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The Chemical Composition of Wood

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This chapter includes overall chemical composition of wood, methods of analysis, structure of hemicellulose components and degree of polymerization of carbohydrates. Tables of data are compiled for woods of several countries. Components include: cellulose (Cross and Bevan, holo-, and alpha-), lignin, pentosans, and ash. Solubilities in 1% sodium hydroxide, hot water, ethanol/benzene, and ether are reported. The data were collected at Forest Products Laboratory (Madison, Wisconsin) from 1927-68 and were previously unpublished. These data include both United States and foreign woods. Previously published data include compositions of woods from Borneo, Brazil, Cambodia, Chile, Colombia, Costa Rica, Ghana, Japan, Mexico, Mozambique, Papua New Guinea, the Philippines, Puerto Rico, Taiwan, and the USSR. Data from more detailed analyses are presented for common temperate-zone woods and include the individual sugar composition (as glucan, xylan, galactan, arabinan, and mannan), uronic anhydride, acetyl, lignin, and ash.

THE CHEMICAL COMPOSITION of wood cannot be defined precisely for a given tree species or even for a given tree. Chemical composition varies with tree part (root, stem, or branch), type of wood (i. e., normal, tension, or compression) geographic location, climate, and soil conditions. Analytical data accumulated from many years of work and from many different laboratories have helped to define average expected values for the chemical composition of wood. Ordinary chemical analysis can distinguish between hardwoods (angiosperms) and softwoods (gymnosperrns). Unfortunately, such techniques cannot be used to identify individual tree species because of the variation within each species and the similarities among many **species. Further identification is possible with detailed chemical anal-**

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ysis of extractives (chemotaxonomy). Chemotaxonomy is discussed fully elsewhere in the literature *(1, 2).*

There are two major chemical components in wood: lignin (18–35%) and carbohydrate (65– 75%). Both are complex, polymeric materials. Minor amounts of extraneous materials, mostly in the form of organic extractives and inorganic minerals (ash), are also present in wood (usually 4– 10%). Overall, wood has an elemental composition of about 50% carbon, 6% hydrogen, 44% oxygen, and trace amounts of several metal ions.

A complete chemical analysis accounts for all the components of the original wood sample. Thus, if wood is defined as part lignin, part carbohydrate, and part extraneous material, analyses for each of these components should sum to 100%. The procedure becomes more complex as the component parts are defined with greater detail. Summative data are frequently adjusted to 100% by introducing correction factors in the analytical calculations. Wise and coworkers *(3)* presented an interesting study on the summative analysis of wood and analyses of the carbohydrate fractions. The complete analytical report also includes details of the sample, such as species, age, and location of the tree, how the sample was obtained from the tree, and horn what part of the tree. The type of wood analyzed is also important; i.e., compression, tension, or normal wood.

Vast amounts of data are available on the chemical composition of wood. Fengel and Grosser *(4)* made a compilation for temperate-zone woods. This chapter is a compilation of data for many different species from all parts of the world, and includes much of the data in Reference 4. The tables at the end of this chapter summarize these data.

Chemical Components

Carbohydrates. The carbohydrate portion of wood comprises cellulose and the hemicelluloses. Cellulose content ranges from 40 to 50% of the dry wood weight, and hemicelluloses range from 25 to 35%.

CELLULOSE. Cellulose is a glucan polymer consisting of linear chains of 1,4-β-bonded anhydroglucose units. (The notation 1,4-β describes the bond linkage and the configuration of the oxygen atom between adjacent glucose units.) Figure 1 shows a structural diagram of a portion of a glucan chain. The number of sugar units in one molecular chain is referred to as the degree of polymerization (DP). Even the most uniform sample has molecular chains with slightly different DP values. The average DP for the molecular chains in a given sample is designated by $\overline{\mathrm{DP}}$.

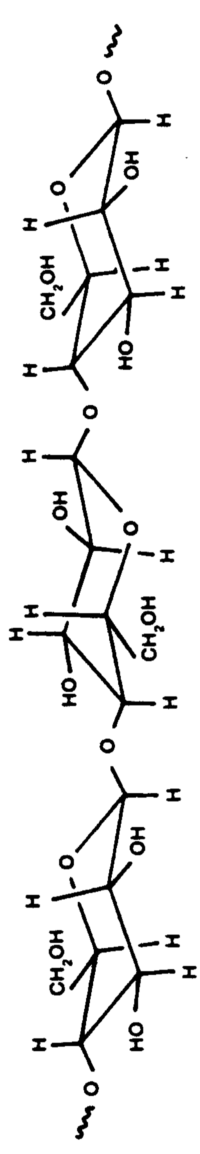

Figure 1. The partial molecular structure of cellulose [$(C_6H_{10}O_5)_x$] in the 1,4-β-D-glucopyranose form.

Goring and Timell *(5)* determined the $\overline{DP}$ for native cellulose from several sources of plant material. They used a nitration isolation procedure that attempts to maximize the yield while minimizing the depolymerization of the cellulose. These molecular weight determinations, done by light-scattering experiments, indicate wood cellulose has a $\overline{DP}$ of at least 9,000-10,000, and possibly as high as 15,000. A DP of 10,000 would mean a linear chain length of approximately 5 μm in wood.

The $\overline{DP}$ obtained from light-scattering experiments is biased upward because light scattering increases exponentially with molecular size. The value obtained is usually referred to as the weighted $\overline{DP}$ or $\overline{DP}_w$. The number average degree of polymerization ($\overline{DP}_n$) is usually obtained from osmometry measurements. These measurements are linear with respect to molecular size and, therefore, a molecule is counted equally as one molecule regardless of its size. The ratio of $\overline{DP}_w$ to $\overline{DP}_n$ is a measure of the molecular weight distribution. This ratio is nearly one for native cellulose in secondary cell walls of plants *(6)*. Therefore, this cellulose is monodisperse and contains molecules of only one size. Cellulose in the primary wall has a lower $\overline{DP}$ and is thought to be polydisperse. *(See* Reference 7 for a discussion of molecular weight distribution in synthetic polymers.)

Native cellulose is partially crystalline. X-Ray diffraction experiments indicate crystalline cellulose *(Valonia uentricosa)* has space group symmetry $P2_1$ with $a = 16.34$, $b = 15.72$, $c = 10.38$ Å, and $\gamma = 97.0°$ *(8)*. The unit cell contains eight cellobiose moieties. The molecular chains pack in layers that are held together by weak van der Waals' forces (Figure 2a). The layers consist of parallel chains of anhydroglucose units, and the chains are held together by intermolecular hydrogen bonds. There are also intramolecular hydrogen bonds between the atoms of adjacent glucose residues (Figure 2b). This structure is called cellulose I.

There are at least three other structures reported for modified crystalline cellulose. The most important is cellulose II, obtained by mercerization or regeneration of native cellulose. *Mercerization* is treatment of cellulose with strong alkali. *Regeneration* is treatment of cellulose with strong alkali and carbon disulfide to form a soluble xanthate derivative. The derivative is converted back to cellulose and reprecipitated as regenerated cellulose. The structure of cellulose II (regenerated) has space group symmetry $P2_1$ with $a = 8.01$, $b = 9.04$, $c = 10.36$ Å, and $\gamma = 117.1°$, and two cellobiose moieties per unit cell *(9)*. The packing arrangement is modified in cellulose II, and permits a more intricate hydrogen-bonded network that extends between layers as well as within layers (Figure 3). The result is a

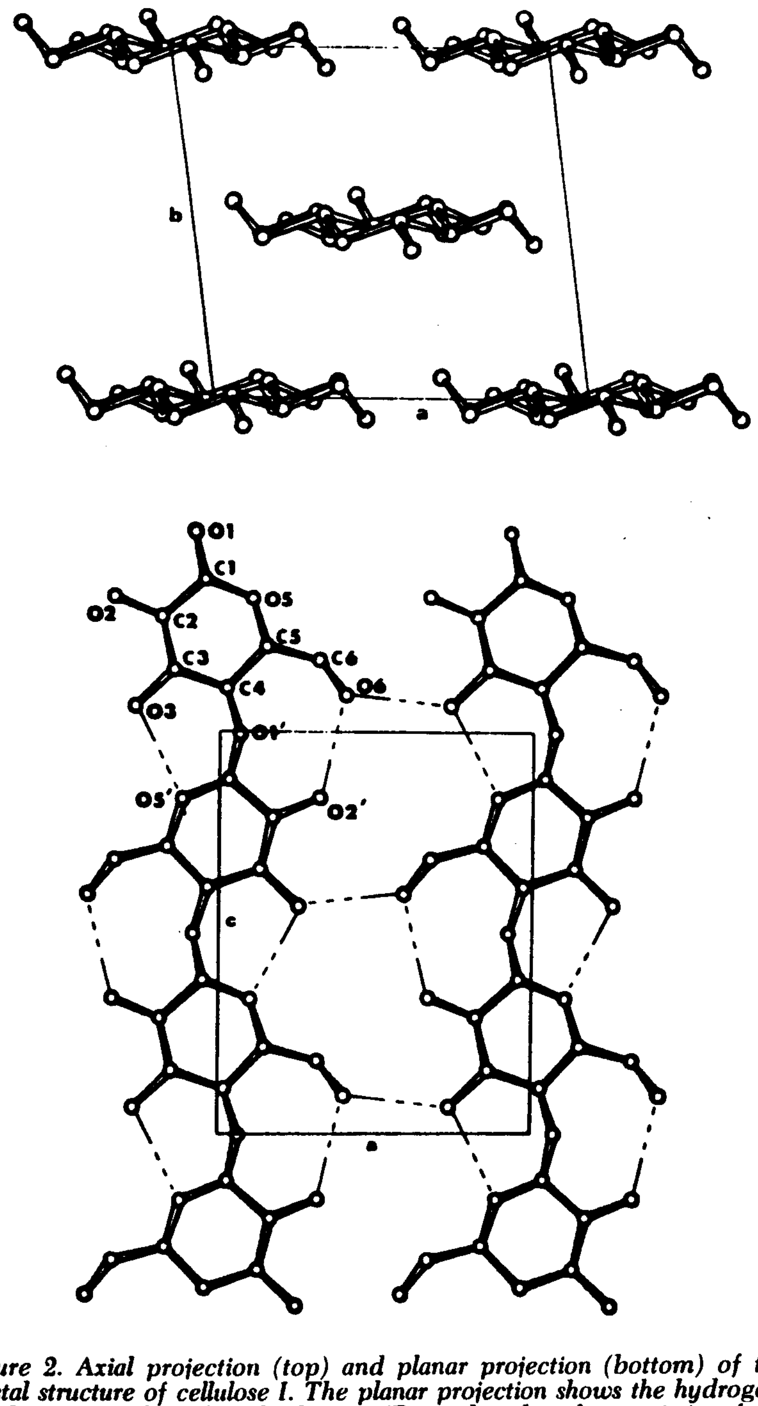

Figure 2. Axial projection (top) and planar projection (bottom) of the crystal structure of cellulose I. The planar projection shows the hydrogen-bonding network within the layers. (Reproduced with permission from Ref. 8. Copyright 1974, Elsevier Scientific Publishing Company, Amsterdam.)

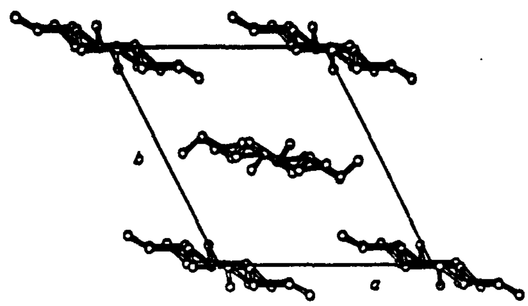

Figure 3. Axial projection of the crystal structure of cellulose II. (Reproduced with permission from Ref. 10. Copyright 1978, Butterworth & Co. (Publishers) Ltd.)

more thermodynamically stable substance. Evidently, all native cellulose have the structure of cellulose I.

Cellulose is insoluble in most solvents including strong alkali. It is difficult to isolate from wood in pure form because it is intimately associated with the lignin and hemicelluloses. Analytical methods of cellulose preparation are discussed in the section on "Analytical Procedures."

HEMCELLULOSES. Hemicelluloses are mixtures of polysaccharides synthesized in wood almost entirely from glucose, mannose, galactose, xylose, arabinose, 4-*O* methylglucuronic acid, and galacturonic acid residues. Some hardwoods contain trace amounts of rhamnose. Generally, hemicelluloses are of much lower molecular weight than cellulose and some are branched. They are intimately associated with cellulose and appear to contribute as a structural component in the plant. Some hemicelluloses are present in abnormally large amounts when the plant is under stress; e.g., compression wood has a higher than normal galactose content as well as a higher lignin content *(11)*. Hemicelluloses are soluble in alkali and easily hydrolyzed by acids.

The structure of hemicelluloses can be understood by first considering the conformation of the monomer units (Figure 4). There are three entries under each monomer in Figure 4. In each entry, the letter designations D and L refer to a standard configuration for the two optical isomers of glyceraldehyde, the simplest carbohydrate. The Greek letters α and β refer to the configuration of the hydroxyl group at carbon atom 1. The two configurations are called *anomers*. The first entry is a shortened form of the sugar name. The second entry indicates the ring structure. Pyranose refers to a six-membered ring in the chair or boat form and furanose refers to a five-membered ring. The third entry is an abbreviation commonly used for the sugar residue in polysaccharides.

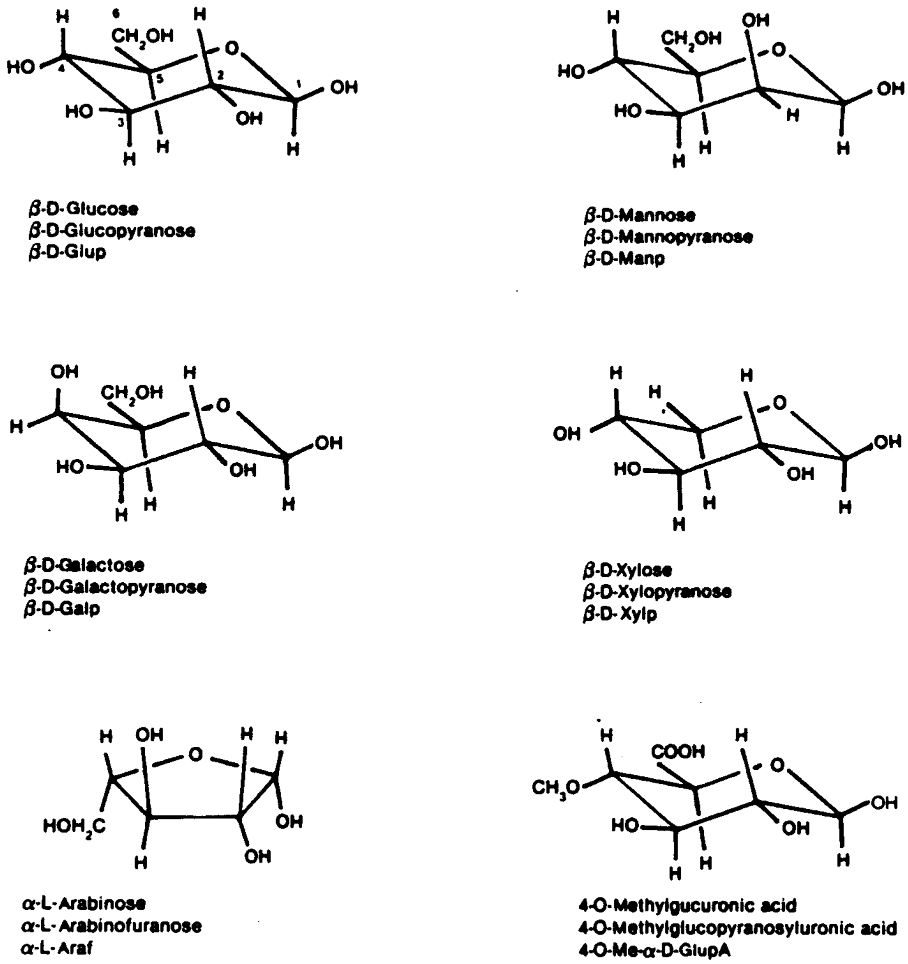

Figure 4. Monomer components of wood hemicelluloses.

Figure 5 shows a partial structure of a common hardwood hemicellulose, *O*-acetyl-4-*O*-methylglucuronoxylan. The entire molecule consists of about 200 β-D-xylopyranose residues linked in a linear chain by (1 → 4) glycosidic bonds. Approximately 1 of 10 of the xylose residues has a 4-*O*-methylglucuronic acid residue bonded to it through the hydroxyl at the 2 ring position. Approximately 7 of 10 of the xylose residues have acetate groups bonded to either the 2 or 3 ring position. This composition is summarized in Figure 5 in an abbreviated structure diagram. Hardwood xylans contain an average of two xylan branching chains per macromolecule. The branches are probably quite short (12).

Table I lists the most abundant of the wood hemicelluloses. The

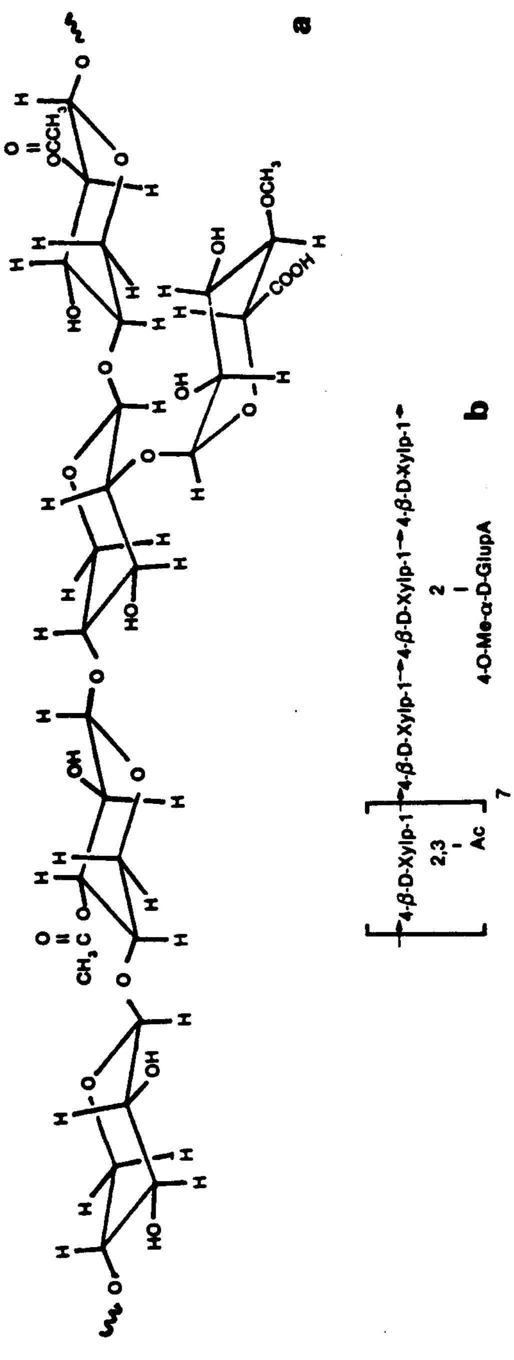

Figure 5. Partial molecular structure (top) and structure representation (bottom) of O-*acetyl-4-*O-*methyl-glucuronoxylan.*

Table I. The Major Hemicellulose Components

Hemicellulose Type	*Occurrence*	*Amount (% of wood)*	*Composition* *Units*	*Molar Ratios*	*Linkage*	*Solubility*[a]	$\overline{DP}_n$[b]
Galactoglucomannan	Softwood	5–8	β-D-Man*p*	3	1 → 4	Alkali, water*	100
			β-D-Glu*p*	1	1 → 4		
			α-D-Gal*p*	1	1 → 6		
			Acetyl				
(Galacto)Glucomannan	Softwood	10–15	β-D-Man*p*	4	1 → 4	Alkaline borate	100
			β-D-Glu*p*	1	1 → 4		
			α-D-Gal*p*	0.1	1 → 6		
			Acetyl	1			
Arabinoglucuro-	Softwood	7–10	β-D-Xyl*p*	10	1 → 4	Alkali,	100
noxylan			4-*O*-Me-α-D-	2	1 → 2	dimethyl	
			Glu*p*A			sulfoxide,*	
			α-L-Ara*f*	1.3	1 → 3	water*	
Arabinogalactan	Larch	5–35	β-D-Gal*p*	6	1 → 3,	Water	200
	wood				1 → 6		
			α-L-Ara*f*	2/3	1 → 6		
			β-L-Ara*p*	1/3	1 → 3		
			β-D-Glu*p*A	Little	1 → 6		
Glucuronoxylan	Hardwood	15–30	β-D-Xyl*p*	10	1 → 4	Alkali,	200
			4-*O*-Me-α-D-	1	1 → 2	dimethyl	
			Glu*p*A	7		sulfoxide*	
			Acetyl				
Glucomannan	Hardwood	2–5	β-D-Man*p*	1–2	1 → 4	Alkaline borate	200
			β-D-Glu*p*		1 → 4		

[a] The asterisk represents a partial solubility.
[b] $\overline{DP}_n$ is the number average degree of polymerization, usually obtained by osmometry.
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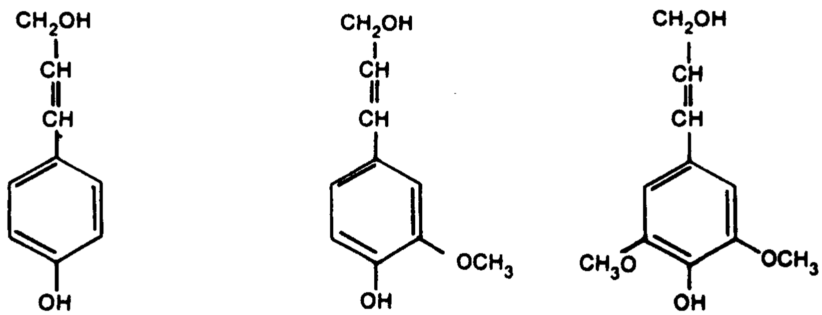
methods used for the isolation and structural characterization of each of these materials are beyond the scope of this chapter *(13-15).*

Lignin. Lignin is a phenolic substance consisting of an irregular array of variously bonded hydroxy- and methoxy-substituted phenylpropane units. The precursors of lignin biosynthesis are *p*-coumaryl alcohol (I), coniferyl alcohol (II), and sinapyl alcohol (III). I is



I II III

a minor precursor of softwood and hardwood lignins; II is the predominant precursor of softwood lignin; and II and III are both precursors of hardwood lignin (15). These alcohols are linked in lignin by ether and carbon–carbon bonds. Figure 6 *(15)* is a schematic structure of a softwood lignin meant to illustrate the variety of structural components. The 3,5-dimethoxy-substituted aromatic ring number 13 originates from sinapyl alcohol, III, and is present only in trace amounts (<1%) *(16).* Figure 6 does not show a lignin-carbohydrate covalent bond. There has been much controversy concerning the existence of this bond, but evidence has been accumulating in its support *(15, 17).*

A structure proposed for hardwood lignin *(Fagus silvatica* L.) is similar to that of Figure 6, except that there are three times as many syringylpropane units as guaiacylpropane units *(18).* These moieties are derived from III and II, respectively. The ratio of syringyl to guaiacyl moieties is often obtained by measuring the relative amounts of syringaldehyde (3, 5-dimethoxy-4-hy droxybenzaldeh yde) and vanillin (4-hydroxy-3-methoxybenzaldehyde) generated as products of nitrobenzene oxidation of lignin *(19).* A better method is to determine the products formed from the two types of moieties on permanganate oxidation of methylated lignins (20).

Lignin can be isolated by one of several methods. Acid hydrolysis of wood isolates Klason lignin, which can be quantified (see "Analytical Procedures"), but is too severely degraded for use in structural studies. Björkman's *(21)* milled wood lignin procedure yields a lignin that is much less degraded and is, thus, more useful

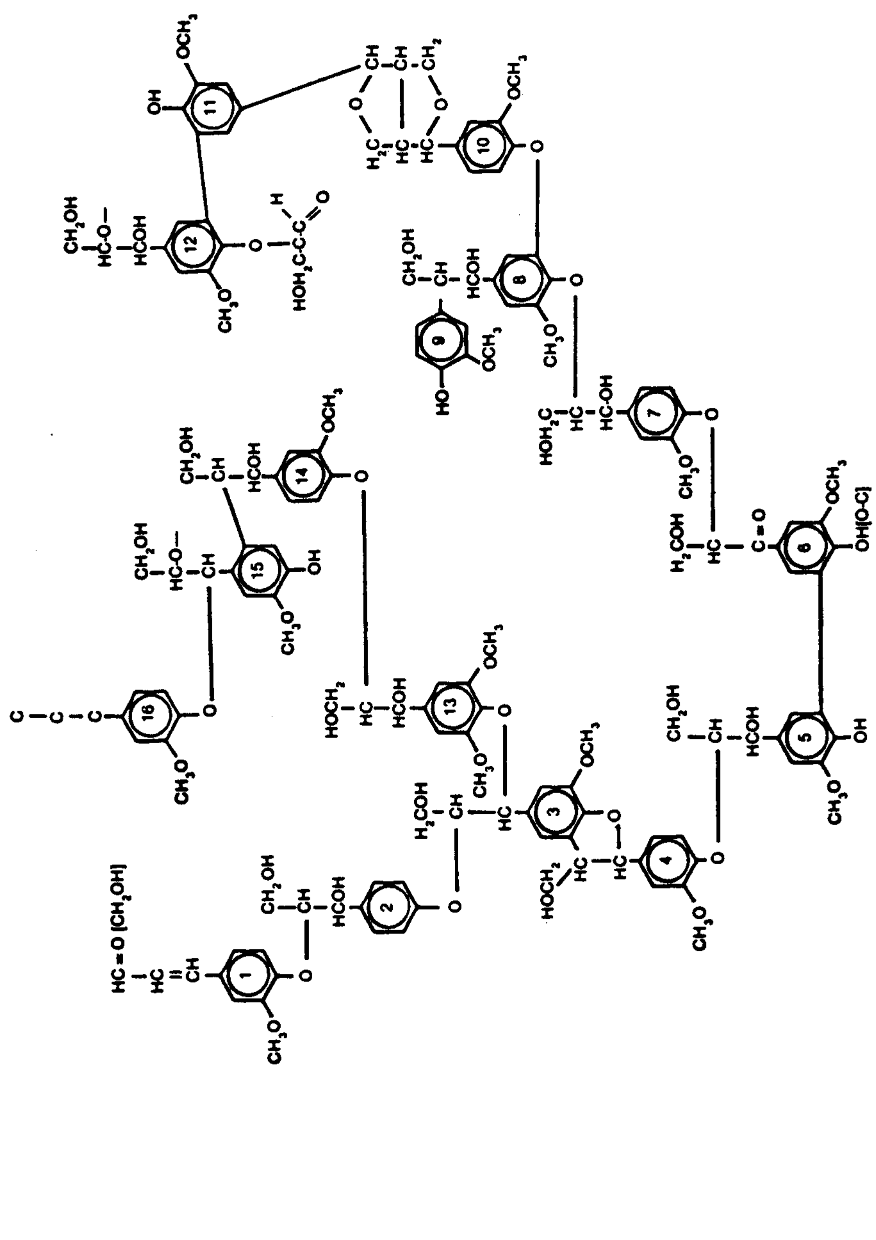


Figure 6. A partial structure of softwood lignin.

for structural studies. The following are examples of the weight average molecular weight of lignins isolated by using the milled wood lignin process: spruce [*Picea abies* (L.) Karst.], 15,000; and sweetgum (*Liquidambar styraciflua* L.), 16,000 *(22).* These values are lower than the molecular weight of the original lignin because fragmentation of the lignin molecules results from the ball milling procedure. Lignin for structural studies can also be obtained by enzymatic hydrolysis of the carbohydrate *(23).* Wood is ground in a vibratory ball mill and then treated with cellulytic enzymes. The isolated lignin contains 12– 14% carbohydrate.

Methoxyl content is used to characterize lignins. Elemental and methoxyl analysis of spruce (*Picea abies* (L.) Karst.) milled wood lignin indicates a composition $C_9H_{7.92}O_{2.40}(OCH_3)_{0.92}$ *(15, 24).* Beech (*Fagus silvatica* L.) milled wood lignin has a composition $C_9H_{7.49}O_{2.53}(OCH_3)_{1.39}$ *(24).* This information helps lignin chemists understand what precursors were used for the biosynthesis of lignin. An excellent, comprehensive book on lignin is edited by Sarkanen and Ludwig *(25).*

Extraneous Components. The extraneous components (extractives and ash) in wood are the substances other than cellulose, hemicelluloses, and lignin. They do not contribute to the cell wall structure, and most are soluble in neutral solvents. The detailed chemistry of wood extractives can be found elsewhere *(26).* A review of extractives in eastern U.S. hardwoods is available *(27).*

Extractives— the extraneous material soluble in neutral solvents —constitute 4– 10% of the dry weight of normal wood of species that grow in temperate climates. They may be as much as 20% of the wood of tropical species. Extractives are a variety of organic compounds including fats, waxes, alkaloids, proteins, simple and complex phenolics, simple sugars, pectins, mucilages, gums, resins, terpenes, starches, glycosides, saponins, and essential oils. Many of these function as intermediates in tree metabolism, as energy reserves, or as part of the tree's defense mechanism against microbial attack. They contribute to wood properties such as color, odor, and decay resistance.

Ash is the inorganic residue remaining after ignition at a high temperature. It is usually less than 1% of wood from temperate zones. It is slightly higher in wood from tropical climates.

Carbohydrate and Lignin Distribution

Carbohydrates. The morphological parts of the cell wall of a conifer are shown in Chapter 1, Figure 1b. Most of wood carbohydrate is in the massive secondary wall, particularly in S_2. Young tracheids have been isolated *(28)* at various stages of cell wail development, and then the separated fractions were analyzed for the five wood sugars. Table II lists the results obtained by using this method on birch *(Betula verrucosa* Ehrh.) and Scots pine *(Pinus sylcestris* L.) *(29)* fibers. The values are relative and sum to 100% for a given morphological part. This method has difficulty in distinguishing the presence of the very thin S_3. A tentative volume ratio was determined for the lignin-free layers of the pine and birch fibers by using photomicrographs of transverse sections. Taking the proportion to be middle lamella + primary cell wall (ML + P): S_1:S_2:S_3, the values are 2:10:78:10 for pine fibers *(28)* and 3:15:76:6 for birch *(29).* Assuming the density of the cell wall to be constant, the volume ratios become a comparison of amounts of polysaccharide in each layer.

Lignin. The distribution of lignin in the different morphological regions of wood microstructure has been studied using UV microscopy *(30).* In spruce *(Picea mariana* Mill.) tracheids, it was determined that 72% and 82% of the lignin was in the secondary cell walls of earlywood and latewood, respectively *(31).* The remainder was located in the middle lamella and cell comers. In birchwood *(Betula papyrifera* Marsh.), 71.3% of the lignin was of the syringyl type and was found in the secondary walls of the fibers (59.9%) and ray cells (11.4%), An additional 10.9% of the lignin was of the guaiacyl type and was found in the secondary walls of the vessels (9.4%) and the vessel middle lamella (1.5%). The remainder (17.7%) was mixed syringyl- and guaiacyl-type and was in the fiber middle lamella *(32),* Caution is needed in interpreting the syringyl/guaiacyl distribution in hardwood lignins; methoxyl analyses of isolated morphological parts of oak fibers and vessels indicates a rather uniform syringyl/guaiacyl content *(33).*

Analytical Procedures

Carbohydrates. There are a number of analytical determinations associated with the carbohydrate portion of wood.

HOLOCELLULOSE. Holocellulose is the total polysaccharide (cellulose and hemicelluloses) content of wood, and methods for its determination seek to remove all of the lignin from wood without disturbing the carbohydrates. The procedure generally used *(34)* was adopted as Tappi Standard T9m[1] (now useful method 249), and as ASTM Standard D 1104.[2] Extracted wood meal is treated alternately with chlorine gas and 2-aminoethanol until a white residue (holocellulose) remains. The acid chlorite method is also used *(3).* The

[1] Tappi Standards are maintained by the Technical Association of Pulp and paper Industry, Atlanta, Ga.

[2] ASTM standards are maintained by the American Society for Testing Materials. Philadelphia, Pa.

Table II. Percentages of Polysaccharides in the Different Layers of the Fiber Wall

Polysaccharide	$Ml + P^a$	S_1	S_2 *(outer part)*	S_2 *(inner part)* $+ S_3$
		Birch (*Betula verrucosa* Ehrh.)		
Galactan	16.9	1.2	0.7	0.0
Cellulose	41.4	49.8	48.0	60.0
Glucomannan	3.1	2.8	2.1	5.1
Arabinan	13.4	1.9	1.5	0.0
Glucuronoxylan	25.2	44.1	47.7	35.1
		Pine (*Pinus sylvestris* L.)		
Galactan	20.1	5.2	1.6	3.2
Cellulose	35.5	61.5	66.5	47.5
Glucomannan	7.7	16.9	24.6	27.2
Arabinan	29.4	0.6	0.0	2.4
Glucuronoarabinoxylan	7.3	15.7	7.4	19.4

[a] Also contains a high percentage of pectic acid.
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product, called chlorite holocellulose, is similar to chlorine holocellulose. The chlorite method removes a fraction more of the hemicelluloses than the chlorine method.

ALPHA CELLULOSE. Alpha cellulose is obtained after treatment of the holocellulose with 17.5% NaOH (*see* ASTM Standard D 1103). This procedure removes most, but not all, of the hemicelluloses.

CROSS AND BEVAN CELLULOSE. Cross and Bevan cellulose consists largely of pure cellulose, but also contains some hemicelluloses. It is obtained by chlorination of wood meal, followed by washing with 3% SO_2 and 2% sodium sulfite (Na_2SO_3 water solutions. The final step is treatment in boiling Na_2SO_3 solution. The absence of a characteristic red (angiosperm) or brown (gymnosperm) color developed in the presence of chlorinated lignin signals complete lignin removal. For a discussion of the method and its modifications, see Reference 35.

KÜRSCHKER CELLULOSE. Kürschner cellulose is obtained by refluxing the wood sample three times for 1 h with a 1:4 volume mixture of concentrated nitric acid and ethyl alcohol *(37)*. The washed and dried residue is weighed as Kürschner cellulose. The product contains a small amount of hemicelluloses. [The cellulose determined for the Ghanan and Russian woods (*see* in Tables VI and XI) is Kürschner cellulose]. The method is not widely used because it destroys some of the cellulose and the nitric acid/alcohol mixture is potentially explosive.

PENTOSAN. Pentosan analysis measures the amount of five-carbon sugars present in wood (xylose and arabinose residues). Although the hemicelluloses consist of a mixture of five- and six-carbon sugars (*see* discussion of hemicelluloses), the pentosan analysis reports the xylan and arabinan content as if the five-carbon sugars were present as pure pentans. Pentoses are more abundant in hardwoods than softwoods; the difference is due to a higher xylose content in hardwoods (*see* Table XIII for examples).

Tappi standard T 223 outlines the procedure for pentosan analysis. Briefly, wood meal is boiled in 3.85 N HCl with some NaCl added. Furfural is generated and distilled into a collection flask. The furfural is determined calorimetrically with orcinol–iron(III) chloride reagent. Another method also generates furfural, and the furfural is determined gravimetrically by precipitation with 1,3,5-benzenetriol. These and other methods of pentosan analysis are described and discussed in Browning's book *(36)*.

CHROMATOGRAPHIC ANALYSIS OF WOOD SUGARS. This analysis requires acid hydrolysis of the polysaccharide to yield a solution mixture of the five wood sugar monomers, i.e., glucose, xylose, galactose, arabinose, and mannose. The solution is neutralized, filtered, and the sugars chromatographically separated and quantified. Generally this method is accepted as the standard of hydrolysis *(37).* In this procedure, wood meal is treated with 72% H_2SO_4 at 30 °C for 1 h to depolymerize the carbohydrates. Reversion products (recombined sugar monomers) are further hydrolyzed in 3% H_2SO_4 at 120 °C for 1 h. The solution is then filtered, and the solid residue is washed, dried, and weighed as Klason lignin *(see* "Lignin" later). The filtrate is neutralized with barium(II) hydroxide or ion exchange resin. The individual sugars are separated by paper, liquid, or gas chromatography (GC). Paper chromatography has been the standard method for many years and all the individual sugar data and hemicellulose data reported in the tables of this chapter were obtained by this method [adopted as Tappi Provisional Test Method T 250 *(37)].* This method uses a modified form of the Somogyi calorimetric assay for reducing sugars *(38).* Timell *(39)* reports a calorimetric method in which the reducing sugars are reacted with 2-aminobiphenyl hydrochloride. There are many other assay methods for reducing sugars.

Sugar separation by GC requires the preparation of volatile derivatives. Tappi Test Method T 249 pm–75 uses the alditol acetate derivitization *(40).* Peracetylated aldonitrile *(41)* or trimethylsilane *(42, 43)* derivatives *can* also be prepared and separated by GC. Wood sugar analysis by GC may be useful for specialized problems, but the derivitization steps make it a time-consuming method for routine work.

High performance liquid chromatography (HPLC) is currently the most efficient means for routine separation and quantification of the five wood sugars *(44).* In this case, no derivitization is necessary, and separation is achieved using water as an eluent. Detection is by a differential refractometer.

URONIC ACID. Uronic acid is determined by measuring carbon dioxide (CO_2) generation when wood is boiled with 12% HCl *(45).* Results from this, method may be somewhat high because of CO_2 evolution from material containing carboxyl groups other than uronic acid. A method developed by Scott *(46)* is rapid and selective. The sample is treated with 96% H_2SO_4 at 70 °C, and a product, 5-formyl-2-furancarboxlic acid, is derived from uronic acids. This compound reacts selectively with 3,5-dimethylphenol to yield a chromophore absorbing at 450 nm.

ACETYL CONTENT. The acetyl content of wood is determined by saponification of the sample in 1 *N* NaOH, followed by acidification, quantitative distillation of the acetic acid, and titration of the distillate with standard NaOH *(47).* A modification here (Forest Products Laboratory) enables acetic acid determination by using GC with propanoic acid as an internal standard. This modification eliminates the tedious, time-consuming distillation step.

WOOD SOLUBILITY IN 1% NAOH. Wood extraction procedures in 1% NaOH (Tappi Standard T 212) extract most extraneous components, some lignin, and low molecular weight hemicelluloses and degraded cellulose. The percent of alkali-soluble material increases as the wood decays *(48).* The extraction is done in a water bath maintained at 100 °C.

Lignin. The lignin contents of woods presented in the tables of this chapter are Klason lignin, the residue remaining after solubilizing the carbohydrate with strong mineral acid. The usual procedure, as in Tappi Standard T 222 or ASTM Standard D 1106, is to treat finely ground wood with 72% H_2SO_4 for 2 h at 20 °C, followed by dilution to 3% H_2SO_4 and boiling or refluxing for 4 h. An equivalent but shorter method treats the sample with 72% H_2SO_4 at 30 °C for 1 h, followed by 1 h at 120 °C in 3% H_2SO_4 *(50).* In both cases the determination is gravimetric.

Softwood lignins are insoluble in 72% H_2SO_4 and Klason lignin provides an accurate measure of total lignin content. Hardwood lignins are somewhat soluble in 72% H_2SO_4, and the acid-soluble portion may amount to 10-20% of the total lignin content *(51).* The *acid-soluble lignin* can be determined spectrophotometrically at 205 nm *(51, 52).* (Table XIV contains lignin values that add the acid-soluble component measured at 205 nm to the Klason lignin. Lignin contents of hardwoods in all the other tables are low).

METHOXYL. Methoxyl groups are determined by a modified method *(53).* Methyl iodide is formed by hydrolysis of the methoxyl groups of wood lignin in hydriodic acid and is distilled under CO_2 into a solution of bromine and potassium acetate in glacial acetic acid. Bromine oxidizes iodide to iodate which is then titrated with standard thiosulfate. The method is difficult and time-consuming, and some experience is necessary before satisfactory results can be obtained. Details are in ASTM Standard D 1166 and Tappi Standard T 209 (withdrawn in November 1979). Additional discussion can be found in Reference 54.

Extraneous Components

Wood Solubility. The solubility of wood in various solvents is a measure of the extraneous components content. No single solvent is able to remove all of the extraneous materials. Ether is relatively nonpolar and extracts fats, resins, oils, sterols, and terpenes. Ethanol/benzene is more polar and extracts most of the ether-solubles plus most of the organic materials insoluble in water. Hot water extracts some inorganic salts and low molecular weight polysaccharides including gums and starches. Water also removes certain hemicelluloses such as the arabinogalactan gum present in larch wood *(see* Table I).

ETHANOL/BENZENE. The solubility of wood in EtOH/benzene (benzene is a known carcinogen; toluene can be substituted) in a 1:2 volume ratio will give a measure of the extractives content. This procedure is Tappi Standard T 204 and ASTM Standard D 1107. The wood meal is refluxed 6-8 h in a Soxhlet flask, and the weight loss of the extracted, dried wood is measured. Sometimes the lignin, carbohydrate, and other components are determined on wood that has been extracted previously with EtOH/benzene (*see* Table XIII).

DIETHYL ETHER. The solubility of wood in diethyl ether is determined in the same way as EtOH/benzene solubility.

Ash Analysis. Ash analysis is performed according to Tappi Standard T 15 and ASTM Standard D 1102. In these standards ash is defined as the residue remaining after dry ignition of the wood at 575 °C, Elemental composition of the ash is determined by dissolving the residue in strong HNO_3 and analyzing the solution by atomic absorption or atomic emission. The inorganic elemental composition of wood can be determined directly by neutron activation analysis. (Table XV contains elemental data using both methods).

Silica (SiO_2 content in wood can be determined by treating the ash with hydrofluoric acid (HF) to form the volatile compound silicon tetrafluoride (SiF_4, The weight loss is the amount of silica in the ash. Silica is rarely present in more than trace amounts in temperate climate woods, but can vary in tropical woods from a mere trace to as much as 990. More than 0.5% silica in wood is harmful to cutting tools *(55).*

Moisture Content. The moisture content of wood is determined by measuring the weight loss after drying the sample at 105 °C. Unless specified otherwise, the percent of all other chemical components in wood is calculated on the basis of moisture-free wood. Moisture content is determined on a separate portion of the sample not used for the other analyses.

Recent Improvements in Techniques

The data reported in this chapter were obtained using standard methods. The methods are routine but require much care and time. Some methods have been replaced by better, more efficient methods. For example, the holocellulose, cellulose, and pentosan tests have been replaced by the single five-sugar chromatographic test. The five-sugar test procedure gives more detailed information in a shorter time. The recent change from paper chromatography to HPLC has improved the efficiency of this test. The test for Klason lignin remains in use, as do the acetyl, methoxyl, and uronic acid tests.

Analytical instruments and data processors have helped to remove some of the tedium and to shorten analysis time. The result has been an increase in the number of analyses performed. More significant is the detail possible with advanced instruments. For example, HPLC can separate and quantitate individual uronic acids. This provides more detail of hemicellulose composition. The structure of lignin can be probed further by mass spectrometry and high-resolution NMR spectrometry. Wood extractives can be isolated and characterized by capillary GC/mass spectrometry. A new mass spectrometer has two or more mass analyzers and eliminates the often limiting chromatographic separation step.

More systematic wood composition studies are needed in the future. It would be useful to study the composition of a select number of prominent species and note the content variability with tree parts, climate, soil conditions, and age.

Tables of Composition Data

Tables III–XIV are organized geographically and list chemical composition data for woods from various countries. The data as published originally were of interest to the local pulp and paper industries. This compilation provides a worldwide view of wood composition. Most of the data were obtained using similar test methods (Tappi Standards). When it is known that other test methods were used, the method is footnoted in the tables. Most of the values reported from all sources had one or two figures beyond the decimal point. Except for the ether solubility and ash values (usually less than 1%), values have been rounded off to the nearest percent because this reflects the precision of the sampling and assay methods.

The data in Table III have not been published previously. The same test methods were used for all tree species in Table III. Most of these methods were developed at the laboratory and were later adopted as Tappi standards. Tables IV–XII contain similar data obtained in many test laboratories. The three Taiwanese sources contain data for more than 400 trees. The trees selected for inclusion in Table X were those described in a book published by the Chinese Forestry Association *(56).* Table XII contains data on trees of unrecorded origin. Except for *Tectonia grandia,* the species reported do not appear in the other tables.

Tables XIII and XIV present more detailed analyses of woods: Table XIII contains data on 30 North American species, and Table XIV contains data on 32 species from the southeastern United States. The lignin values in Table XIV are the sum of Klason and acid-soluble lignins. Pectin (Table XIV) is mainly galacturonic acid. It is the measured total uronic acid value minus the estimated glucuronic acid value. Glucuronic acid content can be estimated from the xylan content by assuming a ratio of xylose to 4-*O*-methylglucuronic acid of 10:1 *(see* Table I *and* Figure 5). The reported values of the carbo-

Table III. Chemical Composition of U.S. Woods as Determined at U.S. Forest Products Laboratory from 1927 to 1968

	Carbohydrate					*Solubility*				
Scientific Name/Common Name	*Holo-cellu-lose*[a]	*Cross and Bevan Cellu-lose*[b]	*Alpha Cellu-lose*[c]	*Pento-sans*[d]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/ Benzene*	*Ether*	*Ash*
					Hardwoods					
Acer macrophyllum **Pursh/ Bigleaf maple**	—	—	46	22	25	18	2	3	0.7	0.5
Acer negundo **L./Boxelder**	—	—	45	20	30	10	—	—	0.4	—
Acer rubrum **L./Red maple**	77 (3)	61 (2)	47 (3)	18 (3)	21 (3)	16 (3)	3 (3)	2 (3)	0.7 (3)	0.4 (3)
Acer saccharinum **L./Silver maple**	—	56	42	19	21	21	4	3	0.6	—
Acer saccharum **Marsh./Sugar maple**	—	60	45	17	22	15	3	3	0.5	0.2
Alnus rubra **Bong./Red alder**	74 (2)	—	44 (3)	20 (3)	24 (3)	16 (3)	3 (3)	2 (3)	0.5 (3)	0.3 (3)
Arbutus menziesii **Pursh/ Pacific madrone**	—	—	44	23	21	23	5	7	0.4	0.7
Betula alleghaniensis **Britton/ Yellow birch**	73	64 (2)	47 (2)	23 (2)	21 (2)	16 (2)	2 (2)	2 (2)	1.2 (2)	0.7 (2)
Betula nigra **L./River birch**	—	57	41	23	21	21	4	2	0.5	—
Betula papyrifera **Marsh./ Paper birch**	78 (2)	63 (3)	45 (5)	23 (5)	18 (5)	17 (4)	2 (4)	3 (4)	1.4 (4)	0.3 (2)
Carya cordiformus **(Wangenh.) K. Koch/ Bitternut hickory**	—	56	44	19	25	16	5	4	0.5	—
Carya glaubra **(Mill.) Sweet/ Pignut hickory**	71 (2)	—	49 (2)	17 (2)	24 (2)	17 (2)	5 (2)	4 (2)	0.4 (2)	0.8 (2)
Carya ovata **(Mill.) K. Koch/ Shagbark hickory**	71	—	48	18	21	18	5	3	0.4	0.6

Carya pallida (Ashe) Engl. & Graebn./Sand hickory	69	—	50	17	23	18	7	4	0.4	1.0
Carya tomentosa (Poir.) Nutt./Mockernut hickory	71 (2)	—	48 (2)	18 (2)	21 (2)	17 (2)	5 (2)	4 (2)	0.4 (2)	0.6
Celtis laevigata Willd./Sugarberry	—	54	40	22	21	23	6	3	0.3	—
Eucalyptus gigantea Hook. f./—	72	—	49	14	22	16	7	4	0.3	0.2
Fagus grandifolia Ehrh./American beech	77 (2)	61 (2)	49 (2)	20 (2)	22 (2)	14 (2)	2 (2)	2 (2)	0.8 (2)	0.4 (2)
Fraxinus americana L./White ash	—	51	41	15	26	16	7	5	0.5	—
Fraxinus pennsylvanica Marsh./Green ash	—	53 (4)	40 (4)	18 (4)	26 (4)	19 (4)	7 (4)	5 (4)	0.4 (4)	—
Gleditsia triacanthos L./Honey locust	—	—	52	22	21	19	—	—	0.4	—
Laguncularia racemosa (L.) Gaertn./White mangrove	—	52	40	19	23	29	15	6	2.1	—
Liquidambar styraciflua L./Sweetgum	—	60 (3)	46 (4)	20 (4)	21 (4)	15 (4)	3 (3)	2 (4)	0.7 (3)	0.3 (3)
Liriodendron tulipifera L./Yellow-poplar	—	62	45	19	20	17	2	1	0.2	1.0
Lithocarpus densiflorus (Hook. & Arn.) Rehd./Tanoak	71 (2)	—	46 (3)	20 (2)	19 (3)	20 (3)	5 (2)	3 (2)	0.4 (2)	0.7 (2)
Milalenca quinquenervia (Cav.) S. T. Blake/Cajeput	—	56	43	19	27	21	4	2	0.5	—
Nyssa aquatica L./Water tupelo	—	59 (2)	45 (2)	16 (2)	24 (2)	16 (2)	4 (2)	3 (2)	0.6 (2)	0.6
Nyssa sylvatica Marsh./Black tupelo	72	57 (4)	45 (5)	17 (4)	27 (5)	15 (5)	3 (5)	2 (5)	0.4 (5)	0.5 (2)
Populus alba L./White poplar	—	67	52	23	16	20	4	5	0.9	—
Populus deletoides Bartr. ex Marsh./Eastern cottonwood	—	64 (3)	47 (3)	18 (3)	23 (3)	15 (3)	2 (3)	2 (3)	0.8 (2)	0.4

Continued on next page

Table III. Continued

Scientific Name/Common Name	Carbohydrate: Holocellulose[a]	Carbohydrate: Cross and Bevan Cellulose[b]	Carbohydrate: Alpha Cellulose[c]	Carbohydrate: Pentosans[d]	Klason Lignin	Solubility: 1% NaOH	Solubility: Hot Water	Solubility: EtOH/Benzene	Ether	Ash
Populus tremoides Michx./ Quaking aspen	78 (9)	65 (13)	49 (20)	19 (19)	19 (22)	18 (15)	3 (15)	3 (14)	1.2 (15)	0.4 (11)
Populus trichocarpa Torr. & Gray/Black cottonwood	—	—	49	19	21	18	3	3	0.7	0.5
Prunus serotina Ehrh./Black cherry	85	60	45	20	21	18	4	5	0.9	0.1
Quercus alba L./White oak	67 (2)	—	47 (2)	20 (2)	27 (2)	19 (2)	6 (3)	3 (2)	0.5 (2)	0.4
Quercus coccinea Muenchh./ Scarlet oak	63	—	46	18	28	20	6	3	0.4	—
Quercus douglasii Hook & Arn./Blue oak	59	—	40	22[e]	27	23	11	5	1.4	1.4
Quercus falcata Michx./ Southern red oak	69	—	42	20	25	17	6	4	0.3	0.4
Quercus kelloggii Newb./ California black oak	60	—	37	23[e]	26	26	10	5	1.5	0.4
Quercus lobata Nee/Valley oak	70	—	43	19[e]	19	23	5	7	1.0	0.9
Quercus lyrata Walt./Overcup oak	—	—	40	18	28	24	9	5	1.2	0.3
Quercus marylandica Muenchh./Blackjack oak	—	57	44	20	26	15	5	4	0.6	—
Quercus prinus L./Chestnut oak	76	—	47	19	24	21	7	5	0.6	0.4
Quercus rubra L./Northern red oak	69	—	46	22	24	22	6	5	1.2	0.4
Quercus stellata Wangenh./ Post oak	—	55	41	18	24	21	8	4	0.5	1.2

Quercus velutina Lam./Black oak	71	—	48	20	24	18	6	5	0.2	0.2
Salix nigra Marsh./Black willow	—	61 (2)	46 (2)	19 (2)	21 (2)	19 (2)	4 (2)	2 (2)	0.6 (2)	—
Tilia heterophylla Vent./ Basswood	77	65	48	17	20	20	2	4	2.1	0.7
Ulmus americana L./American elm	73	61 (3)	50 (3)	17 (3)	22 (3)	16 (3)	3 (3)	2 (3)	0.5 (3)	0.4
Ulmus crassifolia Nutt./Cedar elm	—	—	50	19	27	14	—	—	0.3	—
Softwoods										
Abies amabilis Dougl. ex Forbes/Pacific silver fir	—	61 (3)	44 (3)	10 (3)	29 (3)	11 (3)	3 (3)	3 (3)	0.7 (3)	0.4
Abies balsamea (L.) Mill./ Balsam fir	—	58 (16)	42 (16)	11 (16)	29 (16)	11 (16)	4 (16)	3 (16)	1.0 (16)	0.4 (15)
Abies concolor (Gord. & Glend.) Lindl. ex Hildebr./ White fir	66	—	49	6	28	13	5	2	0.3	0.4
Abies lasiocarpa (Hook.) Nutt./ Subalpine fir	67 (4)	—	46 (4)	9 (4)	29 (4)	12 (4)	3 (4)	3 (4)	0.6 (4)	0.5 (4)
Abies procera Rehd./Noble fir	61	—	43	9	29	10	2	3	0.6	0.4
Chamaecyparis thyoides (L.) B.S.P./Atlantic white cedar	—	53	41	9	33	16	3	6	2.4	—
Juniperus deppeana Steud./ Alligator juniper	57	—	40	5	34	16	3	7	2.4	0.3
Larix larcina (Du Roi) K. Koch/Tamarack	64 (3)	—	44 (3)	8 (3)	26 (3)	14 (3)	7	3 (3)	0.9 (3)	0.3 (2)
Larix occidentalis Nutt./ Western larch	65 (3)	56 (2)	48 (3)	9 (3)	27 (3)	16 (3)	6 (3)	2 (3)	0.8 (3)	0.4 (2)
Libocedrus decurrens Torr./ Incense cedar	56	—	37	12	34	9	3	3	0.8	0.3
Picea engelmanni Parry ex Engelm./Engelman spruce	69 (4)	60 (2)	45 (6)	10 (6)	28 (6)	11 (6)	2 (6)	2 (6)	1.1 (6)	0.2 (2)
Picea glauca (Moench) Voss/ White spruce	—	61 (8)	43 (8)	13 (7)	29 (8)	12 (8)	3 (8)	2 (8)	1.1 (8)	0.3 (2)

Continued on next page

Table III. Continued

Scientific Name/Common Name	Holocellulose[a]	Cross and Bevan Cellulose[b]	Alpha Cellulose[c]	Pentosans[d]	Klason Lignin	Solubility: 1% NaOH	Solubility: Hot Water	Solubility: EtOH/Benzene	Ether	Ash
	Carbohydrate					*Solubility*				
Picea mariana (Mill.) B.S.P./ Black spruce	—	60 (19)	43 (20)	12 (19)	27 (20)	11 (20)	3 (20)	2 (20)	1.0 (20)	0.3 (19)
Picea sitchensis (Bong.) Carr./ Sitka spruce	—	62	45	7	27	12	4	4	0.7	—
Pinus attenuata Lemm./ Knobcone pine	—	—	47	14	27	11	3	1	—	0.2
Pinus banksiana Lamb./Jack pine	66 (6)	58 (25)	43 (27)	13 (27)	27 (27)	13 (27)	3 (26)	5 (27)	3.0 (26)	0.3 (7)
Pinus clausa (Chapm. ex Engelm.) Vasey ex Sarg./ Sand pine	—	57 (3)	44 (4)	11 (4)	27 (4)	12 (2)	2 (2)	3 (2)	1.0	0.4
Pinus contorta Dougl. ex Loud./Lodgepole pine	68 (11)	59 (7)	45 (11)	10 (11)	26 (11)	13 (11)	4 (11)	3 (11)	1.6 (11)	0.3 (11)
Pinus echinata Mill./Shortleaf pine	69	60 (8)	45 (9)	12 (9)	28 (9)	12 (9)	2 (9)	4 (9)	2.9 (9)	0.4 (2)
Pinus elliottii Engelm./Slash pine	64 (3)	59 (13)	46 (15)	11 (15)	27 (15)	13 (15)	3 (15)	4 (15)	3.3 (15)	0.2 (3)
Pinus monticola Dougl. ex D. Don/Western white pine	69 (3)	61 (4)	43 (7)	9 (7)	25 (7)	13 (6)	4 (6)	4 (6)	2.3 (6)	0.2 (3)
Pinus palustris Mill./Longleaf pine	—	59 (7)	44 (5)	12 (7)	30 (6)	12 (7)	3 (5)	4 (7)	1.4 (7)	—
Pinus ponderosa Dougl. ex Laws./Ponderosa pine	68	58	41 (2)	9 (2)	26 (2)	16 (2)	4 (2)	5 (2)	5.5 (2)	0.5

Pinus resinosa Ait./Red pine	71	—	47	10	26	13	4	4	2.5	—
Pinus sabiniana Dougl./Digger pine	—	—	46 (2)	11 (2)	27 (2)	12 (2)	3 (2)	1 (2)	—	0.2 (2)
Pinus strobus L./Eastern white pine	68 (4)	60	45 (5)	8 (5)	27 (5)	15 (5)	4 (5)	6 (5)	3.2 (5)	0.2 (3)
Pinus taeda L./Loblolly pine	68	60 (13)	45 (14)	12 (12)	27 (14)	11 (12)	2 (12)	3 (15)	2.0 (12)	—
Pseudotsuga menziesii (Mirb.) Franco/Douglas-fir	66 (9)	60 (42)	45 (50)	8 (50)	27 (50)	13 (50)	4 (50)	4 (50)	1.3 (50)	0.2 (13)
Sequoia sempervirens (D. Don) Endl./Redwood										
Old growth	55	—	43	7	33	19	9	10	0.8	0.1
Second growth	61	—	46	7	33	14	5	<1	0.1	0.1
Taxodium distichum (L.) Rich./Bald cypress	—	55	41	12	33	13	4	5	1.5	—
Thuja occidentalis L./ Northern white cedar	59	—	44	14[e]	30	13	5	6	1.4	0.5
Thuja plicata Donn ex D. Don/Western red cedar	—	49	38	9	32	21	11	14	2.5	0.3
Tsuga canadensis (L.) Carr./ Eastern hemlock	—	55 (7)	41 (7)	9 (4)	35 (7)	13 (6)	4 (7)	3 (7)	0.5 (7)	0.5 (5)
Tsuga heterophylla (Raf.) Sarg./Western hemlock	67 (2)	58 (22)	42 (22)	9 (22)	29 (22)	14 (22)	4 (22)	4 (22)	0.5 (22)	0.4 (4)
Tsuga mertensiana (Bong.) Carr./Mountain hemlock	60	—	43	7	27	12	5	5	0.9	0.5

NOTE: Numbers in parentheses are independent determinations of the component and in some cases, the trees are from different locations; values are percent moisture-free wood.

[a] Holocellulose is the total carbohydrate content of wood.

[b] Cross and Bevan cellulose is largely pure cellulose but contains some hemicelluloses.

[c] Alpha cellulose is nearly pure cellulose.

[d] Pentosans are the total anhydroxylose and arabinose residues in wood.

[e] Pentosans determined by gravimetric method.

Table IV. Chemical Composition of Woods from South and Central America, Mexico, and Puerto Rico

Scientific Name/Common Name	Carbohydrate: Holocellulose[a]	Carbohydrate: Alpha Cellulose[b]	Carbohydrate: Pentosans[c]	Klason Lignin	Solubility: 1% NaOH	Solubility: Hot Water	Solubility: EtOH/Benzene	Solubility: Ether	Ash	Reference
Brazil										
Brosimum parinarioides Ducke/ Amapa roxo	—	51	10	26	21	2	6	—	0.2	57
Cecropia juranyiana A. Rich./ Imbauba[d]	69	48	17	25	14	6	3	0.3	0.7	58[e]
Corythophora alta Knuth./ Ripeiro vermelho	—	47	10	30	19	6	4	—	0.5	57
Couepia leptostachya Benth./ Uchi de cutia	—	39	9	33	12	4	<1	—	0.8	57
Eclinusa ucuquirana branca Aubr. et Pellegr./Ucuquirana brava	—	55	15	30	17	4	1	—	0.6	57
Eperua bijuga Mart. et Benth./ Muirapiranga	—	41	12	38	31	11	9	—	0.2	57
Eschweiler odora Poepp. et Miers/Matamata	—	50	13	32	18	6	<1	—	0.9	57
Eucalyptus camaldulensis Dehnh./Red river gum	—	50[f]	17	29	11	2	2	—	0.8	59
Eucalyptus cloeziana F. Muell./ Gympie messmate	—	54[f]	16	28	12	2	3	—	0.3	59
Eucalyptus grandis W. Hillex Maid./Flooded gum	—	54[f]	19	26	16	3	3	—	0.3	59

Eucalyptus kirtoniana F. Muell./—	74	50	15	28	14	3	2	0.3	0.1	60
Eucalyptus saligna Sm./Sydney blue gum	74	50	15	27	14	3	1	0.3	0.2	60
Eucalyptus tesselaris F. Muell./—	—	50[f]	21	24	17	5	2	—	0.6	59
Eucalyptus torelliana F. Muell./ Cadaga	—	53[f]	23	22	19	3	2	—	1.0	59
Eucalyptus urophylla S. T. Blake/Timor white gum	—	53[f]	19	24	17	2	2	—	0.4	59
Holopyxidium latifolium (Ducke) Knuth./Jarana	—	50	10	30	17	1	4	—	0.3	57
Licania oblonifolia Standl./ Macuco chiador	—	51	20	33	18	2	1	—	0.5	57
Lucuma dissepala (K. Krause) Ducke/Abiurana	74	48	17	25	14	2	2	0.5	1.0	58[c]
Micropholis rosadinha brava Aubr. et Pellegr./Rosada brava	—	53	11	28	13	2	1	—	0.8	57
Pouteria guianensis Aubr./ Abiurana Abiu	—	54	7	30	13	3	2	—	0.3	57
Protium heptaphyllum March./ Breu branco	70	49	17	27	16	5	2	0.4	0.6	58[c]
Qualea dinizii Ducke/Pau mulato	69	48	14	28	15	3	2	0.3	0.8	58[c]
Schizolobium amazonicum Huber/Parica	—	54	12	26	16	2	2	—	0.8	57
Vantanea parviflora Lam./ Macucu murici	—	51	10	37	14	4	2	—	0.2	57

Continued on next page

Table IV. Continued

	Carbohydrate				*Solubility*					
Scientific Name/Common Name	*Holocellulose*[a]	*Alpha Cellulose*[b]	*Pentosans*[c]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/Benzene*	*Ether*	*Ash*	*Reference*
				Chile						
Eucryphia cordifolia Cav./Ulmo	77	49	15	26	17	3	2	0.3	0.5	60
Laurelia philippiana Looser/Tepa	71	46	16	28	10	2	2	0.4	1.0	60
Nothofagus dombeyi (Mirb.) Oerst/Coigue	70	48	17	23	19	7	6	1.0	0.3	60
				Colombia						
Anacardium excelsum (Bert. & Balb.) Skeels/Caracoli	61	44	10	30	18	6	6	2.9	1.2	60
Ceiba pentandra (L.) Gaertn./Ceiba bruja	62	41	16	25	25	15	2	0.5	2.9	60
Shizolobium parahybum (Vell.) Blake/Gambombo	73	49	14	26	21	2	2	0.5	0.4	60
Spondias purpurea L./Jobo	72	47	17	24	17	3	3	0.7	1.0	60
				Costa Rica						
Anacardium excelsum (Bert. & Balb.) Skeels/Espavel	72	—	8	27	18	7	3	—	1.6	61
Brosimum utile (HBK) Pittier/Baco	79	—	13	26	16	3	2	—	0.4	61
Carapa slateri Standl./Cedro macho	79	—	11	25	14	4	2	—	0.6	61
Caryocar costaricense Donn. Smith/Ajo	75	—	13	24	16	9	3	—	0.4	61

Ceiba pentandra (L.) Gaertn./ Ceiba	77	—	10	26	19	7	1	—	2.7	61
Couratari panamensis Standl./ Campano	76	—	11	31	12	5	2	—	0.7	61
Dialyanthera otoba (Humb. & Bonpl.) Warb./Bogamani	81	—	12	26	14	4	1	—	0.4	61
Dussia sp./Sangrillo amarillo	82	—	10	28	10	3	1	—	0.6	61
Peltogyne purpurea Pittier/ Nazareno	81	—	12	22	13	6	5	—	0.5	61
Platymiscium pinnatum (Jacq) Dugand/Cristobal	76	—	15	26	15	6	6	—	0.6	61
Poulsenia armata Standl./ Calugo	81	—	11	36	20	3	1	—	9.7	61
Qualea paraensis Ducke/ Masicaran	79	—	11	25	17	5	1	—	1.3	61
Sacoglottis excelsa Druke/ Terciopelo	76	—	11	31	19	6	1	—	0.4	61
Sapotaceae sp./Nispero	82	—	14	25	15	3	1	—	1.9	61
Sapotaceae sp./Zapoton	80	—	15	25	18	5	2	—	0.7	61
Symphonia globulifera L.f./ Cerillo	78	—	15	24	15	3	3	—	0.4	61
Terminalia amazonia (J.F. Gmel.) Excell./Escobo amarillo	71	—	12	25	17	10	8	—	0.5	61
Uribea tamarindoides Dugand & Romero/Almendro	73	—	12	33	10	4	5	—	1.1	61
Vantanea barbourii Standl./ Caracolillo	78	—	11	31	11	3	1	—	0.4	61
Virola sp./Fruta dorada	80	—	15	24	17	4	1	—	0.6	61
Vochysia sp./Mayo negro	82	—	17	22	21	6	4	—	0.9	61

Continued on next page

Table IV. Continued

	Carbohydrate				*Solubility*					
Scientific Name/Common Name	*Holo-cellulose*[a]	*Alpha Cellulose*[b]	*Pentosans*[c]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/Benzene*	*Ether*	*Ash*	*Reference*
Vochysia allenii Standley & L. O. Williams/Mayo blanco	81	—	11	22	18	4	3	—	1.1	61
			Mexico, Yucatan							
Allophylus psilospermus Radlk./Kanchunup	60	46	12	34	12	4	4	0.5	1.2	60
Brosimum alicastrum Sw./Ramon	63	44	16	27	17	5	2	0.4	1.6	60
Bursera simaruba (L.) Sarg./Chacha	74	46	17	23	20	5	4	0.8	1.6	60
Calyptranthes millspaughii Urb./Chachi	67	47	12	29	15	5	2	0.7	2.7	60
Cecropia obtusifolia Bertol./Kochle	67	45	15	25	19	5	4	0.7	1.7	60
Ceiba pentandra (L.) Caertn./Ceiba	64	40	18	22	28	14	2	0.5	2.4	60
Coccoloba uvifera (L.) Jacq./Boo	69	48	14	28	17	5	2	0.5	1.6	60

Drypetes lateriflora (Sw.) Krug & Erb./Ekulu	69	48	15	26	17	6	4	0.5	2.5	60
Ficus lapathifolia (Liebm.) Miq./Zacamua	66	44	15	30	17	5	2	0.5	1.7	60
Guazuma tomentosa H.B.K./ Pixoy	70	45	16	27	16	2	1	0.5	1.2	60
Pisonia sp./Tatsi	76	58	14	20	11	2	1	0.4	1.5	60
Poincianella guameri (Greenm.) Britt. & Rose/Kitanche	62	47	14	25	19	10	7	2.0	1.3	60
Spondias mombin L./Jobo	74	46	18	19	22	6	3	0.7	1.2	60
			Puerto Rico							
Cecropia peltata L./Yagrumo hembra	68	46	14	25	16	2	3	0.6	0.7	60
Eucalyptus robusta Sm./Swamp mahogany	67	48	12	28	12	3	2	0.3	0.5	60
Inga vera Willd./Guama	66	50	13	28	11	2	2	0.3	0.2	60

NOTE: Values are percent moisture-free wood.
[a] Holocellulose is the total carbohydrate content of wood.
[b] Alpha cellulose is nearly pure cellulose.
[c] Pentosans are the total anhydroxylose and arabinose residues in wood.
[d] Average of trees from two locations.
[e] The holocellulose, lignin, and pentosans from Ref. 58 are percent extractive-free wood.
[f] Cross and Bevan cellulose is largely pure cellulose but contains some hemicelluloses.

Table V. Supplementary Chemical Composition Data for South and Central American Hardwoods

	Carbohydrate					
Scientific Name/Common Name	*Alpha Cellulose*[a]	*Hemi-cellulose*	*Klason Lignin*	*Acetyl*	*Total extractives*[b]	*Ash*
	Guyana (62)					
Couratari pulchra Sandw./Tauary	47	14	31	1.1	5.3	0.8
Eschweilera sagotiana Miers/Kakeralli	49	13	29	1.4	5.8	0.6
Ocotea rodiaei (Rob. Schomb.) Mez./ Greenheart	45	13	31	1.1	9.5[c]	0.2
	Honduras (63)					
Cordia alliodora (R. & P.) Cham./ Jaurel blanco	45	17	30	1.3	6.6	1.0
Hymenaea courbaril L./Courbaril	43	20	20	2.2	13.8	0.9
Pseudosamanea guachapele (H.B.K.) Harms./Frijolillo	45	13	24	1.5	13.1	0.6
Tabebuia guayacan (Seem.) Hemsl./ Guayacan	46	14	29	1.1	8.6	0.3
	Surinam (63)					
Dicorynia paraensis Benth./ Angelique (64)	45	15	32	1.1	5.4[d]	0.6
Licaria cayennensis (Meissn.) Kosterm./Kaneelhart	46	11	30	0.8	10.4	0.03
Manilkara bidentata (A.D.C.) Chev./ Bulletwood	46	16	26	1.1	7.5	0.4
Ocotea rubra Mez./Determa	48	13	29	0.8	10.1	0.2

NOTE: Analytical methods used for percent moisture-free wood are found in Ref. 3.
[a] Alpha cellulose is nearly pure cellulose.
[b] Total extractives = sum of solubles in ether, 50% EtOH, EtOH/benzene, and hot water (80 °C).
[c] Total extractives = sum of solubles in chloroform, 50% EtOH, and hot water (80 °C).
[d] Total extractives = sum of solubles in ether, 50% EtOH, and hot water (80 °C).

Table VI. Chemical Composition of Woods from Ghana and Mozambique

	Carbohydrate			Solubility			
Scientific Name/Common Name	*Cellulose*[a]	*Pentosans*[b]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/ Benzene*	*Ash*
	Ghana[c]						
Gmelina arborea L./Yemane[d]	47	20	29	13	6	4	0.6
Musanga cecropioides R. Br./Odwuma	50	16	26	14	2	2	0.4
Terminalia ivorensis Chev./Emire	45	15	33	16	5	2	0.3
Triplochiton scleroxylon K. Schum/Wawa	40	17	31	19	10	1	1.8
	Mozambique[e]						
Acacia nigrescens Oliv./Chicocolo	42	14	20	17	8	14	1.6
Adina microcephala (Del.) Hiern.) Galangola[f]	42	12	27	16	6	10	0.7
Albizzia gummifera (Gmel.) C. A. Sm./Galinga	43	20	23	17	4	5	0.4
Amblygonocarpus andongensis (Welw. ex Oliv.) Excell et Torrey/Banga-uanga	35	12	29	24	9	10	0.4
Androstachys johnsonii Prain/Cimbirre	29	16	29	13	2	16	1.0
Bombax rhodognaphalon K. Schum./Meguza[g]	42	14	30	20	3	8	1.6
Cedrela odorata L./—	37	18	33	16	3	4	1.0
Chlorophora excelsa (Welw.) Benth. et Hook. f./Mahundo[h]	41	15	25	20	5	7	3.1
Crossopteryx febrifuga Benth./Mucobenga	36	16	28	18	8	6	1.8
Dalbergia melanoxylan Guill. et Perr./Ampivi	38	12	26	13	2	14	3.4
Diospyros mespiliformis Hochst. ex A.DC./ Chitomane	38	17	31	20	8	1	4.1
Erythrophloeum guineense D. Don/Chaia	38	11	26	18	4	16	0.0

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Table VI. Continued

Guibourtia conjugata (Bolle) J. Leonard/Chacate	34	16	30	20	10	5	1.8
Khaya nyasica Stapf. ex Baker f./Imbáua[i]	41	14	28	27	7	5	1.6
Kirkia acuminata Oliv./Muyumira	39	15	29	17	8	6	2.0
Lannea discolor (Sond.) Engl./Chumbo	51	18	21	24	5	1	2.4
Melaleuca leucadendron L./—[g]	41	14	30	31	5	7	1.9
Morus lactea (Sim.) Mildbr./Mecobze	34	18	28	18	3	12	1.1
Newtonia buchananii (Bak.) Gilbert et Boutique/Mafamuti[f]	42	15	24	23	7	7	1.0
Podocarpus falcatus (Thunb.) R. Br. ex Mirb./Gogogo	44	10	29	18	2	2	0.7
Pterocarpus antunesii (Taub.) Harms/Muchibire	44	16	27	13	6	1	0.9
Spirotachys africana Sond./Chilingamache	36	15	21	17	4	19	2.5
Swartzia madagascariensis Desv./Cimbe[g]	37	15	26	16	4	15	0.2
Syncarpia laurifolia Ten./—	42	15	31	12	7	3	1.6
Syringa vulgaris L./—	44	19	28	19	3	1	0.5
Tectona grandis L.f./—[f]							
Sapwood	43	15	25	18	9	3	1.3
Heartwood	41	14	23	16	12	6	1.4
Trichilia emetica Vahl/Curre	39	18	31	27	7	1	3.9
Vitex doniana Sweet/Mucuvo-sique	40	13	31	18	7	2	2.7
Xylopia holtzii Engl./Mulalabungo	41	17	31	20	4	2	0.5

[a] Cellulose determined using alcoholic nitric acid (Kürschner cellulose) for Ghanan woods. A mixture of concentrated nitric acid and glacial acetic acid was used to determine cellulose in Mozambique woods. *See* Refs. 64 and 65 for details.
[b] Pentosans are the total anhydroxylose and arabinose residues in wood.
[c] Data adapted from Ref. 64.
[d] Common name in Burma.
[e] Data adapted from Ref. 65.
[f] Average of three trees.
[g] Average of two trees.
[h] Average of four trees.
[i] Average of five trees.

Table VII. The Chemical Composition of Japanese Woods (66,67)

Scientific Name/Common Name	Carbohydrate: Holo-cellu-lose[a]	Carbohydrate: Cross and Bevan Cellu-lose[b,c]	Carbohydrate: Alpha Cellu-lose[d]	Pento-sans[e]	Klason Lignin	Solubility: 1% NaOH	Solubility: Hot Water	Solubility: EtOH/Benzene	Ash
Hardwoods									
Acanthopanax sciadophylloides Franch. & Sav./Koshiabura	80	63	45	21	21	23	5	2	0.6
Acer japonicum Thunb./Meigetsukaede	82	61	47	24	21	4	2		0.4
Acer mayrii Schwerin/Beniitaya	78	53	34	26	23	5	2		0.6
Acer mono Maxim./Ezoitaya	81	62	48	22	19	17	4	2	0.4
Acer mono Maxim./Itayakaede	78	—	49	18	24	—	4	2	0.5
Acer palmatum Thunb./Yamanomiji	77	59	42	23	22	24	7	3	0.5
Aesculus turbinata Blume/Tochinoki	79	59	44	22	21	18	5	2	0.3
Aesculus turbinata Blume/Tochinoki	75	—	46	14	27	—	3	1	0.3
Alnus hirsuta Turcz./Keyamahannoki	79	58	43	20	20	22	5	5	0.3
Alnus hirsuta Turcz./Keyamahannoki	73	—	48	15	23	—	4	2	0.3
Alnus japonica Stend./Hannoki	76	56	40	23	22	22	5	4	0.3
Aralia elata Seem./Taranoki	78	57	47	26	20	23	7	4	0.4
Benzoin umbellatum Kuntze/Kuromoji	77	57	34	27	19	26	7	6	0.8
Betula grossa S. et Z./Mizume	78	—	46	27	24	—	2	2	0.4
Betula ermanii Cham./Dakekanba	79	60	46	25	20	17	2	3	0.3
Betula maximowicziana Regel/Udaikanba	82	57	40	26	20	17	2	1	0.2
Betula maximowicziana Regel/Makanba	77	—	47	18	23	—	2	1	0.4
Betula platiphylla Sukatchev/Shirakanba	83	63	46	23	19	16	3	1	0.4

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Table VII. Continued

Scientific Name/Common Name	Carbohydrate					Solubility			
	Holocellulose[a]	Cross and Bevan Cellulose[b,c]	Alpha Cellulose[d]	Pentosans[e]	Klason Lignin	1% NaOH	Hot Water	EtOH/Benzene	Ash
Betula platiphylla Sukatchev/Shirakanba	77	—	56	22	18	—	2	2	0.2
Carpinus cordata Blume/Sawashiba	79	61	43	20	21	23	4	2	0.5
Carpinus laxiflora Blume/Akashide	80	—	46	27	17	—	3	2	0.6
Castanea crenata S. et Z./Kuri	73	52	40	23	26	23	10	3	0.3
Castanea crenata S. et Z./Kuri	70	—	42	15	21	—	11	2	0.8
Cercidiphyllum japonicum S. et. Z/Katsura	78	58	44	23	24	21	6	<1	0.7
Cercidiphyllum japonicum S. et. Z/Katsura	78	—	51	16	26	—	5	3	0.3
Cinnamomum camphora Sieb./Kusunuki	81	—	50	14	29	—	5	2	0.5
Cornus controversa Hemsley/Miznki	82	61	43	23	23	24	5	1	0.3
Cornus controversa Hemsley/Miznki	73	—	46	17	22	—	4	2	0.4
Cyclobalanopsis acuta Oerst./Akagashi	71	—	47	17	25	—	9	4	0.7
Cyclobalanopsis myrsinaefolia Oerst./Shirakashi	75	—	48	19	23	—	7	2	1.0
Cyclobalanopsis gilva Oerst./Ichiigashi	77	—	48	15	27	—	6	1	1.1
Distylium racemosum S. et Z./Isunoki	73	—	47	17	30	—	5	2	0.5
Euonymus macropterus Rupt./Hirobatsuribana	71	49	33	26	27	21	7	4	0.9
Euonymus oxyphyllus Miq./Tsuribana	76	55	44	24	26	18	5	2	0.6
Fagus crenata Blume/Buna	81	60	45	21	21	17	4	1	0.7
Fagus crenata Blume/Buna[f]	81	—	50	18	24	—	2	1	0.5

Fagus japonica Maxim./Inubuna	79	—	47	17	25	—	4	1	0.8
Fraxinum commemoralis Koidzumi/Shioji	78	—	57	14	26	—	3	2	0.5
Fraxinum mandshurica Rupt./Yachidamo	82	59	47	21	20	19	5	1	0.9
Fraxinus mandshurica Rupt./Yachidamo	80	—	51	16	22	—	4	2	1.0
Fraxinus sieboldiana Blume/Aodamo	76	55	44	20	23	19	7	4	0.7
Fraxinus sieboldiana Blume/Aodamo	75	—	45	17	24	—	6	4	0.9
Ilex macropoda Miq./Aohada	81	49	34	18	16	32	7	5	0.7
Juglans ailanthifolia Carr./Onigurumi	80	61	43	24	21	25	6	4	0.4
Juglans sieboldiana Maxim./Onigurumi	78	—	50	13	22	—	7	4	0.4
Kalopanax pictus Nakae/Harigiri	79	60	48	23	22	18	4	1	0.3
Kalopanax ricinifolium Miq./Harigiri	79	—	51	17	23	—	4	2	0.6
Maackia amurensis Rupt. et Maxim./ Inuenju	78	57	45	22	22	24	5	6	0.6
Maackia amurensis Rupt. et Maxim./ Inuenju	77	—	53	17	19	—	5	6	0.3
Machilus thunbergii S. et Z./Tabunoki	73	—	49	15	25	—	7	5	0.3
Magnolia kobus Dc./Kobushi	79	58	43	20	26	20	4	1	0.4
Magnolia obovata Thung./Honoki	81	61	44	20	24	17	3	2	0.2
Magnolia obovata Thunb./Honoki	77	—	47	15	30	—	3	2	0.4
Morus bombycis Koidzumi/Yamaguwa	72	50	35	26	21	28	10	9	0.8
Morus bombycis Koidzumi/Yamaguwa	67	—	42	15	21	—	7	8	0.4
Ostrya japonica Sargent/Asada	78	62	44	21	21	19	5	2	0.7
Ostrya japonica Sargent/Asada	80	—	48	19	23	—	4	2	0.5
Paulownia tomentosa Steud./Kiri	72	—	45	16	20	—	9	8	0.2
Phellodendron amurense Rupt./Kihad	80	62	49	21	19	20	5	1	0.6
Phellodendron sachalinense Sargent/ Kihada	80	—	51	14	23	—	4	1	0.1
Picrasma quassiodes Benn./Nigaki	80	62	49	21	19	20	5	1	0.6

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Table VII. Continued

Scientific Name/Common Name	Carbohydrate: Holo-cellulose[a]	Carbohydrate: Cross and Bevan Cellulose[b,c]	Carbohydrate: Alpha Cellulose[d]	Pentosans[e]	Klason Lignin	Solubility: 1% NaOH	Solubility: Hot Water	Solubility: EtOH/Benzene	Ash
Populus maximowiczii A. Henry/Doronoki	81	64	47	22	22	20	3	2	0.6
Populus maximowiczii A. Henry/Doronoki	82	—	53	14	22	—	2	2	0.7
Populus sieboldii Miq./Yamanarashi	81	—	49	19	18	—	3	3	0.5
Pourthiaea villosa Dcne./Vshikoroshi	82	59	45	24	20	19	5	3	0.3
Prunus donarium Sieb./Yamazakura	73	—	48	21	18	—	6	5	0.3
Prunus grayana Maxim./Uwamizuzakura	78	54	39	23	20	21	5	4	0.7
Prunus maximowiczii Komarov/Shirozakura	82	62	46	24	18	24	5	2	0.2
Prunus padus L./Ezonouwamizuzakura	81	49	36	22	21	28	5	2	0.6
Prunus sargentii Rehd./Ezoyamazakura	80	57	44	23	18	28	9	5	0.3
Prunus ssiori Fr. Schmidt/Shurizakura	74	55	40	24	21	27	6	5	0.4
Pterocarya rhoifolia S. et Z./Sawagurumi	83	61	44	21	18	25	4	4	0.3
Pterocarya rhoifolia S. et Z./Sawagurumi	78	—	48	14	24	—	3	2	0.4
Quercus acutissima Carr./Kunugi	78	—	50	18	19	—	4	<1	0.6
Quercus crispula Blume/Mizunara	79	57	45	22	22	22	9	2	0.3
Quercus crispula Blume/Mizunara[g] (average of 4)	75	—	48	20	26	—	6	1	0.2
Quercus dentata Thunb./Kashiwa	73	47	31	24	25	23	9	5	0.6
Quercus serrata Thunb./Konara	78	—	50	17	22	—	6	1	0.6

Rhamnus japonica Maxim./ Ezokuromemodoki	84	59	42	26	21	20	6	2	0.4
Robinia pseudo-acacia L./Harienju	82	61	50	24	21	18	5	3	0.3
Salix bakko Kimura/Bakkoyanagi	82	62	43	22	20	23	3	2	0.4
Salix pet-susu Kimura/ Ezonokinuyanagi	80	59	41	23	22	23	4	3	0.3
Salix sachalinensis Fr. Schmidt/ Nagabayanagi	84	59	38	19	20	25	4	3	0.3
Sambucus sieboldiana Blume/Niwatoko	79	57	46	23	26	18	3	2	0.6
Shiia cuspidata Makino/Kojii	79	—	48	16	23	—	3	2	0.4
Shiia sieboldii Makino/Shiinoki	65	—	37	15	28	—	13	3	0.2
Sorbus alnifolia K. Koch/Azukinashi	80	60	44	22	20	22	3	1	0.4
Sorbus commixta Hedlund/Nanakamado	80	57	46	21	20	24	7	3	0.6
Stewartia monadelpha S. et Z./Himeshara	69	—	44	15	25	—	3	1	0.6
Styrax obassia S. et Z./Hakuunboku	83	59	45	24	21	30	4	2	0.6
Syringa reticulata (Blume) Hara/Hashidoi	78	60	44	22	20	24	6	4	0.4
Tilia japonica Simonkai/Shinanuki	80	59	43	20	17	26	6	7	0.8
Tilia japonica Simonkai/Shinanuki	79	—	46	18	20	—	3	4	0.2
Tilia maximowicziana Shirasawa/ Obabodaiju	82	61	44	23	17	25	5	6	0.6
Tilia maximowicziana Shirasawa/ Obabodaiju	82	—	46	18	21	—	3	3	0.6
Toisusu urbaniana Kimura/Obayanagi	80	—	50	15	21	—	2	2	0.9
Ulmus davidiana Planch./Harunire	80	62	51	20	21	15	3	1	0.9
Ulmus laciniata Mayr./Ohyo	79	56	36	24	23	23	4	2	1.4
Ulmus propinqua Koidzumi/Harunire	79	—	47	15	27	—	2	<1	0.8
Zelkova serrata Makino/Keyaki	75	—	44	16	27	—	8	1	0.8

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Table VII. Continued

Scientific Name/Common Name	*Carbohydrate*						*Solubility*			
	Holo-cellulose[a]	*Cross and Bevan Cellulose*[b,c]	*Alpha Cellulose*[d]	*Pentosans*[e]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/ Benzene*	*Ash*
				Softwoods					
Abies firma S. et Z./Momi	70	—	49	5	34	—	4	2	1.0
Abies homolepis S. et Z./Urajiromomi	77	—	53	6	29	—	2	2	0.2
Abies mariesii Masters/Aomoritodomatsu	72	—	50	8	30	—	2	2	2.3
Abies mayriana Miyabe & Kudo/Aotodomatsu	74	59	44	13	30	13	3	1	0.2
Abies sachalininensis Fr. Schmidt/ Todomatsu	70	57	41	13	29	12	5	3	0.5
Abies sachalininensis Fr. Schmidt/ Todomatsu	74	—	49	5	30	—	3	3	0.3
Abies veitchii Lindley/Shirabe	73	—	47	6	29	—	2	2	0.2
Chamaecyparis obtusa Endlicher/Hinoki	69	—	39	5	33	—	4	5	0.5
Chamaecyparis pisifera S. et Z./Momi	60	—	47	5	29	—	7	9	0.4
Criptomeria japonica D. Don/Sugi[h]	71	—	47	7	33	—	3	3	0.7
Larix leptolepis Gordon/Karamatsu	67	52	40	12	31	19	7	1	0.4
Larix leptolepis Gordon/Karamatsu	69	—	48	6	28	—	10	3	0.3
Picea abies (L.) Karst./Doitsutohi	73	54	38	12	29	12	2	1	0.4
Picea glehnii Masters/Akaezomatsu	75	60	45	14	27	14	2	<1	0.4
Picea glehnii Masters/Akaezomatsu	74	—	50	7	28	—	2	2	0.2
Picea hondoensis Mayr./Tohi	64	—	42	5	29	—	3	2	0.2
Picea jezoensis Carr./Ezomatsu	75	59	44	14	29	13	3	1	0.1
Picea jezoensis Carr./Ezomatsu	71	—	47	6	28	—	4	1	0.2

Pinus banksiana Lamb./Bankusumatsu	71	55	40	14	28	13	2	1	0.1
Pinus densiflora S. et Z./ Akamatsu[g]	67	—	45	8	27	—	4	3	0.2
Pinus pentaphylla Mayr./Goyomutsu	71	58	32	12	26	19	6	8	0.1
Pinus pentaphylla Mayr./Himekomatsu	68	—	45	5	27	—	3	8	0.3
Pinus pumila (Pallas) Regel/Haimatsu	63	44	30	12	26	23	9	12	0.2
Pinus strobus L./Sutorobumatsu	71	57	41	13	28	19	4	7	0.5
Pinus thunbergii Parlatore/Kuromatsu	63	—	44	7	26	—	3	3	0.2
Podocarpus macrophyllus D. Don/Inumaki	65	—	49	11	36	—	3	2	0.4
Pseudotsuga japonica Beissner/ Toyasawara	68	—	47	5	33	—	4	4	0.1
Sciadopitys verticillata S. et Z./ Koyamaki	61	—	39	5	29	—	7	11	0.2
Taxus cuspidata S. et Z./Onko	63	58	33	12	29	26	14	14	0.2
Taxus cuspidata S. et Z./Ichii	59	—	38	6	28	—	11	12	0.2
Thuja standishii Carr./Nezuko	70	—	48	6	27	—	11	9	0.3
Thujopsis dolabrata S. et Z./Asunaro	62	—	41	6	32	—	4	4	0.4
Thujopsis dolabrata var, Hondai Makino/Hinokiasunaro	71	56	39	13	29	16	5	4	0.3
Thujopsis dolabrata var, Hondai Makino/Hinokiasunaro	75	—	48	6	33	—	5	4	0.7
Torreya nucifera S. et Z./Kaya	64	—	45	5	35	—	7	7	0.7
Tsuga sieboldii Carr./Tsuga	71	—	51	4	31	—	4	3	0.2

NOTE: Data adapted from Ref. 67 are percent moisture-free wood. Data adapted from Ref. 66 are not defined in the English abstract and table.

[a] Holocellulose is the total carbohydrate content of wood.
[b] Cross and Bevan cellulose is largely pure cellulose but contains some hemicelluloses.
[c] Species with a value for Cross and Bevan cellulose from Ref. 66. All others from Ref. 67.
[d] Alpha cellulose is nearly pure cellulose.
[e] Pentosans are the total anhydroxylose and arabinose residues in wood.
[f] Average of five trees.
[g] Average of four trees.
[h] Average of five trees.

Table VIII. Chemical Composition of Woods from Cambodia, Kalimantan (Borneo), and Papua New Guinea

Scientific Name/Common Name	*Carbohydrate*		*Klason Lignin*	*Solubility*			*Ash*
	Holocellulose[a]	*Alpha Cellulose*[b]		*1% NaOH*	*Hot Water*	*EtOH/Benzene*	
Cambodia (68)							
Anisoptera glabra Kurz/Phdiek	75	50	29	21	5	5	0.9
Dacrydium elatum (Boxb.) Wall/Srol kraham	70	51	35	15	3	3	0.4
Dipterocarpus alatus Boxb./Chhoeuteal sar	73	49	33	24	3	3	0.9
Dipterocarpus insularis Hance/Chhoeuteal bangkuoi	64	44	36	28	5	5	0.4
Hopea pierrei Hance/Koki khsach	69	49	27	30	11	12	0.2
Parkia streptocarpa Hance/Ro yong	78	51	30	15	3	1	0.9
Shorea hypochra Hance/Komnhan	69	47	32	21	6	6	1.3
Tristania sp./Rong leang	72	48	36	20	3	1	0.5
Kalimantan (Borneo) (69)							
Aquilaria sp./Karas	74	50	26	—	6	2	1.5
Artocarpus sp./Keledang	72	51	31	—	4	1	1.6
Cotylelobium sp./Giam	62	46	26	—	11	14	0.8
Dipterocarpus sp./Keruing[c]	74	55	29	—	2	3	0.9
Dryobalanops sp./Kapur	72	50	34	—	7	2	0.7
Dyera sp./Jelutong	72	44	27	—	9	5	1.5
Eugenia sp./Kelat	64	47	35	—	5	6	0.8
Michelia sp./Champaka	73	51	29	—	4	2	4.6
Quercus sp./Borneo oak	74	50	28	—	7	4	0.5
Shorea sp./Balau[d]	65	47	29	—	9	10	0.5
Shorea sp./Bangkirai[c]	70	49	34	—	5	7	0.1

Shorea sp./Light red meranti	67	47	35	—	9	5	1.6
Shorea sp./White meranti	69	50	30	—	3	4	0.5
Tarrietia/Teraling	64	45	28	—	4	3	1.4
Vatica sp./Pesak	65	42	27	—	13	12	0.7
Papua New Guinea (*70,71*)[e]							
Aglai litoralis Talbot/—	74	50	34	17	5	4	1.1
Ailanthus intergrifolia Lam./White siris	74	51	31	11	2	1	0.8
Alstonia scholaris (L.) R.Br./White cheesewood	67	44	34	12	4	1	1.3
Amoora cucullata Roxb./Amoora	68	47	37	20	6	1	0.4
Anthocephalus cadamba (Roxb.) Miq./Labula	74	46	26	16	4	3	0.7
Antiaris toxicaria Lesch./—	73	48	31	12	3	1	1.9
Artocarpus incisa L.f./Kapiak	70	48	31	15	3	3	2.3
Burckella macropoda (Krause) Lam./Burckella	67	50	35	15	4	1	1.9
Calophyllum vexans P. F. Stevens/Calophyllum	71	49	33	16	2	2	0.6
Canarium indicum L./Galip	70	46	28	17	4	1	0.9
Castanospermum australe A. Cunn./—	72	40	28	27	12	12	0.3
Celtis kajewskii Merr. et Perry/Light celtis	73	48	26	17	5	2	1.8
Celtis luzonica Warb./Hard celtis	73	46	23	18	3	1	1.2
Cryptocarya massoy (Oken.) Kosterm/Crytocarya	75	48	25	13	3	2	1.1
Dracontomelum puberulum Miq./P.N.G. walnut	65	46	34	18	8	3	2.2
Dysoxylum arnoldianum K. Schum./—	69	47	32	13	4	2	2.3
Dysoxylum gaudichaudianum (Juss.) Miq./—	69	46	27	12	2	1	1.3
Elaeocarpus sphaericus (Gaertn.) K. Schum./ P.N.G. quandong	75	49	27	13	3	2	0.9
Eucalyptus deglupta Blume/Kamarere[d]	73	51	32	10	2	1	0.6
Euodia elleryana F. Muell./—	75	49	29	10	2	1	1.2
Homalium foetidum (Roxb.) Benth./Malas	67	46	32	17	4	2	1.2
Intsia bijuga (Colebr.) O. Kuntze/Kwila	64	41	29	24	10	7	1.0
Neonauclea maluensis S. Moore/Yellow hardwood	69	50	37	10	4	2	0.4

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Table VIII. Continued

Scientific Name/Common Name	Carbohydrate: Holocellulose[a]	Carbohydrate: Alpha Cellulose[b]	Klason Lignin	Solubility: 1% NaOH	Solubility: Hot Water	Solubility: EtOH/Benzene	Ash
Octomeles sumatrana Miq./Erima	70	48	34	8	2	2	1.0
Palaquium erythrospermum H. J. Lam/Pencil cedar	72	50	30	13	3	1	0.8
Pimelodendron amboinicum Hassk./—	74	48	26	17	4	1	1.7
Planchonella thyrosoidea C. T. White/Planchonella	79	47	21	15	1	2	1.3
Pometia pinnata Forst./Taun[d]	67	46	30	19	6	4	0.6
Pterocymbium beccarii K. Schum./Amberoi	77	47	25	13	4	1	1.6
Sloanea insularis A. C. Smith/Sloanea	77	51	30	13	4	2	1.0
Spondias dulcis Forst./Spondias[c]	74	48	27	16	3	2	1.1
Sterculia parkinsonii F. Muell./Sterculia	78	48	26	18	4	1	1.7
Syzygium sp./Water gum	66	44	29	21	5	7	1.0
Terminalia calamansanai (Blco.) Rolfe/ Yellow-brown terminalia	71	49	30	15	5	2	0.9
Terminalia solomonensis Excell./Pale brown terminalia[d]	72	47	33	12	3	1	0.5

NOTE: Values are for percent oven-dry wood.
[a] Holocellulose is the total carbohydrate content of wood.
[b] Alpha cellulose is nearly pure cellulose.
[c] Average of two trees.
[d] Average of three trees.
[e] Common names obtained from Ref. 72.

Table IX. The Chemical Composition of Philippine Woods

	Carbohydrate				*Solubility*					
Scientific Name/Common Name	*Holo-cellulose*[a]	*Alpha Cellulose*[b]	*Pentosans*[c]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/Benzene*[d]	*Ether*	*Ash*	*Reference*
			Hardwoods							
Adenanthera intermedia Merr./—	76	40	—	35	17	7	6	2.0	0.8	73
Aegiceras corniculatum (L.) Blanco/Saging-saging	72	—	23	20	23	2	5	—	0.9	74
Aegiceras floridum Roem. & Schult./Tinduk-tindukan	68	—	21	24	24	2	6	—	0.6	74
Aglaia llanosiana C.DC./—	75	37	—	32	10	4	2	0.7	1.3	73
Alangium chinense (Lour.) Rehder/—	81	42	—	29	23	13	10	0.8	0.8	73
Albizzia acle (Blanco) Merr./—	70	32	—	33	17	12	7	0.9	1.1	73
Albizzia falcataria (L.) Fosb./Moluccan sau	72	—	18	24	14	1	2	—	0.6	75
Albizzia lebbeck (Linn.) Benth/—	71	35	—	28	21	11	6	0.5	0.5	73
Albizzia lebbekoides (DC.) Benth/—	79	43	—	29	14	6	5	1.1	0.2	73
Aleurites moluccana Willd./—	78	46	—	20	21	10	1	0.1	2.1	73
Aleurites trisperma Blanco/—	74	38	—	32	22	6	2	0.6	1.7	73
Alphonsea arborea (Blanco) Merr./—	79	41	—	30	13	5	3	0.9	0.7	73

Continued on next page

Table IX. Continued

	Carbohydrate				Solubility					
Scientific Name/Common Name	*Holocellulose*[a]	*Alpha Cellulose*[b]	*Pentosans*[c]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/Benzene*[d]	*Ether*	*Ash*	*Reference*
Alphanamixis cumingiana (C.DC.) Harms./—	79	40	—	33	18	8	3	0.5	2.7	73
Artocarpus cumingiana Trec/—	76	45	—	29	20	7	6	0.7	2.3	73
Avicennia marina (Forsk.) Vierh./Bungalon	70	—	25	21	25	4	5	—	1.3	74
Avicennia officinalis L./Api-api	69	—	21	17	26	5	7	—	2.3	74
Beilschmiedia glomerata Merr./—	73	33	—	25	16	6	3	0.7	1.1	73
Bischofia javanica Blume/—	73	30	—	48	29	3	<1	0.5	1.5	73
Bombycidendron vidalianum (Naves) Merr. & Rolfe./—	66	38	—	29	14	3	2	0.4	0.5	73
Bruguiera gymnorrhiza (L.) Lam./Busaing	69	—	19	25	19	2	3	—	1.1	74
Bruguiera parviflora (Roxb.) W. A. ex Griff./Langarai	77	—	22	18	15	2	2	—	0.9	74
Bruguiera sexangula (Lour.) Poir/Pototan	69	—	21	24	16	1	4	—	1.1	74
Caesalpin a sappan Linn./—	63	29	—	32	24	9	7	0.4	0.8	73
Calophyllum blancoi PI & Tr./Bitanghol	70	—	15	27	14	1	1	—	0.3	75
Calophyllum inophyllum Linn./	70	34	—	38	16	4	4	0.4	0.5	73

Campostemon philippinense (Vid.) Becc./Gapas-gapas	74	—	20	20	15	1	3	—	1.9	74
Cananga odoratum (Lam.) Hook.f. & Thomas/Ilang-ilang	71	48	13	29	11	2	1	0.3	0.8	76
Canarium aspersum Benth/—	70	32	—	26	29	15	2	0.2	2.1	73
Canarium hirsutum Willd./—	77	45	—	24	20	8	1	0.3	1.6	73
Casuarina rumphiana Miq./ Mountain agoho	76	—	21	22	14	1	1	—	0.3	75
Celistocalyx operculatus (Roxb.) Merr. & Perry/Malaruhat	70	—	17	22	21	5	3	—	0.6	75
Celtis philippensis Blanco/—	75	43	—	27	13	7	3	0.5	1.8	73
Ceriops tagal (Perr.) C. B. Rob/ Tangal	68	—	20	17	26	6	8	—	1.5	74
Delonix regia (Boj.) Raf/—	78	46	—	25	17	8	4	0.2	1.8	73
Diospyros discolor Willd./—	71	35	—	34	21	8	6	1.4	1.3	73
Diospyros pilosanthera Blanco/ —	82	44	—	28	15	7	4	0.5	1.5	73
Diplodiscus paniculatus Turcz/ —	80	39	—	33	11	5	2	0.5	3.4	73
Dipterocarpus basilanicus Foxw./Basilan apitong[e]	70	—	13	25	15	1	3	—	0.4	77
Dipterocarpus caudatus Foxw./ Leaf-tailed panau	66	—	17	30	23	3	1	—	0.5	77
Dipterocarpus graclis Blume/ Panau[f]	66	—	15	27	16	2	4	—	0.6	77
Dipterocarpus grandiflorus Blanco/Apitong[g]	64	—	15	27	22	2	6	—	0.9	77
Dipterocarpus hasseltii Blume/ Hasselt panau	63	—	17	29	17	3	4	—	1.2	77

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Table IX. Continued

Scientific Name/Common Name	Carbohydrate: Holocellulose[a]	Carbohydrate: Alpha Cellulose[b]	Carbohydrate: Pentosans[c]	Klason Lignin	Solubility: 1% NaOH	Solubility: Hot Water	Solubility: EtOH/Benzene[d]	Ether	Ash	Reference
Dipterocarpus kerrii King/Malapanau[f]	65	—	16	28	15	4	3	—	0.8	77
Dipterocarpus orbicularis Foxw./Round-leaf apitong[g]	65	—	16	30	16	2	3	—	0.8	77
Dipterocarpus speciosus Brandis/Broad-winged apitong[e]	65	—	15	29	16	2	3	—	0.7	77
Dipterocarpus warburgii Brandis/Hagakhak[e]	63	—	16	31	14	2	3	—	0.8	77
Drypetes bordenii Pax & K. Hoffm./—	80	42	—	32	16	6	3	0.7	1.7	73
Dysoxylum turczaninowii C.DC./—	77	41	—	35	6	5	1	0.7	1.6	73
Endospermum peltatum Merr./—	81	44	—	31	18	8	3	0.4	0.8	73
Eucalyptus deglupta Blume/Bagras	71	—	16	26	14	1	2	—	0.7	75
Euphoria didyma Blanco/—	69	34	—	36	14	3	2	0.2	1.4	73
Excoecaria aggallocha L./Buta-buta	75	—	22	18	18	3	3	—	1.3	74
Ficus conora King/—	74	35	—	34	18	9	3	0.1	2.6	73
Ficus malunuensis Warb./—	77	43	—	30	13	5	3	0.6	3.0	73

Ficus nota (Blanco) Merr./—	73	33	—	34	18	8	3	0.5	4.0	73
Garciana venulosa (Blanco) Choisy/—	74	38	—	35	22	8	7	4.8	1.5	73
Heritiera littoralis Ait./ Dungon-late	69	—	18	21	22	4	5	—	1.9	74
Hopea plagata (Blanco) Vidal/—	75	31	—	34	24	9	7	6.2	2.0	73
Intsia bijuga (Colebr.) O. Ktze./—	71	41	—	33	22	11	7	1.2	1.3	73
Koordersiodendron pinnatum (Blanco) Merr./—	77	40	—	34	18	2	2	1.0	1.1	73
Lagerstroemia speciosa (Linn.) Pers./—	75	34	—	35	18	9	2	0.2	2.3	73
Lithocarpus lianosii (A.D.C.) Rehd./Ulaian	71	—	17	22	17	5	2	—	0.6	75
Lumnitzera littorea (Jack.) Voigt./Tabau	58	—	15	29	17	3	9	—	1.6	74
Macaranga tanarius (Linn.) Muell-Arg./—	80	40	—	32	15	6	3	0.2	0.9	73
Mangifera altissima Blanco/—	71	38	—	31	14	5	5	0.3	0.7	73
Melanolepsis multiglandulosa (Reinw.) Reichb.f. & Zoll./—	75	38	—	29	25	13	2	0.5	1.3	73
Myristica elliptica Hook.f. & Thomas. Var. Simiarum (A.D.C.) J. Sinal./Tanghas	67	—	15	24	23	6	2	—	0.8	75
Ochroma lagopus Schwartz/—	74	40	—	29	22	4	3	1.2	0.9	73
Osbornia octodonta F. Muell./ Taualis	66	—	16	24	20	7	3	—	0.9	74
Pahudia rhamboidea (Blco.) Prain/—	73	33	—	26	26	3	3	0.5	0.9	73

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Table IX. Continued

	Carbohydrate				*Solubility*					
Scientific Name/Common Name	*Holocellulose*[a]	*Alpha Cellulose*[b]	*Pentosans*[c]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/Benzene*[d]	*Ether*	*Ash*	*Reference*
Parashorea malaanonan (Blanco) Merr./—	77	42	—	32	14	7	2	1.3	1.0	73
Parashorea plicata Brandis/ Bagtikan[h]	65	—	15	30	13	2	3	—	1.2	78
Parinarium corymbosum (Blume) Miq./—	74	37	—	36	13	5	3	1.0	3.7	73
Pentacme contorta (Vidal) Merr./White lauan	67	51	9	31	11	2	3	1.0	—	76
Pentacme contorta (Vidal) Merr./White lauan[i]	65	—	14	29	14	2	3	—	0.8	78
Planchonia spectabilis Merr./—	75	37	—	40	20	9	6	1.5	0.4	73
Polyalthia rumphii (Blume) Merr./—	74	34	—	28	20	11	5	0.5	1.9	73
Polyscias nodosa (Blume) Seem/ —	73	36	—	30	25	10	5	0.9	0.9	73
Pometia pinnata Forst./Malugai	68	—	14	27	18	3	2	—	0.7	75
Pterocarpus indicus Willd./—	80	41	—	32	17	10	4	0.7	1.1	73
Pterospermum diversifolium Blume/—	76	38	—	37	15	6	7	0.7	1.2	73
Pterospermum niveum Vidal/—	79	44	—	33	12	2	2	1.0	0.9	73
Pterospermum obliquum Blanco/—	80	45	—	35	13	4	4	0.9	0.6	73

Pygeum vulgare (Koehne) Merr./—	78	41	—	33	16	3	2	2.4	0.2	73
Quercus bennettii Miq./—	71	41	—	35	16	7	4	0.3	0.3	73
Radermachera pinnata (Blanco) Seem/—	75	34	—	38	14	7	5	0.9	0.8	73
Rhizaphora mucronata Lam./ Bakanan-babae	72	—	18	22	17	1	3	—	0.9	74
Samanea saman (Jacq.) Merr./ —	75	38	—	30	20	9	5	0.9	0.3	73
Sandoricum koetjape (Burm.f.) Merr./—	78	40	—	29	18	6	4	2.5	0.6	73
Sapium luzonicum (Vidal) Merr./—	78	44	—	31	16	7	8	0.2	1.6	73
Scyphophora hydrophyllacea Gaertn./Nilad	67	—	23	17	26	2	13	—	0.7	74
Shorea agsaboensis Stern/ Tiaong	66	—	12	31	15	1	2	—	0.2	78
Shorea almon Foxw./Almon[f]	67	—	14	26	16	2	5	—	0.3	78
Shorea negrosensis Foxw./Red lauan	62	50	7	34	14	3	2	0.6	—	76
Shorea negrosensis Foxw./Red lauan[j]	58	—	12	35	20	2	5	—	0.3	78
Shorea philippinensis Brandis/ Manggasihoro	64	52	8	34	14	2	2	0.6	—	76
Shorea polysperma (Blanco) Merr./Tangile	61	45	8	37	15	3	2	0.7	—	76
Shorea polysperma (Blanco) Merr./Tangile[j]	64	—	13	32	17	1	3	—	0.3	78
Shorea squamata (Turcz.) Dyer/ Mayapis[i]	64	—	12	30	19	2	5	—	0.3	78

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Table IX. Continued

Scientific Name/Common Name	Carbohydrate			Klason Lignin	Solubility				Ash	Reference
	Holocellulose[a]	Alpha Cellulose[b]	Pentosans[c]		1% NaOH	Hot Water	EtOH/Benzene[d]	Ether		
Sonnertia albe J. Sm./Pagatput	63	—	15	26	22	3	5	—	2.2	74
Strombosia philippinensis (Baill.) Rolfe/—	82	41	—	37	12	3	2	0.8	0.6	73
Swietenia mahagoni Jacq./—	73	36	—	25	20	12	7	3.9	0.8	73
Tectona grandis Linn.f./—	73	33	—	35	22	11	4	2.8	1.7	73
Terminalia catappa Linn./—	67	30	—	33	19	11	5	0.4	0.7	73
Terminalia comintana (Blanco) Merr./—	76	36	—	35	16	7	5	0.2	1.8	73
Terminalia edulis Blanco/—	71	36	—	34	20	8	5	0.4	0.4	73
Trema orientalis (L.) Blume/ Anabiong	71	—	17	24	19	3	2	—	0.9	75
Vatica mangachapoi Blanco/—	74	39	—	30	24	7	7	1.8	0.5	73
Vitex parviflora Juss./—	73	36	—	39	7	2	8	0.7	1.6	73
Wallaceodendron celebicum Koord/—	75	40	—	32	14	4	3	1.4	1.2	73
Xylocarpus granatum Koen./ Tabigi	68	—	20	17	26	6	8	—	1.5	74

Zizyphus talanai (Blanco) Merr./—	76	40	—	32	11	6	4	0.8	1.7	73
			Softwoods							
Agathis philippinensis Warb./ Almaciga[e]	64	—	8	32	14	1	2	—	0.6	79
Araucaris bidwilli Hook./Bunya pine	67	—	14	28	14	2	3	—	0.5	79
Pinus insularis Endl./Benguet pine[g]	66	—	11	30	14	2	2	—	0.3	79
Pinus merkusii Jungh. & de Vr./Mindoro pine[k]	65	—	10	28	17	2	4	—	0.3	79
Podocarpus imbricatus R.Br./ Igem	70	—	10	29	10	1	<1	—	0.2	79
Podocarpus philippinensis Foxw./Malakauayan[e]	58	—	13	38	10	1	2	—	0.4	79

NOTE: Moisture-free wood specified in Refs. 73 and 76. All others were not specified. Analytical methods from Ref. 73 based on methods developed at U.S. Forest Products Laboratory.

[a] Holocellulose is the total carbohydrate content of wood. The values here are 100 − (the sum of percent ash, EtOH/benzene solubles, hot-water solubles, and lignin). Values from Refs. 73 and 76 were experimentally determined.

[b] Alpha cellulose is nearly pure cellulose.

[c] Pentosans are the total anhydroxylose and arabinose residues in wood.

[d] Woods from Ref. 73 extracted with alcohol (probably ethanol).

[e] Average of two trees.

[f] Average of five trees.

[g] Average of three trees.

[h] Average of six trees.

[i] Average of eight tress.

[j] Average of nine trees.

[k] Average of four trees.

Table X. Chemical Composition of Woods from Taiwan

	Carbohydrate				Solubility				
Scientific Name/Common Name	*Holo-cellulose*[a]	*Alpha Cellulose*[b]	*Pentosans*[c]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/ Benzene*	*Ether*	*Ash*
	Hardwoods								
Acacia confusa Merr./Taiwan acacia	87	54	19	19	21	7	6	1.5	0.4
Actinodaphne nantoensis Hay./Nantou actinodaphne	87	51	17	26	21	3	3	1.5	0.7
Aleurites montana Wils./Wood oil tree	86	46	23	25	19	3	3	1.5	1.1
Alnus formosana Makino/Formosan alder	86	45	24	24	17	2	2	1.8	0.6
Bischoffia trifoliata Hook./Bishop wood	—	—	15	33	17	—	4	—	0.9
Cassia siamea Lam./Kassod tree	87	51	19	25	16	4	5	1.7	1.6
Castanopsis carlesii Hay. var. Carlessi Li./Candate-leaved chinkapin	78	48	14	23	22	11	3	1.5	0.6
Castanopsis kawakamii Hay./Kawakami chinkapin	84	46	19	26	20	3	4	0.8	0.3
Cinnamomum camphora Sieb./Camphor tree	80	48	17	29	19	5	8	1.6	1.2
Cinnamomum micranthum Hay./Stout camphor tree	86	56	18	20	12	5	3	1.5	0.9
Cinnamomum randaiense Hay./Fragrant cinnamon	86	53	18	22	18	3	5	1.1	0.7
Cryptocarya chinensis Hemsl./Chinese cryptocarya	80	43	16	26	16	7	4	0.4	0.9
Cyclobalanopsis gilva Oerst./Red bark oak	83	46	21	23	21	4	5	1.6	1.7
Cyclobalamopsis longinux Schot./Narrow-leaved oak	84	53	16	22	23	5	3	1.6	0.5
Cyclobalamopsis morii Hay./Mori oak *(81)*	88	48	17	32	15	2	2	0.2	0.8
Engelhardtia chrsolepis Hance/Taiwan engelhardtia	86	50	16	24	19	2	3	1.6	1.4
Euphoria longana Lam./Dragon's eye lungan	78	53	16	30	28	5	4	0.8	1.7
Lagerstroemia subcostata Koehne/Subcostata crape myrtle	73	37	17	27	18	7	4	1.5	1.4
Lithocarpus amygdalifolius Hay./Almond-leaved tanoak	87	52	23	21	29	8	3	1.5	1.1
Machilus kusanoi Hay./Large-leaved machilus	88	49	17	22	13	4	2	0.5	0.8
Machilus thunbergii S. et Z./Red machilus	81	53	20	19	21	4	5	1.5	1.0
Machilus zuihoensis Hay./Incense machilus	86	49	15	24	23	5	4	1.5	1.9
Michelia formosana Masamune/Formosan michelia	80	43	18	29	15	2	4	1.6	0.5

Pasania brevicaudata Schot./Short-tailed leaf tanoak	82	55	17	26	18	2	3	1.6	0.6
Pasania ternaticupula Schot./Nanban tanoak	80	44	20	26	26	6	3	0.6	0.8
Pasania uraiana Schot./Urai tanoak	82	54	18	23	19	9	3	1.4	0.5
Paulownia kawakamii Ito/Kawakami paulownia	82	54	17	26	15	6	2	0.9	0.7
Sassafras randaiense Rhed./Taiwan sassafras	80	42	19	22	25	5	6	2.4	0.4
Schefflera octophylla Harms./Schefflera tree	84	45	20	22	21	4	3	0.7	0.6
Schima superba G. et Ch./Chinese guger tree	86	47	14	29	19	3	2	1.5	0.5
Ternstroemia gymnenthera Sprague/Japanese ternstroemia	76	42	18	30	21	6	6	1.4	0.5
Trema orientalis Bl./India-charcoal trema	84	50	16	28	24	4	2	1.6	1.6
Trochodendron aralioides S. et Z./Bird-lime tree	86	46	17	29	27	6	6	1.5	0.8
Zelkova formosana Hay./Taiwan zelkova	86	56	17	18	21	7	6	1.4	0.7
	Softwoods[d]								
Abies kawakamii Ito/Taiwan white fir	51	35	9	31	16	4	2	—	—
Calocedrus formosana Florin/Taiwan incense cedar	51	33	10	34	14	4	3	—	0.4
Chamaecyparis formosensis Matsam./Taiwan red cypress	50	38	11	33	13	5	4	—	—
Chamaecyparis taiwanensis Matsam. et Suzuki/Taiwan yellow cypress (82)	51	37	10	30	14	5	4	—	—
Cryptomeria japonica D. Don/Japanese fir	47	38	14	33	16	4	4	—	1.4
Cunninghamia lanceolata Hook./China fir	51	39	11	33	13	3	4	—	0.9
Picea morrisonicola Hay./Taiwan spruce	52	38	10	31	15	4	2	—	—
Pinus armandi Franch/Armand pine	54	40	9	33	19	5	7	—	0.8
Pinus luchuensis Mayr./Luchu pine	49	38	10	28	17	6	3	—	—
Taiwania cryptomerioides Hay./Taiwania	45	37	10	32	15	6	7	—	1.2
Tsuga chinensis Pritz./Chinese hemlock	53	42	38[e]	36	13	3	3	—	0.2

[a] Holocellulose is the total carbohydrate content of wood.
[b] Alpha cellulose is nearly pure cellulose.
[c] Pentosans are the total anhydroxylose and arabinose residues in wood.
[d] Values for softwoods are total cellulose obtained by method of Sieber and Walter (83). This method requires successive chlorinations, extractions with 1% aqueous $NaHSO_3$, and bleaching with 0.1% $KMnO_4$ solution.
[e] Probably a typing error in original report.
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Table XI. Chemical Composition of Woods from the U.S.S.R.

Scientific Name/Common Name	Carbohydrate: Kürschner Cellulose[a]	Carbohydrate: Pentosans[b]	Klason Lignin	Solubility: Ether	Solubility: Alcohol	Solubility: Water	Ash	Region
		Hardwoods						
Ailanthus glandulosus Desf./Tree of heaven	46	18	14	6.0	3	3	0.9	Caucasus
Alnus glutinosa Medic./European alder	48	24	22	0.9	3	<1	0.3	Leningrad
Ammodendron conollyi Bel./Sandy acacia	43	21	26	4.2	3	2	0.4	Central Asia
Arbutus andrache L./Strawberry tree	38	26	24	0.7	11	1	0.8	Crimea
Betula dahurica Pall./Dahurian birch	50	27	19	1.6	2	<1	0.2	Far Eastern
Betula mandshurika Nakai/Manchurian white birch	43	—	20	1.5	1	3	0.3	Maritime Territory
Betula pubescens Ehrh./White birch	46	29	20	—	—	—	—	Karelia
Betula schmidtii Bgt./Schmidt's birch	47	25	18	1.2	9	<1	0.2	Far Eastern
Betula tianschanica Rupr./Tien shan birch	43	32	19	2.2	2	1	0.3	Central Asia
Buxus sempervirens L./Box tree	40	26	30	0.8	3	1	0.5	Caucasus
Carpinus betulus L./Common hornbeam	47	26	19	0.9	1	1	0.5	Caucasus
Castanea sativa Mill./Sweet chestnut	43	20	22	1.4	8	3	0.4	Caucasus
Celtis austriaca australis L./Hackberry	42	29	21	0.8	7	2	1.3	Crimea
Corylus avellana L./European filbert	47	29	22	0.6	3	1	0.4	Central Chernozem
Cotoneaster vulgaris/Juneberry	44	31	22	0.5	1	<1	0.4	Leningrad
Disopyros lotus L./Date-plum persimmon	45	24	19	2.3	4	2	0.8	Caucasus
Fraxinus excelsior L./Common ash	44	25	25	1.2	3	1	0.5	Central Chernozem
Haloxylon aphyllum Bunge/Black haloxylon	32	21	28	0.7	1.3	3	2.9	Central Asia
Juglans manschurica Max/Manchurian walnut	51	16	20	2.2	4	2	0.4	Far Eastern
Juglans regia L./Persian walnut	49	20	22	2.2	5	1	0.5	Caucasus
Laurus nobilis L./True bay	43	29	21	0.7	5	3	0.7	Crimea
Maclura aurantiaca Nutt./Osage orange	40	21	19	3.0	9	2	0.6	Caucasus
Olea europaea L./Common olive	43	24	20	2.4	14	1	1.0	Crimea
Ostrya carpinifolia Scop./Hop hornbeam	49	24	21	0.8	2	1	0.6	Caucasus
Paulownia tomentosa (Thunb) Steud./Royal pavlownia	46	24	20	1.2	6	2	0.3	Caucasus
Parrotia persica D.A. Med./Persian ironwood	46	26	20	1.4	2	1	0.5	Caucasus
Phellodendron amurense Rupr./Amur cork tree	48	20	22	0.8	2	2	0.4	Far Eastern
Pirus communis L./Common pear	44	26	24	0.7	2	1	0.4	Caucasus
Pirus malus L./Apple tree	45	24	25	0.8	1	1	0.5	Caucasus
Pistacia mutica F./Turkish terebinth	34	23	22	3.3	9	4	0.2	Caucasus

Platanus orientalis L./Oriental plane	44	21	21	1.2	3	1	1.3	Caucasus
Populus nigra L./Black poplar	48	23	19	1.8	5	1	0.4	Central Eastern
Prunus avium L./Gean tree	45	24	18	2.8	7	1	0.3	Caucasus
Prunus laurocerasus L./Cherry laurel	45	26	27	0.5	1	1	0.5	Caucasus
Prunus padus L./Bird cherry	47	28	20	0.5	1	1	0.2	Leningrad
Punica granatum L./Pomegranate	39	25	21	0.8	4	3	1.2	Crimea
Quercus mongolica Fisch./Mongolian oak	47	24	22	0.9	2	2	0.2	Far Eastern
Quercus sessiliflora Salisb./Sessile oak	44	23	24	0.9	3	2	0.3	Central Chernozem
Salix alba L./White willow	46	25	28	1.2	2	1	0.5	Central Chernozem
Sambucus nigra L./Common alder	48	25	30	0.4	2	1	0.6	Caucasus
Sorbus aucuparia L./Mountain ash	46	30	22	0.9	3	1	0.6	Leningrad
Sorbus torminalis Crtz./Birch	42	27	26	0.4	1	<1	0.7	Caucasus
Tamarix gallica L./Tamarisk	35	21	18	0.7	8	9	5.4	Crimea
Tilia amurensis L./Amur linden	43	23	18	7.7	4	2	0.7	Far Eastern
Tilia cordata Mill/Small-leaved linden	50	23	18	5.7	2	1	0.6	Central Chernozem
Ulmus laevis Pall./Russian elm	52	20	22	1.0	2	2	0.7	Central Chernozem
Zelcova carpinifolia Dipp./Zelkova elm	33	21	20	1.7	15	1	0.8	Caucasus
		Softwoods						
Abies holophylla Max./Manchurian fir	43	—	30	1.4	2	3	0.6	Maritime Territory
Abies nephrolepis (Traut.) Maxim./Khingan fir	56	5	28	0.7	—	3	0.4	Far Eastern
Abies nordmannana (Stev.) Spach/ Nordmann fir	46	10	29	2.5	4	<1	0.4	Caucasus
Abies sachalinensis Masters/Sakhalin fir	55	6	29	3.7	—	2	0.2	Sakhalin
Abies sibirica Ledeb./Siberian fir	51	5	30	0.9	2	1	0.7	Siberia
Larix dahurica Turcz./Dahurian larch	52	12	27	1.3	1	2	0.2	Far Eastern
Larix sibirica Ledeb./Siberian larch	46	9	30	1.8	2	5	1.0	Siberia
Picea fennica Regel/Finnish Siberian spruce	48	10	29	1.4	—	1	0.3	Karelian ASSR
Picea jesoensis (S. et Z.) Carr./Jeddo spruce	47	7	29	3.1	—	4	0.2	Sakhalin
Picea obovata Led./Siberian spruce	46	10	28	1.5	—	1	0.3	Karelian ASSR
Picea schrenkiana Fish & Meyer/Schrenk spruce	.41	13	33	0.6	2	1	0.6	Central Asia
Pinus koraiensis Sieb. & Zuss/Korean pine	44	—	26	6.7	3	8	0.2	Maritime Territory
Pinus sibirica Rupr./Siberian stone pine	53	9	30	2.4	3	2	0.1	Siberia
Pinus sylvestris L./Scotch pine	54	11	28	1.6	1	1	0.2	Leningrad
Taxus baccata L./English yew	43	12	29	2.3	3	1	0.4	Caucasus

[a] Kürschner cellulose is nearly pure cellulose.
[b] Pentosans are the total anhydroxylose and arabinose residues in wood.
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Table XII. Chemical Composition of Woods of Unrecorded Origin

	Carbohydrate				*Solubility*		
Scientific Name/Common Name	*Cross and Bevan Cellulose*[a]	*Alpha Cellulose*[b]	*Pentosans*[c]	*Klason Lignin*	*1% NaOH*	*Hot Water*	*EtOH/Benzene*
Eucalyptus marginata Sm./Jarrah	41	36	11	43	26	7	1
Juniperus procera Hochst./African pencil cedar	42	33	13	37	25	6	7
Mitragyna stipulosa Kuntze/Abura	50	44	17	33	12	5	2
Pinus palustris Mill./Pitch pine							
Highly resinous	45	33	7	21	36	3	24
Slightly resinous	53	41	11	30	15	4	2
Quercus spp./English oak	53	38	23	22	24	10	3
Tectonia grandis L.f./Teak	45	37	13	31	21	7	11
Triplochiton nigericum Sprague/Obeche	49	—	19	33	16	6	3

NOTE: Values are for percent oven-dry wood.
[a] Cross and Bevan cellulose is largely pure cellulose but contains some hemicelluloses.
[b] Alpha cellulose is nearly pure cellulose.
[c] Pentosans are the total anhydroxylose and arabinose residues in wood.
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Table XIII. Chemical Composition of Some North American Woods

Scientific Name/ Common Name	*Glucan*	*Xylan*	*Galactan*	*Arabinan*	*Mannan*	*Uronic Anhydride*	*Acetyl*	*Lignin*	*Ash*	*Reference*
Hardwoods (Angiosperms)										
Acer rubrum **L./Red maple**	46	19	0.6	0.5	2.4	3.5	3.8	24	0.2	11
Acer saccharum **Marsh./Sugar maple**	52	15	<0.1	0.8	2.3	4.4	2.9	23	0.3	86
Betula alleghaniensis **Britton/ Yellow birch**	47	20	0.9	0.6	3.6	4.2	3.3	21	0.3	86
Betula papyrifera **Marsh./White birch**	43	26	0.6	0.5	1.8	4.6	4.4	19	0.2	11
Fagus grandifolia **Ehrh./Beech**	46	19	1.2	0.5	2.1	4.8	3.9	22	0.4	11
Liquidambar styraciflua **L./ Sweetgum**	39	18	0.8	0.3	3.1	—	—	24	0.2	87
Platanus occidentalis **L./ American sycamore**										
Fast growth	44	18	2.0	0.7	2.2	5.6	5.3	20	0.8	88
Slow growth	43	15	2.2	0.6	2.0	5.1	5.5	23	0.7	88
Populus deltoides **Bartr. ex Marsh./Eastern cottonwood**										
Fast growth	42	19	1.3	0.5	2.9	5.5	4.0	24	0.7	88
Slow growth	47	15	1.4	0.6	2.9	4.8	3.1	24	0.8	88
Populus tremuloides **Michax./ Quaking aspen**	49	17	2.0	0.5	2.1	4.3	3.7	21	0.4	11
Quercus falcata **Michx./ Southern red oak**	41	19	1.2	0.4	2.0	4.5	3.3	24	0.8	87
Ulmus americana **L./White elm**	52	12	0.9	0.6	2.4	3.6	3.9	24	0.3	11
Softwoods (Gymnosperms)										
Abies balsamea **(L.) Mill/ Balsam fir**	46	6.4	1.0	0.5	12	3.4	1.5	29	0.2	11

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Table XIII. Continued

Gingo biloba L./Ginko	40	4.9	3.5	1.6	10	4.6	1.3	33	1.1	89
Juniperus communis L./Common juniper	41	6.9	3.0	1.0	9.1	5.4	2.2	31	0.3	89
Larix decidua Mill./Common larch (sapwood)	46	6.3	2.0	2.5	11	4.8	1.4	26	0.2	89
Larix laricina (Du Roi) K. Koch/Tamarack	46	4.3	2.3	1.0	13	2.9	1.5	29	0.2	90
Picea abies (L.) Karst./Norway spruce	43	7.4	2.3	1.4	9.5	5.3	1.2	29	0.5	89
Picea glauca (Moench) Voss/ White spruce	45	9.1	1.2	1.5	11	3.6	1.3	27	0.3	11
Picea mariana (Mill.)B.S.P./ Black spruce	44	6.0	2.0	1.5	9.4	5.1	1.3	30	0.3	89
Picea rubens Sarg./Red spruce	44	6.2	2.2	1.4	12	4.7	1.4	28	0.3	89
Pinus banksiana Lamb./Jack pine	46	7.1	1.4	1.4	10	3.9	1.2	29	0.2	90
Pinus radiata D. Don/ Australian radiata[a]	42	6.5	2.8	2.7	12	2.5	1.9	27	0.2	91,92
Pinus resinosa Ait./Red pine	42	9.3	1.8	2.4	7.4	6.0	1.2	29	0.4	89
Pinus rigida Mill./Pitch pine	47	6.6	1.4	1.3	9.8	4.0	1.2	28	0.4	89
Pinus strobus L./Eastern white pine	45	6.0	1.4	2.0	11	4.0	1.2	29	0.2	11
Pinus sylvestris L./Scots pine	44	7.6	3.1	1.6	10	5.6	1.3	27	0.4	89
Pinus taeda L./Loblolly pine	45	6.8	2.3	1.7	11	3.8	1.1	28	0.3	87
Pseudotsuga menziesii (Mirb.) Franco/Douglas-fir	44	2.8	4.7	2.7	11	2.8	0.8	32	0.4	87
Thuja occidentalis L./Northern white cedar	43	10.0	1.4	1.2	8.0	4.2	1.1	31	0.2	11
Tsuga canadensis (L.) Carr./ Eastern hemlock	44	5.3	1.2	0.6	11	3.3	1.7	33	0.2	11

NOTE: The values expressed are for percent oven-dry wood and extractive-free wood.
[a] Australian-grown wood. Percent oven-dry wood.

Table XIV. Chemical Composition of Selected Hardwoods from the Southeastern United States (Percent Oven-Dry Wood)

Scientific Name/Common Name	Carbohydrate: Cellulose	Carbohydrate: Total Hemicellulose	Components of Hemicellulose: Glucomannan	Components of Hemicellulose: Acetylglucuronoxylan	Components of Hemicellulose: Arabinogalactan	Components of Hemicellulose: Pectin	Lignin[a]	Total Extractives[b]	Ash	Location[c]
Acer rubrum L./Red maple	39.9	28.2	3.5	21.0	1.8	1.9	23.0	8.6	0.3	G
Acer rubrum L./Red maple	40.7	30.4	3.5	23.5	1.6	1.9	23.3	5.3	0.3	T
Aesculus octandra Marsh./Yellow buckeye	40.6	25.8	3.6	18.6	1.0	2.6	30.0	3.1	0.5	T
Carya glabra (Mill.) Sweet/ Pignut hickory	46.2	26.7	1.1	22.1	1.2	2.3	23.2	3.4	0.6	T
Carya illinoensis (Wangenh.) K. Koch/ Pecan	38.7	30.2	1.6	24.7	1.6	2.3	23.3	7.4	0.4	G
Carya sp. Nutt./Hickory	37.7	29.2	0.8	24.9	1.8	1.7	23.0	9.0	1.1	G
Carya tomentosa (Poir.) Nutt./Mockernut	43.5	27.7	1.5	21.5	1.3	3.5	23.6	5.0	0.4	T
Cornus florida L./Flowering dogwood	36.8	35.4	3.4	27.2	1.0	5.0	21.8	4.6	0.3	T
Fagus grandifolia Ehrh./American beech	36.0	29.4	2.7	23.5	1.3	1.8	30.9	3.4	0.4	T
Fraxinus americana L./White ash	48.7	22.4	1.9	16.4	1.7	2.4	23.3	5.4	0.3	G
Fraxinus americana L./White ash	39.5	29.1	3.8	22.1	1.4	1.9	24.8	6.3	0.3	T
Gordonia lasianthus (L.) Ellis/ Loblolly-bay	43.8	29.1	4.1	22.1	1.1	1.8	21.5	5.2	—	G
Liquidambar styraciflua L./Sweetgum[d]	42.8	30.1	3.6	23.6	1.0	1.9	25.7	1.1	0.3	G
Liquidambar styraciflua L./Sweetgum	40.8	30.7	3.2	21.4	1.3	4.9	22.4	5.9	0.2	T
Liriodendron tulipifera L./Yellow-poplar	39.1	28.0	4.9	20.1	0.7	2.4	30.3	2.4	0.3	T
Magnolia virginiana L./Sweetbay	44.2	37.7	4.3	20.2	1.6	1.6	24.1	3.9	0.2	G
Nyssa aquatica L./Water tupelo	45.9	24.0	3.5	18.6	0.8	1.1	25.1	4.7	0.4	G
Nyssa sylvatica Marsh./Black tupelo	44.9	23.2	3.8	17.3	1.2	0.9	28.9	2.6	0.4	G
Nyssa sylvatica Marsh./Black tupelo	42.6	27.3	3.6	18.0	1.0	4.8	26.6	2.9	0.6	T

Continued on next page

Table XIV. Continued

Oxydendron arboreum (L.) DC./Sourwood	40.7	34.6	1.3	31.9	1.0	0.4	20.8	3.6	0.3	T
Persea borbonia (L.) Spreng./Redbay	45.6	25.6	1.0	23.2	0.9	0.5	23.6	5.0	0.2	G
Platunus occidentalis L./Sycamore	43.0	27.2	2.3	22.3	1.4	1.2	25.3	4.4	0.1	G
Populus deltoides Bartr. ex Marsh./ Eastern cottonwood[e]	46.5	24.6	4.4	16.8	1.6	1.8	25.9	2.4	0.6	G
Populus deltoides Bartr. ex Marsh./ Eastern cottonwood[f]	47.0	25.0	5.0	18.4	0.8	0.8	26.0	1.6	0.4	G
Quercus alba L./White oak	43.7	24.2	1.4	18.0	2.2	2.6	24.3	5.4	1.0	G
Quercus alba L./White oak	41.7	28.4	3.1	21.0	1.6	2.7	24.6	5.3	0.2	T
Quercus coccinea Muenchh./Scarlet oak	43.2	29.2	2.3	23.3	1.4	2.2	20.9	6.6	0.1	T
Quercus falcata Michx./Southern red oak	40.5	24.2	1.7	18.6	1.7	2.2	23.6	9.6	0.5	G
Quercus ilicifolia Wangenh./Scrub oak	37.6	27.5	1.0	22.3	1.8	2.4	26.4	8.0	0.5	G
Quercus marylandica Muenchh./Blackjack oak	33.8	28.2	2.0	21.0	2.3	2.9	30.1	6.6	1.3	T
Quercus nigra L./Water oak	41.6	34.8	3.0	28.9	2.2	0.7	19.1	4.3	0.3	G
Quercus prinus L./Chestnut oak	40.8	29.9	2.9	23.8	1.8	1.4	22.3	6.6	0.4	T
Quercus rubra L./Northern red oak	42.2	33.1	3.3	26.6	1.6	1.6	20.2	4.4	0.2	T
Quercus stellata Wangenh./Post oak	37.7	29.9	2.6	23.0	2.0	2.3	26.1	5.8	0.5	G
Quercus velutina Lam./Black oak	39.6	28.4	1.9	23.2	1.1	1.9	25.3	6.3	0.5	T
Quercus virginiana Mill./Live oak	38.1	22.9	1.0	18.3	1.7	1.9	25.3	13.2	0.6	G
Sassafras albidum (Nutt.) Nees/Sassafras	45.0	35.1	4.0	30.4	0.9	<0.1	17.4	2.4	0.2	T
Ulmus americana L./American elm[d]	42.6	26.9	4.6	19.9	0.8	1.6	27.8	1.9	0.8	G
Ulmus americana L./American elm	41.9	29.7	3.2	20.6	1.4	4.3	25.6	2.4	0.5	T

NOTE: The data are for percent oven-dry wood.
[a] Klason lignin + acid soluble lignin.
[b] Total extractives = sum of solubles in petroleum ether, diethyl ether or chloroform, 95% EtOH, and hot water.
[c] G = southeast Georgia (swampy); T = eastern Tennessee (dry, upland).
[d] Average of 20 trees.
[e] Average of 2 trees, age 32 y ears.
[f] Average of 2 trees, age 46 years.
(Data adapted from a private communication with H. L. Hergert and others.)

Table XV. Elemental Composition of Some Woods

Wood	Parts Per Thousand					Parts Per Million					Reference
	Ca	*K*	*Mg*	*P*	*Mn*	*Fe*	*Cu*	*Zn*	*Na*	*Cl*	
Temperate Woods											
Abies balsamea **(L.) Mill/Balsam fir**[a]	0.8	0.8	0.27	—	0.13	13	17	11	—	—	93
	0.9	0.5	—	—	0.09	—	—	—	18	—	93
Acer rubrum **L./Red maple**[a]	0.8	0.7	0.12	0.03	0.07	11	5	29	—	—	93
	0.7	0.5	—	—	0.07	—	—	—	5	18	93
Betula papyrifera **Marsh./White birch**[a]	0.7	0.3	0.18	0.15	0.03	10	4	28	—	—	93
	0.9	0.2	—	—	0.03	—	—	—	9	10	93
Fraxinus americana **L./White ash**[b]	0.3	2.6	1.8	0.01	—	—	—	—	31	—	94
Liquidambar styraciflua **L./ Sweetgum**[c]											
Bottomland	0.65	0.4	0.37	0.26	0.06	—	—	22	88	—	95
Upland	0.55	0.3	0.34	0.15	0.08	—	—	19	81	—	95
Picea rubens **Sarg./Red spruce**[a]	0.8	0.2	0.07	0.05	0.14	14	4	8	—	—	93
	0.7	0.1	—	—	0.11	—	—	—	8	0.3	93
Pinus strobus **L./Eastern white pine**[a]	0.2	0.3	0.07	—	0.03	10	5	11	—	—	93
	0.3	0.1	—	—	0.02	—	—	—	9	19	93

Continued on next page

Table XV. Continued

Populus deltoides Bartr./Eastern cottonwood[a,d]	0.9	2.3	0.29	—	0.02	1×10^2	—	30	9.4×10^2	—	94
	1.2	2.5	[e]	—	<0.01	—	—	—	1.1×10^2	30	94
Populus tremuloides Michx./Quaking aspen[a]	1.1	1.2	0.27	0.10	0.03	12	7	17	—	—	93
	0.8	0.9	—	—	0.04	—	—	—	5	—	93
Quercus alba L./White oak[b]	0.5	1.2	0.31	—	<0.01	—	—	—	21	15	94
Quercus falcata Michx./Southern red oak[c]	0.3	0.6	0.03	0.02	0.01	30	73	38	44	—	76
Tilia americana L./Basswood[b]	0.1	2.8	0.35	—	—	—	—	—	63	38	94
Tsuga canadensis (L.) Carr./Eastern hemlock[a]	0.8	0.4	0.11	0.12	0.15	6	5	2	—	—	93
	1.1	0.3	—	—	0.12	—	—	—	6	—	93
Tropical Woods[b]											
Eriotheca sp.	0.1	8.7	4.0	—	<0.01	—	—	—	1.5×10^2	2.5×10^2	93
Peltogyne prophyrocardia Griseb.	0.2	9.8	8.6	—	0.06	—	—	—	48	97	93
Stryphnodendron polystachum (Miq.) Kleinh.	0.5	26.1	1.0	—	0.01	—	—	—	6.8×10^2	1.1×10^3	93

NOTE: Values of parts per thousand or parts per million are for oven-dry wood.

[a] Values in the first row obtained by atomic spectrometric methods. Values in second row for same tree species obtained by neutron activation method.

[b] Values obtained by neutron activation method.

[c] Values obtained by atomic spectrometric methods.

[d] Sawdust.

[e] Observed, but not measured.

Table XVI. Summary of Carbohydrate, Lignin, and Ash Compositions for Woods of 13 Nations

Country	*Holocellulose*[a]	*Alpha Cellulose*[b]	*Other Cellulose*	*Pentosans*[c]	*Klason Lignin*	*Ash*
Brazil (Table IV)	71.7 ± 26.6(6)	49.4 ± 4.1(18)	52.3 ± 1.9(6)[d]	14.5 ± 4.2(24)	28.6 ± 3.9(24)	0.5 ± 0.3(24)
Cambodia (Table VIII)	71.3 ± 4.3(8)	48.6 ± 2.3(8)	—	—	32.3 ± 3.4(8)	0.7 ± 0.4(8)
Costa Rica (Table IV)	78.1 ± 3.3(22)	—	—	12.3 ± 2.1(22)	26.5 ± 3.7(22)	1.3 ± 2.0(22)
Ghana (Table VI)	—	—	45.5 ± 4.2(4)[e]	17.0 ± 2.2(4)	29.8 ± 3.9(4)	0.8 ± 0.7(4)
Japan (Table VII)						
Hardwoods	78.0 ± 3.7(100)	45.0 ± 4.9(100)	58.0 ± 3.9(56)[d]	20.1 ± 3.7(100)	22.1 ± 3.0(100)	0.5 ± 0.2(100)
Softwoods	68.9 ± 4.8(36)	43.8 ± 5.5(36)	55.8 ± 4.4(12)[d]	8.3 ± 3.5(36)	29.6 ± 2.6(36)	0.4 ± 0.4(36)
Kalimantan (Table VIII)	69.0 ± 4.2(15)	48.3 ± 3.3(15)	—	—	29.9 ± 3.2(15)	0.9 ± 0.5(14)[f]
Mexico (Table IX)	67.8 ± 4.9(13)	46.5 ± 4.1(13)	—	15.1 ± 1.9(13)	25.8 ± 4.1(13)	1.7 ± 0.5(13)
Mozambique (Table VI)	—	—	39.8 ± 4.1(29)[g]	15.1 ± 2.4(29)	27.3 ± 3.4(29)	1.6 ± 1.1(29)
Papua New Guinea (Table VIII)	71.4 ± 3.7(35)	47.4 ± 2.5(35)	—	—	29.8 ± 3.8(35)	1.1 ± 0.6(37)
Philippine Islands (Table IX)						
Hardwoods	71.8 ± 5.5(112)	39.1 ± 5.1(70)	—	16.3 ± 4.1(47)	29.4 ± 5.6(112)	1.2 ± 0.7(108)
Softwoods	65.0 ± 4.0(6)	—	—	11.0 ± 2.2(6)	30.8 ± 3.8(6)	0.4 ± 0.1(6)
Taiwan (Table X)						
Hardwoods	83.3 ± 3.7(33)	48.8 ± 4.7(33)	—	17.9 ± 2.4(34)	25.0 ± 3.8(34)	0.9 ± 0.4(34)
Softwoods	—	—	50.4 ± 2.6(11)[h]	10.4 ± 1.4(11)	32.2 ± 2.1(11)	0.8 ± 0.5(6)

Continued on next page

Table XVI. Continued

U.S.A. (Table III)						
Hardwoods	71.7 ± 5.7(25)	45.4 ± 3.5(39)	59.1 ± 4.3(26)[d]	19.3 ± 2.2(49)	23.0 ± 3.0(40)	0.5 ± 0.3(34)
Softwoods	64.5 ± 4.6(22)	43.7 ± 2.6(35)	58.2 ± 3.0(23)[d]	9.8 ± 2.2(35)	28.8 ± 2.6(35)	0.3 ± 0.1(30)
U.S.A. and Canada (Table XIII)						
Hardwoods	—	—	44.6 ± 4.1(11)[i]	31.7 ± 3.8(10)[j]	22.5 ± 1.8(11)	0.4 ± 0.2(11)
Softwoods	—	—	41.9 ± 1.8(19)[i]	28.5 ± 1.7(19)[j]	29.2 ± 2.0(19)	0.3 ± 0.2(19)
U.S.A. (Table XIV)	—	—	41.7 ± 3.3(39)[i]	28.6 ± 3.6(39)[j]	24.5 ± 3.0(39)[k]	0.4 ± 0.3(39)
U.S.S.R. (Table XI)						
Hardwoods	—	—	44.3 ± 5.1(47)[e]	24.2 ± 3.4(46)	21.9 ± 3.2(47)	0.6 ± 0.4(45)[l]
Softwoods	—	—	48.3 ± 4.8(15)	8.8 ± 2.5(12)	29.0 ± 1.6(15)	0.5 ± 0.4(16)

NOTE: Values are mean ± standard deviation (number of data).
[a] Holocellulose is the total carbohydrate content of wood.
[b] Alpha cellulose is nearly pure cellulose.
[c] Pentosans are the total anhydroxylose and arabinose residues in wood.
[d] Cross and Bevan cellulose is largely pure cellulose but contains some hemicelluloses.
[e] Kürschner cellulose is nearly pure cellulose.
[f] One value of 4.6% not included.
[g] Modified Kürschner cellulose.
[h] Modified Cross and Bevan cellulose.
[i] Pure glucan calculated from glucose and mannose content.
[j] Hemicelluloses calculated from five-sugar, acetyl, and uronic acid content.
[k] Klason lignin + acid-soluble lignin.
[l] One value of 5.4% not included.

hydrate components in Table XIV have been adjusted by a hydrolysis-loss factor. This factor was calculated for each species, such that the sum of total extractives, lignin, cellulose, hemicellulose, and ash equals 100%. The hemicellulose components were calculated using the adjusted value of the five individual sugars and the measured values for acetyl and uronic acid.

Table VII reports the trace element composition of some woods. Calcium, potassium, magnesium, and phosphorus are the principal trace elements in temperate woods. The three tropical woods have a higher potassium and magnesium content and a lower calcium content than the temperate woods.

Table XVI is a summary of average wood composition in 13 countries. The mean, standard deviation, and number of data are tabulated for carbohydrate, lignin, and ash compositions. Hardwoods and softwoods are separated when both are available. All other values are only for hardwoods. Be careful comparing values between countries because techniques and methods vary. For example, the mean holocellulose content of Costa Rican hardwoods is 78.1%, higher than that of woods from Brazil (71.7%) and Mexico (67.8%). The holocellulose determined for the Costa Rican hardwoods probably contained some lignin. The mean value of Taiwanese hardwood holocellulose is obviousiy high (83.3%) because the means for holocellulose and lignin sum to 108%.

Literature Cited

1. Hegnauer, R. "Chemotaxonomie der Pflanzen," Volumes I–VI; Birkhäuser Verlag: Basel and Stuttgart, 1962–1973.
2. Gibbs, R. Darnley "Chemotaxonomy of Flowering Plants," Volumes 1–4; McGill-Queens University Press: Montreal and London, 1974.
3. Wise, L. E.; Murphy, M.; D'Addieco, A. A. *Pap. Trade J.* **1946,** *122*(2), 35–43.
4. Fengel, Dietrich; Grosser, Dietger *Holz Roh- Werkst.* **1975,** *33*(1), 32–34.
5. Goring, D. A. I.; Timell, T. E. *Tappi* **1962,** *45*(6), 454–60.
6. Sjöström, Eero "Wood Chemistry. Fundamentals and Applications"; Academic Press: New York, 1981; p. 56, 65.
7. Billmeyer, F. W., Jr. *J. Polym. Sci., Part C* **1965,** No. 8, 161–78.
8. Gardner, K. H.; Blackwell, J. *Biochim. Biophys. Acta* **1974,** *343*, 232–37.
9. Kolpak, F. J.; Blackwell, J. *Macromolecules* **1976,** 9(2), 273–78.
10. Kolpak, F. J.; Weik, M.; Blackwell, J. *Polymer* **1978,** *19*, 123–31.
11. Timell, T. E. *Wood Sci. Technol.* **1982,** *16*, 83–122.
12. Timell, T. E. *Wood Sci. Technol.* **1967,** *1*, 45–70.
13. Timell, T. E. *Adv. Carbohydr. Chem. Biochem.* **1964,** *19*, 247–302.
14. Timell, T. E. *Adv. Carbohydr. Chem. Biochem.* **1965,** *20*, 409–83.
15. Adler, Erich *Wood Sci. Technol.* **1977,** *11*, 169–218.
16. Leopold, B.; Malmström, I. L. *Acta Chem. Scand.* **1952,** *6*, 49–54.
17. Obst, John R. *Tappi* **1982,** *65*(4), 109–12.
18. Nimz, H. *Angew. Chem., Int. Ed. Engl.* **1974,** *13*, 313–21.
19. Creighton, R. N. J.; Hibbert, H. *J. Am. Chem. Soc.* **1944,** *66*, 37–38.
20. Larsson, Sam; Miksche, Gerhard E. *Acta Chem. Scand.* **1967,** *21*(7), 1970–71.

21. Björkman, Anders *Sven. Papperstidn.* **1956,** *59*(13), 477–85.
22. Chang, H.-M.; Cowling, E. B.; Brown, W.; Adler, E.; Miksche, G. *Holzforschung* **1975,** *29*(5), 153–59.
23. Pew, John C. *Tappi* **1957,** *40*(7), 553–58.
24. Freudenberg, K.; Neish, A. C. "Constitution and Biosynthesis of Lignins"; Springer-Verlag: Berlin and New York, 1968; p. 113.
25. "Lignins: Occurrence, Formation, Structure and Reactions"; Sarkanen, K. V.; Ludwig, C. H., Eds.; Wiley-Interscience: New York, 1971.
26. "Wood Extractives"; Hillis, W. E., Ed.; Academic Press: New York, 1962.
27. Rowe, John W.; Conner, Anthony H. "Extractives in Eastern Hardwoods—A Review"; General Technical Report FPL 18, Forest Products Laboratory, Madison, WI, 1979.
28. Meier, H.; Wilkie, K. C. B. *Holzforschung* **1959,** *13*(6), 177–82.
29. Meier, Hans *J. Polym. Sci.* **1961,** *51*, 11–18.
30. Scott, J. A. N.; Procter, A. R.; Fergus, B. J.; Goring, D. A. I. *Wood Sci. Technol.* **1969,** *3*, 73–92.
31. Fergus, B. J.; Procter, A. R.; Scott, J. A. N.; Goring, D. A. I. *Wood Sci. Technol.* **1969,** *3*, 117–38.
32. Fergus, B. J.; Goring, D. A. I. *Holzforschung* **1970,** *24*(4), 118–24.
33. Obst, John R. *Holzforschung* **1982,** *36*(3), 143–53.
34. Van Beckum, W. G.; Ritter, G. J. *Pap. Trade J.* **1937,** *105*(18), 127–30.
35. Wise, L. E.; Jahn, E. C. "Wood Chemistry," 2d ed.; Reinhold: New York, 1952; pp. 1148–52.
36. Browning, B. L. "Methods of Wood Chemistry," Volume II; Interscience: New York, 1967; pp. 406, 615–24.
37. Saeman, J. F.; Moore, W. E.; Mitchell, R. L.; Millett, M. A. *Tappi* **1954,** *37*(8), 336–43.
38. Nelson, N. *J. Biol. Chem.* **1944,** *153*, 375–80.
39. Simson, B. W.; Timell, T. E. *Tappi* **1967,** *50*(10), 473–77.
40. Borchardt, L. G.; Piper, C. V. *Tappi* **1970,** *53*(2), 257–60.
41. Seymour, F. R.; Chen, E. C. M.; Bishop, S. H. *Carbohydr. Res.* **1979,** *73*, 19–45.
42. Sweeley, C. C.; Bentley, Ronald; Makita, M.; Wells, W. W. *J. Am. Chem. Soc.* **1963,** *85*, 2497–507.
43. Brower, H. E.; Jeffery, J. E.; Folsom, M. W. *Anal. Chem.* **1966,** *38*(2), 362–64.
44. Wentz, F. E.; Marcy, A. D.; Gray, M. J. *J. Chromatogr. Sci.* **1982,** *20*, 349–52.
45. Bylund, M.; Donetzhuber, A. *Sven. Papperstidn.* **1968,** *71*(15), 505–8.
46. Scott, R. W. *Anal. Chem.* **1979,** *51*(7), 936–41.
47. Wisenberger, E. *Makrochem.* **1947,** *33*, 51–69.
48. Procter, A. R.; Chow, W. M. *Pulp Pap. Mag. Can.* **1973,** *74*(7), 97–100.
49. Effland, Marilyn J. *Tappi* **1977,** *60*(10), 143–44.
50. Musha, Y.; Goring, D. A. I. *Wood Sci.* **1974,** *7*(2), 133–34.
51. Schöning, Arnt G.; Johansson, Gösta *Sven. Papperstidn.* **1965,** *68*(18), 607–13.
52. Swan, Brita *Sven. Papperstidn.* **1965,** *68*(22), 791–95.
53. Zeisel, S. *Monatsh. Chem.* **1885,** *6*, 989–96.
54. Steyermark, A. "Quantitative Organic Microanalysis"; 2d ed.; Academic Press: New York, 1961; p. 422–43.
55. Koeppen, Robert C. in "Papers for Conference on Improved Utilization of Tropical Woods"; Forest Products Laboratory: Madison, WI, 1978; p. 33.
56. Chinese Forestry Association "Important Wood Species of Taiwan"; Taipei, Taiwan, 1967.
57. Corrêa, A. A.; Ribeiro, E. B. P.; Lobato, R. de F. *Assoc. Téc. Bras. Cellul. Pap. Bol.* **1970,** *31*, 95–138.
58. Lauer, Karl *Tappi*, **1958,** *41*(7), 334–35.
59. Barrichelo, L. E. G.; Brito, J. O. *IPEF* **1976,** *13*, 9–38.

60. U.S. Forest Products Laboratory, unpublished data for 1948–1957 on file at Madison, WI.
61. Inoue, Hideo; Masao, Moriya; Akiyama, Takeshi *J. Jpn. Tappi* **1972,** *26*(6), 256–62.
62. Wise, Louis E.; Rittenhouse, Ruth C.; Dickey, Edgar E.; Olson, Harry O.; Garcia, Consuelo *J. For. Prod. Res. Soc.* **1952,** *2*(5), 237–49.
63. Wise, Louis E.; Rittenhouse, Ruth C.; Garcia, Consuelo *Tappi* **1951,** *34*(4), 185–88.
64. Smith, J. B.; Primakov, S. F. *Appita* **1977,** *30*(5), 405–6.
65. Oliveira, J. Santos *Rev. Cien. Agron.* **1971,** Ser. B4, No. 3, 3–32.
66. Satonaka, Seiichi *J. Jpn. Wood Res. Soc.* **1963,** 9, 26–34.
67. Yonezawa, Yasumasa; Kayama, Tsutomu; Kikuchi, Fumihiko; Usami, Kuninori; Takano, Isao; Ogino, Takehiko; Honda, Osamu *Bull. Gov. For. Exp. Stn. (Jpn.)* **1973,** *253*, 55–99.
68. Kayama, Tsutomu; Kikuchi, Fumihiko; Takano, Isao; Usami, Kuninori *Bull. Gov. For. Exp. Stn. (Jpn.)* **1967,** *197*, 155–62.
69. Kayama, Tsutomu *J. Jpn. Tappi* **1968,** *22*(11), 581–90.
70. Working Group on Utilization of Tropical Woods *Bull. Gov. For. Exp. Stn. (Jpn.)* **1977,** *294*, 1–49.
71. Working Group on Utilization of Tropical Woods *Bull. Gov. For. Exp. Stn. (Jpn.)* **1978,** *299*, 85–104.
72. Eddowes, Peter J. "Commercial Timbers of Papua New Guinea"; Hebamo Press: Port Moresby, Papua New Guinea, 1977.
73. Reyes, Luis J. "Philippine Woods"; Bureau of Printing: Manila, 1938; p. 479–82.
74. Francia, P. C.; Escolano, E. U.; Bautista, C. S.; Semana, J. A. *Philippine Lumberman* **1971,** *17*(5), 21–24.
75. Escolano, Eugenia U.; Semana, Jose A. *Philippine Lumberman* **1978,** *24*(12), 16–20.
76. Escolano, E. U.; Francia, P. C.; Semana, J. A.; Bawagan, B. O. *Philippine Lumberman* **1970,** *16*(12), 26–28.
77. U.S. Forest Products Laboratory, unpublished data on file at Madison, WI.
78. Semana, J. A.; Escolano, E.; Francia, P. C.; Bautista, C. S. *Philippine Lumberman* **1968,** *14*(2), 20–25.
79. Francia, P. C.; Escolano, E. U.; Semana, J. A.; Bawagan, B. O. *Philippine Lumberman* **1970,** *16*(11), 26–30.
80. Chao, S. C.; Ku, Y. C.; Lin, S. J.; Pan, T. T. *Bull. Taiwan For. Res. Inst. (Co-Op. Taiwan For. Bur.)* No. 14, **1971,** Taipei, Taiwan.
81. Ku, Y. C. *Bull. Taiwan For. Res. Inst. (Co-Op. Taiwan For. Bur.)* No. 142, **1966,** Taipei, Taiwan.
82. Ku, Y. C.; Haung, L. Y.; Lin, T. N.; Pan, T. T. *Co-Op. Bull. Taiwan For. Res. Inst. Co-Op. Natl. Sci. Counc., Jt. Comm. Rural Reconstr., Taiwan For. Bur.* No. 8, **1965,** Taipei, Taiwan.
83. Sieber, R.; Walter, L. E. *Papier-Falst.* **1913,** *11*, 1179–83.
84. Nikitin, N. I. "The Chemistry of Cellulose and Wood"; trans. from Russian by J. Schmorak. Israel Program for Scientific Translations, Jerusalem, 1966. First published in Russian in 1962.
85. Campbell, W. G.; Bamford, K. F. *J. Soc. Chem. Ind., London, Trans. Commun.* **1939,** *58*, 180–85.
86. Timell, T. E. *Pulp Pap. Mag. Can.* **1958,** *59*(8), 139–40.
87. "The Chemistry of Wood"; Browning, B. L., Ed.; Krieger: Huntington, NY, 1975; p. 70–71.
88. Moore, W. E.; Effland, M. J. *Tappi* **1974,** *57*(8), 96–98.
89. Côté, W. A., Jr.; Simon, B. W.; Timell, T. E. *Sven. Papperstidn.* **1966,** *69*(17), 547–58.
90. Timell, T. E. *Tappi* **1957,** *40*(7), 568–72.
91. Smelstorius, J. A. *Holzforschung* **1971,** *25*(2), 33–39.
92. Smelstorius, J. A. *Holzforschung* **1974,** *28*(2), 67–73.

93. Young, H. E.; Guinn, V. P. *Tappi* **1966**, *49*(5), 190–97.
94. Osterhaus, C. A.; Langwig, J. E.; Meyer, J. A. *Wood Sci.* **1975**, *8*(1), 370–74.
95. Choong, Elvin T.; Chang, Bao-Yih; Kowalczuk, Joseph "LSU Wood Utilization Notes"; No. 27, December 1974.

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Pettersen, Roger C. The chemical composition of wood. In: Rowell, Roger M., ed. The chemistry of solid wood. Advances in chemistry series 207. Washington, DC: American Chemical Society; 1984: Chapter 2.

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