphey et al. (21)

Solubility

| Acetone, %     | 13.0         |

Other Information. For carbohydrates and extractives in sap see Rowe and Conner (27). Wood and bark contain glucose, ß-sitosterol, ß-catechin, and a pro-cyanidin.

For elements in wood and the complete tree see Young et al. (28) and Young and Guinn (29).
Ethanol, %  16.4
Ethanol-benzene, %  13.1
1% NaOH, %  16.3
Hot water, %  16.0
Cold water, %  9.2

Alcohol-benzene extractives are 16.4% (25) and 6.0% (24).

Other Information. The ash content is 5.2%, calcium content, 1.5%, and silica content, 0.37% (as a percent of oven-dry weight of the bark) (24). For elements in branches and unmerchantable top, bole, stump and roots see Young (30).

The bark contains pyrogallol and gallic acid (28).

Pulping

Alkaline. The yield is low, and bleach consumption is high (31).

Chlorine Dioxide. A concentration of 8% chlorine dioxide gave a yield of 65-70% unbleached pulp (32).

Kraft. The wood is readily pulped and the yield of pulp is normal (33). It is easily bleached, requiring 4.50% total chlorine for a GE brightness of 80 at a permanganate number of 12.9 (19). For yields and pulp properties see Chase et al., (34). For properties of kraft pulps bleached to GE brightness of 80, see Jett and Zobel (13).

Mechanical: The pulp has short fibers, and its strength is low compared with common softwoods. It is stronger than yellow birch, white ash, and beech (35). Energy consumption is reasonable.

NSSC. For a kinetic study of the pulping reactions see Findley and Nolan (36). For other information see Chidester (37).

Soda. The wood is pulped very easily; the yield is normal and the pulp is fairly easy to bleach (38, 39).

Sulfite. The wood is pulped very easily; yield is normal; the pulp has a rather poor color and is easily bleached (39).

Oxygen. Institute of Paper Chemistry Project 3264 is a source of information on oxygen pulping of red maple.

Utilization of Wood and Bark

Use Properties of Wood. The wood is very similar to hard maple but is not so hard, strong, or heavy as hard maple; in these respects it is superior to silver maple.

Calorific Value of Wood

\[ 24.0 \times 10^6 \text{ BTU/air-dry cord} \]

\[ 7845 \text{ BTU/oven-dry lb} \]

\[ 4360 \text{ k cal/kg oven-dry} \]

\[ 5810 \text{ BTU/air-dry lb} \]

\[ 3230 \text{ k cal/kg air-dry} \]

Calorific Value of Bark

\[ 7595 \text{ BTU/oven-dry lb} \]

\[ 4220 \text{ k cal/kg oven-dry} \]

\[ 210,160 \text{ BTU/ft}^3 \]

\[ 1500 \text{ k cal/m}^3 \]

Chemical Uses of Wood. Destructive distillation: methanol, 1.69%; acetic acid, 6.30%; tar, 12.1%; charcoal, 41.2%.

Other Uses of Wood. See bigleaf maple. Much less soft maple is cut than hard maple. The uses of red maple are practically the same as those for hard maple and, except for the most exacting requirements with respect to hardness and strength, they are not differentiated in commercial use.

Red maple is worth consideration as a sugar producer (40).

Other Uses of Bark. It is used in folk medicine as an anthelmintic, tonic, and ophthalmic (28).

Literature Cited


18. Forest Products Laboratory. Unpublished data.


SILVER MAPLE

Scientific Name Acer saccharinum L.

Synonyms Soft maple, white maple, river maple, water maple, swamp maple

Family Name Aceraceae

Range Silver maple, found throughout eastern United States, is most common and reaches its best development in the southern Ohio River Valley. The range extends from southeastern Canada westward to the borders of the Prairie States where it grows along streams. Only in the coastal areas or the higher, colder elevations of the Appalachians is this species sparsely present or entirely absent.

Pathology Resistance to decay: low+

The foliage of silver maple is subject to spotting by many fungi. They include Venturia acerina, Cristulariella depraedens, C. pyramidalis, Gloeosporium apocryptum, G. saccharinum and others. The only noteworthy stem disease is Verticillium wilt (V. dahliae), although silver maple is not as susceptible to this disease as Norway maple. Shoestring root rot (Armillariella meliae) is common. Fungi known to rot the heartwood or inner sapwood include Oxyporus populinius, Phellinus igniarius, Hydnium erinaceus, H. septentrionale and others.

A number of scale insects attack silver maple, including the cottony maple scale (Pulvinaria innumerabilis), the maple leaf scale (P. acricola), and the oystershell scale (Lepidosaphes ulceris). Borers include the gall-making maple borer (Xylothereus aceris) and the maple callus borer (Sylwora aceris). Leaf feeders include the white-marked tussock moth (Hemerocampa leucostigma) and the fruit-tree leaf roller (Archips anthyropus).

Gross Features of the Wood Similar to red maple. The wood is generally straight-grained and moderately heavy with a wide white sapwood and light-brown heartwood. Growth rings, delineated by a narrow, darker line of denser fibrous tissue, are not very distinct. Small, indistinct pores are distributed throughout the growth ring. On the tangential surface, rays are visible as short, crowded lines.

Microscopic Structure of the Wood

Vessels. Numbering 30-80 per sq mm, silver maple vessels, with spiral thickenings, may have diameters up to 60-80 μm. The average vessel segment length is 0.41 mm. Volume occupied, approx. 21%.

Fibers. Average, 0.76 mm in length and 16-30 μm in diameter. Thin to moderately thick walled. Volume occupied, approx. 67%.

Parenchyma. Sparse.

Rays. Unstoried, 1-5-seriate and generally homogeneous. Volume occupied, approx. 12%.

Lamb (7) grew silver maple seedlings for 10 weeks in Ca, B, Mg and P-deficient and control solutions. All nutrient
deficiencies increased tangential fiber tracheid diameter. All solutions except Mg-deficient resulted in significantly larger tangential vessel diameter than controls, with fewer vessels per unit area. Only Mg and Ca-deficient seedlings had significantly reduced secondary xylem width.

Cross section of silver maple showing two full growth rings. Vessel diameters in this species are equal to or less than the ray widths. Magnification – 30X.

Gross Features of the Bark. The bark on young trees is silvery gray and later breaks up into long, thin scaly plates which are unattached at the ends. On old trunks, it is thick, reddish brown and furrowed.

Microscopic Structure of the Bark

Outer Bark. The outer bark of one sample was limited to a periderm layer composed of 2-4 layers of phellem, a layer of phellogen and several layers of phellem cells. There was a lack of rhytidome formation in this particular specimen. However, thin, smooth bark appears to be fairly typical of pulpwood-sized trees and tops of larger trees.

Cortical Region. The cortical region occupies a proportionally narrow zone of the whole bark and is composed principally of cortex cells and some expanded secondary phloem tissues. The cortical zone does not show distinct demarcation from the secondary phloem. These two parts are merged together by cortical parenchyma, the dilated phloem rays, phloem parenchyma and scattered groups of sclerenchyma.

Secondary Phloem. The secondary phloem is composed of alternate bands of sieve tube elements, phloem parenchyma and sclerenchyma cells. These cells are bounded radially by rays which are 2-4-seriate and essentially homogeneous. Some of the rays have become sclerified and have merged into sclereid groups. Only the sieve tube groups in the proximity of the cambium zone have retained their fully developed shape and size. The remaining zones of sieve tubes have become more or less crushed. The sclerenchyma consists of sclereids and fibers. The sclereids are narrow, branched, fiberlike cells which appear at the middle portion of the inner bark with the more or less tangential bands of phloem fibers. The cambium zone is generally separated by 3-4 rows of sieve tubes and parenchyma cells from the last-formed, narrow (1-2 cells wide), tangential band of phloem fibers. Harder, et al. (2) found a fibrous yield of 6% when silver maple bark was pulped to a solids yield of 32.0%.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Green volume</th>
<th>Air-dry volume</th>
<th>Oven-dry volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td></td>
<td>45 (721)</td>
<td>33 (529)</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td></td>
<td>31 (497)</td>
<td></td>
</tr>
<tr>
<td>Oven-dry weight per green volume</td>
<td></td>
<td>28 (448)</td>
<td></td>
</tr>
</tbody>
</table>

An additional publication related to specific gravity is Maeglin (3).

Percent shrinkage, dried to 0% moisture content: \( r \approx 3.0, \ t \approx 7.2, \ v \approx 12.0 \).

Kandeel and Bendaad (4) cover the structure, density and shrinkage variation within a silver maple tree.

Percent moisture content, when green

<table>
<thead>
<tr>
<th>Moisture Content</th>
<th>Green basis</th>
<th>Oven-dry basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>66</td>
<td>97</td>
</tr>
</tbody>
</table>
Physical Properties of Bark

<table>
<thead>
<tr>
<th></th>
<th>Inner bark</th>
<th>Outer bark</th>
<th>Total bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.51</td>
<td>0.61</td>
<td>0.57</td>
</tr>
<tr>
<td>Density (100% moisture content)</td>
<td>Green weight/green volume</td>
<td>1.11</td>
<td></td>
</tr>
<tr>
<td>Specific gravity oven-dry weight &amp; volume (6)</td>
<td></td>
<td>0.67</td>
<td></td>
</tr>
</tbody>
</table>

Chemical Composition of Wood

Proximate Analyses. The wood contains 22.1% pentosans. It contains 3.5% alcohol-benzene extractives (7).

Chemical Composition of Bark

Proximate Analyses. The bark contains 3.6% ash and 6.6% alcohol-benzene extractives (7).

Other Information. Bark contains 0.6% calcium, 0.18% silica (as a percent of oven-dry weight of the bark) (7) and β-sitosterol, gallic acid, and proanthocyanidins.

Pulping

Soda. The wood is readily pulped; yield is normal or slightly high (8, 9, 10).

Calorific Value of Wood

\[ 21.7 \times 10^6 \text{ BTU/air-dry cord} \]

Calorific Value of Bark

\[ 297,615 \text{ BTU/ft}^3 \]
\[ 2120 \text{ kcal/m}^3 \]
\[ 8360 \text{ BTU/oven-dry lb} \]
\[ 4645 \text{ kcal/kg oven-dry} \]

Chemical Uses of Wood. It is worth consideration as a sugar producer (77).

Other Uses of Wood. It is used for lumber (mixed with red and sugar maples, except for most exacting uses), fuel, and destructive distillation.

Literature Cited

**BIGLEAF MAPLE**

**Scientific Name**  *Acer macrophyllum* Pursh

**Synonyms** Broadleaf maple, Oregon maple

**Family Name** Aceraceae

**Range** Pacific Coast from British Columbia south to southern California.

**Silvics** The forest tree has a straight, clear bole, a rather narrow crown, and a shallow, spreading root system. It is found on a variety of soils but makes its best growth on rich bottomlands. Usually, it occurs in mixture with red alder, black cottonwood, Douglas-fir, western red-cedar, western hemlock, grand fir, and California-laurel but in sections of southwestern Oregon it is the principal species. Bigleaf maple is rated as tolerant.

**Tree Dimensions** 60-80 ft (18-24 m) tall and 14-30 in (36-76 cm) in diameter.

**Pathology** Resistance to decay: low+

Many fungi will form lesions on leaves of bigleaf maple, but none are considered economically important. A number of root and trunk rots are important, including *Heterobasidion annosum*, *Armillariella mellea* and *Oxy- porus populinus*. Many typically conifer fungi will attack bigleaf maple. The *Verticillium* wilt disease (*V. albo- atrum*) is an important killing disease, particularly on trees used as ornamentals. Bier (7) covers the relation of bark moisture to the development of canker diseases.

Bigleaf maple is attacked by a variety of insects, none of which cause extensive damage. Twig borers include *Agrilus politus*, the flatheaded apple tree borer (*Chrysobothris femorata*) and *Phymatodes vulneratus*. Defoliators include the polyphemus moth (*Antheraea polyphemus*), the spotted tussock moth (*Halisidota maculata*), and the ceanothus silk moth (*Hyalophora euryalus*).

**Gross Features of the Wood** The sapwood is reddish white, sometimes with a grayish cast and the heartwood is pinkish brown. The wood is moderately heavy, moderately hard, generally straight but occasionally wavy grained, without characteristic odor or taste. The rather indistinct growth rings are marked by a narrow light line of fibrous tissue. The wood is diffuse-porous with moderately small to medium-sized pores, indistinct without a hand lens, evenly distributed throughout the growth ring or somewhat more numerous in the early springwood, mostly solitary or in short radial groups of 2 or more. The rays are visible with the naked eye and intergrade in width, the broadest being about as wide as the largest pores. They form a pronounced close fleck on the r-surface and on the t-surface are visible with the naked eye as short, crowded lines. The longitudinal parenchyma are not visible.

**Microscopic Structure of the Wood**

**Vessels.** 30-80 per sq mm, the largest 80-120 μm in diameter; average 0.33 mm (0.28-0.38) in length; perforation plates simple; spiral thickening present; intervessel pits orbicular or angled through crowding, 4-10 μm in diameter; gummy deposits not uncommon.

**Fibers.** Average, 0.74 mm (0.3-1.2) in length and 16-30 μm in diameter; thin to moderately thick walled.

**Rays.** Unstoriied, 1-5 (mostly 3-5)-seriate, essentially homogeneous. Upper occupied, approx. 18%.

**Longitudinal Parenchyma.** Sparse, marginal, paratracheal, and diffuse.
Gross Features of the Bark. Light gray brown and smooth on young stems, but becoming darker and deeply furrowed on old trunks.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>g/cm³</td>
<td>0.44</td>
</tr>
<tr>
<td>Air-dry volume</td>
<td>g/cm³</td>
<td>0.48</td>
</tr>
<tr>
<td>Oven-dry volume</td>
<td>g/cm³</td>
<td>0.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Density, lb/ft³ (kg/m³)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>47 (753)</td>
<td></td>
</tr>
<tr>
<td>Air-dry</td>
<td>34 (545)</td>
<td></td>
</tr>
<tr>
<td>Oven-dry</td>
<td>31 (497)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Density, lb/ft³ (kg/m³) per green volume</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven-dry weight</td>
<td>27 (432)</td>
<td></td>
</tr>
</tbody>
</table>

Percent shrinkage, dried to 0% moisture content: \( r = 3.7 \), \( t = 7.1 \), \( v = 11.6 \).

Percent moisture content, when green

<table>
<thead>
<tr>
<th>Basis</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green basis</td>
<td>42</td>
</tr>
<tr>
<td>Oven-dry basis</td>
<td>72</td>
</tr>
</tbody>
</table>

Physical Properties of Bark

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>g/cm³</td>
<td>0.66</td>
</tr>
<tr>
<td>Inner bark</td>
<td>g/cm³</td>
<td>0.45</td>
</tr>
</tbody>
</table>

| Specific gravity oven-dry weight & volume   | g/cm³         | 0.55        |

<table>
<thead>
<tr>
<th>Percent moisture content</th>
<th>g/cm³</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner bark</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td>Outer bark</td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

Chemical Composition of Wood

Proximate Analysis (based on extractive-free wood)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>23.4</td>
</tr>
<tr>
<td>Holocellulose, %</td>
<td>76.4</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.26</td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>17.7</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>4.24</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>4.51</td>
</tr>
</tbody>
</table>

Carbohydrates. Wise et al. (5) found 1.6% mannan by a modified Haglund-Bratt method.

Extractives. Kurth (4) found unextracted wood to contain 7.04% extractives consisting of 0.03% ether soluble, 5.12% alcohol soluble, and 1.62% hot water soluble.

Pulping

Kraft and Magnefite. These processes have been used; the pulps are readily bleached to 70-80% brightness (6).

For kraft pulp properties see Wang (7) and Fahey and Martin (8).

NSSC. This pulp is exceptionally crush resistant and is well qualified for corrugating medium (6).

Other Information. Bigleaf maple is generally pulped in mixture with other hardwoods like aspen, birch, beech, and oak. They are pulped mostly by the soda, sulfate, and semichemical processes. Maples are used for white printing and writing papers.

Utilization of Wood and Bark

Use Properties of Wood. The wood is generally straight grained and occasionally is wavy grained. It is moderately hard and is moderately well worked with tools; it takes a good polish, takes paints and stains readily, is difficult to glue, and shrinks moderately. Growth rings are not very distinct. Bigleaf maple is intermediate in strength between silver and red maple. It is difficult to penetrate with a preservative.

Chemical Uses of Wood. Maple is used for the production of charcoal, acetic acid, and methanol.

Other Uses of Wood. Maple is used principally for lumber, veneer, and crossties. Most of the maple lumber is used for flooring, furniture, boxes and crates, shoe lasts, handles, woodenware, novelties, spools, and bobbins.

Literature Cited


CUCUMBERTREE

Scientific Name  *Magnolia acuminata* L.

Synonyms Cucumber magnolia, mountain magnolia, cucumber

Family Name Magnoliaceae

Range Appalachians and the Mississippi and Ohio valleys.

Silvics This medium-sized tree has a straight, clear bole, a short, dense, pyramidal crown, and a deep, widespread root system. It is usually found on moist, deep, fertile soils of loose texture with red oak, white oak, yellow-poplar, white ash, black birch, beech, sugar maple, basswood, and red maple. This species reaches its best development in the southern Appalachians but is not abundant. It is the most hardy of the tree-sized species of *Magnolia*. It is rated as intermediate in tolerance.

Tree Dimensions 80-90 ft (24-27 m) tall and 3-4 ft (91-122 cm) in diameter.

Pathology Cucumbertree has no important disease enemies. It is attacked by the Nectria canker (*Nectria galligena*) which seldom kills trees although it can cause defects and deformity. The only leaf spot reported on this species is *Phyllosticta cookei*. However, it is very susceptible to ground fires.

The wood borer (*Xyloterinus politus*) breeds in injured or dying trees and infested wood may be severely degraded. Cucumbertree is susceptible to several scales, among them the magnolia scale (*Neolecanium cornuviarum*), the European fruit lecanium (*Lecanium corni*) and the San Jose scale (*Quadraspidiotus perniciosus*). Damage to trees from these scales can be severe and weakened trees are then subject to attack by boring insects.

Gross Features of the Wood The sapwood is whitish and the heartwood yellow or greenish yellow to brown. The wood is moderately hard to hard, medium heavy, with no characteristic odor or taste. The growth rings are distinctly delineated by a whitish line of terminal parenchyma. The diffuse-porous wood has small pores, indistinct without a hand lens, quite uniform in size, fairly evenly distributed throughout the ring, solitary or in radial groups of 2 or more. Parenchyma are terminal and plainly visible with the naked eye. The rays are distinct with the naked eye in the x-section, nearly uniform in width.

Microscopic Structure of the Wood

Vessels: 60-120 per sq mm, the largest 80-100 μm in diameter; perforation plates simple or occasionally scalariform in early rings; intervessel pitting scalariform (the pits linear or rarely elliptical), 12-50 μm in diameter; volume occupied, approx. 39%.

Fibers. Average, 1.6 mm (0.8-2.3 mm) in length and 28-40 μm in diameter; thin to moderately thick walled; volume occupied, approx. 48%.

Rays. 4-7 per mm tangentially on the x-section, unstoried, 1-5 (mostly 1-2)-seriate, homogeneous to heterogeneous; where heterogeneous, the upper and lower margins generally consist of one row of upright cells less than 60 μm in height; volume occupied, approx. 14%.

Longitudinal Parenchyma. Terminal, 1 or more seriate. Trace.

Gross Features of the Bark The dark brown bark is fissured into narrow flaky ridges.

Microscopic Structure of the Bark

Periderm. Superficial, continuous, with few- to many-layered thin-walled phellem and poorly developed phellogen.
**Sieve Tube Elements.** 500-700 μm long; abundant, grouped; groups large, irregularly scattered.

**Parenchyma.** Much less abundant than sieve tube elements and usually associated with fiber bands, but also occur within the sieve tube group; much narrower than the sieve tube elements.

**Physical Properties of Wood**

<table>
<thead>
<tr>
<th>Property</th>
<th>Green Volume</th>
<th>Air-Dry Volume</th>
<th>Oven-Dry Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.44</td>
<td>0.49</td>
<td>0.52</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>49 (785)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air-Dry</td>
<td>34 (545)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oven-Dry</td>
<td>32 (513)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Density, lb/cu ft (kg/cu m)

<table>
<thead>
<tr>
<th>Property</th>
<th>Oven-Dry Weight per Green Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent shrinkage, dried to 0% moisture content: r - 5.2, t - 8.8, v - 13.6.</td>
<td></td>
</tr>
</tbody>
</table>

Percent moisture content, when green

<table>
<thead>
<tr>
<th>Basis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Green basis</td>
<td>44</td>
</tr>
<tr>
<td>Oven-dry basis</td>
<td>80</td>
</tr>
</tbody>
</table>

**Physical Properties of Bark**

<table>
<thead>
<tr>
<th>Property</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity oven-dry weight &amp; volume (2)</td>
<td>0.44</td>
</tr>
</tbody>
</table>

**Chemical Composition of Wood**

**Proximate Analysis**

**Pentosans** 17.7%

**Pulping**

**Kraft.** Is readily pulped.

**Soda.** The wood is readily pulped, yield is normal and the pulp is rather difficult to bleach (3).

**Sulfite.** The wood is readily pulped, yield is normal, and the pulp is dark and rather difficult to bleach (3).

**Utilization of Wood and Bark**

**Use Properties of Wood.** The wood is easily worked, can be finished with a satiny luster, and takes stain well. It is fairly easily dried, and it has a slight tendency to warp and twist.

**Other Uses of Wood.** Little lumber is sold under the name of cucumbertree; most is included with yellow-poplar. The wood is used for furniture, boxes and crates, general millwork, fixtures, and musical instruments. Some of the wood is used along with yellow-poplar for veneer.

**Literature Cited**

2. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv.
SOUTHERN MAGNOLIA

Scientific Name  *Magnolia grandiflora* L.

Synonyms  Evergreen magnolia

Family Name  Magnoliaceae

Range  South Atlantic and Gulf Coastal plains. The greatest abundance of southern magnolia occurs in Louisiana, Mississippi, and Texas.

Silvics. This medium-sized to large tree has a tall, straight bole and a pyramidal crown. It is usually found on moist, well-drained soils along streams and on other moist locations in the uplands in mixture with beech, yellow-poplar, sweetgum, oaks, and southern red-cedar. Southern magnolia is tolerant when young but becomes less so as it grows older.

Tree Dimensions  60-80 ft (18-24 m) tall and 2-3 ft (61-91 cm) in diameter.

Pathology  Southern magnolia is relatively free from disease. Many leaf spot and blotch fungi occur on southern magnolia but none appear serious to forest-grown trees. Fungi capable of causing heart rot or rot at wounds include *Daedalea amigua*, *Fomes applanatus*, *F. geotropus*, *F. marmoratus*, *Polyporus calkinsii*, *P. curtisi*, and *P. suphureus*.

Southern magnolia has few insect pests. A borer on this species is *Xyloterinus politus*, which breeds on injured and dying trees. Several scales attack magnolia, including the magnolia scale (*Neolecanium cornparvum*) and the San Jose scale (*Quadraspidiotus perniciosus*). Heavily infested trees may be seriously weakened.

Gross Features of the Wood  Similar to cucumbertree, but a greenish-black heartwood is said to be common in this species.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Green volume</th>
<th>Air-dry volume</th>
<th>Oven-dry volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.46</td>
<td>0.50</td>
<td>0.53</td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>59 (945)</td>
<td>35 (561)</td>
<td>33 (529)</td>
</tr>
<tr>
<td>Air-dry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oven-dry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density, lb/cu ft (kg/cu m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oven-dry weight per green volume</td>
<td></td>
<td></td>
<td>29 (464)</td>
</tr>
</tbody>
</table>

Jett and Zobel (5) list the wood properties of magnolia.

Percent shrinkage, dried to 0% moisture content: r = 5.4, t = 6.6, v = 12.3.

Percent moisture content, when green

<table>
<thead>
<tr>
<th>Property</th>
<th>Basis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>Oven-dry</td>
<td>105</td>
<td></td>
</tr>
</tbody>
</table>

Percent moisture content oven-dry basis (6)

<table>
<thead>
<tr>
<th>Property</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heartwood</td>
<td>80</td>
</tr>
<tr>
<td>Sapwood</td>
<td>104</td>
</tr>
</tbody>
</table>
Chemical Composition of Wood

Proximate Analyses

Ash content 0.60%

Extractives. The wood and bark contain a wide variety of lignans and alkaloids (Rowe and Conner) (7).

Pulping

Kraft. A yield of 42.5% was obtained for a permanganate number of 12.25 (8). The wood is readily pulped. For pulp strengths before and after bleaching see Perkins (9). The yield from alkaline pulping is lower than for gum wood; the breaking length is almost identical, while burst strength is higher and tear strength is slightly higher; freeness is only slightly higher (10).

Utilization of Wood and Bark

Use properties of Wood. See sweetbay.

Other Uses of Wood. See sweetbay.

Literature Cited

Scientific Name  Liriodendron tulipifera L.

Synonyms Tuliptree, tulip-poplar, "poplar", white-poplar, whitewood

Family Name  Magnoliaceae

Range  Widely distributed throughout the eastern United States, growing from southern New England west to Michigan and south to central Florida and Louisiana. Christopher, et al. (7) estimated the proportion of yellow-poplar on pine sites to be 7%.

Silvics  This large-sized tree has a straight, clear trunk, a small oblong crown, and a deep, wide-spreading root system. Yellow-poplar is a component of 16 forest cover types and grows under a variety of climatic conditions but develops best where rainfall is distributed over a long growing season. Soil and moisture requirements are exacting, with aspect, position on slope and elevation important factors influencing site quality. It is commonly found on moist but well-drained soils of loose texture and moderate depth. Well-stocked stands on good sites may require thinning at about 20 years to prevent serious retardation in individual tree growth. Thinnings at this time are usually sufficient for pulpwood production. This species is usually associated in mixtures with white oak, red oak, chestnut, black oak, hickories, hemlock, black tupelo, and sweetgum. Yellow-poplar reproduces both by seed and by stump sprouts. The tree is intolerant except when quite young.

Tree Dimensions  100 ft (30 m) tall and 4-6 ft (122-183 cm) in diameter. In 50-60 years, good second-growth trees may attain heights of over 120 ft (37 m) and diameters of 18-24 in (46-61 cm).

Pathology  Resistance to decay: intermediate

Yellow-poplar is unusually free of serious disease. Small, suppressed trees are susceptible to cankers caused by Nectria magnoliae. Other cankers include Fusarium solani and Botryosphaeria ribis. Leaf diseases generally appear late in the growing season and have little impact on growth. The most serious disease of yellow-poplar is sapstreak, a vascular disease involving a form of the common lumber blue-stain fungus, Ceratocystis coerulescens. Fortunately, the incidence is low.

The Columbian timber beetle (Corthylus columbianus) is a borer of yellow-poplar, preferring vigorous trees of all sizes. The flathead apple borer (Chrysobothris femorata) adults feed on foliage, sometimes causing severe defoliation. Larvae bore into the bark and feed in the phloem and outer sapwood. Adults and larvae of the yellow-poplar weevil (Odontopus calceatus) feed on buds and leaves. Yellow-poplar is also attacked by the European fruit lecanium (Lecanium corni).

Gross Features of the Wood  The sapwood is wide in young trees but narrow in virgin ones; it is whitish, often variegated or striped; the heartwood is clear yellow to dark yellowish, greenish, or pinkish brown. The wood is soft to moderately soft, moderately light, uniformly textured, straight-grained, and has no characteristic taste or odor. The growth rings are distinctly delineated by a whitish line of terminal parenchyma. The wood is diffuse-porous with small pores which are invisible without a lens, fairly uniformly distributed throughout the ring, solitary and in radial groups of 2 or more. Parenchyma are terminal, the line plainly visible to the naked eye. The rays are distinct with the naked eye on the x-section, nearly uniform in width.

Microscopic Structure of the Wood

Vessels  60-180 per sq mm, the largest 80-130 µm in diameter, ave. length 0.89 mm; perforation plates scalariform with 2-10 thin bars; intervessel pits oval or angular or rarely linear, 6-20 µm in diameter; volume occupied, approx. 37%.

Fibers  Thin to moderately thick walled, 24-40 µm in diameter and 1.9 mm (0.8-2.7 mm) long; volume occupied, approx. 49%. Weight factor (unbleached kraft)
of 0.70. Taylor (2, 3, 4, 5) discusses variation in fiber length of yellow-poplar. He found no significant differences among geographic locations in fiber length. In a study on fiber length within annual rings, he found that summerwood fibers are approximately 25% longer than springwood fibers. No statistically significant differences in fiber length were found between branches from the top and bottom of the crown, nor within sampling points within branches (6).

Rays. 4-7 per mm tangentially on the x-section, unstoried, 1-5 (mostly 2-3)-seriate, homogeneous to heterogeneous (one row of upright cells on the upper and lower margins, less than 60 μm high); volume occupied, approx. 14%.

Longitudinal Parenchyma. Terminal, 1 or more seriate. Trace.

Cross section of yellow poplar, a diffuse-porous wood, showing portions of three growth rings. Vessel density is high, leading to lower specific gravity than maple or birch. Magnification – 45X

Gross Features of Bark The bark on young trees is dark green and smooth, with small white spots. The bark soon breaks up into long, rough, interlacing, rounded furrows separated by ashy-gray fissures. The inner bark is aromatic but bitter. According to Koch (7), the ratio of bark thickness to d.o.b. varied only slightly with height but decreased significantly with increasing d.b.h. Koch (8) also found that bark volume percent remained essentially constant, regardless of the size of the tree or position within the tree.

Microscopic Structure of the Bark

Outer Bark. Composed of 12-14 layers of periderm and dead secondary phloem tissue. The last-formed periderm had 2-3 layers of phelloderm, a layer of phellogen and several layers of phellem cells. The secondary phloem tissues in the rhytidome were expanded or deformed as compared with those in the inner bark. The peridermal cells and secondary phloem tissue outside the last-formed periderm were mostly lignified.

Inner Bark. Composed of phloem rays and narrow, alternate bands of sieve tube elements with associated companion cells, phloem parenchyma and sclerenchyma, which was confined to phloem fibers. A band of parenchyma cells, 1-2 cells in width, was usually developed above and below the 1-3 tangential layers of sieve tubes. Occasionally, a few parenchyma cells were intermixed with the layers of sieve cells. These cell types were bordered by tangential bands, usually numbering 1-3 cells, of phloem fibers which appeared very close to the cambium region. The sieve tubes, parenchyma cells and phloem fibers were bordered radially by rays which were mostly 1-3-seriate and essentially homocellular. Some of the rays were conspicuously dilated in the outer region of the inner bark. Harder, et al. (9) found a fibrous yield of 13% when yellow-poplar bark was pulped to a solids yield of 32.3%. Cheadle and Esau (10) cover the secondary phloem of yellow-poplar.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Green Volume</th>
<th>Air-dry Volume</th>
<th>Oven-dry Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.38</td>
<td>0.40</td>
<td>0.43</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Density, lb/cu ft</th>
<th>Green (kg/cu m)</th>
<th>38 (609)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air-dry</td>
<td>28 (448)</td>
</tr>
<tr>
<td></td>
<td>Oven-dry</td>
<td>27 (432)</td>
</tr>
</tbody>
</table>

| Density, lb/cu ft | Oven-dry Weight per Green Volume | 24 (384) |

Taylor (6) found an average stemwood specific gravity of 0.46 and an average branchwood specific gravity of 0.50 (dry weight & green volume). Sluder (77) found
that specific gravity decreased as site index, latitude, and elevation increased. No significant differences among geographic locations were found in specific gravity (4). Wooten, et al. (72) found that, following release of trees, a slight increase in specific gravity occurred. Koch, et al. (73) found that specific gravity was greatest at stump height and least at 10-28 ft (3-8.5 m) above ground on trees with a mean age of 30 and a mean diameter of 11 in (28 cm). At most heights except the stump, specific gravity increased from the pith outward. Mitchell (14) found a trend toward increased specific gravity with increased growth rate. Six years after a single application of fertilizer and yearly irrigation, specific gravity of 80 trees was unaffected (75).

Additional publications on specific gravity include Manwiller (76) and Jett and Zobel (77).

Percent shrinkage, dried to 0% moisture content: r - 4.0, t - 7.1, v - 12.3.

A publication related to shrinkage of normal and abnormal wood is Barefoot (18).

Percent moisture content, when green

<table>
<thead>
<tr>
<th></th>
<th>Basis</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>39</td>
<td>64</td>
</tr>
<tr>
<td>Oven-dry</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percent moisture content oven-dry

<table>
<thead>
<tr>
<th></th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heartwood</td>
<td>83</td>
</tr>
<tr>
<td>Sapwood</td>
<td>106</td>
</tr>
</tbody>
</table>

Measurements made on 10 50-year-old trees showed that wood moisture content did not vary significantly with the season (20). Additional publications on moisture content are Schroeder and Phillips (21) and Manwiller (22).

**Physical Properties of Bark**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>Inner bark</td>
<td>0.38</td>
</tr>
<tr>
<td>green volume</td>
<td>Outer bark</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Total bark</td>
<td>0.38</td>
</tr>
<tr>
<td>Density (100% moisture content)</td>
<td>Green weight/ green volume</td>
<td>0.82</td>
</tr>
<tr>
<td>Specific gravity oven-dry weight &amp; volume (23)</td>
<td></td>
<td>0.39</td>
</tr>
</tbody>
</table>

Koch (24) found that bark specific gravity was less at the stump than at b.h. and specific gravity increased at a given height with increasing d.b.h. classes except in the largest diameter classes. B.h. samples give an adequate mean value for the tree. Koch (7) also found that the specific gravity of inner bark decreases slightly to around 30 ft (9 m) above the ground and then increases. Specific gravity of the outer bark is significantly greater than that of inner bark at all heights above the stump. Manwiller (76) obtained a stem bark specific gravity of 0.39 and a branch bark specific gravity of 0.34 for 6-in (15 cm) trees growing on southern pine sites.

**Chemical Composition of Wood**

**Proximate Analyses**

<table>
<thead>
<tr>
<th></th>
<th>Karchesy and Koch (25)</th>
<th>Ritter and Fleck (26)</th>
<th>Bray and Paul (27)</th>
<th>Isenberg (28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>30.3</td>
<td>23.1</td>
<td>22.2</td>
<td>23.1</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>58.1</td>
<td>59.6</td>
<td>58.0</td>
<td>58.1</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>29.1</td>
<td>36.5</td>
<td>19.9</td>
<td>21.8</td>
</tr>
<tr>
<td>Cellulose, %</td>
<td>39.1</td>
<td>0.3</td>
<td>0.48</td>
<td>0.36</td>
</tr>
<tr>
<td>Ash, %</td>
<td>28.0</td>
<td>0.08</td>
<td>0.39</td>
<td>0.33</td>
</tr>
<tr>
<td>Hemicelluloses, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pentosans</td>
<td>Total, %</td>
<td>In cellulose, %</td>
<td>Acetyl, %</td>
<td>Acetic acid, %</td>
</tr>
<tr>
<td></td>
<td>21.7</td>
<td>10.3</td>
<td>3.12</td>
<td>5.81</td>
</tr>
<tr>
<td></td>
<td>21.6</td>
<td>10.4</td>
<td>2.89</td>
<td>5.86</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
<td>11.5</td>
<td>3.33</td>
<td>5.89</td>
</tr>
<tr>
<td></td>
<td>20.2</td>
<td>11.5</td>
<td>2.73</td>
<td>6.03</td>
</tr>
<tr>
<td></td>
<td>18.4</td>
<td>15.5</td>
<td>3.32</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>18.8</td>
<td>19.0</td>
<td>2.96</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>23.06</td>
<td>23.7</td>
<td>—</td>
<td>—</td>
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</table>
Solubility in

<table>
<thead>
<tr>
<th></th>
<th>Ether, %</th>
<th></th>
<th>Alcohol-benzene, %</th>
<th></th>
<th>50% alcohol, %</th>
<th></th>
<th>1% NaOH, %</th>
<th></th>
<th>Hot water, %</th>
<th></th>
<th>Cold water, %</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>0.27</td>
<td>0.43</td>
<td>0.13</td>
<td>0.58</td>
<td>-</td>
<td></td>
<td>2.93</td>
<td>4.30</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Alcohol-benzene, %</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>2.93</td>
<td>4.30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>50% alcohol, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<tr>
<td>1% NaOH, %</td>
<td>-</td>
<td>16.7</td>
<td>17.7</td>
<td>16.9</td>
<td>17.6</td>
<td>16.7</td>
<td>16.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Hot water, %</td>
<td>-</td>
<td>1.98</td>
<td>2.08</td>
<td>2.51</td>
<td>2.89</td>
<td>2.51</td>
<td>2.89</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cold water, %</td>
<td>-</td>
<td>1.29</td>
<td>1.50</td>
<td>1.45</td>
<td>1.45</td>
<td>1.29</td>
<td>1.50</td>
<td>1.45</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.25</td>
</tr>
<tr>
<td>Extractives, %</td>
<td>2.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Alcohol-benzene extractives of wood are 3.9% (29) and 2.5% (30).

Extractives. The sapwood contains 0.1-0.3% ether solubles, and heartwood contains 0.4-0.6% ether solubles (37). The wood contains alkaloids (32).

Other Information. A nitrogen-containing yellow pigment has been extracted from heartwood (33).

Chemical Composition of Bark

Proximate Analyses. The ash content of bark is 2.8% and alcohol-benzene extractives are 13.8% (29) and 18.4% (30).

Extractives. The bark contains alkaloids (32), and other substances including a lignan diglucoside (38).

Other Information. The bark contains 1.0% calcium, 0.05% silica (as a percent of oven-dry weight of the bark) (29).

Pulping

Alkaline. This superior grade of pulp has greater tear strength, breaking length, and burst strength than gum at a higher permanganate number and is more easily and quickly refined (34).

Kraft. The wood is readily pulped and the pulp is stronger than aspen pulp. It is fairly easily bleached (35).

Mechanical. The pulp is nearly equal in burst and tensile strengths to the average of commercial newsprint pulps. It is produced with an energy consumption of about 90 HP-days/ton. The color is good and averages nearly 60% in brightness (36).

NSSC. See Chidester (37).

Soda. The wood is fairly readily pulped, and the yield is normal. The pulp, stronger than aspen, is fairly easily bleached (35), requiring 15-20% bleach.

Sulfite. The wood is readily pulped. The pulp, of poor color, is difficult to bleach (35), requiring 20-25% bleach.

Other Information. This wood can be pulped by chemical processes or by the groundwood process. It yields short-fibered pulps relatively low in strength. The bleached chemical pulps are used in printing papers of higher grades, and the unbleached pulps, in the cheaper printing and wrapping papers, container boards, and insulating boards. Groundwood pulps are used in book, tissue papers, and heavy structural boards, such as insulation. Experiments have demonstrated that appreciable proportions of aspen NSSC and groundwood pulps may be utilized in the manufacture of newsprint and other printing grades.

Utilization of Wood and Bark

Use Properties of Wood. The wood is rather soft and light in weight and moderately weak in end compression. It is fairly stiff and elastic. It has an intermediate tendency to warp. It is easily worked with hand tools and is glued satisfactorily over a rather wide range of gluing conditions. It is easily kiln dried. It weathers with inconspicuous checking and will cup and pull loose from fastenings. It is about average in its ability to accept nails and screws without splitting. It takes a smooth and lasting finish.

Calorific Value of Wood

7775 BTU/oven-dry lb
4320 k cal/kg oven-dry

Calorific Value of Bark

212,260 BTU/ft³
1515 k cal/m³

7695 BTU/oven-dry lb
4275 k cal/kg oven-dry

Other Uses of Wood. The wood is cut principally into lumber, veneer, pulpwood, and bolts. Lumber goes mostly into furniture and fixtures, boxes and shooks, millwork, core stock for veneer panels, dimension stock, and miscellaneous uses such as musical instruments, toys, and sporting goods. Most veneer is used for plywood.


28. Isenberg, I. H. Personal communication.


30. Manwiller, F. G. Personal communication. (letter of April 8, 1975 to Einspahr).


**Scientific Name**  *Magnolia virginiana* L.

**Synonyms** Swampbay, swamp magnolia, laurel magnolia, southern sweetbay, sweetbay magnolia, magnolia, white bay

**Family Name** Magnoliaceae

**Range** Southeastern United States. The greatest abundance of sweetbay occurs in Florida, Georgia, South Carolina, and Alabama.

### Silvics

This small tree is a moisture-loving species which grows in mixtures with other species and is commonly found near streams, ponds, or swamps but not in bottomlands. It occurs with loblolly-bay, swamp tupelo, water tupelo, black tupelo, pond pine, slash pine, and various oaks. Sweetbay is fairly tolerant when young but becomes less so as it grows older.

**Tree Dimensions** Rarely exceeds 25 ft (7.6 m) in height, except on hummocks in Florida when it reaches 50-75 ft (15-23 m) and 2 or more ft (61+ cm) in diameter.

**Pathology** Many leaf spot and blotch fungi occur on sweetbay, including *Mycosphaerella milleri*, which causes small, angular spots and *M. glauca*, which causes large, circular spots. Other fungi causing leaf spots include *Phyllosticta glauca*, *P. magniflora*, *Cephaluros virescens*, *Phyllosticta cookei*, and *Cercospora magnoliae*.

A scale attacking sweetbay is the magnolia scale (*Neolecanium cornutum*). Heavily infested trees may be seriously weakened. Carter, et al. (1) discuss the resistance of sweetbay to wood-decay fungi and subterranean termites.

### Gross Features of the Wood

**Similar to cucumbertree.**

### Microscopic Structure of the Wood

**Vessels.** 60-120 per sq mm, the largest 60-110 μm in diameter; perforation plates scalariform with 2-12 bars; intervessel pits lenticular to linear (these pits have a scalariform appearance at low magnification; however, there are from 1-5 pits per row), 5-60 μm in diameter; ray crossing pits round, oval to elliptical, 6-35 μm in diameter.

**Fibers.** Moderately thick walled, 10-60 μm (averages 15-30 μm) in width and 1.3 mm in length.

**Rays.** 5-10 per mm tangentially on the x-section, unstoried, 1-4 (mostly 2-3)-seriate, heterogeneous, generally consisting of one row of upright cells on upper and lower margin less than 60 μm in height.

**Longitudinal Parenchyma.** Terminal, 1 or more seriate. Trace.

**Gross Features of the Bark**  Gray brown, superficially scaly on the larger trunks.

### Microscopic Structure of the Bark

**Periderm.** Composed of 3-6 layers of phelloderm, a layer of phellogen and very thick phellem. Phellem cells are rectangular to square in cross section and tend to be collapsed slightly in the outer part of the phellem.

**Sieve Tube Elements.** Expanded greatly and have very thick nacreous walls in the conducting phloem. The nacreous walls become thin when sieve elements cease functioning.

**Fibers.** Arranged in nearly radial files. Length varies from 420-1430 μm (mean length 1041 μm). In cross section, the fibers are rectangular to polygonal in shape and 15 X 25 μm in diameter at the broadest portion of the fibers. The secondary wall is very thick and lignified, and the lumina are almost occluded.

**Sclereids.** Develop mostly from ray parenchyma and occasionally from axial parenchyma. Sclereids developed from ray parenchyma cells tend to be aligned with the
fiber bands. Sclereids also form a few contiluious
tangential bands in the cortical region. They are mostly
expanded and of the stone cell type.

Rays. Rays are 1-2 (mostly 2)-seriate and essentially
differentiated.

Physical Properties of Wood. Manwiller (3) obtained a
stem wood specific gravity of 0.44 and a branch wood
specific gravity of 0.42 for 6-in (15 cm) hardwoods
growing on southern pine sites (based on oven-dry weight
and green volume).

Moisture content (dry weight basis) of the stem wood
was 100.8% (4).

Physical Properties of Bark

Specific gravity oven-dry
weight & volume (5) 0.64

Moisture content (dry weight basis) of the stem bark was
104.6% (4).

Chemical Composition of Wood

Proximate Analyses

Karchesy and
Koch (6)

Lignin, % 24.1
Hemicellulose, % 37.7
Cellulose, % 44.2
Ash, % 0.2
Extractives, % 3.9

The stem wood contains 3.0% alcohol-benzene extrac­
tives (7).

Chemical Composition of Bark

Proximate Analyses. The bark contains 16.4% alcohol­
benzene extractives (7).

Pulping

Kraft. The wood is readily pulped; the yield of pulp is
low. The pulp is rather difficult to bleach (8). A yield of
43.9% and screenings less than 0.5% was obtained at a
permanganate number of 12.2 (9).

Soda. The wood is readily pulped, and the yield is low.
The pulp is rather difficult to bleach (8).

Sulfite. The wood is readily pulped and yield is low.
The poor-colored pulp is easily bleached (8).

Utilization of Wood and Bark

Use Properties of Wood. The wood is even textured and
moderately heavy. It is fairly hard and straight-grained,
closely resembling yellow-poplar and cucumber-tree. It is
moderately stiff, high in shock resistance, rather low in
shrinkage, and has average nail-holding ability. It stays in
place well when properly seasoned, is readily worked,
and is satisfactorily glued. It takes paint, stains, and
natural finishes well. It is only moderately decay
resistant. It imparts little if any odor or taste when used
in food containers.

Calorific Value of Wood

7735 BTU/oven-dry lb.
4300 k cal/kg oven-dry

Calorific Value of Bark

7820 BTU/oven-dry lb.
4345 k cal/kg oven-dry

Other Uses of Wood. It is used principally for furniture,
especially frames for upholstered items. It is also used
for lumber, veneer, and plywood, for framing for boxes
and other kinds of containers, and for interior trim,
cabinet work, and doors. Veneer is used for containers
and packages, particularly wire-bound boxes and fruit
baskets. It is also used for plywood and face veneer on
items destined for painting, staining, or natural finish.

Literature Cited

1. Carter, F. L.; Amburgey, T. L.; Manwiller, F. G.

2. Nanko, H.; Cote, W. A. Bark structure of hard-
woods grown on southern pine sites. Syracuse


7. Manwiller, F. G. Personal communication. (letter of April 8, 1975 to Einspahr).


Scientific Name : *Liquidambar styraciflua* L.

Synonyms : Redgum, sapgum, starleaf-gum, bilsted, hazelwood, gumwood, alligator tree

Family Name : Hamamelidaceae

Range : Connecticut south to central Florida, west to Texas, Oklahoma, and Missouri, and north to southern Illinois. It is also found sporadically throughout Mexico and Central America. Christopher, et al. (7) estimate sweetgum to occupy 13.2% of the hardwood volume on pine sites. The largest volume of sawtimber is said to be in Louisiana.

Silvics : This large tree has a long, straight bole, a small oblong or pyramidal crown, and a shallow, wide-spreading root system. This is a typical southern bottomland species and occurs for the most part on rich, moist, alluvial soils, although it is widely distributed on a great variety of sites with the exception of poorly drained locations. It is very common also on old fields in dense, even-aged stands. Growth of sweetgum varies greatly with environmental conditions. The species tolerates elevations in the U.S. from sea level to 2000 ft (610 m), rainfall of 40-80 in (102-203 cm) per year, and average annual minimum temperatures ranging from -10 to 60°F. Where conditions are suitable, natural regeneration is abundant from both seeds and sprouts. This species is found associated with many species of hardwoods and softwoods throughout its range because of its adaptation to a great variety of sites. A very important associate is swamp red oak throughout the southern forest within the alluvial floodplains, on very high flats or ridges, distinctly elevated above typical low flats or glades. Nuttall oak, water oak, and willow oak are common associates on adjacent lands. On the Atlantic coastal plain yellow-poplar is a common associate and sweetgum is frequently found with lobolly pine in the South. Sweetgum is rated as intolerant.

Tree Dimensions : 80-120 ft (24-37 m) tall and 3-4 ft (91-122 cm) in diameter.

Pathology : Resistance to decay: intermediate

Sweetgum is very resistant to disease, although a large number of fungi can rot the wood, including *Fomes geotropus*, *Lentinus tigrinus*, *Pleurotus corticatus*, *P. ostreatus*, *Polyporus fisses*, *P. lucidus*, and *P. zonalis*. Sweetgum is susceptible to decay following fire injury. Trunk cankers are caused by *Botryosphaeria ribis* and its var. *chromogena*. A common leaf spot is caused by *Cercospora liquidambaris*.

Gross Features of the Wood : The sapwood is white, frequently with a pinkish tinge and often discolored with bluish sap stain. The heartwood is pinkish gray to varying shades of reddish brown, the darker grades frequently with darker streaks of pigment figure. The wood is moderately hard, moderately heavy, uniformly textured, frequently with interlocked grain, without characteristic odor or taste. A faint growth ring is evident with occasionally irregular darker streaks in “figured” gum. The diffuse-porous wood has small pores invisible with the naked eye, quite uniform in size throughout the growth ring, numerous and frequently crowded, solitary or in short radial groups. Parenchyma are not visible. The rays are not distinct with the naked eye, are very close and apparently form half the area on the transverse surface. Longitudinal traumatic (wound) gum ducts are sometimes present in tangential rows which usually appear at wide intervals, frequently occluded with white deposits. Interlocked grain in sweetgum is discussed by Webb (2, 3).

Microscopic Structure of the Wood

Vessels : 120-180 per sq mm, the largest 60-95 µm in diameter and 1.32 mm in length; perforation plates
scalariform with many bars; spiral thickening present, restricted to the tapering ends of the vessel segments; intervessel pits in transverse rows of 1-3, orbicular to oval or linear through fusion, 6-30 μm in diameter; volume occupied, approx. 55%. Variation in the proportion of vessels, rays and fibers in the wood of sweetgum in central Alabama is covered by Waldrip (4).

Gum Canals. When present, they are arranged in a uniseriate tangential row, with angled orifice.

Fiber Tracheids. Moderately thick walled, 20-40 μm in diameter, with conspicuous bordered pits 7-9 μm in diameter, and 1.7 mm (1.0-2.5 mm) long; weight factor (unbleached kraft) of 0.80; coarseness 26.6 mg/100 m (5); volume occupied, approx. 27%. Taylor (6) found that fiber length increased from the earlywood to the latewood and decreased in the last-formed latewood. Fiber length was greater and more variable in mature than in juvenile rings. According to Webb (3), fiber length was shortest near the center of the tree and increased with distance from the center. In addition, fiber length was longest at stump height and decreased with increasing height above ground. Other publications on fiber length include Hunter and Goggans (7), Ezell and Schilling (5), Jurbergs (9), and Chow (10).

Rays. 6-9 per mm tangentially on the x-section, unstoried, 1-3 (mostly 1-2)-seriate, mostly heterogeneous; upright cells in 1-5+ rows, 30-100 μm in height; volume occupied, approx. 18%.

Longitudinal Parenchyma. Paratracheal and metatracheal-diffuse; sparse.

Gross Features of the Bark. Generally, the bark of mature sweetgum is grayish-brown in color and deeply furrowed into narrow, flaky ridges. The outer bark is soft and rather loose and the inner bark somewhat more fibrous and lighter in color, turning dark after exposure. Bark of the more vigorous trees appears lighter, thick, and more deeply fissured with pronounced, rounded ridges. That of trees of low vigor is darker, thinner and flatter. According to Choong and Cassens (17), bark thickness of sweetgum averaged 0.35 in (0.89 cm).

Microscopic Structure of the Bark

Outer Bark. Generally broader than the inner bark, rhytidome formation begins very early in young trees and has conspicuous and sometimes broader periderm layers. In the mature tree, a periderm band is composed of 2-4 layers of phellem, a layer of phellogen and a number of layers of phellem. The first developed phellem cells are slightly suberized, rectangular in shape and thin-walled. Occasionally, a few of these cells become lignified. The regular phellem cells, typically suberized, are usually rectangular in shape, about 30μm in tangential diameter and 8 μm in radial diameter. Phelloderm cells are parenchymatous in nature but sometimes become lignified. In 8-year-old bark, rhytidome formation and sclerenchyma in the secondary phloem are developed and a basic pattern of mature bark is established (72).

Inner Bark. Sieve tubes, parenchyma cells, sclerenchyma and phloem rays make up the secondary phloem (inner bark) of the mature sweetgum.

Sieve Tube Elements. Rather long with compound sieve plates at the ends, sieve tube elements are aligned in radial rows of 1-6. Usually about 30μm, although up to 50 μm in diameter, the sieve tube elements are variable in length from 545-1240 μm. The mean length is 840 μm with a standard deviation of 133. Associated with the sieve tube elements are companion cells, 6-8 in a strand.

Parenchyma Cells. Parenchyma cells appear both sporadically distributed throughout the secondary phloem and as a narrow band aligned more or less continuously along the tangential plane. The bands consist of usually 1-3 layers of parenchyma cells which may eventually originate a few periderm. Cells in the scattered parenchyma strands often enlarge or become lignified, and with the phloem ray cells, are the origin of sclereid formation in the rhytidome.
Sclerenchyma. Sclerenchyma in the secondary phloem of sweetgum consist of fibers and sclereids. Appearing sporadically very close to the cambium, and often 20 cells away from this region, small groups or bands composed of 6-8 layers of fibers mixed with the sclereids, are aligned in more or less tangential rows. The fibers, often slightly twisted and with rounded ends, are variable in length from 0.51-1.56 mm. The mean length is 1.05 mm with a standard deviation of 0.28. With very thick cell walls showing lamellate layers, the diameter of the fiber is usually 20-30 μm, and up to 50 μm or more. The short sclereids originate and are transformed from the parenchyma strands and a portion of the adjacent ray cells. They may be simply lignified, retaining their original size and shape, or become irregular in size and twisted. Harder, et al. (73) found a fibrous yield of 5% when sweetgum bark was pulped to a solids yield of 34.9%.

Physical Properties of Wood

Specific gravity
- Green volume: 0.44
- Air-dry volume: 0.49
- Oven-dry volume: 0.52

Density, lb/ft³ (kg/m³)
- Green: 50 (801)
- Air-dry: 34 (545)
- Oven-dry: 32 (513)

Additional publications relating to wood moisture content include Choong and Cassens (17) and McElwee, et al. (23).

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th></th>
<th>F.P.L.</th>
<th>Anon.</th>
<th>Aung (25)</th>
<th>Karchesy and Koch (26)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin, %</td>
<td>21.4</td>
<td>23.5</td>
<td>22.3</td>
<td>23.9</td>
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<tr>
<td>Hemicellulose, %</td>
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<td>-</td>
<td>75.4</td>
<td>-</td>
</tr>
<tr>
<td>Hemicellulose, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>30.6</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>60.5</td>
<td>59.0</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Manwiller (22) obtained a stem bark moisture content of 120.4% and a branch bark moisture content of 108.8% on a dry weight basis.

Hunter and Goggans (15) found that growth rate appeared to have little bearing on specific gravity.

Specific gravity was lowest near the center of the tree and increased with distance from the center (3). However, specific gravity increased and then leveled off more abruptly than fiber length.

Other publications relating to specific gravity include Carpenter and Hopkins (16), Taylor (17, 18), Jett and Zobel (19), and Manwiller (20).

Percent shrinkage, dried to 0% moisture content: r = 5.2, t = 9.9, v = 15.0.

Percent moisture content, when green
- Green basis: 45
- Oven-dry basis: 81

Percent moisture content oven-dry basis (21)
- Heartwood: 79
- Sapwood: 137

Manwiller (22) obtained a stem bark moisture content of 89.3% and a branch bark moisture content of 108.9% on a dry weight basis.
The lignin content is 21.8% (27). The lignin content is 20.9%, and the methoxyl content is 1.51 (28). The ash content of sapwood is 0.5% (29). Choong and Fogg (30) report the extractives content of sapwood and heartwood. The content of alcohol-benzene extractives is 2.6% (37) and 2.3% (32).

### Carbohydrates

<table>
<thead>
<tr>
<th>Glucose, %</th>
<th>Unknown substances, %</th>
<th>Galactose, %</th>
<th>Mannose, %</th>
<th>Arabinose, %</th>
<th>Xylose, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>11</td>
<td>20</td>
</tr>
</tbody>
</table>

**Other Information.** The calcium content is 3.8%, and silica, 1.4% (as percent of oven-dry weight of the bark) (31).

### Pulping

**Kraft.** The wood is readily pulped, the yield is high, strength is good, and the pulp is easily bleached (37, 38, 39, 40, 41), requiring 5.7% total chlorine for GE brightness of 80 at a permanganate number of 14.9 (25). The wood is completely reduced in 1/2 hr at 170°C to give an easily-bleached pulp of 51.2% yield and only 0.2% screenings. The yield is 48% for a permanganate number of 12; burst strength is 1.35 pt/lb, and tear is 1.70 (38). For pulp strengths before and after bleaching see Perkins (42). Kraft and NSSC pulps made from 25% sweetgum and 75% southern pine can be used for liner boards (43). Prehydrolysis kraft pulping is used to produce nitrating-grade pulps and waterleaf sheets; for properties see Simmonds and Chidester (44). For kraft pulping information see Horn (45). For properties of
Kraft pulps bleached to GE brightness of 80 see Jett and Zobel (19).

Mechanical. Pulps are short fibered and generally low in strength; the freeness is generally low, and the color is dark (46). Mechanical pulp is best bleached with peroxide and hydrosulfite (47).

NSSC. This is good pulp (48, 49). It is used with other pulp for improved kraft test liner board (50).

Soda. The wood is fairly readily pulped, the yield is low, and the pulp is rather difficult to bleach (37, 41). Cold soda pulp is slightly stronger than southern pine groundwood and is darker in color (57). It is of good quality for insulation board (52).

Sulfite. The wood is readily pulped, yield is normal, and the dark-colored pulp is rather difficult to bleach (53). Chips have been pulped by a two-stage process of bisulfite and neutral sulfite; for properties of the pulp see Sanyer et al. (54).

Other Information. An easily bleached sulfate pulp contains 83% alpha-cellulose and 22% pentosans (55). The wood is readily pulped by sulfate and semichemical processes. The sulfate pulp is generally bleached for use in fine papers, such as book and writing papers. The semichemical pulp is widely used in corrugated board and is bleached for use in greaseproof, glassine, and book papers. The wood is made into dissolving pulp by a modified sulfate process followed by bleaching and purification.

Utilization of Wood and Bark

Use Properties of Wood. It is intermediate for planing, shaping, bending, splitting, and for nail- and screw-holding ability. The heartwood is nondurable, difficult to treat, and does not glue readily. The wood has a mild, uniform texture that is prized by cabinetmakers and woodworking industries. It often has interlocked grain which is largely responsible for the warping tendencies of lumber and the chipping that may occur in working. It shrinks considerably. The sapwood can be readily kiln-dried and is likely to stain. The heartwood is more difficult to season and requires time and care. Gluing requires care. The wood is of intermediate decay resistance. The heartwood is difficult to penetrate by preservatives.

Calorific Value of Wood

$$17.7 \times 10^6 \text{BTU/air-dry cord}$$

$$4260 \text{ kcal/kg oven-dry}$$

$$7665 \text{ BTU/oven-dry lb}$$

Calorific Value of Bark

$$200,430 \text{ BTU/ft}^3$$

$$1430 \text{ kcal/m}^3$$

$$7450 \text{ BTU/oven-dry lb}$$

$$4140 \text{ kcal/kg oven-dry}$$

Chemical Uses of Wood. Destructive distillation of heartwood: methanol, 1.76%; acetic acid, 5.70%; tar, 11.7%; charcoal, 36.8%.

Other Uses of Wood. The wood is used primarily for lumber, veneer, plywood, pulpwood, and slack co-opera. It goes into boxes and crates, general usage, dimension stock, and is remanufactured into furniture parts and fixtures. The wood is also used for UF-bonded particle boards.

Other Uses of Bark. The gum collected from the bark of living trees, called storax, is used as a flavoring and base for tobacco and in perfumes, adhesives, and pharmaceuticals.

**Literature Cited**


27. I.P.C. memo of July 17, 1953, file 1527 from code office.
32. Manwiller, F. G. Personal communication (letter of April 8, 1975 to Einspahr).


53. Carpenter, C.; McCall, F. Rayon Textile Mo. 19:538, 618(1938).


Scientific Name  *Platanus occidentalis* L.

Synonyms Buttonwood, platetree, buttonball tree, American sycamore, American planetree

Family Name  Platanaceae

Range  Sycamore is widely distributed in the eastern United States, occurring in all states east of the Great Plains except Minnesota. As a north temperate species, the natural range is limited in the north by cold temperatures and in the west by the dry climate of the plains. Sycamore is also found in southern Ontario.

Silvics  Sycamore is one of the largest hardwoods in the eastern states. Anywhere from 20-80 ft (6-24 m) from the ground, the large trunk usually branches into a massive, spreading, open, somewhat irregular, pendulous crown. The root system is superficial. Tolerant of wet soil, sycamore makes its best growth in alluvial soils where there is a good supply of ground water. Good growth seldom occurs on old, eroded field sites although sometimes excellently stocked natural stands appear on the coal-stripped land of the central states. Such sites in the northeast and central states are recommended for plantings. This tree is one of the commonest of streambank and bottomland species. Its associates include red and silver maples, river birch, cottonwoods, and willows. Sycamore sprouts readily from young stumps and cuttings root easily. It is a fast-growing tree throughout its life and is windfirm due to a strongly branched root system. Sycamore is generally rated as intolerant.

Tree Dimensions  100-120 ft (30-37 m) tall and 3-8 ft (91-244 cm) in diameter. The largest eastern hardwood in trunk diameter.

Pathology  Resistance to decay: low

Sycamore is relatively unaffected by disease problems. The most important is anthracnose, caused by *Gnomonia platani* and sycamore may be completely defoliated by this disease. The most destructive heart rot fungi of sycamore include *Hydnium erinaceus*, *Fomes applanatus*, *Polyporus cuticularis* and several others. The canker-stain disease (*Ceratocystis fimbriata* f. sp. *platani*) can be lethal but is much more damaging to London plane (*Platanus acerifolia*).

The flat-headed apple borer (*Chrysobothris femorata*) attacks sycamore, occasionally causing serious defoliation or otherwise seriously injuring the tree. Sycamore is the preferred host for the sycamore lace bug (*Corythucha ciliata*) and severe injury from defoliation may result during dry weather. The Japanese beetle (*Popillia japonica*) also attacks sycamore. An additional defoliator is the white-marked tussock moth (*Hemerocampa leucostigma*). However, none of these insects is of serious economic importance in the forest.

Gross Features of the Wood  The sapwood is whitish to light reddish brown, and the heartwood is a light to dark reddish brown. The wood is moderately hard, moderately heavy, generally with interlocked grain, with no characteristic taste or odor. The growth rings are distinct, delineated by a narrow band of lighter tissue at the outer margin. The wood is diffuse-porous with small pores, indistinct or barely visible with the naked eye, numerous and frequently crowded. Parenchyma are not visible. The rays are comparatively wide, conspicuous with the naked eye, nearly uniform in width, close, appearing as short, closely packed lines on the tangential surface, forming a high, reddish-brown or silvery fleck on the radial surface.

Microscopic Structure of the Wood

Vessels.  100-140 per sq mm, the largest 60-100 μm in diameter; av. length 0.63 mm (0.43-0.85); perforation plates simple for the most part, occasionally scalariform with a few bars; intervessel piths oval to orbicular, widely spaced, 4-6 μm in diameter; volume occupied, approx. 52%.
Fibers. Average, 1.7 mm in length and 20-36 μm in diameter; moderately thick walled; volume occupied, approx. 29%. Saucier and Ike (1) found that fiber length was positively correlated with rate of growth two years after nitrogen fertilization and thinning treatments were applied to 7-year-old sycamore. An additional publication by Saucier and Ike (2) examines the effect of fertilization on selected wood properties.

Rays. Unstoried, 1-14-seriate, up to 3+ mm in height, homogeneous; volume occupied, approx. 19%. Saucier and Ike (2) found that ray volume was significantly influenced by applications of N, and N + P to a 7-year-old planting.

Longitudinal Parenchyma. Paratracheal and metatracheal-diffuse; the paratracheal are restricted to occasional cells, never forming a sheath; the metatracheal are abundant, scattered and zonate in short lines which exhibit no regularity.

Gross Features of the Bark. The thin bark on young branches is creamy white, soon turning brown; characteristically mottled (brown and white) by the exfoliation of the outer bark exposing the lighter layers beneath; the bark near the base of older trees is often entirely brown and scaly. Low winter temperatures may injure the cork cambium and cause the outer bark to slough off, but the tree health is not affected.

Microscopic Structure of the Bark

Periderm. The usually thin rhytidome caused by the frequent exfoliation has been attributed to a separation between the thin and thick-walled phellem or cork cells of the periderm. The last-formed periderm usually consists of 3-5 layers of phelloderm, a layer of phellogen and 10 or more layers of phellem. The phelloderm cells are quite uniformly thick walled, rectangular in shape and contain "resinous" substances. Just outside the layer of phellogen are usually 3-5 layers of phellem cells with unevenly thick walls forming a narrow and eccentric cell cavity and showing conspicuous lamellate layers, simple pits and cell contents. These cells are structurally similar to the phelloderm except the latter are relatively smaller and narrower and the cell walls are evenly thickened and lignified rather than suberized. The other form of phellem tends to be more square shaped and has much thinner, but evenly thick walls, no pits and large empty cell cavities. The transition between the two phellem types is usually abrupt although there may be 1-2 layers of an intermediate form.

Sieve Tube Elements. Confined by the broad phloem rays and tangentially aligned parenchyma, sieve tubes retain their shape and size only in groups close to the cambium, becoming deformed and crushed at the third or fourth zone beyond. They appear solitary or in short radial rows and are usually about 40-60 μm in tangential diameter and vary between 420-820 μm in length with a mean length of 634 μm. Companion cells about the same length or less are associated at the narrow dimension of sieve tube elements.

Parenchyma. Form sporadic strands which are usually concentrated in narrow, tangential bands. Parenchyma cells contiguous with the phloem ray cells merge with them and a tangential zone of phloem rays line up with the parenchyma bands. Individual cells are rectangular in cross section, vary from 50-150 μm high and contain tanniferous substances.

Sclereids. Formed from parenchyma strands and ray cells as their cell walls become strongly lignified and often uneven in thickness. Between the rays, sclereids form broad bands, squeezing the functional elements to a narrow zone, and within the ray, begin at the central portion, forming zones. These lignified cells, sclereids, often contain solitary crystals (probably calcium oxalate) and usually retain their original shape and size but often tend to expand and deform at the outer part of the secondary phloem. According to Chang (3), sclereids make up 31.7% of the tissue elements of the secondary phloem.

Phloem Rays. Usually high and broad, homogeneous, multiseriate rays, about 10-16 cells wide, with a few uniseriate rays. The ray cells are procumbent and square in shape and those at the margins of the rays and in the narrow zones associated with the parenchyma bands are parenchymatous in nature and contain tanniferous substances. The lignified cells begin very close to the cambium and in the central portion of the rays and broad sclerified zones alternate with those of the parenchymatous ray cells. According to Chang (3), rays make up 27.7% of the tissue elements of the secondary phloem.

Phloem Fibers. Absent in the secondary phloem.
Physical Properties of Wood

Specific gravity
- Green volume: 0.46
- Air-dry volume: 0.50
- Oven-dry volume: 0.54

Density, lb/cu ft (kg/cu m)
- Green: 52 (833)
- Air-dry: 35 (561)
- Oven-dry: 34 (545)

Density, lb/cu ft (kg/cu m) per green volume
- Oven-dry weight: 29 (464)

According to Taylor (4), working with six dominant trees in a 50-year-old stand, specific gravity was almost unaffected by normal variations in growth rate, was unaffected by sampling height, increased with age in the lower stem but decreased with age at heights greater than 40 feet (12 m). Taylor (5) also found that density was positively correlated to ray content.

Specific gravity was positively correlated with rate of growth two years after nitrogen fertilization and thinning treatments were applied to 7-year-old sycamore (7).

Additional publications include McElwee, et al. (6), Taylor and Wooten (7), and Jett and Zobel (8).

Percent shrinkage, dried to 0% moisture content: r - 5.1, t - 7.6, v - 14.2.

Percent moisture content, when green
- Green basis: 45
- Oven-dry basis: 83

Percent moisture content, oven-dry basis (9)
- Heartwood: 114
- Sapwood: 130

Physical Properties of Bark

Specific gravity
- Green volume
  - Inner bark: 0.60
  - Outer bark: –
  - Total bark: 0.60
- Oven-dry weight & volume (10): 1.21

Specific gravity
- Oven-dry weight & volume: 0.67
- Green weight/green volume: 1.21

Cross Sections of Sycamore Inner and Outer Bark. Bottom Photograph Shows Xylem (X), Cambium Zone (CZ), Sieve Tube Elements (ST), Bands of Phloem Parenchyma (PP) and Phloem Rays (PR). Top Photograph Shows Part of the Outer Bark with Periderm Layers (P). Magnification – 30X.
Chemical Composition of Wood

Carbohydrates

<table>
<thead>
<tr>
<th>Carbohydrates</th>
<th>Chang and Mitchell (74)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose, %</td>
<td>50</td>
</tr>
<tr>
<td>Unknown substances, %</td>
<td>2</td>
</tr>
<tr>
<td>Galactose, %</td>
<td>4</td>
</tr>
<tr>
<td>Mannose, %</td>
<td>1</td>
</tr>
<tr>
<td>Arabinose, %</td>
<td>4</td>
</tr>
<tr>
<td>Xylose, %</td>
<td>30</td>
</tr>
</tbody>
</table>

Extractives. The bark is rich in triterpenes and contains betulinic acid, betulinic aldehyde, β-sitosterol, platanic acid, stearic acid, and docosanoic acid (73).

Other Information. The bark contains 3.0% calcium and 0.06% silica (as percent of oven-dry weight of the bark) (72).

Pulping

Alkaline. The wood is not difficult to pulp and produces good quality pulp with excellent yields; it has slightly better physical properties than gum (75).

Kraft. The wood is easily pulped (76).

Soda. The wood is easily pulped, yield is high, and the pulp is fairly easy to bleach (76).

Sulfite. The wood is readily pulped, yield is normal, and the pulp is easy to bleach (76). Pulp made from young whole trees made a corrugating medium that compared favorably to a commercial corrugating medium made of 75% NSSC of mixed hardwoods and 25% secondary fibers. Mullen, break length, ring crush, and concora tests were comparable, and the board had a lower tear strength than the commercial board (8).

Other Information. The pulp is also used for liner boards and dry-formed hardboards.

Utilization of Wood and Bark

Use Properties of Wood. The wood is moderate in weight, hardness, stiffness, shock resistance, bend strength, endwise compression, and in hail-holding ability. It has a close texture, is satisfactorily glued, and, because of its interlocked grain, resists splitting by nails and screws. It maintains its shape well when bent after steaming, and it is easily machined. The wood shrinks moderately in drying, is inclined to warp when plain-sawn, and is not durable when exposed to conditions
that are conducive to decay. The wood is odorless, tasteless, and stain-free, which makes it desirable for containers for food and tobacco.

**Calorific Value of Wood**

- 18.5 x 10^6 BTU/air-dry cord

**Calorific Value of Bark**

- 7405 BTU/lb
- 4115 kcal/kg
- 298,380 BTU/ft^3
- 2125 kcal/m^3

**Other Uses of Wood.** It is used for millwork, flooring, furniture drawer sides, pallets, wire-bound and nailed boxes, veneers for furniture, butcher blocks, handles for brushes and brooms, ties, cooperage, and fuel.

**Literature Cited**


12. Institute of Paper Chemistry, Project 3212, Progress Rept. 7.


YELLOW BUCKEYE

Scientific Name  *Aesculus octandra* Marsh.

Synonyms  Sweet buckeye, big buckeye, buckeye

Family Name  *Hippocastanaceae*

Range  Central States, chiefly Ohio Valley and Appalachian regions.

Silvics  This medium-sized tree, with an oblong, rounded crown, grows best on deep, fertile soils in the mountains of Tennessee and North Carolina. It occurs scattered sparsely through the forest in mixture with yellow birch, beech, sugar maple, red spruce, hemlock, and Fraser fir. In other parts of its range, it is a bottomland species.

Tree Dimensions  60-90 ft (18-27 m) tall and 2-3 ft (61-91 cm) in diameter.

Pathology  Resistance to decay: low

Yellow buckeye is subject to few diseases and none of them are important economically. The most destructive disease is the leaf blotch (*Guignardia aesculi*). Trees may be severely affected by this blotch, although it does not seem to noticeably affect growth. The species is also relatively free of defects caused by wood-rotting fungi. The only wood-rotting fungi reported infecting living trees are *Polyporus squamosus* and *Collybia velutipes*.

Buckeye is occasionally attacked by the walnut scale (*Quadraspidiotus juglandisregiae*) and the oystershell scale (*Lepidosaphes ulmi*). The sapwood timberworm (*Dyleocetus lugubris*) tunnels under the bark and across the sapwood. However, none of these insects are of serious consequence.

Gross Features of the Wood  The sapwood is white to grayish white, gradually merging into the heartwood which is creamy white to pale yellowish white, frequently with grayish streaks of stain. The wood is light, soft, straight grained, uniformly textured, and without characteristic taste or odor. The growth rings are not visible or barely distinct and delineated by a light-colored line, generally narrow. The diffuse-porous wood has numerous minute pores not visible without a hand lens, nearly constant in size and quite evenly distributed throughout the growth ring, solitary and in radial groups of 2 or more. Parenchyma are not visible or barely visible as a light line terminating the growth ring. The rays are very fine, scarcely visible with a hand lens, close and often apparently forming half of the area on the cross section, usually storied and forming fine ripple marks on the tangential surface.

Microscopic Structure of the Wood

**Vessels.** 120-200 per sq mm, the largest 40-80 μm in diameter; perforation plates simple; spiral thickening present; intervessel pits orbicular to oval to angular, 5-10 μm in diameter.

**Fibers.** Average 0.9 mm (0.5-1.4 mm) in length and 16-30 μm in diameter; thin walled.

**Rays.** Usually storied, uniseriate, homogeneous to heterogeneous.

**Longitudinal Parenchyma.** Marginal and paratracheal; the terminal in a more or less continuous, 1 or more seriate line; paratracheal sparse, restricted to occasional cells.

Gross Features of the Bark  Breaking up into fine scales.

Physical Properties of Wood

<table>
<thead>
<tr>
<th>Property</th>
<th>Specification</th>
<th>Specific gravity</th>
<th>Density, lb/cu ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green volume</td>
<td></td>
<td>0.33</td>
<td>50 (801)</td>
</tr>
<tr>
<td>Air-dry volume</td>
<td></td>
<td>0.36</td>
<td>25 (400)</td>
</tr>
<tr>
<td>Oven-dry volume</td>
<td></td>
<td>0.38</td>
<td>24 (384)</td>
</tr>
<tr>
<td>Density, lb/cu ft</td>
<td></td>
<td>Green</td>
<td>50 (801)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Air-dry</td>
<td>25 (400)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oven-dry</td>
<td>24 (384)</td>
</tr>
<tr>
<td>Oven-dry weight per green volume</td>
<td></td>
<td>21 (336)</td>
<td></td>
</tr>
</tbody>
</table>

Percent shrinkage, dried to 0% moisture content:  $r - 3.6$, $t - 8.1$, $v - 12.5$. 


Percent moisture content, when green

Green basis 58
Oven-dry basis 141

Utilization of Wood and Bark

Use Properties of Wood. The wood is light, soft, straight grained, weak, difficult to split, not very stiff, and has low resistance to wear. It has little or no figure, the heartwood is not distinct, and blue stain is common during seasoning.

Other Uses of Wood. The wood is used for furniture, boxes and crating, caskets, trunks, and fuel.
BLACK TUPELO

Scientific Name  *Nyssa sylvatica* Marsh.

Synonyms  Blackgum, sour gum, tupelo, pepperidge, tupelo-gum

Family Name  Cornaceae

Range  Eastern United States from southwestern Maine to eastern Texas. Black tupelo amounts to 5.5% of the hardwood volume on pine sites in 12 southern states (7).

Pathology  Resistance to decay: low

The eastern leafy mistletoe (*Phoradendron serotinum*) is common on black tupelo in the South. A number of fungi are capable of causing rot of either the central cylinder or at wounds. They include, among others, *Daedalea ambiguа* and *Oxyporus populinus*. Branch cankers in the south are caused by *Fusarium solani*. In the north, *Nectria galligenа* causes branch and stem cankers.

Silvics  This medium-sized tree has a long, clear bole and a narrow crown. It grows on moist or wet sites but will not live under extreme swampy conditions. Further north it occurs on high, dry ground as well as in wet locations. Throughout most of its range its chief associates are various oaks, hickories and pines, yellow-poplar, sweetgum, red maple and beech. Black tupelo is rated as tolerant.

Tree Dimensions  60-80 ft (18-24 m) tall and 2-3 ft (61-91 cm) in diameter. On favorable sites, black tupelo can reach a mature height of 120 ft (37 m) and diameters of 4 ft (122 cm) or more.

The forest tent caterpillar (*Malacosoma disstria*) attacks black tupelo, preferring it for feeding in the South, along with water tupelo, sweetgum and various species of oaks. Black tupelo is also attacked by the gypsy moth (*Porthetria dispar*).

Gross Features of the Wood  The wide sapwood is white to grayish white, and the heartwood is greenish or brownish gray in color. This diffuse-porous wood is moderately hard and moderately heavy, usually with interlocked grain, and without characteristic odor or taste. Flat grain boards exhibit a faint growth ring, although even under a lens the growth rings in the x-section are generally indistinct. In quarter section a distinct but not pronounced ribbon figure is present because of the interlocked grain. The texture is fine. The pores are small, not visible with the naked eye, quite uniform in size, numerous and fairly evenly distributed, solitary or occasionally in short radial groups. Parenchyma are not visible. The rays are fine, not distinct in the x-section without a hand lens, very close and appearing to form about half the area.

Microscopic Structure of the Wood  Vessels. 80-180 per sq mm, the largest 60-90 \( \mu \)m in diameter and 1.33 mm in length. The perforation plates are scalariform with numerous thin bars. Spiral thickening is occasionally present and is restricted to the
tapering ends of the vessel segments. Intervessel pits in transverse rows of 1-5+, 5-12 (mostly 8-10) μm in diameter. Volume occupied, approx. 38%.

Fibers. Average, 1.80 mm (0.8-2.7 mm) in length and 20-32 μm in diameter; moderately thick to thick walled; weight factor (bleached kraft) of 0.75 and coarseness of 22.7 mg/100 m² (2). Branchwood fiber length averaged 1.28 mm (3). Fiber length increased from the pith to the bark at an almost constant rate (4). No significant differences in fiber length were found among geographic locations (5). Additional publications in this area include Horn (6) and Manwiller (7).

Rays. 8-13 per mm tangentially on x-section, unstoried, 1-4-seriate, heterogeneous with the upright cells generally restricted to one row on the upper and lower margins and less than 60 μm high. Volume occupied, approx. 17%.

Longitudinal Parenchyma. Paratracheal and apotracheal-diffuse, scattered. Trace.

Gross Features of the Bark Bark of the young black tupelo is gray with shallow fissures and flaky scales. Old trunks are grayish brown and deeply furrowed, similar in pattern to alligator hide. Rhytidome layers form broad, flat ridges that are often checked horizontally. The light brown inner bark, on cross section, shows discontinuous broad bands of sclerenchyma aligned tangentially and often above or closely connected to fine bands. In the outer bark, the sclerenchyma bands are fewer in number but distinct to the naked eye as are the brownish-yellow peridermal lines.

Microscopic Structure of the Bark

Young Bark The periderm consists of suberized phellem cells and a layer each of phellogen and phelloderm. The cortex is composed of a few layers of collenchyma and ordinary parenchymatous cortex cells often containing crystals, which are probably calcium oxalate. Primary phloem fibers are in isolated groups with sclereids distributed among them and forming connected bands encircling the phloem. Parenchymatous cells and sieve tubes form most of the secondary phloem in the young bark.

Mature Bark.

Periderm. The periderm in mature bark usually consists of a broad band of phellem, a layer of phellogen and 1-2 layers of poorly developed phelloderm. There are usually 5 layers of thick-walled, conspicuously suberized phellem cells close to the phellogen, followed by 5 or more layers of larger, thinner-walled, first-formed phellem. The phelloderm and phellogen cells, much narrower than the phellem, often become lignified. Periderm formation is frequent.

Sieve Tube Elements. Usually, 30-50 μm in diameter, sieve tubes are solitary or in short radial multiples. Sieve tube elements vary from 520-1205 μm in length with companion cells at the narrow dimension.

Parenchyma. Sporadic or in reticulate formation, parenchyma, in 1-3 layers, appear adjacent to the fiber bands on the cambium side and may initiate new periderm. Cells often contain tanniferous substances and crystals and may become sclerified and form sclereid groups with other cells.

Sclerenchyma. Sclereids and typical phloem fibers form the sclerenchyma. Sclereids of transformed parenchyma strands and phloem ray cells are thick-walled and not much branched, often containing solitary crystals, probably composed of calcium oxalate. A sclereid group is often 10 or more cells wide on radial dimension and always closely connected with a fiber band. Fibers, developing earlier than the sclereids, are aligned in generally tangentially narrow bands of 3-4 layers. On cross section, they are polygonal in shape, about 25 μm in diameter and have very thick walls and narrow lumina. With pointed ends, the fibers vary in length from 0.72-2.33 mm. According to Chang (8), the mean length is 1.47 mm with a standard deviation of 0.39. Harder, et al. (9) found a fibrous yield of 6% when black tupelo was pulped to a solids yield of 31.4%.

Phloem Rays. Heterogeneous and both uniseriate and multiseriate with high marginal cells. The uniseriate rays, usually 6-10 cells high but up to 20+, are composed of generally square and upright cells. Multiseriate rays, 2, 3 and sometimes 4-seriate, often vertically fuse and form a very high ray of mainly upright cells. Rays are spaced quite closely and do not dilate much at the outer margin of the inner bark.
Physical Properties of Wood

Specific gravity
- Green volume: 0.46
- Air-dry volume: 0.50
- Oven-dry volume: 0.54

Density, lb/cu ft (kg/cu m)
- Green: 45 (721)
- Air-dry: 35 (561)
- Oven-dry: 34 (545)

Density, lb/cu ft (kg/cu m)
- Oven-dry weight per green volume: 29 (464)

Manwiller (70) obtained a stem wood specific gravity of 0.50 and a branch wood specific gravity of 0.49 (oven-dry wt. and green vol.) for 6-in (15 cm) trees growing on pine sites.

No significant differences among geographic locations were found in specific gravity for black tupelo (5).

Other publications in this area include Jett and Zobel (77), and Taylor (3, 4).

Percent shrinkage, dried to 0% moisture content: r - 4.4, t - 7.7, v - 13.9.

A publication related to shrinkage is Hann (72).

Percent moisture content, when green
- Green basis: 35
- Oven-dry basis: 55

Percent moisture content on oven-dry basis (73)
- Heartwood: 87
- Sapwood: 115

Physical Properties of Bark

Specific gravity
- Inner bark: 0.38
- Outer bark: 0.37
- Total bark: 0.44

Density (100% moisture content)
- Green weight/green volume: 0.85

Specific gravity oven-dry weight & volume (74)
- 0.55

Manwiller (75) obtained a stem bark moisture content of 69.8% and a branch bark moisture content of 88.4% (dry weight basis).
### Chemical Composition of Wood

#### Proximate Analyses

<table>
<thead>
<tr>
<th></th>
<th>Bray and Eastwood ((16))</th>
<th>Wise and Pickard ((17))</th>
<th>Karchesy and Koch ((18))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sap</td>
<td>Heart</td>
<td>Separate trees</td>
</tr>
<tr>
<td>Lignin, %</td>
<td>28.6</td>
<td>24.66</td>
<td>26.65</td>
</tr>
<tr>
<td>C. &amp; B. cellulose, %</td>
<td>57.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>42.5</td>
<td>43.54(^a)</td>
<td>43.15(^a)</td>
</tr>
<tr>
<td>Cellulose, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hemicellulose A, %</td>
<td>-</td>
<td>19.02</td>
<td>19.38</td>
</tr>
<tr>
<td>Hemicellulose B, %</td>
<td>-</td>
<td>3.35</td>
<td>2.85</td>
</tr>
<tr>
<td>Hemicellulose, %</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.65</td>
<td>0.86</td>
<td>0.4</td>
</tr>
<tr>
<td>Pentosans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total, %</td>
<td>20.8</td>
<td>16.36(^b)</td>
<td>16.60(^b)</td>
</tr>
<tr>
<td>In cellulose, %</td>
<td>12.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>-</td>
<td>3.54</td>
<td>2.14</td>
</tr>
<tr>
<td>Uronic anhydride, %</td>
<td>-</td>
<td>4.49</td>
<td>4.98</td>
</tr>
<tr>
<td>CH(_2) from methoxyl not in lignin, %</td>
<td>-</td>
<td>0.89</td>
<td>0.65</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol-benzene, %</td>
<td>3.4</td>
<td>2.44</td>
<td>2.41</td>
</tr>
<tr>
<td>Ether, %</td>
<td>0.3</td>
<td>0.44</td>
<td>0.54</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>4.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cold water, %</td>
<td>-</td>
<td>0.27</td>
<td>0.32</td>
</tr>
<tr>
<td>Extractives</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^a\)Corrected for xylan,

\(^b\)Calculated as xylan, corrected for uronic anhydride.

Sapwood contains 27.0% lignin \((19)\); heartwood contains 28.7% lignin. Ether solubles constitute 0.3-0.4% of whole wood, 0.4% of sapwood, and 0.5% of heartwood \((17)\). Wood contains 3.0% \((20)\) and 3.2% alcohol-benzene extractives \((21)\).

#### Extractives

<table>
<thead>
<tr>
<th></th>
<th>Walkup et al. ((22))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition of ether extractives</td>
<td></td>
</tr>
<tr>
<td>Free fatty acids, %</td>
<td>47</td>
</tr>
<tr>
<td>Fats, %</td>
<td>16</td>
</tr>
<tr>
<td>Unsaponifiables, %</td>
<td>37</td>
</tr>
</tbody>
</table>

**Other Information.** The hydrolysis of carbohydrates in wood shavings was studied by Bernardin \((23)\).

### Chemical Composition of Bark

#### Proximate Analyses

<table>
<thead>
<tr>
<th></th>
<th>Chang and Mitchell ((24))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, %</td>
<td>7.2</td>
</tr>
<tr>
<td>Methoxyl, %</td>
<td>4.97</td>
</tr>
<tr>
<td>Solubility in</td>
<td></td>
</tr>
<tr>
<td>Benzene, %</td>
<td>2.5</td>
</tr>
<tr>
<td>95% alcohol, %</td>
<td>4.6</td>
</tr>
<tr>
<td>Hot water, %</td>
<td>5.3</td>
</tr>
<tr>
<td>1% NaOH, %</td>
<td>27.8</td>
</tr>
</tbody>
</table>

The ash content is 7.3%, and alcohol-benzene extractives are 10.6% \((20)\) and 12.0% \((21)\).
Carbohydrates

Reducing sugars from extractive free bark

<table>
<thead>
<tr>
<th>Sugar</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose</td>
<td>60</td>
</tr>
<tr>
<td>Unknown substances</td>
<td>3</td>
</tr>
<tr>
<td>Galactose</td>
<td>4</td>
</tr>
<tr>
<td>Mannose</td>
<td>1</td>
</tr>
<tr>
<td>Arabinose</td>
<td>8</td>
</tr>
<tr>
<td>Xylose</td>
<td>24</td>
</tr>
</tbody>
</table>

Other Information. The calcium content of bark is 2.9%, and silica content is 0.11% (as percent of oven-dry weight of the bark) (20).

Pulping

Kraft. The wood is readily pulped, yield is normal, strength is relatively low, and the pulp is rather difficult to bleach (25, 26). For information on strength of pulp before and after bleaching see Perkins (27). For kraft pulping information see Horn (6).

Mechanical. The pulp is about equal in burst and tensile strength and lower in tear strength than an average of a number of commercial newsprint grade pulps. It was prepared with slightly higher energy consumption than 100 HP-days/ton. The color is good (28, 29, 26).

NSSC. This pulp is good; it is used in corrugating medium and improved kraft test linerboard (76, 30, 31, 32).

Soda. The wood is readily pulped; yield is low; the pulp, slightly stronger than aspen pulp, is rather difficult to bleach (33, 26).

Sodium Borohydride and Sodium Bisulfite. For pulp properties see Ruffini and Gandini (34).

Sulfite. The wood is readily pulped and yield is normal. The pulp is fairly easy to bleach and is suitable for absorbent materials, tissues, book papers and specialty papers (35, 36, 26).

Utilization of Wood and Bark

Use Properties of Wood. The wood has a natural tendency to warp when dried, especially when plain sawn. It can be dried satisfactorily with proper drying methods. It is moderately strong, is easily penetrated by preservatives, and holds paint well. It is somewhat difficult to glue. It takes a finish, holds nails well, has good resistance to wear, is tough, and is difficult to split.

Calorific Value of Wood

7865 BTU/oven-dry lb
4370 k cal/kg oven-dry

Calorific Value of Bark

222,805 BTU/ft³
1590 k cal/m³

7790 BTU/oven-dry lb
4330 k cal/kg oven-dry

Other Uses of Wood. Large quantities of wood are used in the production of furniture, shipping containers, and millwork. Wood is used for lumber, plywood, veneer, cooperage, cross ties, bridge ties, and crossing planks. The wood is desirable for pulpwood. Where it is accessible and plentiful, its use for hardwood pulp is probably second only to that of sweetgum.

Literature Cited


35. Carpenter, C.; McCall, F. Rayon Textile Mo. 19:538, 618(1938).

WATER TUPELO

Scientific Name  *Nyssa aquatica* L.

Synonyms  Tupelo, tupelo-gum, swamp tupelo, cotton-gum, sour-gum, bay poplar

Family Name  Cornaceae

Range  South Atlantic and Gulf coastal plains; lower half of Mississippi Valley.

Silvics  The trunk of this medium-sized to large tree is enlarged at the base but tapers rapidly to a long, clear bole. This species is a characteristic southern swamp tree and grows on sites periodically inundated. Water tupelo occurs in almost pure stands, or mixed with bald-cypress, red maple, and swamp tupelo in some areas. The growth on well-drained bottomlands is rapid, whereas that on extremely swampy sites is much slower. This tree occurs also with various pines, oaks, yellow-poplar, sweetbay, redbay, black tupelo, and pond-cypress. Heavy seed crops are borne annually.

Tree Dimensions  80-100 ft (24-30 m) tall and 3-4 ft (91-122 cm) in diameter.

Pathology  Resistance to decay: low

Because of its thin bark, fire is a major enemy of water tupelo. The scorching of bark by fire opens a path for the entrance of rot. Fortunately, the progress of rot is very slow. The most conspicuous leaf disease is caused by *Mycosphaerella nyssaeola*. *Aplospora nyssa* is a rust that occurs occasionally on water tupelo.

Water tupelo is a preferred species for feeding by the forest tent caterpillar (*Malacosoma disstria*) and it is also attacked by the gypsy moth (*Lymantria dispar*). The species is not bothered seriously by other insects.

Gross Features of the Wood  Similar to black tupelo but usually somewhat softer, lighter, and more porous, and with more crowded, slightly larger vessels.

Microscopic Structure of the Wood  See black tupelo.

Vessels  Average length, 1.11 mm.

Fibers  Average length, 1.89 mm.

McElwee and Faircloth (1) found that fiber length variation was much greater within an individual tree than between trees and stands. No relationship was found between fiber length and specific gravity or overall growth rate.

Gross Features of the Bark  Thin, brownish gray, with longitudinal scaly ridges. Exposed areas are light brown with a strong yellowish hue.

Microscopic Structure of the Bark  (2)

*Periderm.* Periderm formation is frequent and sometimes a layer of periderm becomes locally broadened. Within one periderm the well-developed phellem cells show conspicuous changing of size and the thickness of cell walls from those first-formed layers to the last-formed ones.

*Sieve Tube Elements.* Sieve tubes are solitary in arrangement and tend to be in short radial multiples.

*Parenchyma.* Parenchyma is sporadic or in tangential lines. The latter type is usually close to the previously developed fibers and the cells are related to the periderm formation. Crystaliferous parenchyma strands are present.

*Phloem Rays.* Two sizes, uniseriate and multiseriate, with long, uniseriate marginal cells. They are heterogeneous, and composed mostly of square and upright cells.

*Sclerenchyma.* Well-developed phloem fibers are present, which are aligned in regular tangential bands that are often nearly continuous. Sclereids are poorly developed and often absent along the fiber bands.
Physical Properties of Wood

| Specific gravity | Green volume | 0.46 |
| Air-dry volume   | 0.50         |
| Oven-dry volume  | 0.52         |

Density, lb/cu ft (kg/cu m)

| Density, kg/cu m | Green | 57 (913) |
|                 | Air-dry | 35 (561) |
|                 | Oven-dry | 32 (513) |

Oven-dry weight per green volume 29 (464)

McElwee and Faircloth (7) found that between-tree variation in specific gravity was greater than between-stand variation. No relationship was found between specific gravity and fiber length or overall growth rate.

Percent shrinkage, dried to 0% moisture content: \( r - 4.2, \ t - 7.6, \ v - 12.5. \)

Percent moisture content, when green

<table>
<thead>
<tr>
<th>Percent moisture content oven-dry basis (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heartwood</td>
</tr>
<tr>
<td>Sapwood</td>
</tr>
</tbody>
</table>

Physical Properties of Bark. Choong and Cassens (4) obtained an average bark specific gravity of 0.508 (oven-dry weight & volume basis). Bark moisture content averaged 81.4%.

Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th></th>
<th>Wise and Pickard (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sap</td>
</tr>
<tr>
<td>Lignin, %</td>
<td>24.90</td>
</tr>
<tr>
<td>Alpha-cellulose, %</td>
<td>40.70</td>
</tr>
<tr>
<td>Hemicellulose A, %</td>
<td>17.46</td>
</tr>
<tr>
<td>Hemicellulose B, %</td>
<td>3.00</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.90</td>
</tr>
<tr>
<td>Pentosans calculated as xylan, corrected for uronic anhydride, %</td>
<td>15.75</td>
</tr>
<tr>
<td>Acetyl, %</td>
<td>3.74</td>
</tr>
<tr>
<td>Uronic anhydride, %</td>
<td>4.39</td>
</tr>
</tbody>
</table>

CH\(_3\), from methoxyl not in lignin, % 0.65 0.60

Solubility in

<table>
<thead>
<tr>
<th></th>
<th>Ether, %</th>
<th>Alcohol-benzene, %</th>
<th>50% ethanol, %</th>
<th>70% acetone, %</th>
<th>Cold water, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.95</td>
<td>4.20</td>
<td>1.53</td>
<td>0.12</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>0.88</td>
<td>4.00</td>
<td>2.15</td>
<td>0.21</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Walkup et al. (6)

Solubility in

<table>
<thead>
<tr>
<th></th>
<th>Hot alcohol, %</th>
<th>Cold alcohol, %</th>
<th>Ether, %</th>
<th>Hot water, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.82</td>
<td>0.40</td>
<td>0.34</td>
<td>2.08</td>
</tr>
</tbody>
</table>

The wood contains 25.8% lignin (7).

Extractives

[Composition of ether extractives]

| Free fatty acids, % | 52 |
| Fats, %             | 16 |
| Unsaponifiables, %  | 32 |

Ether solubles are 0.3-0.9% of whole wood, 1.0% of sapwood, and 0.9% of heartwood (5).

Heartwood contains 0.26% benzene extractives, 0.3% acetone extractives, and 1.6% methanol extractives; the acetone and methanol extracts contain alkaloids (8).

Pulping

Kraft. The wood is readily pulped, yield is low, strength is low, and the pulp is rather difficult to bleach (9, 10, 17). The pulp is slightly stronger than aspen pulp. The yield is 44% at a permanganate number of 13; burst strength is 0.9-1.0 pt./lb and tear strength is 1.59. The bleached pulp is of good quality and well suited for greaseproof papers (72).

NSSC. The pulp is suitable for good quality corrugating medium (72).
Soda. The wood is readily pulped; yield is low for a pulp that is slightly stronger than aspen pulp and rather difficult to bleach (17).

Sulfite. The wood is readily pulped and yield is normal. The pulp, of fair color, is fairly easily bleached, requiring 15-25% bleach (13, 10, 11).

Utilization of Wood and Bark

Use Properties of Wood. Similar to black tupelo. The wood has a close, uniform texture; it is tough and not inclined to split.

Other Uses of Wood. Similar to black tupelo. The rootwood has been used occasionally as a substitute for cork.

Literature Cited


Scientific Name  A number of species of eucalyptus have been planted in the United States, both commercially and as ornamentals, including: *E. globulus*, *E. robusta*, *E. grandis*, *E. tereticornis*, *E. camaldulensis*, *E. viminalis*, *E. macarthurii*, and *E. diversicolor*.

Synonyms Eucalypt

Common names for the various eucalyptus species include *E. globulus* — southern blue gum, Tasmanian bluegum, Maiden's gum or Victorian eurabbie (depending on the subspecies); *E. robusta* — swamp mahogany; *E. grandis* — flooded gum; *E. tereticornis* — forest red gum; *E. camaldulensis* — river red gum; *E. viminalis* — manna gum; *E. macarthurii* — Camden woollybutt; *E. diversicolor* — karri.

Family Name  Myrtaceae

Range  Introduced and widely planted in subtropical areas, especially California and Florida. Many have also been planted in Hawaii.

Silvics  Eucalyptus has the capacity for rapid growth if soil and climatic conditions are suitable. Although the species can exist under conditions of low fertility, they respond markedly in growth if nutrient supplies, particularly nitrogen and phosphorus, are increased. Low temperature is the main limiting factor in planting eucalyptus and they will not survive in areas where the ground freezes. *E. globulus*, *E. viminalis* and *E. macarthurii* are adapted to cool, temperate areas and *E. camaldulensis* is very adaptable to a wide range of site conditions. Most eucalyptus species will not grow in heavy-textured soils with a high pH but withstand drought well. The majority of the fast-growing eucalypts are intolerant of competition. Among the least tolerant are *E. grandis* and *E. diversicolor*. Eucalypts are capable of very rapid height growth at an early age. Bare root planting of eucalyptus in Mississippi is discussed by Hunt (7).

Pathology  Eucalyptus is susceptible to rots in the United States such as the white, mottled rot (*Fomes applanatus*), white spongy sap rot (*Polyporus hirsutus*), the brown rot (*P. sulphureus*), and sap rot (*P. versicolor*). It is also attacked by a number of leaf spots, including the eucalyptus leaf blotches (*Hendersonia eucalypticola* and *Phyllosticta gallarum*), and the eucalyptus leaf spot (*Mycosphaerella molleriana*). Most insect pests of eucalyptus are eliminated when the various species are planted outside their natural range as exotics. The fast growth of eucalyptus in the United States can be attributed, in part, its freedom from indigenous pests.

Gross Features of the Wood  Eucalyptus is a diffuse-porous wood, usually with indistinct growth rings. Generally, the sapwood is yellow-white and 0.6-2.0 in (1.5-5.0 cm) in width. Fast-grown trees can have sapwood of greater width than slow-grown trees. Chudnoff (2) found the width of sapwood remained the same regardless of the height above ground. The heartwood, which forms after about five years of growth, is reddish-pink or pale brown.

Microscopic Structure of the Wood  Vessels. (3) *E. globulus* — solitary, tangential diameter 85-350 μm, av. 160 μm; *E. diversicolor* — mostly solitary, but occasionally in radial groups of 2-4, tangential diam. 85-285 μm, av. 207 μm; *E. tereticornis* — mostly solitary but occasionally in pairs, tangential diam. 85-195 μm, av. 155 μm.

Fibers. (4) Average length (mm) and width (μm) respectively: *E. diversicolor* — 1.26 mm and 19 μm; *E. tereticornis* — 0.88 mm and 14 μm; *E. camaldulensis* — 0.97 mm and 14 μm; *E. viminalis* — 1.01 mm and 15 μm. Hans and Burley (5) found that fertilization had no significant effect on fiber length. Brasil and Ferreira found that in 16-year-old *E. grandis* lumen diameter increased from the bark to the pith while fiber length and wall thickness increased from the pith to the bark. According to Hillis (4) plantation-grown trees, particularly if fast grown, had shorter, thinner-walled fibers than naturally grown trees. Bamber and Humphreys (7) found the fiber length of 5-year-old *E. grandis* approached the fiber length of mature wood. According to Hans, et al. (8), fiber length of 7-year-old *E. grandis* increased from 0.87-1.01 mm from the pith outwards.

Parenchyma. (3) *E. globulus* — vasicentric, 1-3 cells wide, and diffuse; *E. diversicolor* — vasicentric, 1-3 cells wide, and diffuse-aggregate, forming short, broken, tangential lines between the rays in certain areas; *E. tereticornis* — vasicentric, 1-3 cells wide, and diffuse-aggregate, forming short, broken, tangential lines between the rays.

Rays. (3) *E. globulus* — heterogeneous type III* to homogeneous, 1-3 cells wide; *E. diversicolor* — homog-
geneous, rarely heterogeneous type III*, 1-3 cells wide; *E. tereticornis* — predominantly uniseriate heterogeneous to homogeneous, rarely biseriate, 5-20 cells high.

Gum Ducts. (3) Absent in *E. globulus, E. diversicolor* and *E. tereticornis*.

Microscopic Structure of the Bark (74)

**Young Bark.** The structure of the young stem is very uniform throughout the genus with only minor differences in detail. The phloem of young bark consists of sieve tubes and their companion cells and an accompanying layer of parenchyma; outside these is a layer of tanniferous parenchyma; then a layer of rather large-celled crystaliferous parenchyma; and finally a band of fibers is formed, varying in width from 1-5 cells.

**Old Bark.** Many species of eucalyptus shed their bark, giving a characteristic smooth trunk. Those species with a shedding bark usually have very thick-walled cells in the phellem. When the rhytidome is shed, these layers provide the outer smooth surface, as they do in the young stem. *E. diversicolor, E. grandis,* and *E. camaldulensis* have a deciduous rhytidome. *E. tereticornis* and *E. globulus* have a deciduous rhytidome and conspicuous parenchyma wedges. *E. macarthurii* and *E. viminalis* have a semideciduous rhytidome and conspicuous parenchyma wedges with oil glands.

Gross Features of the Bark (9) *E. diversicolor* has bark with a smooth surface, and short fiber strands in the outer and inner bark. Also, the bark tends to come off in platelets. *E. grandis* has bark with a smooth surface, short fiber strands in the outer bark and long fiber strands in the inner bark. The bark tends to come off in strips. *E. globulus* and *E. viminalis* have bark intermediate between these two types. Fahraeus (10) found that bark ranked from 12% of the total volume in Australian plantation-grown *E. grandis* with a diameter of 19.7 in (50 cm) at breast height to 28% for *E. tereticornis* of 4 in (10 cm) diameter. Wick (11) determined, in measuring *E. robusta*, that no position (relative to slope orientation) around the circumference of a tree is superior for measuring bark thickness. Ceroni (12) found the moisture content of the bark of several eucalypts averaged 45-55% of green weight. According to Chudnoff (13), some eucalypts can form callus and regenerate bark and xylem when girdled to the cambium. Tissue regeneration was poorest in trees of low vigor.

Physical Properties of Wood  Specific gravity (oven-dry wt., green vol.) of *E. diversicolor* was 0.70 (15).

According to Franklin (16), the density in lb/ft³ was 36 for *E. tereticornis*, 28 for *E. robusta* and 33 for *E. camaldulensis* (577, 448, 529 kg/cu m for the three species respectively).

Villiers (17) obtained a b.h. density of 40 lb/ft³ (641 kg/cu m) airdry for *E. grandis*.

Bamber and Humphreys (7) found that, in 5-year-old wood, the relationship between basic density and seed source was highly significant. However, basic density was not related to rate of growth. Others reporting the lack of significance between the growth rate and density include Skolmen (18) and Bamber, et al. (19).

Brasil and Ferreira (6) found that wood density increased from the bark to the pith in 16-year-old *E. grandis*. 
According to Taylor (20) specific gravity of *E. grandis* decreased between 5-15 ft (1.5-4.5 m) above the ground and increased with increasing height above 15 ft (4.5 m).

Hans, et al. (8) found that specific gravity of 7-year-old *E. grandis* increased from 0.420-0.472 from the pith outward.

According to Hans and Burley (5), fertilization had no significant effect on density, although any treatment that favored volume production tended to lower density.

Hillis (4) found that eucalyptus from plantations, particularly if fast grown, had lower density wood than naturally grown trees.

Bochetti Foelkel, et al. (27) found that average wood density was somewhat higher in *E. grandis* affected by canker compared to normal wood.

According to Bamber, et al. (19), the basic density of wood formed when *E. grandis* was 16-20 years old was 1.25 times greater than that formed in the 1-5-year period and the density of the outermost wood of mature trees was 1.37 times greater.

Genetics of wood and bark characteristics of *E. viminalis* is discussed by Otegbeye and Kellison (22).

Chemical Composition of Wood

**Extractives.** For volatile substances, mainly hydrocarbons, see Donetzhuber et al. (23). For sinapyl and related aldehydes see Gibbard and Schoental (24).

**Pulping**

*Chemigroundwood.* Wood from Brazil (*E. saligna*) is weak and extremely difficult to bleach; it can be bleached to 55% brightness with 20% calcium hydrochlorite and to 37% with 5% sodium hydrosulfite (25).

*Groundwood.* Wood from Brazil (*E. saligna*) is too weak for papermaking; it requires about 10% available chlorine or 1.5% sodium hydrosulfite to reach 60% brightness and 15% chlorine for 70% brightness (25).

*Kraft.* Pulp from Brazil (*E. saligna*) bleached by a 3-stage process was stronger than bleached kraft pulps made from U.S. hardwoods and equal to commercial eucalyptus pulp in opacity, bulk, porosity, and softness. Wrapping paper made of kraft pulp from Brazil (*E. saligna*) and commercial northern pine kraft pulp had good formation and burst strength, comparable to paper from southern pine kraft pulp and of lower tear resistance. Writing paper characteristic of No. 1 bond paper was made from 85% bleached kraft from *E. saligna* and 11% bleached pulp from western softwood. Wood from Brazil (*E. saligna*) makes pulp that compares favorably in strength with good-quality sulfate pulps made from other hardwoods. Semibleached pulp is used for newsprint that is slightly stronger than commercial newsprint and is more absorbent and porous and slightly less opaque.

Wood from Brazil (*E. saligna*) gives a high-strength pulp. Pulps were as strong as or stronger than similar pulps made from North American hardwoods and had higher yield and lower chemical requirement for pulping. Pulps were stronger than soda pulps of the same grade and had the advantage of higher yield and lower chemical requirement for pulping. Wood from Australia (*E. regnans*) is used for creped tissue paper (25).

*Kraft Semichemical.* Pulp was comparable to a NSSC pulp from Tasmanian wood (25).

*Nitric Acid.* "Nitrocell" pulp is about as strong as sulfite pulp but not so strong as kraft (26).

**NSSC.** This pulp (*E. tereticornis*) is used for dissolving pulp (76). Wood from Tasmania (*E. gigantea*) gives pulps that, except for tear strength, are weaker than aspen semichemical pulp. Bleached pulp was weaker in burst and tensile strength than bleached aspen and about equal to it in folding strength and stronger in tear strength. Unbleached pulp is used for linerboard. Pulp from Puerto Rico (*E. robusta*) gave good tear strength and stiffness. Corrugating board was higher in compression strength than commercial corrugating grade pulp (25).

**Cold Soda.** Pulps of a mixture of *E. saligna*, *E. kertoniana*, *E. tereticornis*, and *E. alba* are bulky and slightly darker and weaker than the average made from U.S. hardwoods. They are used for newsprint of low opacity and oil penetration (25).

**Soda.** Wood from Brazil (*E. saligna*) gave a high-strength pulp. Pulps were as strong as or stronger than similar types of pulps made from North American hardwoods (25).

**Soda/Oxygen.** This process was particularly effective in brightening bark components and in reducing dirt levels
of whole-tree (*E. viminalis*) pulps; the pulp was bleachable and it had refined strength properties 10-30% lower than those of kraft bolewood pulp (27).

**Sulfitie**. Wood from Brazil (*E. tereticornis* and *E. salvina*) is satisfactory for use as a chemical pulp component in newsprint and similar printing paper (25).

**Literature Cited**

AILANTHUS

Scientific Name  *Ailanthus altissima* (Mill.) Swingle

Synonyms  Tree-of-heaven, Chinese tree-of-heaven, copal tree, Chinese sumach

Family Name  Simaroubaceae

Range  Native of China but widely naturalized in temperate regions (7). It is found from Massachusetts west to southern Ontario; from Iowa south to Texas and then east to Florida. It is also found from New Mexico west to California and then north to Washington. Introduced into the United States approximately 200 years ago.

Silvics  This medium-sized tree has a short bole with a few, stout, ascending limbs, dividing 6-10 ft (1.8-3.0 m) above the ground to form a broad, open flat-topped crown. The tree has a large system of lateral roots which are capable of producing many root suckers. Juvenile growth tends to be very rapid, with maturity reached in 30-35 years. Little height growth occurs after maturity, although diameter growth may continue for another 10-20 years. Although ailanthus prefers soil of limestone origin, it will adapt to marly soils and a wide range of climatic conditions. Salt spray or road salt have little effect upon it. Ailanthus is rated as intolerant and requires virtually full sun at all times. Feret and Bryant (2) found significant differences between five each of Chinese and American seed sources in 11 of 14 variables (morphological, physiological and biochemical). There was no evidence of inbreeding depression in the American sources. Apparently, significant alternations of genetic content in the American sources have occurred. Plass (3) found ailanthus adapted to surface mine acid spoils in eastern Kentucky.

Tree Dimensions  Generally 30-65 ft (9-20 m) tall and up to 2 ft (61 cm) in diameter. However, under favorable conditions, it can reach 100 ft (30 m) in height.

Pathology  The major problems of ailanthus are heart rot and frost damage. However, ailanthus is subject to attack by the shoestring root rot (*Armillariella melia*) which is present in the soil of every mature stand of trees. The trunk rot affecting ailanthus is white trunk rot (*Daedalea unicolor*). Leaf spots of ailanthus are *Cercospora glandulosa* and *Phyllosticta ailanthi*. The anthracnose affecting ailanthus is *Gloeosporium ailanthi*.

Gross Features of the Wood (4)  The wood is ring porous; sapwood not ordinarily distinguishable from the pale brownish-white to yellowish heartwood. Springwood pores are large; transition from springwood to summerwood is abrupt; summerwood pores minute and often indistinct under a hand lens. Longitudinal parenchyma are abundant, plainly visible as ensheathing tissue around the clusters of summerwood pores as viewed in transverse section. Wood rays are variable in width, the broadest plainly visible on transverse sections, without the aid of a lens, the widest about as broad as the largest pores.

Microscopic Structure of the Wood (4)

Vessels  Springwood vessels mostly oval to oval-oblong in transverse section, thin-walled, the largest 250-300 μm in diameter, often partially or wholly occluded with tyloses or occasionally with deposits of pale yellow gummy infiltration; vessel members mostly 0.15-0.30 mm in length; summerwood vessels mostly irregularly polygonal in transverse section, ranging from 15-50 μm in tangential diameter; summerwood vessel members 0.2-0.5 mm in length.

Fibers  Irregularly polygonal in transverse section; thin to moderately thick walled, the majority 10-15 μm in tangential diameter; up to 2.0 mm in length. Berchem, et al. (5) obtained an average fiber length of 1.21 mm (standard deviation 0.199 mm) for 15 trees in Illinois, Missouri, and Ohio. Vasiljevic (6) divided growth rings into five equal parts and numbered them from 1-5 from the pith toward the bark. Cells in 1 were shorter than in 5.

Parenchyma  Longitudinal parenchyma abundant, paratracheal, paratracheal-zonate, and metatracheal.

Rays  Homogeneous or bordering on the heterogeneous type; unstoried, 1-12 (mostly 4-8) cells in width, uniseriate rays mostly 3-8 cells high, multiseriate rays mostly 40-60 cells in height.

Gross Features of the Bark (4)  Smooth and light gray on young stems; on older trunks, thin, gray, and broken at the surface by narrow, shallow, whitish to pinkish fissures into moderately narrow, flattened ridges.

Physical Properties of Wood  Moslemi and Bhagwat (7) found ailanthus to be similar in physical and mechanical properties to native U.S. medium density hardwoods. The specific gravity at 12% moisture content was 0.531.
Pulping

Calcium Bisulfite. The wood is readily pulped and produces a satisfactory pulp that is easy to bleach.

Soda. The wood is readily pulped and produces a satisfactory pulp that is easy to bleach; its strength is near that of spruce sulfite pulp; brightness before beating is 46% (8).

Sodium Bisulfite. The wood is readily pulped and the satisfactory pulp is easy to bleach. Brightness before beating is 72%; the pulp is likely to be suitable for rayon (8).

Other Information. Ailanthus altissima, because of its fast growth, gives a yield of wood which is well above that of many American pulpwood species. Compared with other hardwoods, ailanthus is more easily barked. It is easily pulped by alkaline or acid cooking. The unbleached pulps have a relatively high brightness and are easily bleached with low quantities of chlorine. Ailanthus pulps could be universally usable in the paper industry as a substitute for aspen and other hardwood pulps. The high smoothness of the handsheets shows that ailanthus pulp may be used to improve surface qualities, especially for writing papers. This pulp may partly replace spruce sulfite pulp in fine and semifine writing papers, in glassine, and in toilet tissue and other papers (8).

Literature Cited

**EUROPEAN BLACK ALDER**

**Scientific Name** *Alnus glutinosa* (L.) Gaertn.

**Synonyms** Black alder, European alder

**Family Name** Betulaceae

**Range** Native of Europe, North Africa and Asia. Planted, escaped and naturalized locally from Newfoundland and Quebec southwest to Pennsylvania, Delaware and Illinois.

**Silvics** The tree has an ovoid or oblong crown with very dark foliage, which remains green until late autumn. It is a nitrogen-fixing plant, is hardy to low temperatures, is very responsive to soil moisture, and obtains its best growth along streams and lakes on acidic soils. It is a prolific seeder and is easily coppiced from stump sprouts. Saucier (3) made a comparison of black alder with sycamore seedlings and sycamore cuttings. The comparison was made 1 and 2 years after planting on 3 sites in Georgia. He concluded that alder could prove as good as sycamore for short-rotation culture on bottomland sites.

**Tree Dimensions** Morin (4) reported heights of 30-35 ft (9-11 m) and diameters of 6-7 in (15-18 cm) dbh at 8-10 years of age.

**Pathology** Several rots attack European black alder planted in the United States. They include root rot (*Phymatotrichum omnivorum*) which is limited to an area of calcareous soil of a peculiar type and attacks European black alder in Texas and sap rot (*Polyporus versicolor*), which ultimately results in the death of the affected tree. The leaf spot affecting European black alder is *Septoria alni*.

**Gross Features of the Wood** The wood is reddish-white, soft and light, and possesses a smooth, fine grain. The annual rings are distinct in cross-section. The pores are invisible to the naked eye, as are most of the medullary rays, but some of the latter, when aggregated, form dull-edged "false rays". Pith flecks are present. Hoster (6) found that reaction wood contains fewer vessels, less longitudinal parenchyma and more fibers than normal wood.

**Microscopic Structure of the Wood** The following description applies to the Betulaceae family in general.

**Vessels** Small, sometimes with a loose, oblique pattern, perforation plates scalariform.

**Fibers** Medium length to moderately long; with small, but distinctly bordered pits. Bruun et al. (8) obtained a fiber length of 0.89 mm. According to Vurdu and Bensend (9), in two 8-year-old black alder, fiber length was 0.92 mm in the roots, 0.89 mm in the lower parts of the stems, and 0.80 mm in the upper parts of the stem and in the branches. Fiber length increased 59% from the pith to the bark in the stem.

**Parenchyma** Diffuse and terminal.

**Rays** Up to 3-4 cells wide or exclusively uniseriate, sometimes aggregated, homogeneous.

**Physical Properties of Wood** According to Vurdu and Bensend (9), specific gravity (green volume basis) was 0.247 in the roots, 0.430 in the branches, and 0.428 in the stems of two 8-year-old European black alder.

Morin (4) obtained an average weighted specific gravity of 0.458 for five black alder trees 10-12 years old.

**Chemical Composition of Wood**

**Proximate Analyses**

<table>
<thead>
<tr>
<th></th>
<th>Morin (4)</th>
<th>Musha and Goring (10)</th>
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</thead>
<tbody>
<tr>
<td>Lignin, %</td>
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<td>Ash, %</td>
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<td>Acid, %</td>
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</tbody>
</table>

**Pulping**

**Kraft** Satisfactory pulps can be obtained, although they are usually slightly inferior to other hardwood pulps (8, 17).

**Sulfite** Problems have been reported in debarking, delignification and fiberizing the pulp (12).

**NSSC** Yield and pulp physical properties were in the general range expected for good NSSC pulp made from aspen and other northern hardwoods (4).


**WHITE POPULAR**

**Scientific Name** *Populus alba* L.

**Synonyms** Alamo blanco

**Family Name** Salicaceae

**Range** Native of Europe and Asia. Planted in southern Canada and across continental United States. Has escaped cultivation and become naturalized along roadsides and borders of fields.

**Silvics** The tree has a straight trunk with moderate taper and a rounded, spreading crown, comprised of several profusely branched limbs. The root system is widespread and penetration into the substrate is deep. White poplar and its hybrids are adaptable to a wide range of soil types but best growth occurs in areas where there is an abundance of deep alluvial soil, rich in organic matter. It is propagated through cuttings, coppice shoots and root suckers. Breeding and establishment of hybrids with *P. alba* is discussed by Benson (2).

**Pathology** Because of its thin bark, white poplar is subject to fire damage. Sunscald can be a problem on white poplar and its hybrids. Common leaf spots are caused by *Cercospora populina*, *Septoria musiva*, and *Didymosphaeria populina*. White poplar and its hybrids also appear susceptible to a leaf disease closely resembling *Plagiostoma populina*. Rots attacking white poplar include white mottled rot (*Fomes applanatus*), root rot (*Phymatotrichum omnivorum*), and white spongy sap rot (*Polyporus hirsutus*). Cankers of white poplar are caused by *Valsa nivea* and *V. sordida*. Hybrids of white poplar with *P. tremuloides* are susceptible to attack by hypoxylon canker (*Hypoxylon mammatum*) (3).

Many insects that attack *Populus* species have been introduced into the United States. Some of these include the poplar and willow borer (*Sternochetus lapathi*), the satin moth (*Stilpnotia salicis*) and the European poplar sawfly (*Trichiocampus viminalis*). In addition, several native American insects are related to important European species. These include the poplar borer (*Saperda calcarata*) and the poplar-gall saperda (*Saperda concolor*). The bronze birch borer (*Agrilus anxius*) attacks poplars with the same effect as the related European species.

**Gross Features of the Wood** (4). The wood is diffuse-porous with pale yellowish-white or creamy sapwood; the heartwood is light yellowish-brown to pale brown and odorless and tasteless. Growth rings are broad, often 1/4-1/2-in (0.6-1.3 cm) or more in width, delineated by a narrow band of moderately dense fibrous tissue and a fine whitish line of terminal parenchyma; pores are abundant, seemingly to comprise nearly half of the transverse section, their orifices indistinct without the aid of a hand lens, mostly solitary and in radial pairs. Rays are of uniform width, narrow and rather crowded, not discernible without the aid of a hand lens; the wood with virtually no figure on the longitudinal faces. Popescu (5) found that the proportion of tensionwood was fairly constant in white poplars growing in Roumania regardless of tree age or growth conditions.

**Microscopic Structure of the Wood** (4)

**Vessels.** Solitary and in short contiguous radial rows; isolated vessels mostly oblong-oval to long-oval in transverse section, those in chains mostly irregularly rounded-polygonal; thin-walled, the largest mostly 50-60 μm in tangential diameter; vessel members mostly 400-700 μm in length.

**Fibers.** Thin-walled for the most part, rounded to irregular polygonal in transverse section, the majority 20-30 μm in diameter, 0.8-1.3 mm in length. Einspahr, et al. (6) obtained an average fiber length of 1.10 mm for *P. alba* hybrids aged 18-30 years. Markov and Matselo (7) found that the average fiber length increased rapidly with age in trees 5-10 years old and rather slowly in older trees.

**Parenchyma.** Longitudinal parenchyma terminal, the cells in cambiform strands along the grain, forming a more or less continuous uniseriate line at the extremities of the growth rings, thin walled.

**Rays.** Homogeneous, unstoried, wholly uniseriate, mostly 6-10 but up to 15 cells in height along the grain.

**Gross Features of the Bark** (4). Light yellowish-gray to ashy-gray, often thick at the base of the trunk, then nearly black and deeply and irregularly furrowed. Knezevic (8) found the proportion of bark in white poplar to average 11.9%.

**Physical Properties of Wood** Einspahr, et al. (6) found specific gravity of *P. alba* hybrids averaged 0.392 between the ages of 18-30 and 0.358 at 31+ years of age.

Avanzo and Ghisi (9) obtained an average wood density at 12% moisture content of 0.356 g/cu cm and an average basic density of 0.321 g/cu cm in 36-year-old trees.
Chemical Composition of Wood

Proximate Analyses

<table>
<thead>
<tr>
<th>Solubility in</th>
<th>Simionescu, et al. (10)</th>
<th>Constantinescu &amp; Popescu (11)</th>
<th>Abdoh and Zandie Faez (12)</th>
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<tr>
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<tr>
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<tr>
<td>Pentosans, %</td>
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<td>20.3</td>
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</tbody>
</table>

According to Markov and Matselo (7), the maximum content of cellulose was observed in trees 9-17 years old and tended to decrease in older trees.

The 7-O-methylether of 4',5,7-trihydroxyflavanon-3-ol has been isolated from P. alba (13).

Pulping

Kraft. No significant differences were observed in the papermaking properties of kraft pulps (55-59% yield) obtained from normal vs. tension wood (11). Best yields obtained by pulping with 16% active alkali (Na_2O/dry wood) at 160°C. (14). Oxygen bleaching of kraft pulps is discussed by Kubicza (15). Additional papermaking properties are discussed by Markov and Matselo (7).

Utilization of Wood and Bark

Use Properties of Wood. The wood is light, soft, and weak, usually straight grained and normally uniform in texture and workability. It holds nails and screws well, can be glued readily except where tensionwood is present. It is easily stained and takes paint and varnish well.

Literature Cited

7. Markov, I. G.; Matselo, V. G. Bumazh. Prom. no. 5:8-10(1968).


WORD LIST*

Cambium. A cylinder, strip, or layer of meristematic cells which divide to give cells that ultimately form a permanent tissue. The cambium in the stem and root gives rise to xylem and phloem.

Cell. A nucleus with the cytoplasm with which it is in intimate contact; in plants it is usually bounded by a definite cell wall.

Cellulose. A condensation product of a various number of glucose units, giving a fibrous structure. The main constituent of plant cell walls.

Cortex. The tissue in a stem or root between the vascular bundles and the epidermis. Typically, it is parenchyma.

Dbh. Diameter breast height (4.5 feet).

Deciduous. The seasonal shedding of leaves.

Family. The taxonomic division between an order and a genus; it may be a subdivision of a suborder or super-family. It contains similar genera. The names of botanical families usually end in acceae.

Gelatinous fiber. A fiber, the inner wall of which appears in the light microscope to be more or less gelatinous or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Lumen. The space enclosed by a cell wall, especially after the contents have disappeared.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark; the rhytidome.

Paratracheal. Said of xylem parenchyma in hardwoods which occurs in association with the vessels but nowhere else.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Pentosan. A gum made up of pentose sugars, e.g., arabinose and xylose, by condensation.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Phellem. Cork. Suberized cells formed in the outside regions of a stem or root, from a phellogen.

Phloem. The vascular tissue which conducts synthesized foods in vascular plants. It is characterized by the presence of sieve tubes, and in some plants companion cells, fibers, and parenchyma.

Phloem fiber. An element of sclerenchyma (or a strand of such elements) in the phloem. It probably helps to support the sieve tubes.

Phloem parenchyma. The unspecialized cells found in the phloem.

Phloem ray. The part of a vascular ray that passes through the phloem.

Race. A subspecies, which forms a genetically, and usually geographically, distinct mating group within a species.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin. An acidic substance, either a phenolic derivative or an oxidation product of terpenes. The resins are insoluble in water but soluble in alcohol, ether, and carbon disulphide, and burn with a sooty flame. They are products of secretion or disintegration which are usually found in special cavities or passages.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die, leaving a crust made up of alternate layers of cork and dead phloem or cortex; the zone from the innermost periderm outward; the outer bark.

*Some of these definitions were taken from Usher, G. A Dictionary of Botany.
Scalariform. Like a ladder.

Sclereid. See sclerenchyma.

Sclerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elongated, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Sclerotic. Hard, thick-walled, and often lignified.

Secondary phloem. Inner bark.

Sieve cell. A characteristic cell of softwood phloem. It translocates food materials synthesized in the plant. Sieve cells are elongated, tapering, and lack sieve plates.

Sieve tube element. A characteristic cell of hardwood phloem. It translocates food synthesized in the plant. The cells are living, thin-walled, and in longitudinal rows. They are connected by perforations (sieve plates) in their transverse walls, through which pass strands of cytoplasm.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface of a tangential section.

Tracheid. Fibrous, lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Tylosis. A balloonlike enlargement of the membrane of a pit in the wall of a vessel or trachted, and a xylem parenchyma cell lying next to it. It protrudes and blocks the cavity of the wood element.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vasicentric. Paratracheal; forming a sheath (around vessels).

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Woods. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers, and some parenchyma.
<table>
<thead>
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<th>Species</th>
<th>Decay Resistance</th>
<th>Length, mm</th>
<th>Width, μm</th>
<th>Weight Factor (unbl. kraft)</th>
<th>Coarseness mg/100 m</th>
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### SUMMARY TABLE II

#### WOOD AND BARK SPECIFIC GRAVITY

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<tr>
<th>Species</th>
<th>Wood</th>
<th>Bark</th>
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<td></td>
<td>Green Volume</td>
<td>O.D. Volume</td>
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<td>Quaking aspen</td>
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### SUMMARY TABLE III

#### CALORIFIC VALUE OF WOOD AND BARK

*(oven-dry unless otherwise stated)*

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## SUMMARY TABLE IV
### CHEMICAL COMPOSITION OF WOOD

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<sup>a</sup>Corrected for ash.
<sup>b</sup>On chlorite holocellulose, %.
<sup>c</sup>Corrected for ash and lignin.
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aPercent of oven-dry weight of the bark.
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