U.S. Forest Service Research Note

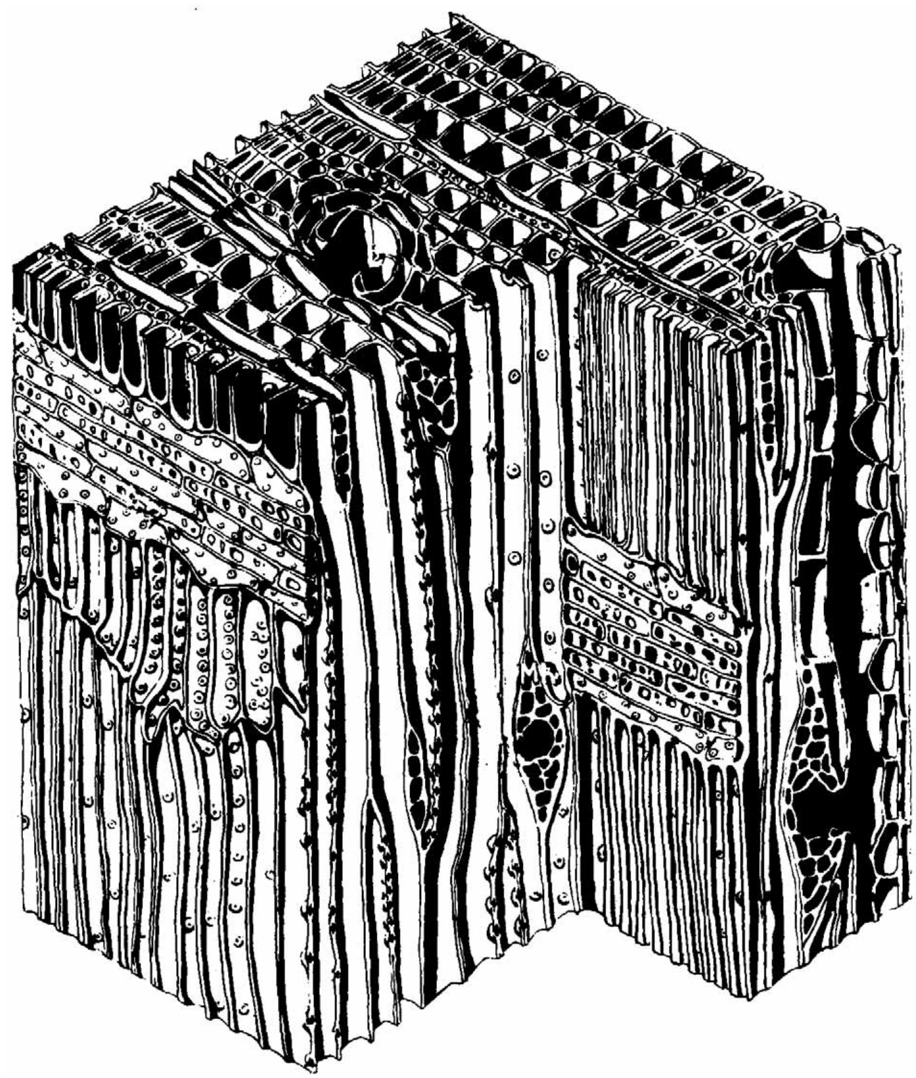
UNITED STATES DEPARTMENT OF AGRICULTURE • FOREST SERVICE • FOREST PRODUCTS LABORATORY • MADISON WIS

In Cooperation with the University of Wisconsin

INSIDE WOOD--A SHORT TRIP INTO THE INTERIOR FOR THE LAYMAN

OCTOBER 1963

FPL-014



ZM 724 F

softwood

This diagram, based on microscopic viewing of thin sections of wood, shows a block of wood measuring about one-fourth inch on a side.

INSIDE WOOD--A SHORT TRIP INTO THE INTERIOR FOR THE LAYMAN[1]

Forest Products Laboratory,[2] Forest Service
U.S. Department of Agriculture

Wood is a fairly complex material, whether you think of it in terms of boards or timbers or string along with what the chemist says it is. For ages wood has been vital to an ever-mounting scale of living. If it is to continue to serve in more ways and in new forms, most of the means for these changes will have to be found by looking into the physical and chemical maze that lies below the surface.

Wood is made up of fibers--tiny needle-shaped wisps about a seventh of an inch long and perhaps seven-thousandths of an inch thick. That's roughly the size of a day-old whisker. Taken alone the single fiber, for its size exhibits surprising strength. When this fiber unites with millions of others in typical wood structure the total strength is astonishing. The strength of wood is the springy strength of millions of the tiny fibers bound tightly together, all lined up in the same direction and with the ends of any one fiber overlapping some of the length of its neighbors.

Under the microscope the lone fiber turns out to be no simple one-piece job. It is a pipe-like affair of layers and windings and pierced with openings. The size and arrangement of the parts are influenced by the way the wood was nourished in the tree. As the parts are so altered the strength of the fiber is increased or diminished. And as the strength of the fiber goes, so goes the strength of the beam or board of which it is a part.

The job of inspecting the parts of a wood fiber would be simple if the fiber were blown up to 500 times its present size. Then the fiber would be just a shade under six feet tall, three inches thick, and bluntly pointed. Aside from being bluntly pointed at both ends the fiber would look something like a slim medium-length pipe organ pipe.

[1] Original report dated August 1954. by F. J. Champion. formerly Information Specialist now retired.

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

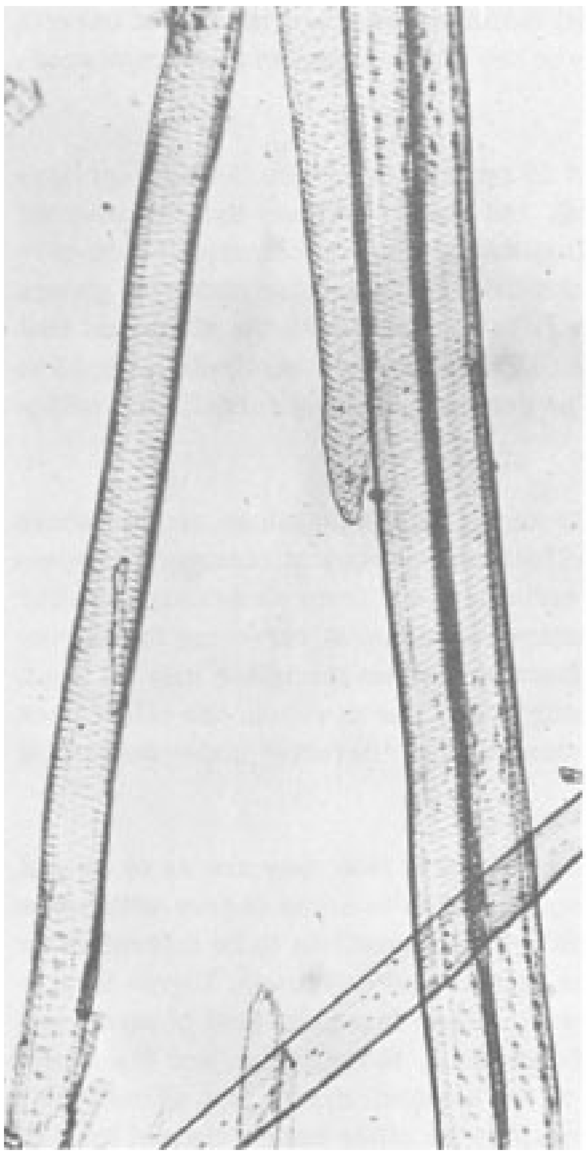
One of the surprising things about the blown–up fiber would be a layer almost at the surface. This would reveal itself as a tight cordlike winding––like the winding on old–style split–bamboo fishing rods. But this ‘round–and–’round winding is only one layer deep. If we break it and start unwinding its tight coils we are beginning to get into the fiber wall. The wall, at this stage of dissection, might look a little like the hundreds of wires in a communications cable. But in the case of the fiber the wires (the wood anatomist calls them fibrils) run as much as thirty degrees away from being parallel with the long axis of the fiber. It has been found that the smaller this angle, which depends on what happened to the parent tree while it grew, the stronger the fiber and all of the structures of which it is a part. There are several layers or ‘sleeves” of the fibrils––all adding up to a wall thickness of about an inch in our 500–times–enlarged fiber.

The fibrils––those tightly–packed slightly angling strands in the fiber’ wall––make up by far the greatest percentage of the fiber substance.

Wood experts have actually reduced fibrils to smaller parts––by using some mild chemicals, a delicate touch, and a lot of old–fashioned patience. Perhaps the job would be easier in the giant fibrils we have been dreaming about. Hard or easy, the fibrils would break down into a series of short spindles called fusiform bodies. In turn these units, if chemically softened, would finally resolve themselves into tiny particles that are visible only by means of the tiny halo of light that surrounds them. In the real fiber this is a frontier of the human eye for these small chunks of cellulose––that's what they are––are at the end of the line as far as the high–powered optical microscope is concerned. Anything smaller must be examined with the aid of X–rays or the electron microscope. A golf ball beside the Washington Monument––that’s the way they stack up beside the fibers they come from.

The fact that a wood fiber consists of so many distinct parts, some of them actually separated by crevices that are staggeringly small even in the micro–maze of the fiber, spells out a total internal surface area that defies belief. Because only the shallowest section of wood is in focus under a high–powered microscope the eye sees only a little way into the wood structure. Yet in that little way ten square feet of surface is revealed in the inner surfaces of fibers and pores and between structural units. In a cubic inch of wood the infolded and intertwined surfaces mount up to 22,000 square feet, or about a half acre.

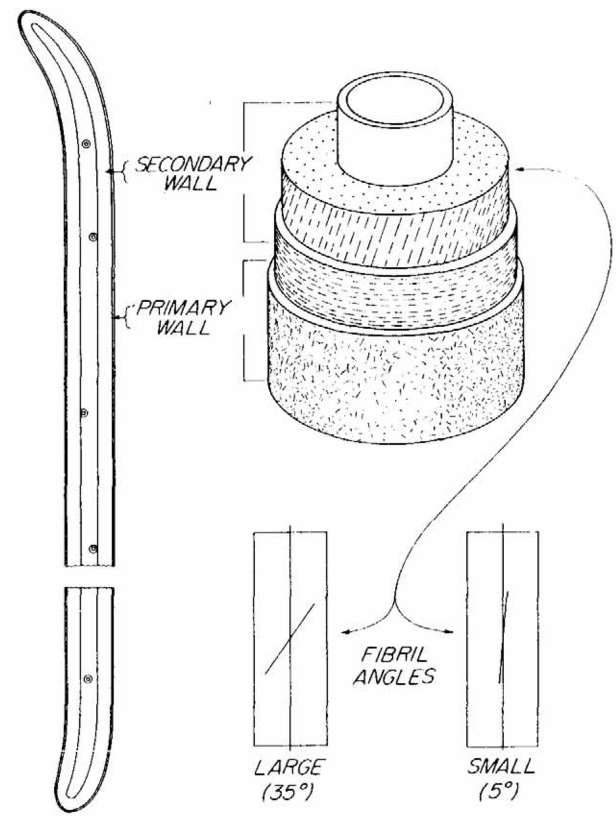
Within wood structure, in addition to simple internal surfaces, there are openings of various sizes that are peculiar to the structureand the life of the tree. The largest openings are resin ducts and pores between the individual fibers, and which can in some kinds of wood, be seen with the naked eye. Next smaller are the fiber cavities or lumens, the hollows inside. Still smaller are the pit membrane openings––tiny valves in the fiber walls. When the cell wall is swollen by some fluid capillary ‘channels in the cell wall are created, tiniest of all of the openings in the structure, and quite beyond the resolving power of the microscope.



M 17423 F

Douglas-fir fibers enlarged many times.

DIAGRAM OF FIBER WALL



ZM 93561 F

These diagrams show that the wall of the wood fiber is far from simple. A large fibril angle is associated with wood that is inferior in strength.

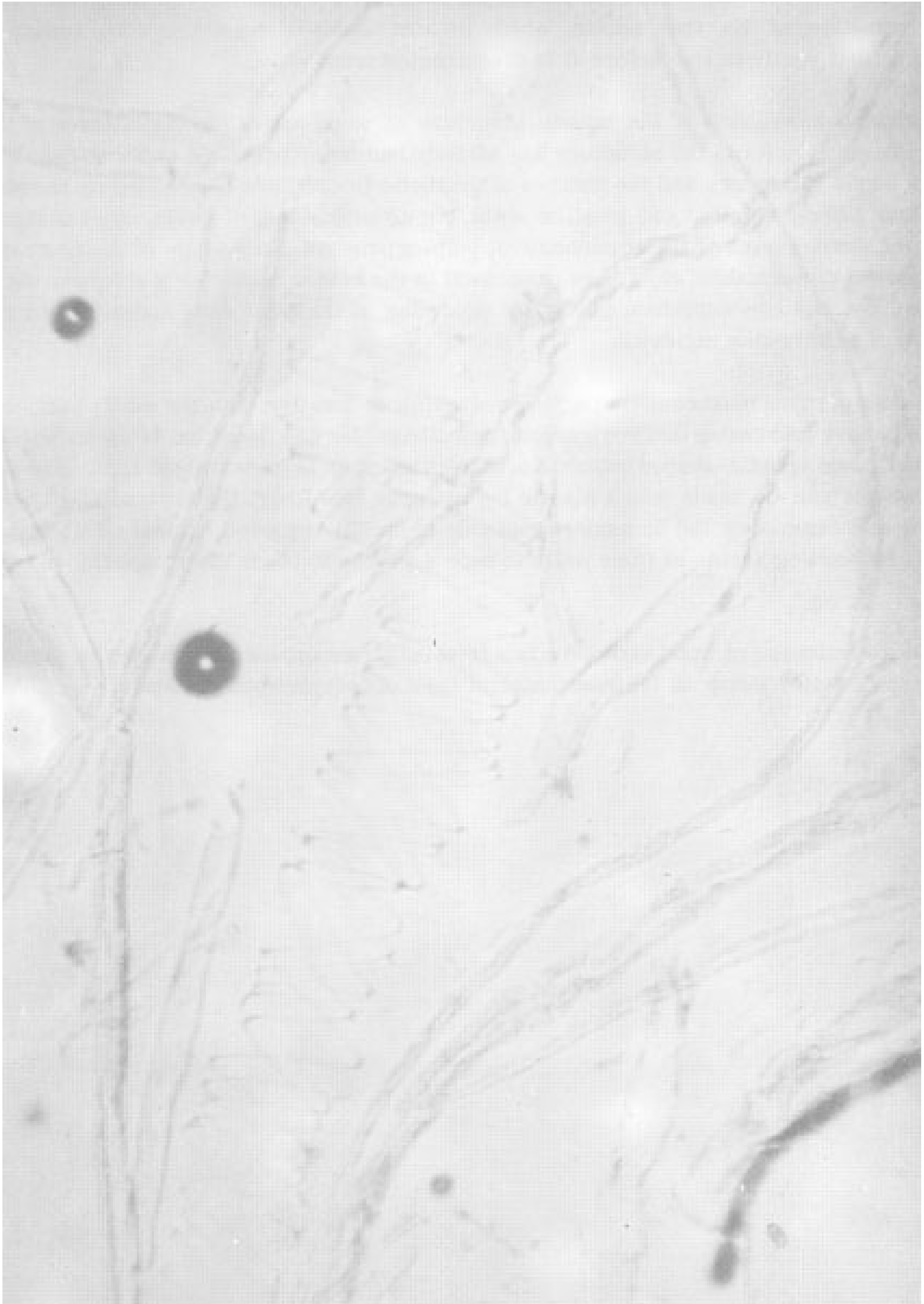
Wood fibers are bound together by a cementing material known as lignin that for all practical purposes fills the spaces between fibers.

The engineer is willing to accept the wood fiber with little question regarding its fine details and its relation to neighboring fibers andbotanical parts. But the chemist has an urgent need to dissect the fiber from the lignin, for the fiber is a source of cellulose, the raw material for many important industries. And the lignin which now is generally treated as a nuisance in the cellulose processing industries, is regarded with determined curiosity. It is suspected that, with all its seeming chemical formlessness, and in view of current trends in chemical raw material demands, this maybe the hidden pearl in the forest products oyster.

Of the entire wood substance it is known that about 50 percent is carbon, 44 percent oxygen (with a small amount of nitrogen and minerals), and about 6 percent hydrogen––aset of figures that can be said to be true without revealing much useful information since carbon, oxygen, and hydrogen can combine in so many different ways to form chemical groups with varying characteristics. A good deal more news is imparted with the statement that wood is composed of 40 to 55 percent of cellulose, 15 to 25 percent hemicellulose, 15 to 30 percent lignin, and 2 to 15 percent extractives. The general chemical formula for cellulose is ($C_6H_{10}O_5$).

The cellulose and hemicellulose make up what is known as holocellulose or the "whole carbohydrate" fraction of wood. The hemicelluloses include a number of compounds resembling the sugars, constructed in many chemical variations, all from chemically similar material. Many of the processes of industrial chemistry are aimed at removing the lignin–and–extractives fraction from the holocellulose fraction so that the latter may be used. In certain refined products, like purified "dissolving' cellulose in rayon, the effort goes further with the need to get out the pure alpha–cellulose that is "durable" under industrial treatment .

Chemists are a good deal more certain as to where lignin is than they are as to what it is. The great bulk of it is betweenthe fibers, an area it shares to some degree with some hemicelluloses (so named because they were thought by early scientists to be intermediate between the water–soluble carbohydrates, such as starch, and cellulose). Lignin is also believed to be present in a slight degree in the fiber wall. There is a good deal of disagreement among chemists as to whether lignin is bonded chemically to cellulose, and if so, how it is bonded. There is some evidence that it is tied to the hemicelluloses. But agreement is quite general that lignin is tightly bonded to one or more of the other materials and that, in the process of separating lignin from wood, its chemical identity is seriously changed. As a result lignin is designated as the residue after treatments that convert the carbohydrates to simple water–soluble substances––with the strong conviction that in place this residue was somehow different. It seems sure that lignin is neither fibrious nor crystalline like



ZM 10330 F (F-1)

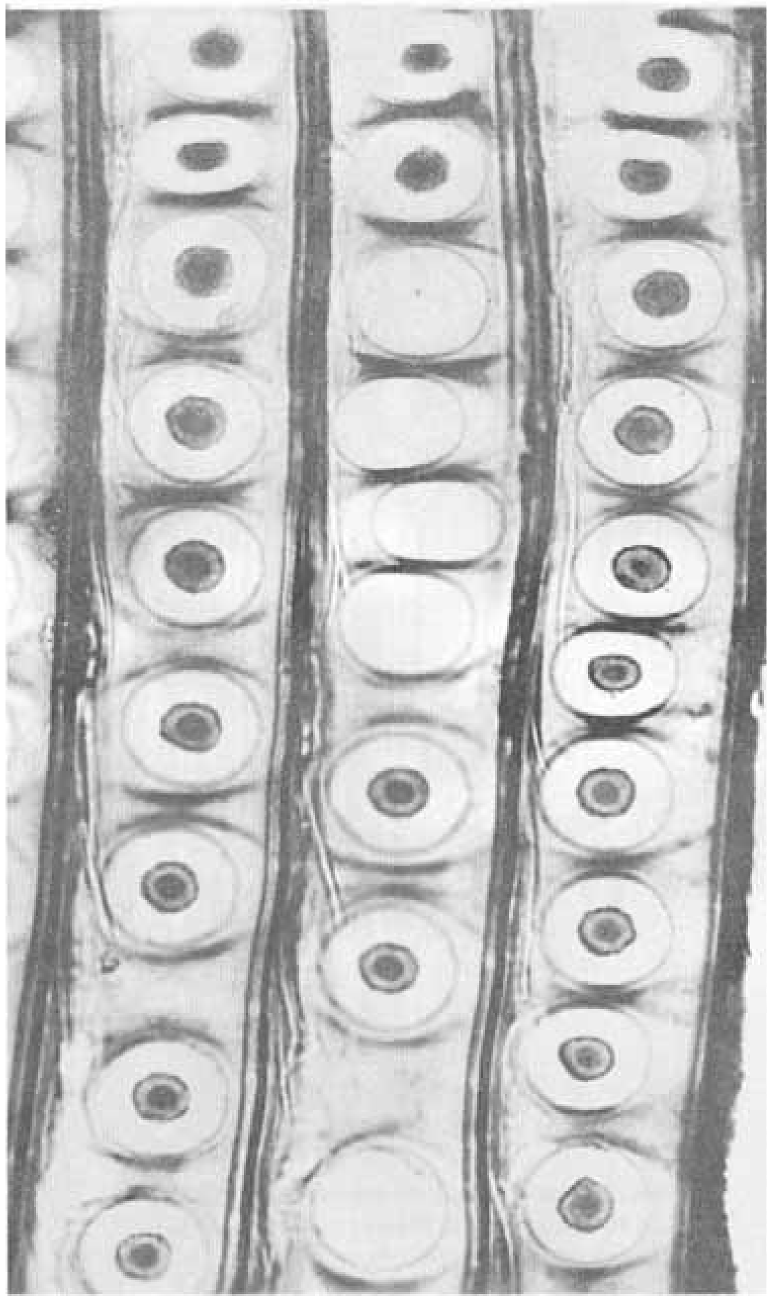
Part of the strength of the individual wood fiber lies in the helical winding that is shown here as it appeared under the microscope after a wood fiber had been patiently dissected with the aid of mild chemicals.

cellulose. Its transformation from an industrial nuisance to a valuable raw material waits on determination of its true nature, which in turn seems to depend on some means of learning what it really is like before it is disentangled from wood.

The growing knowledge of the minute structure of wood and of the distribution of the various chemical units in the structure has already had many practical applications. The pulp and paper producers and the makers of synthetic fibers have been aided by knowing more about fibers, fibrils, and smaller units. An understanding of the location of lignin aided in the development of the semichemical pulping process. Knowledge of the fiber explained to the papermaker why fibers processed in the beater make for a stronger sheet than those not beaten--explained partly by brooming of the fiber ends and partly by the. formation of gelatin-like material.

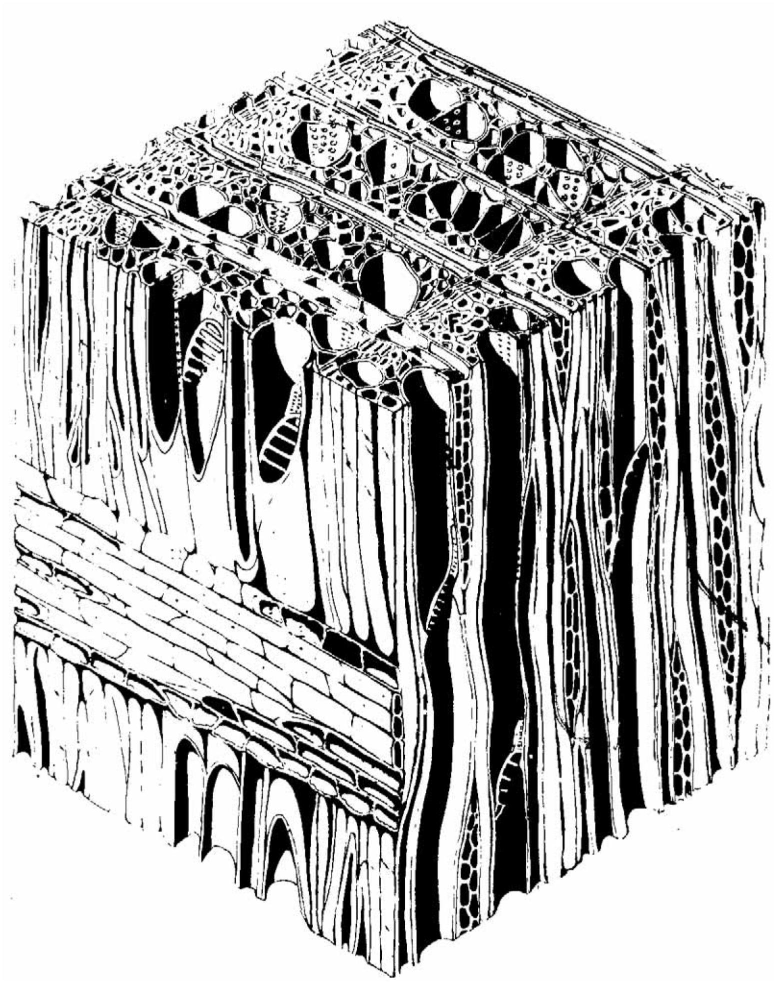
The maker of rayon must combine particles of cellulose smaller than the small particles mentioned above into chains that are spun into new fibers. He has benefited from knowledge of the fibrils and spindle-shapedbodies. Knowing as much as is known about lignin has explained why it can be made into a plastic but not spun into fiber. Understanding of fiber structure and chemistry led to modern methods of stabilizing wood against swelling and shrinking by bonding resins to fiber walls in such a way as to block their capacity to bond water.

The micro-universe of wood structure is a frontier whose exploration holds the secrets of tomorrow's better living on the raw material base of today's wood residues.



M 98677 F

These bordered pits in ponderosa pine play an important part in the movement of fluids through the sap-wood during the life of the tree. The bordered pits act like valves to open and close apertures in the fiber wall.



hardwood

M 725 F

This diagram, based on microscopic viewing of thin sections of wood, shows a block of wood measuring about one-fourth inch on a side.

GPO 805-292-3