Properties of Wood

Society of Wood Science and Technology

Teaching Unit Number 2

Slide Set 1

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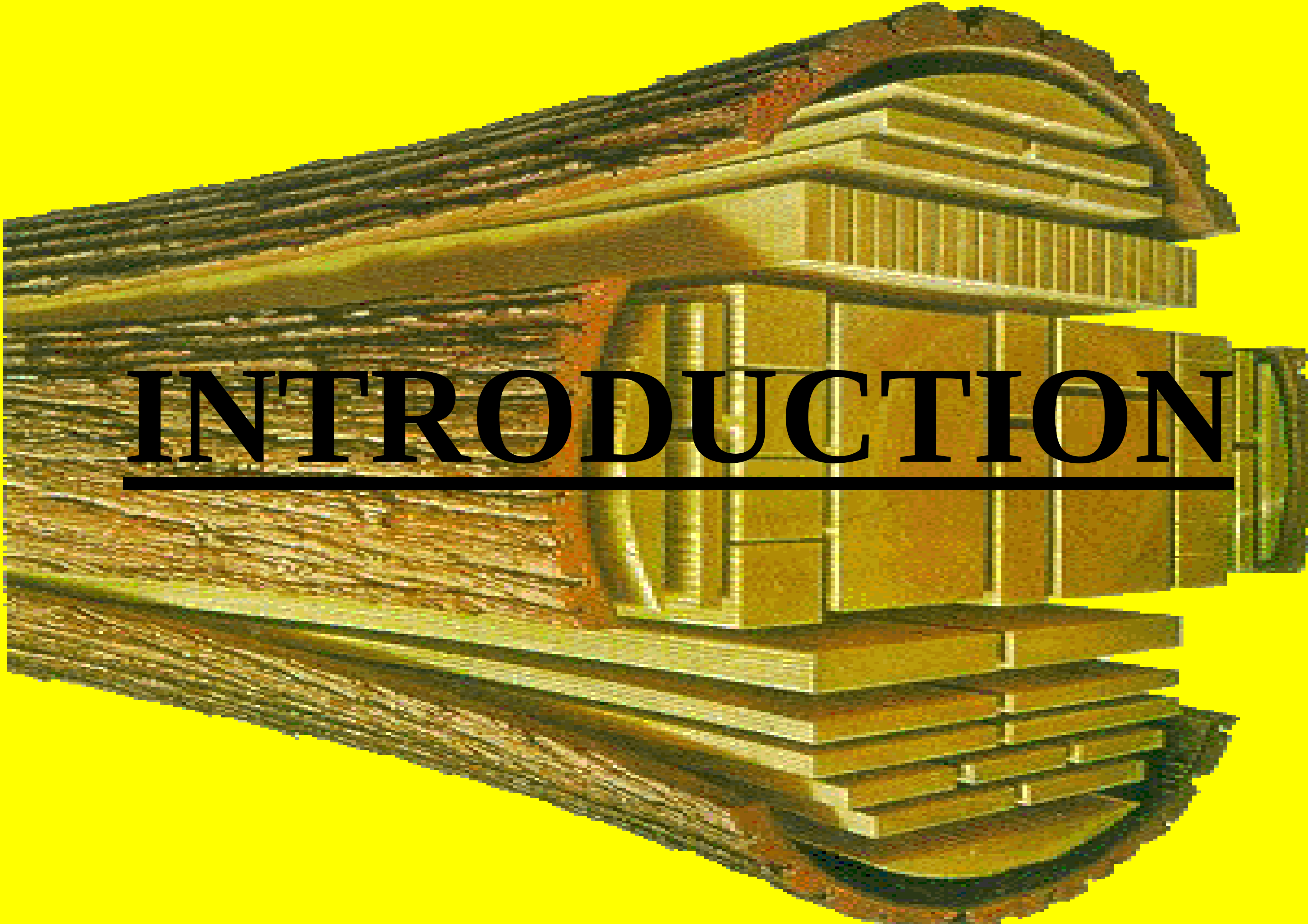
What we will cover

Wood Properties

- Moisture Relations
- Density
- Mechanical properties
- Thermal properties
- Electrical properties
- Acoustical properties

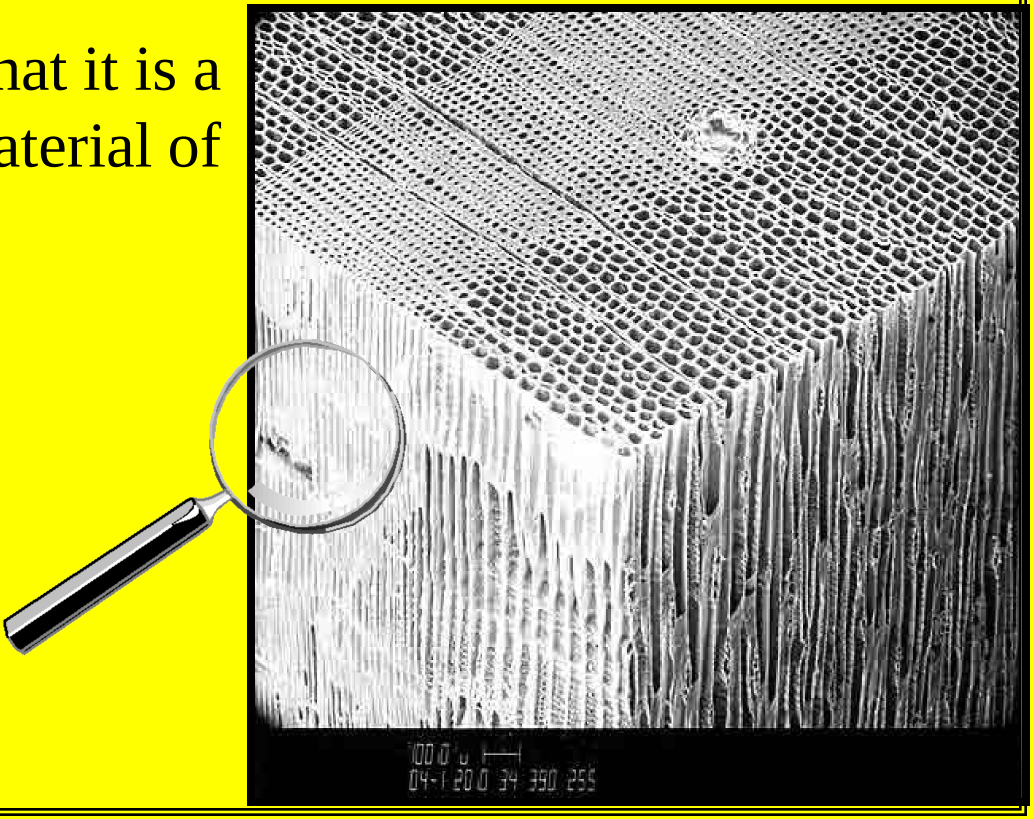


INTRODUCTION

Wood is our **most important raw material**. It is important not only because it is used for literally hundreds of products, but also because it is a renewable natural resource. Through careful planning and use, forests will provide a perpetual supply of wood.

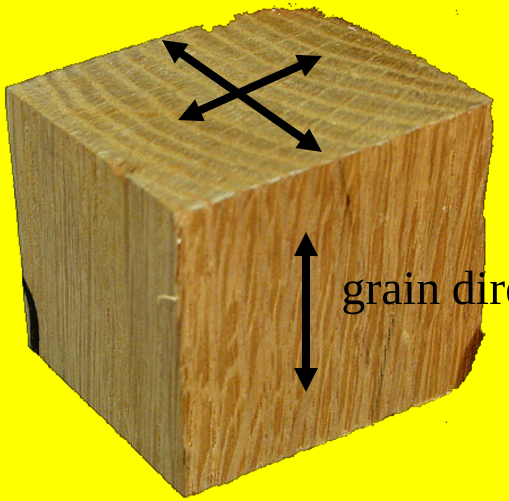
Wood is a cellular material of biological origin. Even though it is all around us, it isn't as simple as we often think. As you learned in Unit 1 Slide Set 2, it is a very complex material with many properties.

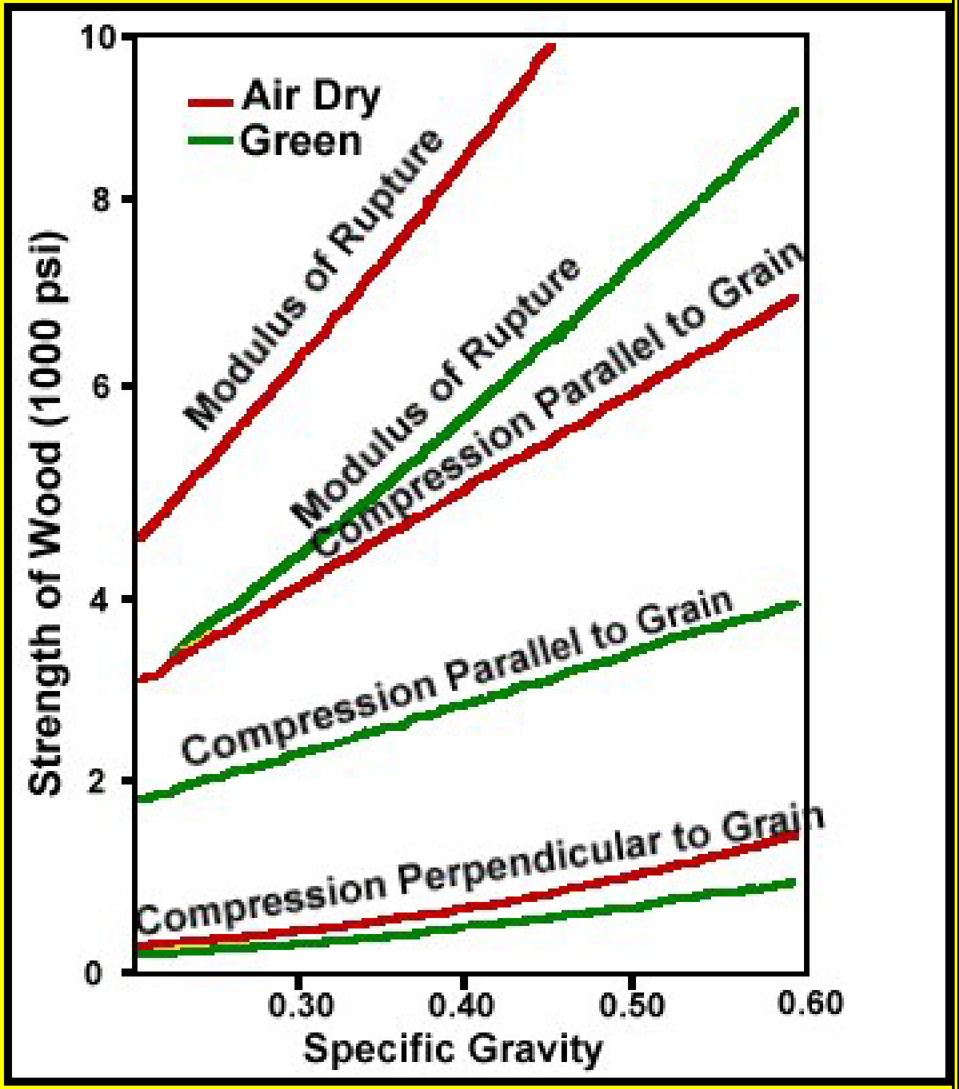
One definition of wood is that it is a hygroscopic, anisotropic material of biological origin.



Hygroscopic means it has the ability to attract moisture from the air.

Anisotropic means that its structure and properties vary in different directions.

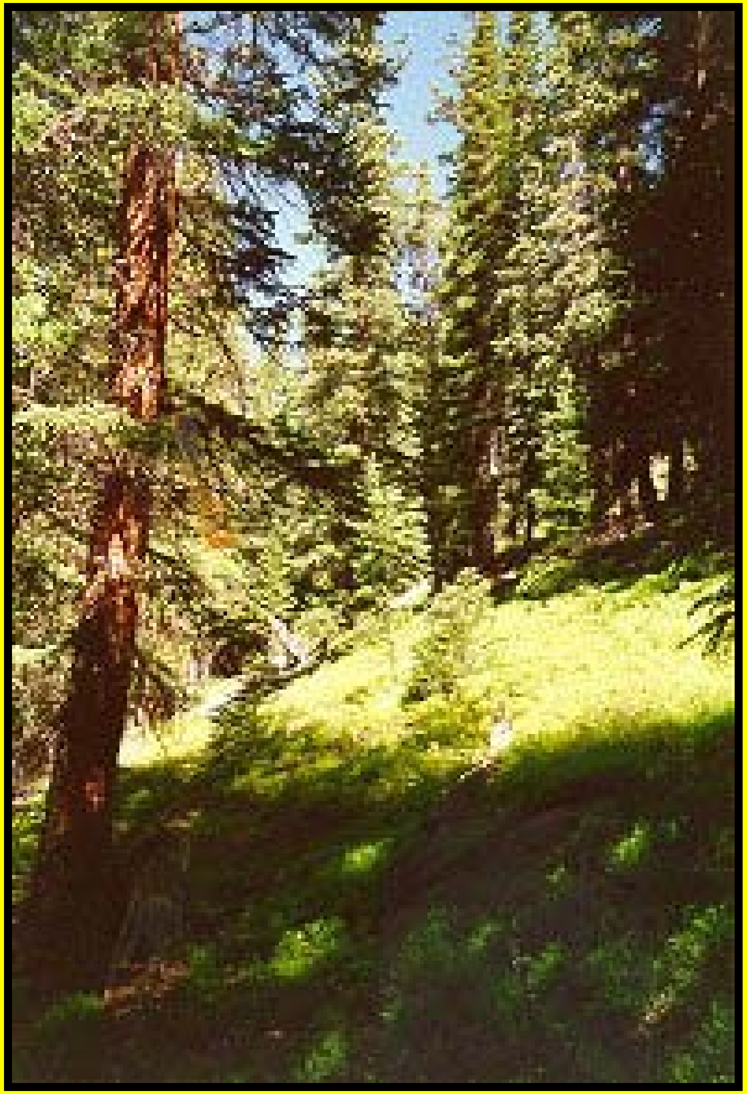




The biological origin of wood implies diversity and variation, between and within different species of trees. These things are among the many factors, which affect wood properties.

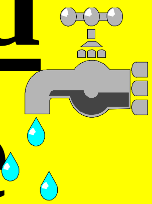
The fundamental structure of wood, from the molecular to cellular or anatomical level, determines the properties and behavior of wood.

In the slides that follow, we will discover some important wood properties that are linked to its structure.



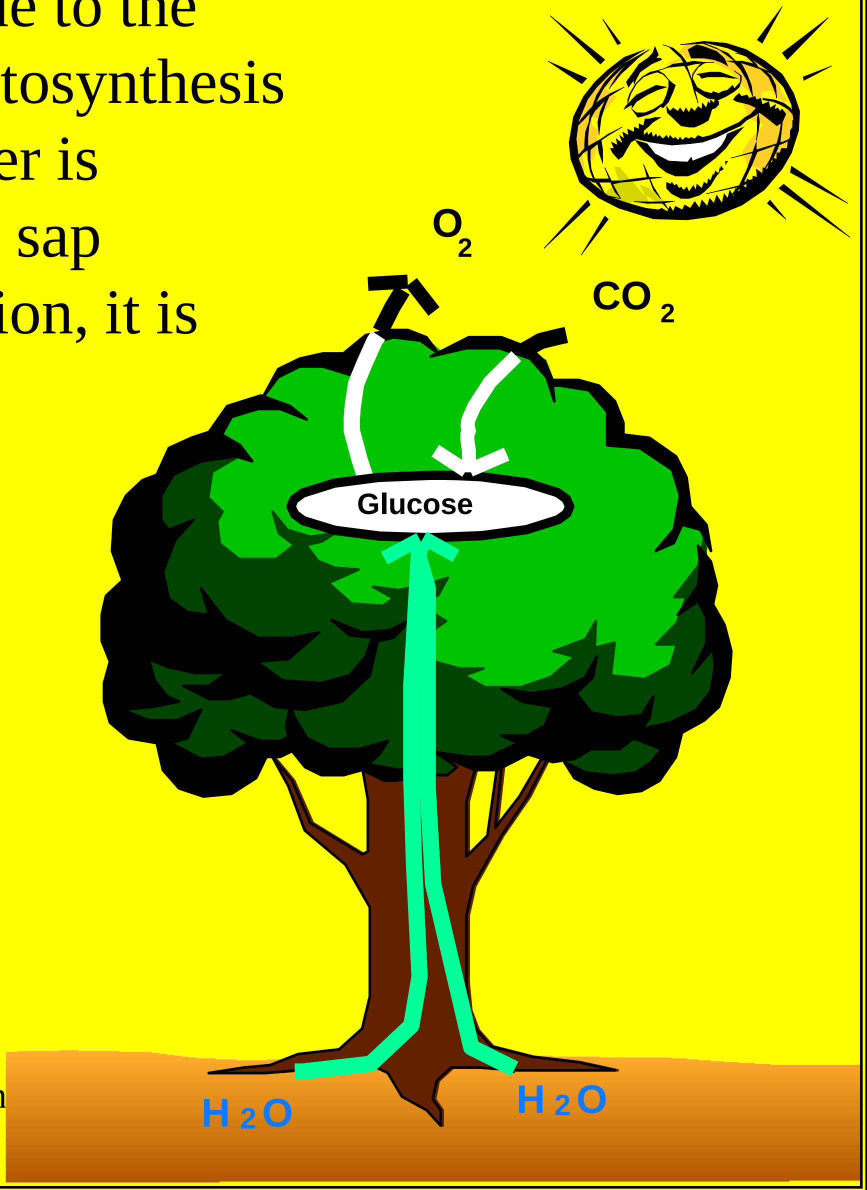
Let's get started……………………………….

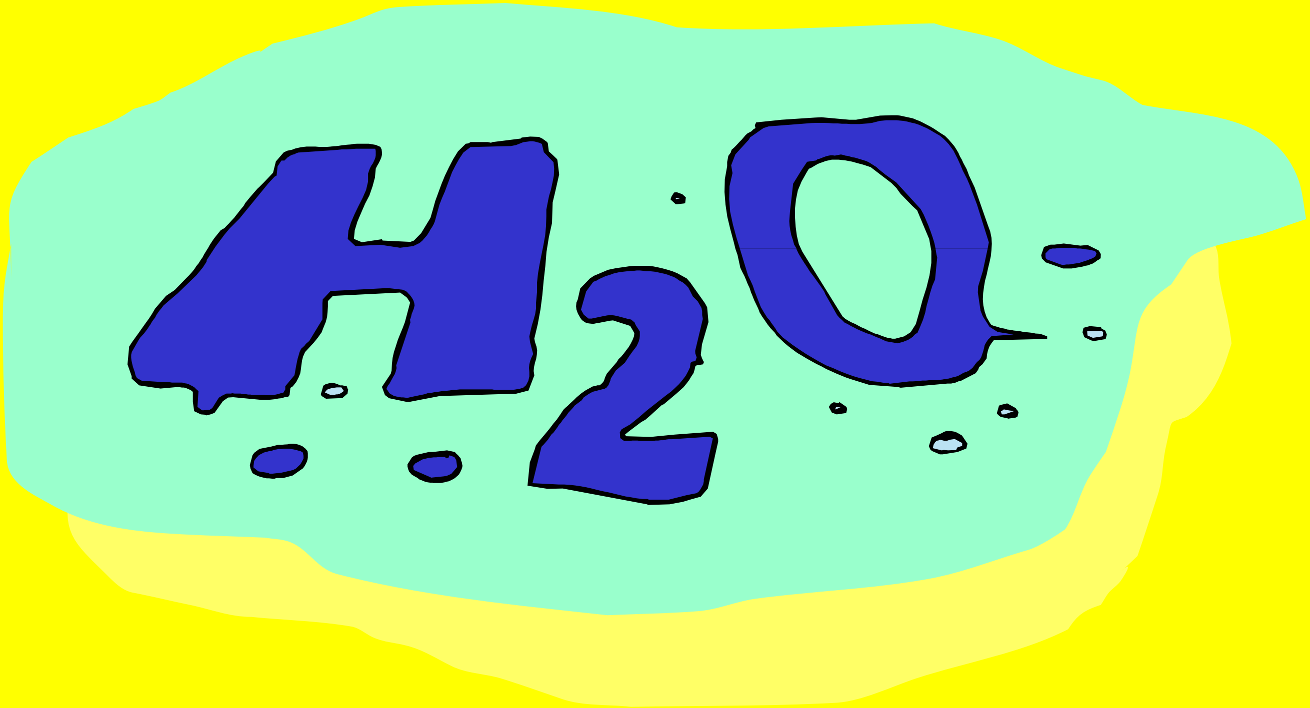
Wood and Moisture Relationships:



The Hygroscopic Nature of Wood

All wood in growing trees contains a considerable amount of water due to the need for water as part of the photosynthesis and growth processes. This water is commonly called sap. Although sap contains some materials in solution, it is mainly made of water.

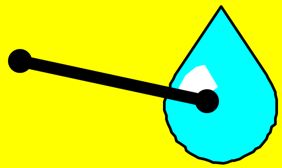




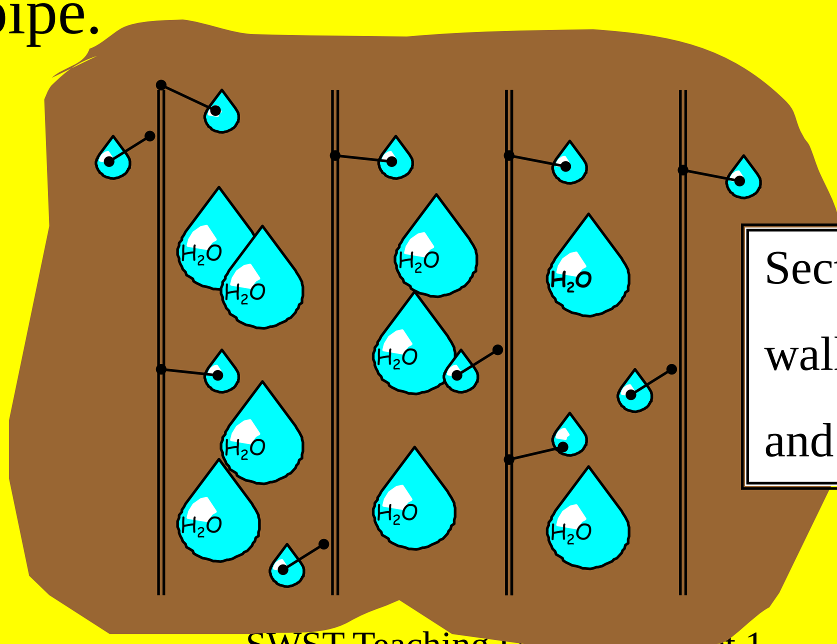
Forms of water in wood

Water is contained in wood as either bound water or free water.

Bound water is held within cell walls by bonding forces between water and cellulose molecules.



Free water is contained in the cell cavities and is not held by these forces – it is comparable to water in a pipe.

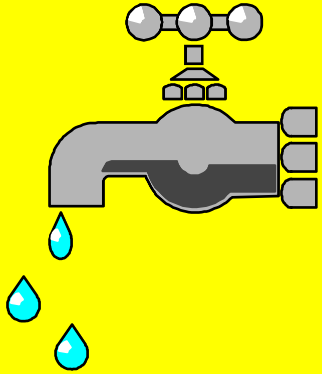


Section of wood cell wall with bound water and free water

The amount of water in wood expressed as a percent of the dry weight is called the "Moisture Content"

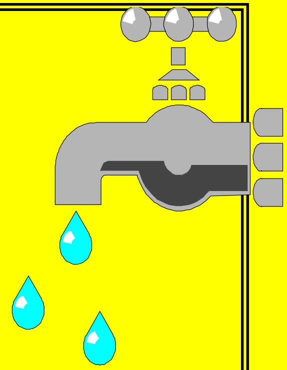
Moisture content is calculated with the following formula:

$$\text{Moisture content (\%)} = \left(\frac{\text{Weight of water in wood}}{\text{Weight of totally dry wood}} \right) \text{X } 100$$



Water movement in wood

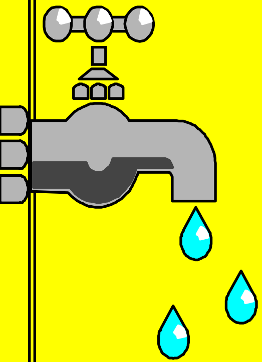
There are two things we are interested in concerning water movement in wood:



1)drying that occurs before manufacture and use as finished wood products;

2)and the gain and loss of water in response to changes in environmental conditions surrounding the wood.

In both drying and end use, water normally moves from higher to lower zones of moisture concentration, although extreme temperature differences on opposite sides of a board can reverse this normal direction.



Water moves through wood as liquid or vapor through several kinds of passageways.

These are:

--cell cavities of fibers and vessels,

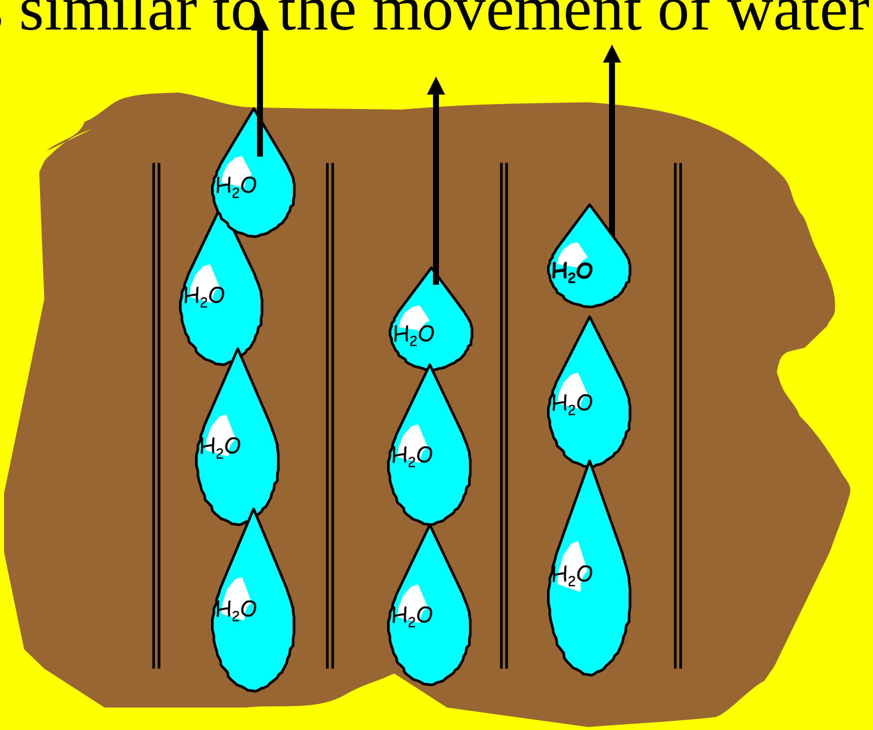
--ray cells, pit chambers (microscopic openings on the sides of cell walls) and their pit membrane openings,

--and the cell walls themselves.

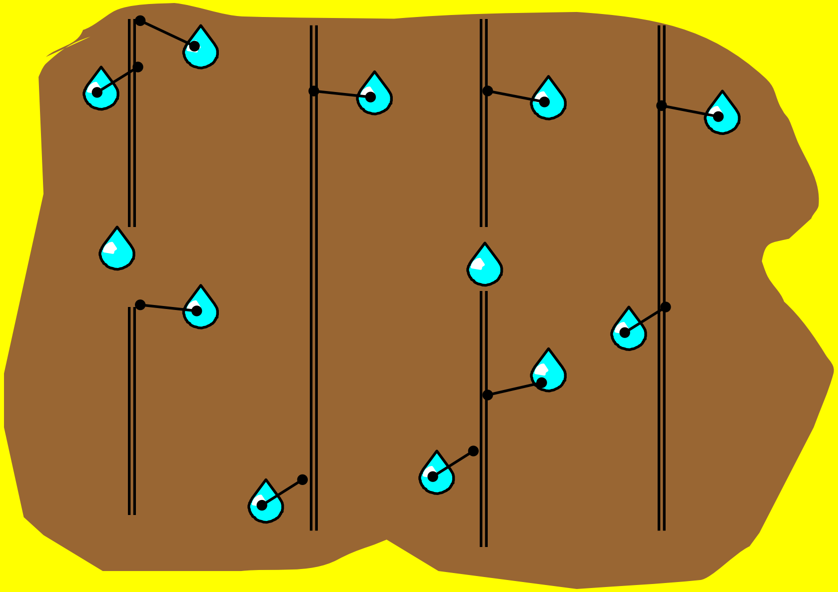
Water movement along the grain is **many** times faster than across the grain.

Free water moves through cell cavities and pit openings (microscopic openings on the sides of cell walls). During drying it is moved by capillary forces that exert a pull on the free water deeper in the wood.

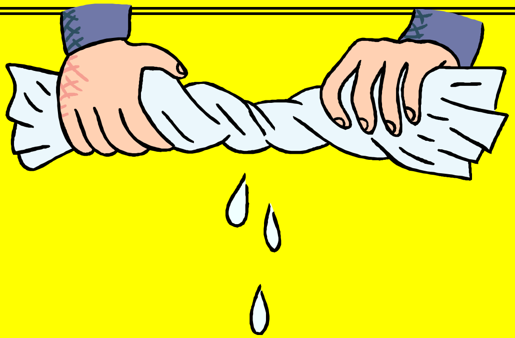
This is similar to the movement of water in a wick.



Bound water moves as vapor through empty cell cavities and pit openings as well as directly through cell walls. The basic cause of bound water movement is differences in water vapor pressure caused by relative humidity, moisture content, and temperature differences.



Equilibrium Moisture Content (EMC) Relationship

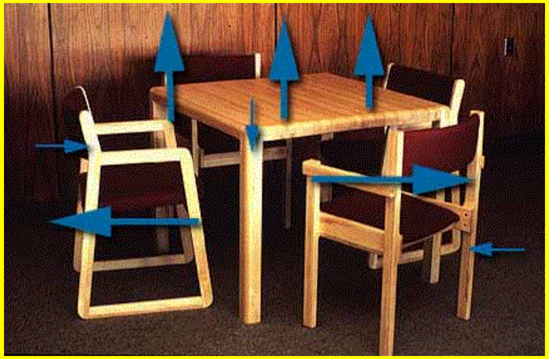


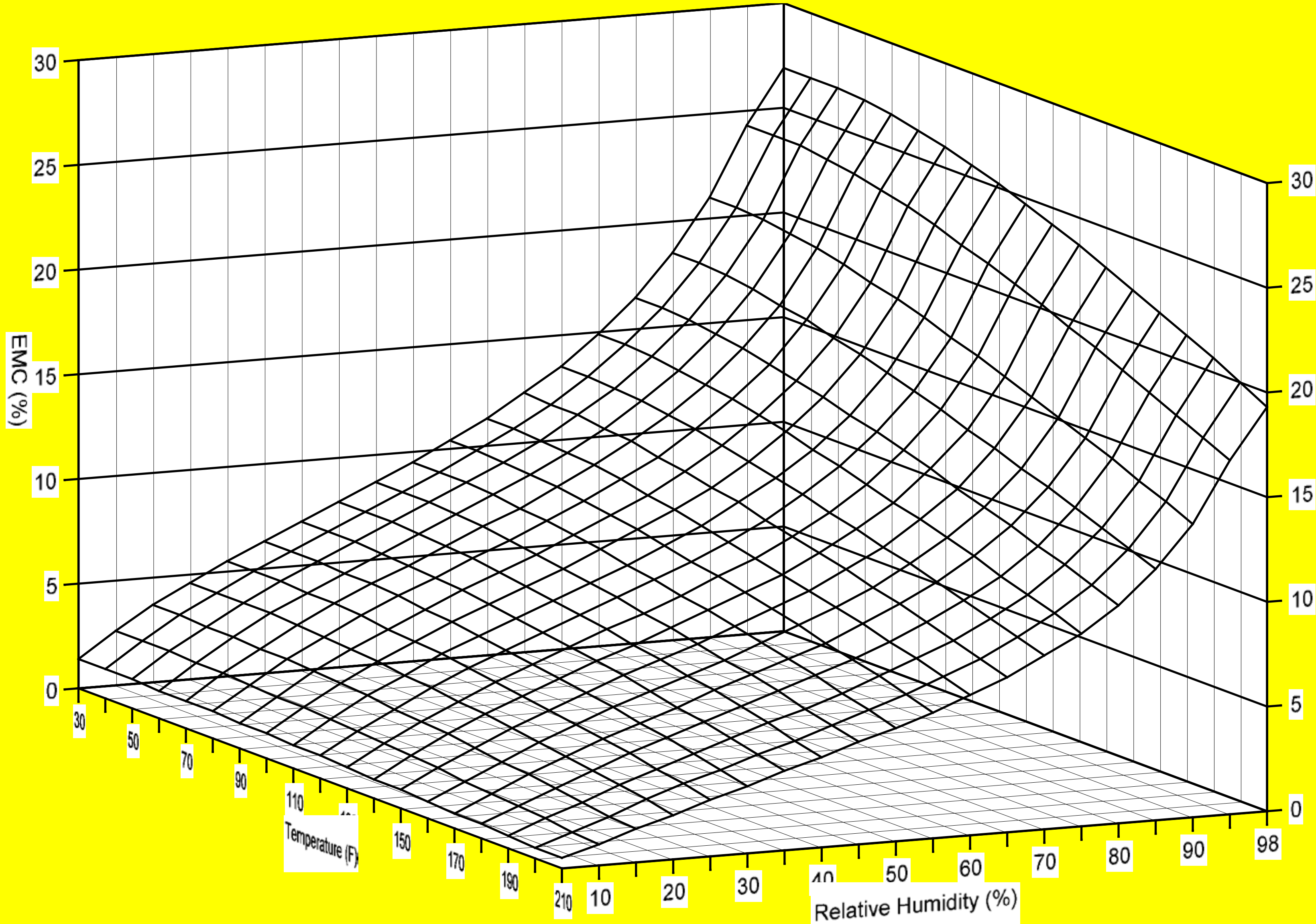
Once wood has been dried below the fiber saturation point (the point when the cell walls are still fully saturated but there is NO free water remaining), it seldom regains any free water that would increase the moisture content above that point. Only prolonged soaking in water will do so.

Wood loses or gains bound water until the amount it contains is in balance with that of the surrounding atmosphere. The amount of water at this point of balance is called the **equilibrium moisture content (EMC),** and is always below 30 percent.

The EMC a piece of wood achieves depends on the relative humidity and temperature of the surrounding air. The relationship between EMC, relative humidity, and temperature is shown in the next slide.

As seen from the plot in the next slide, if wood is kept in air at 70^{o}F and 65 percent relative humidity, it will either gain or lose water until it reaches approximately 12.5 percent moisture content. EMC increases as relative humidity increases and decreases as temperature increases.





Moisture Content obtained at each Temperature and RH

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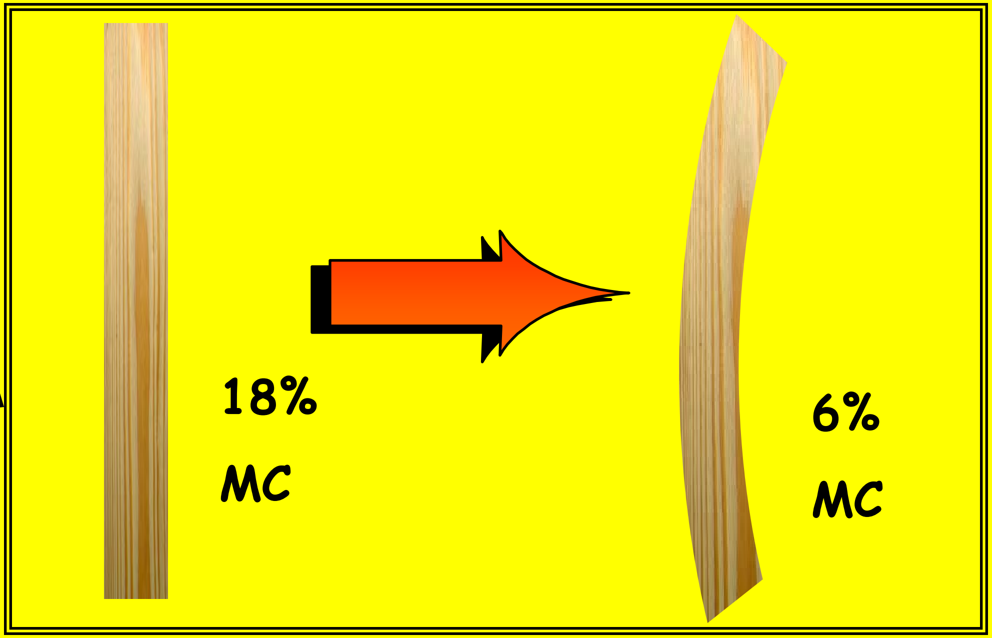
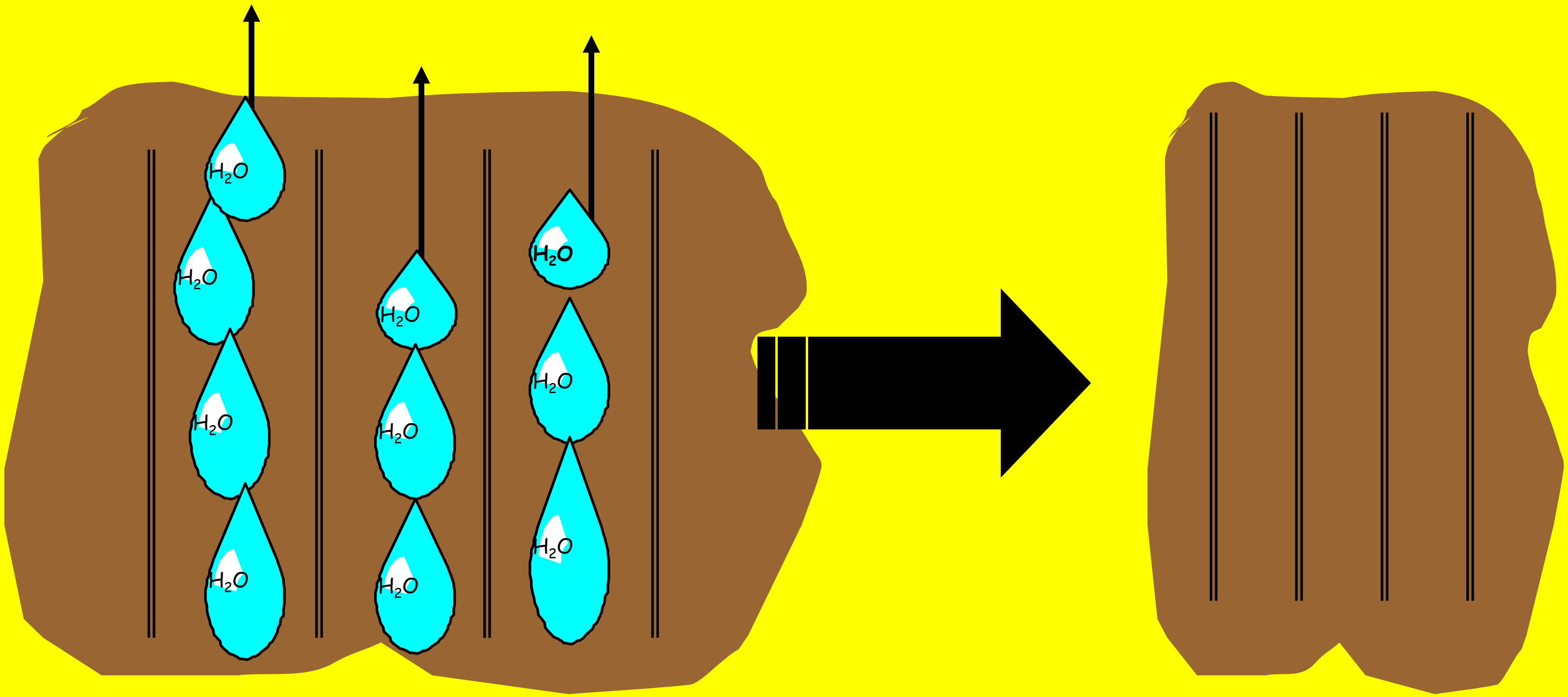
Shrinkage and Swelling

Shrinkage and swelling are the cause of many of the problems that occur in wood during drying and in use, therefore, an understanding of them will help minimize such problems.

Splitting, warping, and open joints are examples of problems that occur due to uneven shrinkage.



When water begins to leave the cell walls at the fiber saturation point, the walls begin to shrink. Even after drying is complete, wood will shrink and swell as relative humidity varies and water either leaves or enters the cell walls.



Stresses that can cause **splitting** and **warp** develop because <u>wood shrinks or swells by different amounts in the radial, tangential, and longitudinal directions</u> due to its anisotropic nature, and because during any moisture content change, different parts of a piece of wood are at different moisture contents.

These differences cause internal stresses in parts of the wood that are attempting to shrink or swell without success due to restraint from the surrounding wood.

Shrinkage and swelling are defined as:

$$\textbf{Shrinkage}\ \text{(percent)} = \left(\frac{\text{wet dimension} - \text{dry dimension}}{\text{wet dimension}} \right) \times 100$$

$$\textbf{Swelling}\ \text{(percent)} = \left(\frac{\text{wet dimension} - \text{dry dimension}}{\text{dry dimension}} \right) \times 100$$

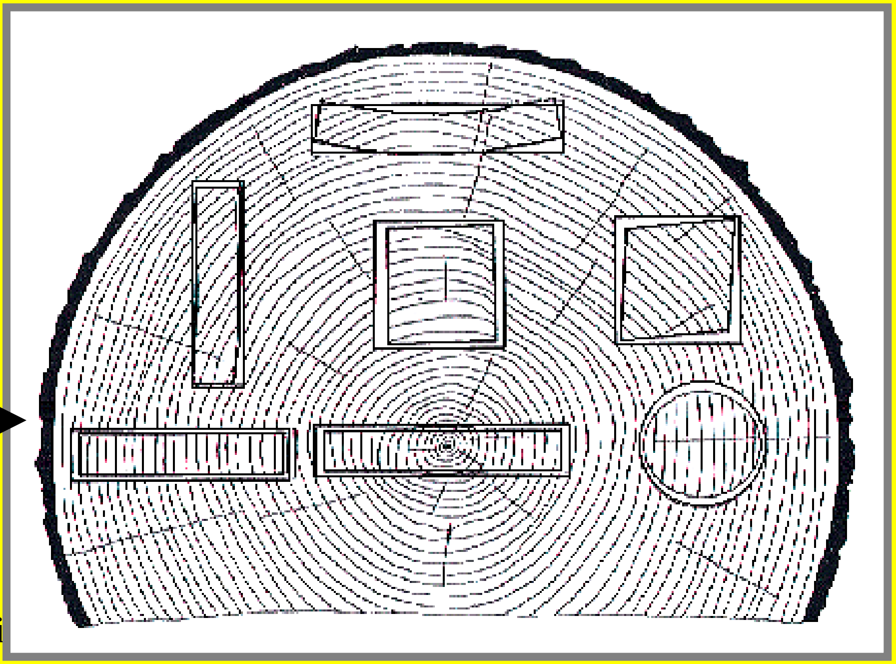
Typical shrinkage values for wood are shown in this slide. **Tangential** shrinkage is generally about twice as large as **radial** shrinkage, and **longitudinal** shrinkage ranges from approximately one-tenth to one-hundredth of either radial or tangential shrinkage.

The result is uneven dimensional changes.

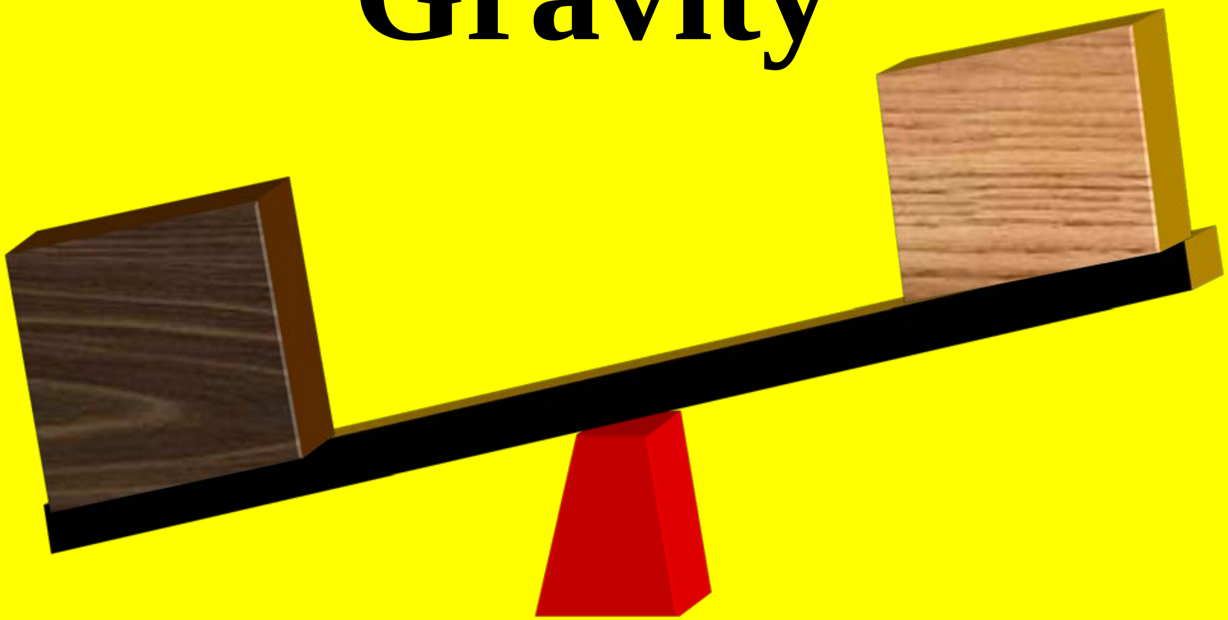
Three Dimensions in which Wood Shrinks

Maximum Longitudinal Shrinkage = 0.1% to 0.3%
Maximum Radial Shrinkage = 2.1% to 7.9%
Maximum Tangential Shrinkage = 4.7% to 12.7%

Tangential shrinkage is generally 1.5 to 2 times greater than radial shrinkage.



Density and Specific Gravity



Density (ρ)

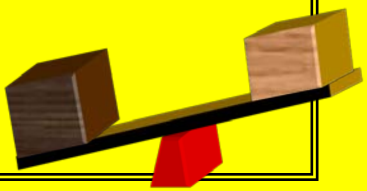
Density (ρ) of a material is defined to be the mass per unit volume and is calculated using the following equation:

$$\rho = \text{mass/volume}$$

Density of the substance that makes up a wood cell wall has been found to be about 1.5 g/cm^3. However, an actual sample of wood also contains air in the cell lumens, so most woods have a density less than 1 g/cm^3.

Density of a sample of wood is usually calculated as the weight density instead of mass:

$$\text{Wt density} = \frac{\text{weight of wood with moisture}}{\text{volume of wood with moisture}}$$



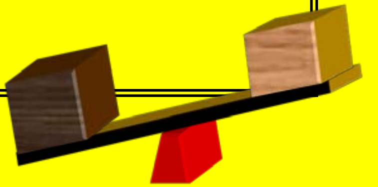
Specific gravity:

your best predictor of all other physical properties

Specific gravity is a measure of the amount of solid cell wall substance and is also known as “relative density”. It is a ratio of the density of a substance to the density of water. In our case, the ovendry (OD) weight of a wood sample is used as the basis and comparison is made with the weight of the displaced volume of water. In equation form this is:

$$SG = \frac{\text{OD weight of wood}}{\text{Weight of an equal volume of water}}$$

Be sure to note: OD ovendry weight is *always* used as the numerator in this equation. Ovendry weight is the weight with no water in the sample, MC = 0%



Factors that influence wood specific gravity include:

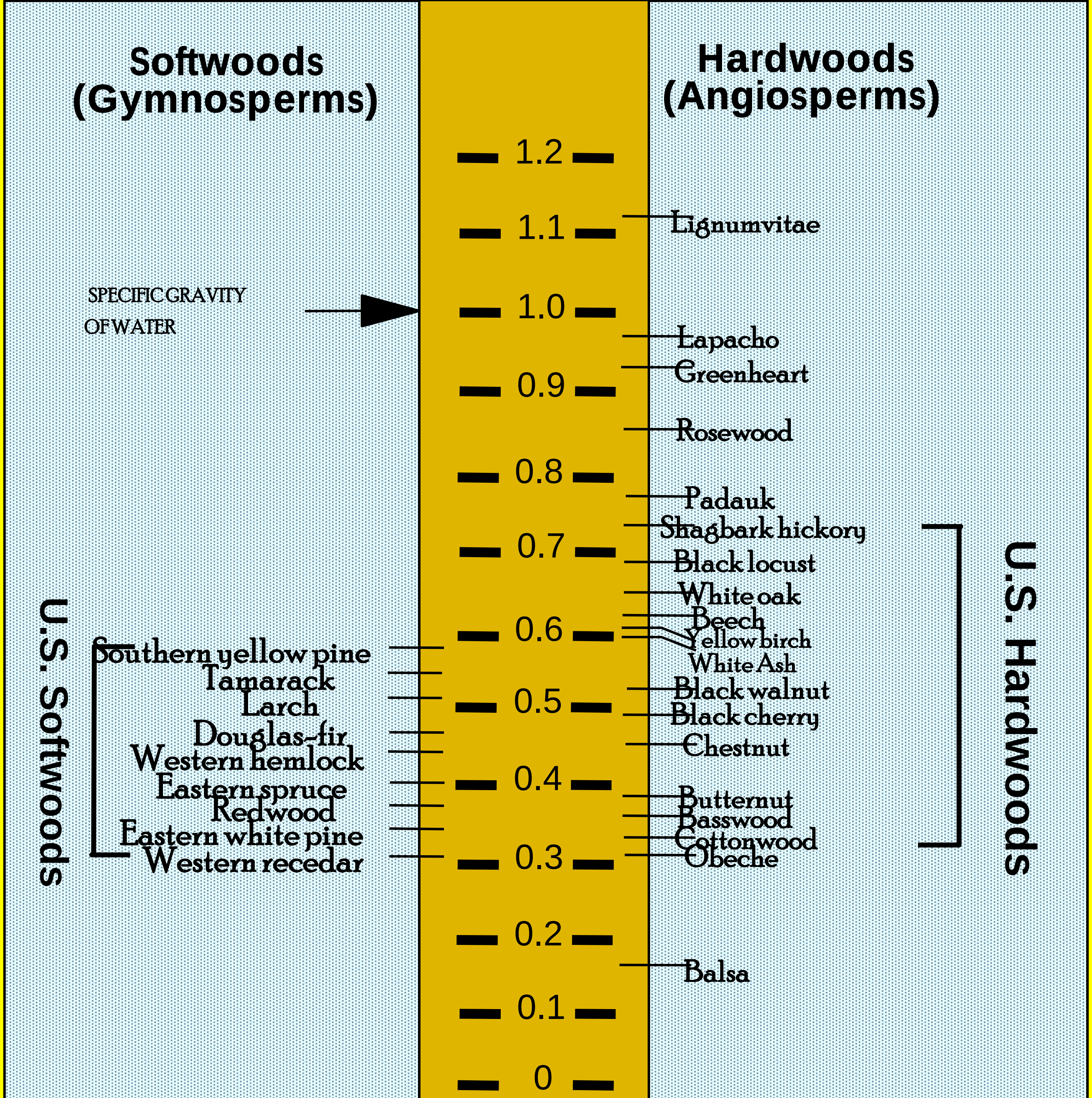
- moisture content: higher MC = lower SG, up to the fiber saturation point; above the FSP no change in SG with changes in MC, SG is highest at MC = 0
- proportion of wood volume made of various kinds of cell types and cell wall thicknesses: numerous, thick cell walls = high SG
- size of cells and cell lumens: large cells with large lumens = low SG

The range of SG for a few commercial woods is shown on the specific gravity ruler in the next slide. Most of them fall between 0.35 and 0.65. Woods from other parts of the world exhibit a much greater range, with SGs reported as low as 0.04 and as high as 1.40.

Specific Gravity

Ruler

12% MC basis

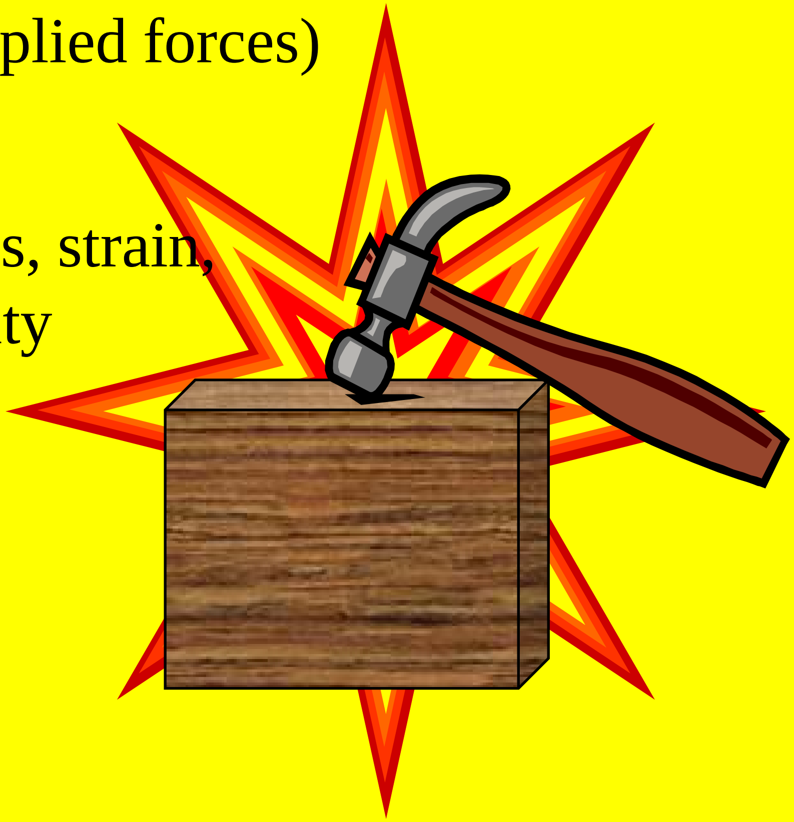


Source: Wood Handbook. 1974. USDA Agr. Handb 72, rev.

Mechanical Properties

(behavior of wood under applied forces)

for example: strength, stress, strain, toughness, stiffness, elasticity

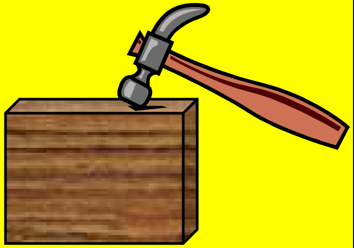


An understanding of wood and moisture relationships is of great importance to the manufacture and use of wood products, as is an understanding of the mechanical properties of wood.

And, just as shrinking and swelling of wood vary in the radial, tangential, and longitudinal directions, so do various mechanical properties of wood.

So, wood is anisotropic in both its hygroscopic behavior as well as its mechanical behavior.

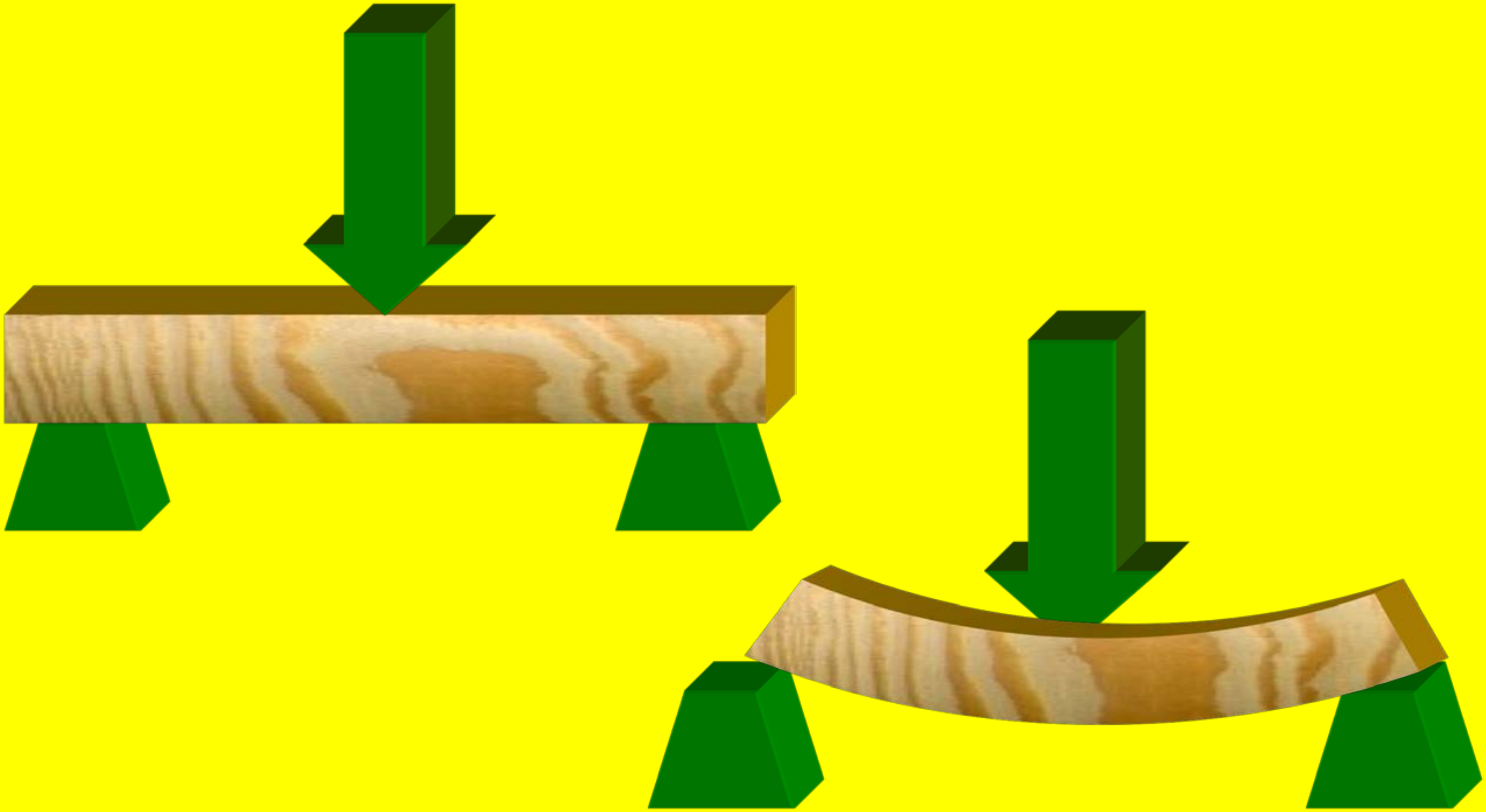
How strong is the wood?



Wood is one of the most useful raw materials for human beings. Wood can be used for building houses, bridges, chairs, tables and other things.

One thing we have to know before building a house is “how strong is the wood?”

Wood is an elastic material, which is bent, but not broken, when the load is small.



How strong is the wood?

But if the load is too big, then the wood will break.

The **elastic nature** of wood is illustrated in the next slide. The degree of deformation a piece of wood will undergo is proportional to the amount of load applied.

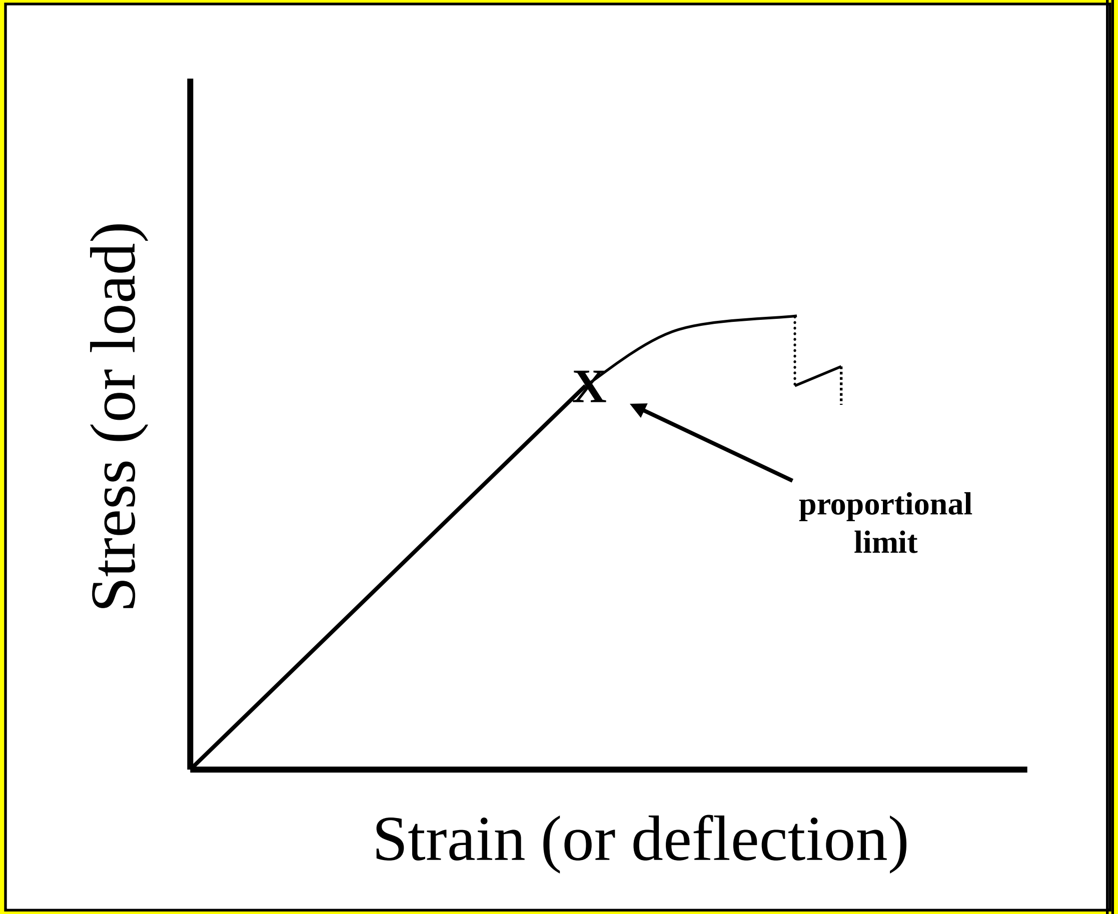
Wood is elastic up to a point, called the **elastic** or **proportional limit**. If loads are applied below the elastic limit and then removed, the wood will go back or spring back to its original shape. If a load is applied that exceeds the elastic limit and is then removed, the wood will go back only partially to its original shape. This is because the load applied was too much for the wood to stand and damage to the wood occured.

If the applied load is very, very high, the wood is no longer able to support this high load and the wood breaks.

Wood behaves in an elastic manner up to a point called the elastic or proportional limit.

This means that for values of load below the elastic limit, the load and deflection are proportional to each other.

Once the load level passes the elastic limit, the load and deflection are no longer proportional. For 1 unit increase in load, there is greater than a 1 unit increase in deflection, until the ultimate breaking point.

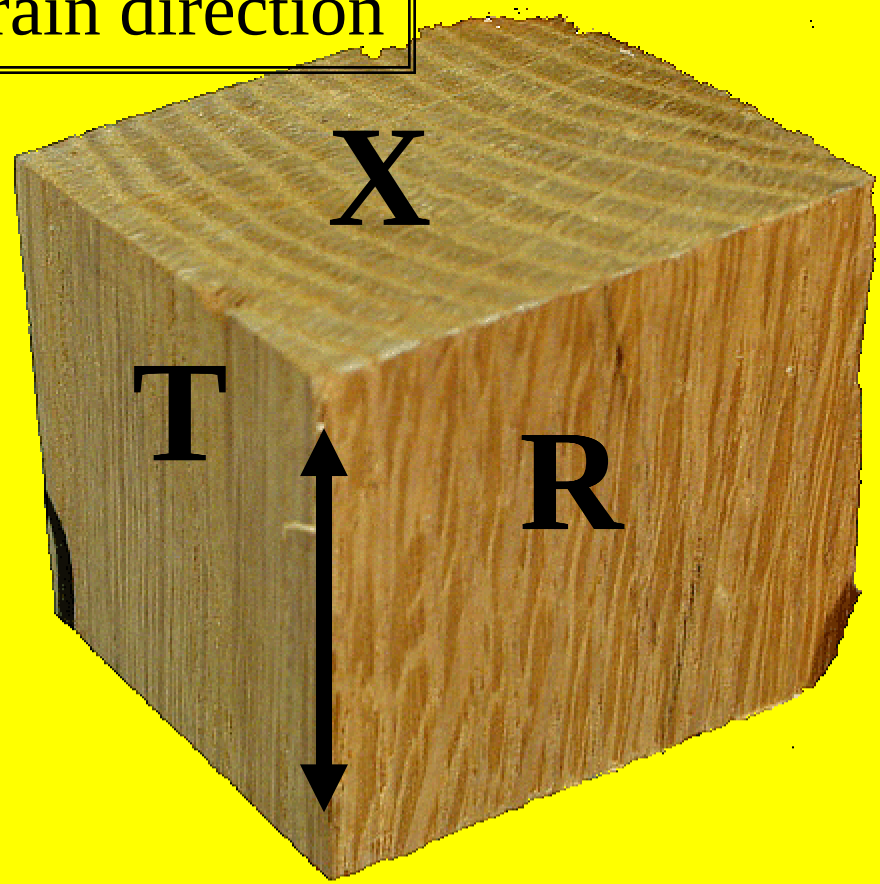


In general, wood is stronger when loads are applied parallel to the grain than perpendicular to the grain. This is because wood is an anisotropic material.

The 3-D structure of a wood cube is shown in the next slide. An arrow indicates the direction of wood grain. **R** indicates the radial surface. **T** indicates the tangential surface. The **X** stands for the cross-sectional surface. As shown by the cube, the structure of the three surfaces is different.

As a result, the strength of wood varies with grain direction.

X indicates the cross section
R = Radial surface
T = Trangential surface
arrow indicates grain direction



Three important mechanical properties of wood are used as a measure of its strength. These properties are **compression, tension,** and **bending.**

Compression is defined as two forces or loads acting along the same axis, trying to shorten a dimension or reduce the volume of the wood. As shown in this slide, compressive forces can act on the wood parallel to the grain or perpendicular to the grain.

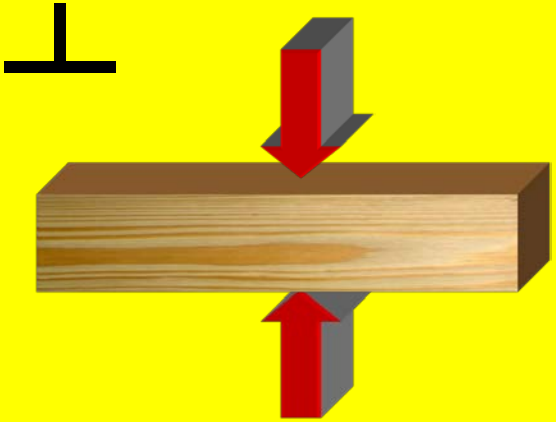
Compressive forces can also act at an angle to the grain. As a general rule, compressive strength parallel to the grain is greater than compressive strength perpendicular to the grain.

$$\parallel \; > \; \perp$$

$\parallel$

parallel to grain

$\perp$



perpendicular to grain

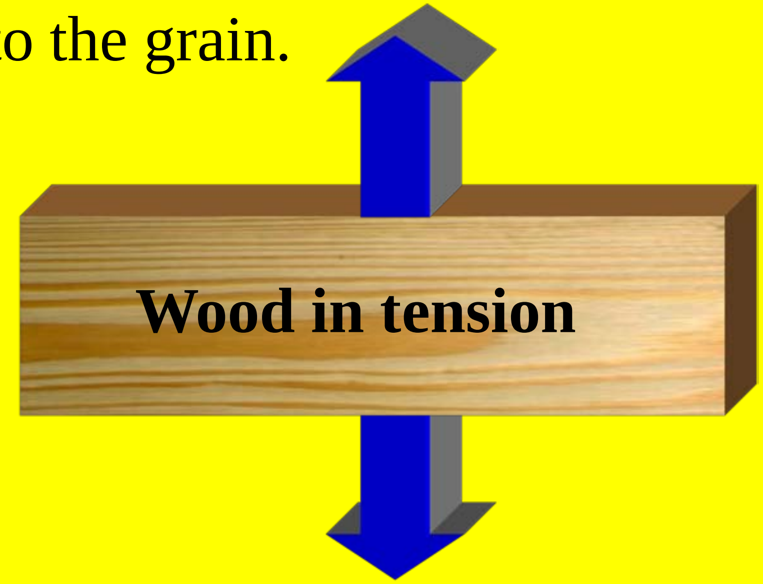
Wood is a very strong material in compression parallel to the grain. A piece of air-dry Douglas-fir wood an inch square on the cross section and 3 inches in length can support 4900 psi (pounds per square inch) which is strong enough to support a police car.

Amazing!

One tiny piece of wood can support a heavy car without breaking.

Tension is defined as two forces or loads acting along the same axis trying to lengthen a dimension or increase the volume of the wood. Wood is the strongest in tension parallel to the grain due to the orientation of wood fibers. Wood is not strong in tension perpendicular to the grain.

$\parallel > \perp$



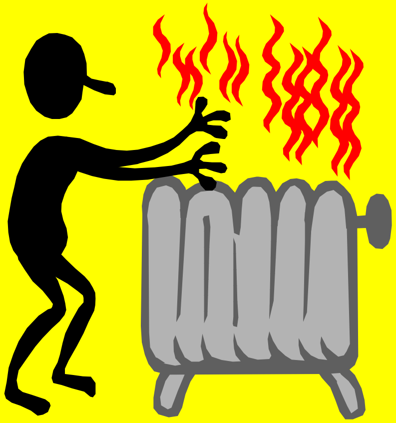
Pound for pound, ***wood is stronger than steel*** in tension parallel to the grain.

Bending strength is expressed as a degree of deflection with a given force or load on a wood beam. A test of bending strength is set up as shown on this slide. The load is applied at the center of the wood beam with two support ends. Both compression and tension stresses are present. Bending strength is a measure of the resistance to failing. Stiffness is a measure of the ability to bend freely and regain normal shape.

The ability of a tiny piece of wood to support a heavy police car shows just how strong a building material wood is. As mentioned earlier, the anisotropic nature of wood affects its strength.

However, on top of this anisotropic nature, a great number of other factors can affect the strength of wood. For example, the density, moisture content, temperature of the surrounding service area, duration of wood service, and the defects of wood play important roles in determining the mechanical properties of wood. Many of the characteristics of wood which may be considered as defects arise from the biological origin of wood.

Thermal Properties



Thermal Conductivity (K)

Thermal conductivity is a measure of the rate of heat flow in response to a temperature gradient. In wood, the rate depends on the direction of heat flow with respect to the grain orientation. Remember (?) wood is an anisotropic material.

K in the radial direction is about equal to K in the tangential direction. BUT, K parallel to the grain is 2 to 3 times what it is radially or tangentially. What this means is that heat will flow 2 to 3 times faster along the grain than across it.

K is also influenced by the amount of water in a piece of wood. For wood with a moisture content greater than 40%, K is about 1/3 greater than a piece with a MC less than 40% (more H_2O, more conductivity).

Density influences K. K is linearly proportional to density, so for denser woods, the thermal conductivity is higher.

Thermal Insulating value (R)

Thermal insulating value (better known as the R value) is the reciprocal of thermal conductivity. So,

$$R = 1/K$$

Just like thermal conductivity, R values depend on wood structure direction, and it is influenced by density and moisture content.

Because R is the inverse of K, insulating value is lower along the grain, it is lower for higher density woods (more air = more insulation), and lower for higher MC (more water, lower R).

Values of K and R for various materials are shown on the next slide.

Thermal conductivity (K) and resistivity (R)

Material	K	R
air	0.16	6.25
water	4	0.25
glass	5	0.20
brick	4.5	0.22
concrete	7.5	0.13
steel	310	0.003
aluminum	1,400	0.0007
wood 12% MC	0.4 - 1.2	0.8 - 2.5

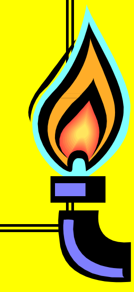
In units of Btu/in/(h)(ft^2)(F°)

Thermal expansion (α)

Thermal expansion is a measure of dimensional changes caused by changes in surrounding temperature. It is usually called the coefficient of thermal expansion and given the symbol **α**

In wood, the amount of thermal expansion varies with density in a straight-line relationship, e.g., for higher density woods, α is proportionally higher.

It also varies with wood structure direction (*BIG SURPRISE*?). Expansion parallel to the grain is VERY small compared with other common solid materials and is about 1/2,000,000 inch per deg. F temperature change.



So, if an 8' long wall stud went from 90 to -100°, it would become 0.018 inch shorter. An 0.018 inch isn’t much change in an 8 foot long piece.

Steel, however, would shrink 3 times that and aluminum more than 7 times the wood.

That’s the good news, α across the grain is greater than all metals and other building materials. In fact, α across the grain is up to 10 times what it is along the grain. This is not a big problem, however, because we use wood in fairly temperature stable situations.

Ignition of Wood

The ignition temperature of wood is usually given as about 275 °C (525 °F). This is actually the temperature at which wood begins to decompose exothermically, i.e., with liberation of heat. The speed with which combustion is initiated is dependent upon the rate of accumulation of heat at the surface. Several factors influence the accumulation: size of the piece, rate of heat loss from the surface, presence of thin outstanding edges, and rate at which heat is supplied.

Small pieces with sharp projecting edges, such as match sticks, ignite easily because a small amount of heat is needed to raise the temperature of the whole stick to the ignition point. Large pieces, with rounded edges like poles and logs in log homes, are much slower to catch fire because conduction of heat into the interior keeps the surface below ignition temperature for some time.

This is why wood construction members maintain their strength during fires which cause failure of steel members designed to carry the same loads. Large wood members burn slowly and then only if there is a continous supply of heat, and the low thermal conductivity of wood delays weakening on the unburned interior.

Fuel value

Using wood for fuel is the number one largest single use of wood in the world.

Sources of wood for fuel are roundwood from trees, mill residues, logging or woods residues, recycled materials & energy plantations.

Combustion is the most common method of converting wood into fuel energy. The 1st stage is evaporation of water, then the components are volatilized, and lastly, the carbon is oxidized. From 75 - 85% of wood can be volatilized.

Total heat generated by complete combustion of wood is about 9000 Btu/dry lb for resinous softwoods and about 8300 for nonresinous softwoods and hardwoods. Heat of combustion bears little relationship to the kind of wood and vary only from 5 to 8 percent.

Fuel value of wood is primarily determined by density and moisture content. Higher density woods have a higher fuel value.

The ratio of recoverable heat to available potential heat is called the “combustion efficiency”. Combustion efficiency of wood is very dependent on moisture content. For dry fuels, it is about ~80% and ~60% for wet wood fuels.

Electrical Properties

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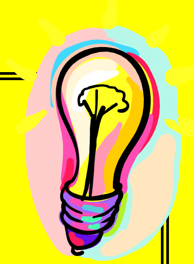
Direct-Current (dc) properties



The direct current properties of materials are measured by resistivity or by its reciprocal, conductivity. In wood, any electrical conductivity occurs primarily by migration of metallic ions which are in wood as impurities. There aren't very many of these, so airdry wood is an excellent electrical insulator. This is one of the reasons utility poles are made from wood.

For woods with higher moisture contents, the dc resistivity is lower (water is a VERY good conductor of electricity!) Also, when the temperature is increased, the electrical resistivity is decreased.

DC conductivity is 2.3 - 4.5 times greater along the grain than across it for softwoods (gymnosperms – trees with needles and cones) and 2.5 - 8.0 times greater along the grain than across it for hardwoods (angiosperms – trees with broad leaves).

Some values for dc resistivity are:

airdry wood	3 x 10E17
glass	10 E10-14
silicon	2300
aluminum	2.7 x 10E-8

in units of ohm-m

Alternating-Current (ac) characteristics

Alternating current characteristics of a material are measured by the dielectric constant **ε**

ε varies directly with density & MC, in other words, for increased density or moisture, the value of the dielectric constant is also increased.

ε also is influenced by wood structure

The value parallel to the grain is 1.3 - 1.5 times greater than across it. And **ε** has larger values for earlywood in ring porous woods such as oak, hickory, ash, locust, elm, hackberry.

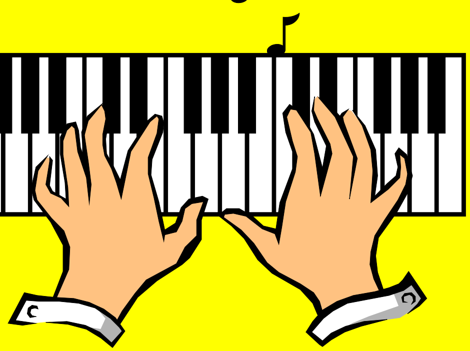
Some values of **ε** for common materials are:

air = 1, glass = 4-7, dry wood = 4, water = 80

all measured at 20 HZ and 20 deg. C

Accoustical Properties



SWST Teaching Unit 2 Slide Set 1

Sound Velocity

The velocity of sound waves travelling parallel to the grain in wood is directly proportional to the wood’s elasticity (E) and inversely proportional to the density (D).

But, since the ratio of E to D tends to be constant, speed tends to be constant along the grain. Sound velocity is slower across the grain because the transverse E is much less that than parallel to the grain (about 1/20th less).

So, speed across the grain is 1/5 - 1/3 that along the grain.

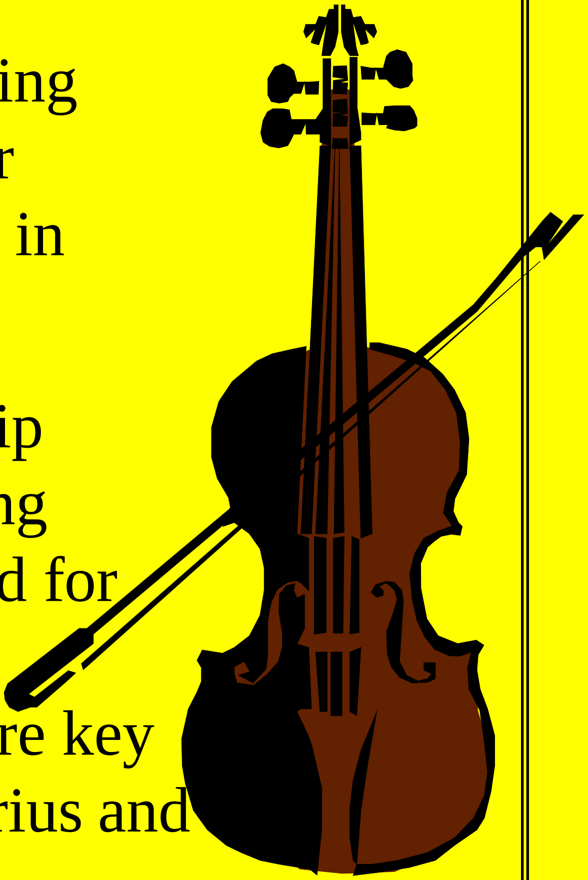
As MC or temperature increases, speed of sound decreases.

Because the velocity of sound waves in wood is quite slow, wood is a very good insulator for sound.

Musical instruments

The acoustical properties of wood have interesting implications in the construction of violins, other stringed musical instruments, and sound boards in pianos.

We have much left to learn about the relationship between wood structure and the sound-producing properties of vibrating wood. Selection of wood for musical instruments ia a blend of mystique and science. Methods of selection and treatment were key to the success of master violin makers Stradivarius and Guarneri.



The acoustical properties are also important as they relate to architectural acoustics.

A piece of wood (or parts of it) vibrates when periodic forces act upon it. When the driving force is removed, the successive amplitudes of vibration will decrease – this is called damping. Energy is dissipated partly by radiation of sound and partly in the form of heat by internal friction.

Damping due to sound radiation depends mainly on the ratio of sound velocity to material density.

In musical instruments, low damping due to internal friction and high damping due to sound radiation are desirable. This is the case with wood – it provides high damping due to sound radiation and low internal friction. Wood is used in a variety of musical instruments such as piano and violin sound board and to make clarinets, oboes, and drum sticks.

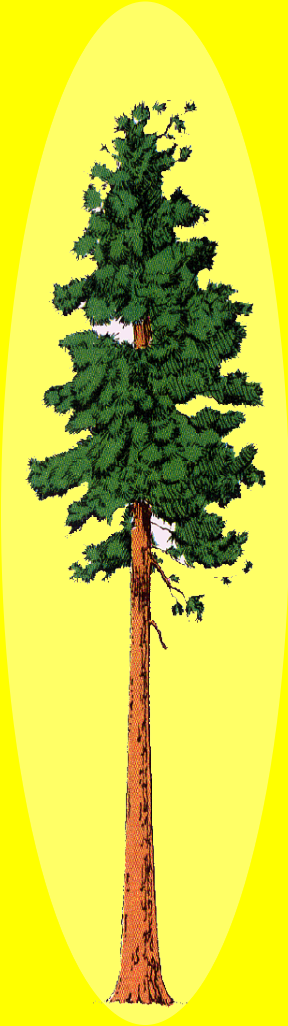
Spruce is used in violins because it has exceptional resonant qualities and it is favored for soundboards. We think Stradivarius' secret is related to the fact that the spruce he used was floated down mountain rivers to his workplace in Cremona, where the water was heavily silted. The combination of the silt and long immersion is thought to have given his wood its peculiarities that, so far, has been unduplicated.

African blackwood (rosewood) and ebony (white ebony or persimmon) is used in woodwind instruments and castanets. It is traditional for the sharp/flat keys of a piano to be ebony to contrast with the ivories. This is to symbolize forces of good and evil in everyday life.

Fiddleback sycamore and maple are traditionally used for the backs of violins and cellos. Apparently that's why those woods are called fiddleback sycamore and maple.

Now you have some knowledge of the physical properties of wood. You can use this knowledge to understand the many hundreds of products you use everyday that are made of wood.

AND, you are now prepared for the activities that follow in Teaching Unit No. 2, Slide Set 2.



A number of books are available on the topic of wood structure and properties. A couple of recommend references are:

Bowyer, J.L., R. Shumlsky, J. G., Haygreen. 2003. Forest Products and Wood Science - An Introduction, 4th ed. Iowa State Univ Press, Ames, Iowa.

Hoadley, R. B. 1980. <u>Understanding Wood: A Craftsman's Guide to Wood Technology</u>. Taunton Press, Newtown, CT.

Panshin, A.J. and C. deZeeuw. 1980. <u>Textbook of Wood Technology</u>, 4th ed. McGraw Hill Book Company, New York.

The Nature of Wood and Wood Products. 1996. CD ROM, Forest Products Society, Madison, WI. http://www.forestprod.org/

Wood Handbook: Wood as an Engineering Material. 1999. Forest Products Society, Madison, WI. http://www.forestprod.org/

Wood Reference Handbook. A Guide to the Architectural Use of Wood in Building Construction. 1991. Canadian Wood Council, Ottawa, Ontario Canada.

Additional information concerning careers in the general field of wood science and technology, including those in production management, process engineering, technical sales, and product development can be obtained by contacting:

Society of Wood Science and Technology
P.O. Box 6155
Monona, WI 53716

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