Wood and water

Physical and Mechanical Properties of Wood Practicum

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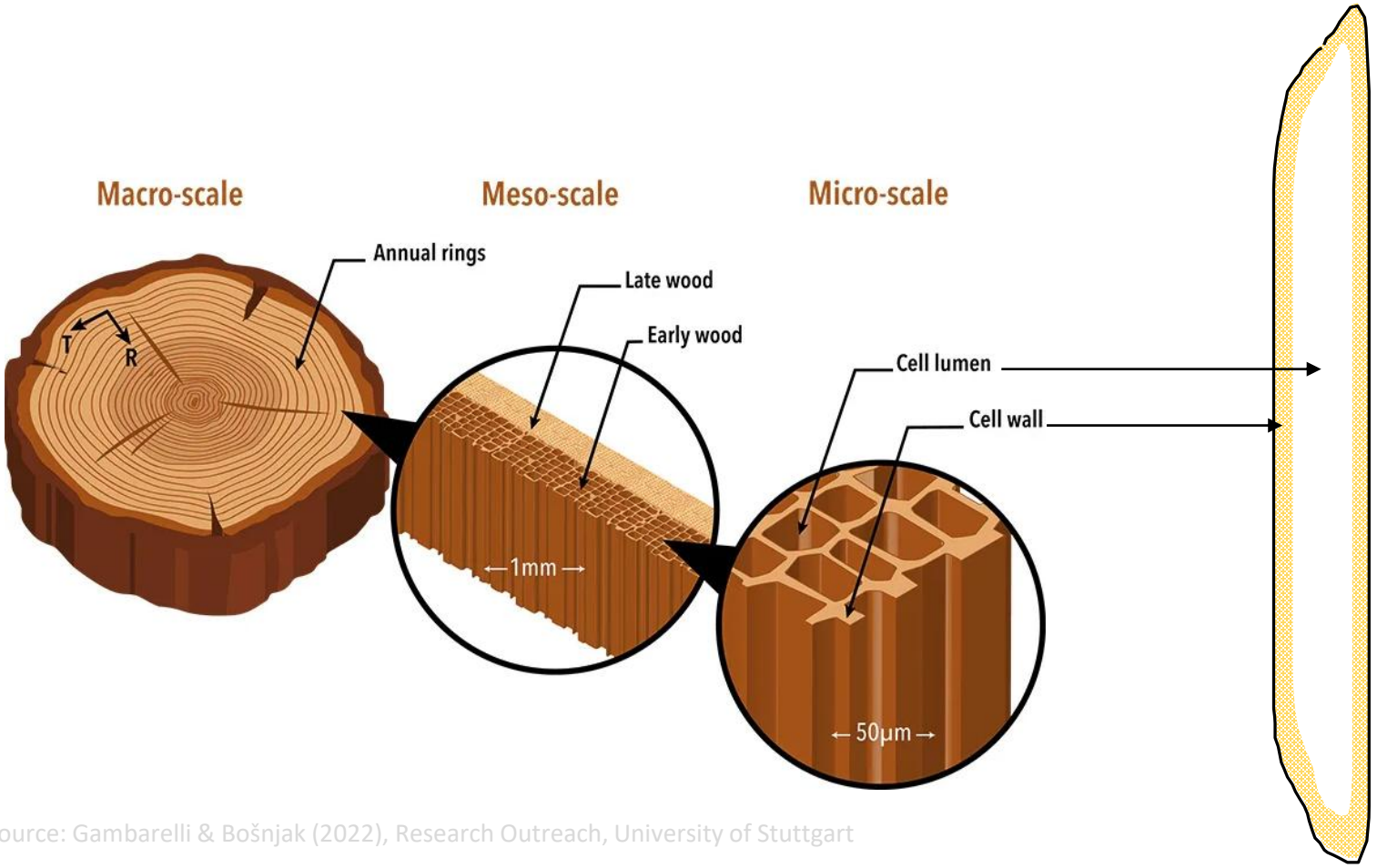


Photo: Abed Mhajne, Unsplash (2020)

Water and wood

- Learning objectives
  - Define the types of water in wood and the fiber saturation point
  - Tell the difference between relative and absolute humidity
  - Calculate MC, weight, or oven-dry weight given the other two values
  - Describe the relationship between relative humidity, temperature, and equilibrium MC. Be able to look up values and understand what low and high EMC conditions are
  - Describe methods that are used to measure the moisture content of wood
  - Tell how moisture meters work and how they are used

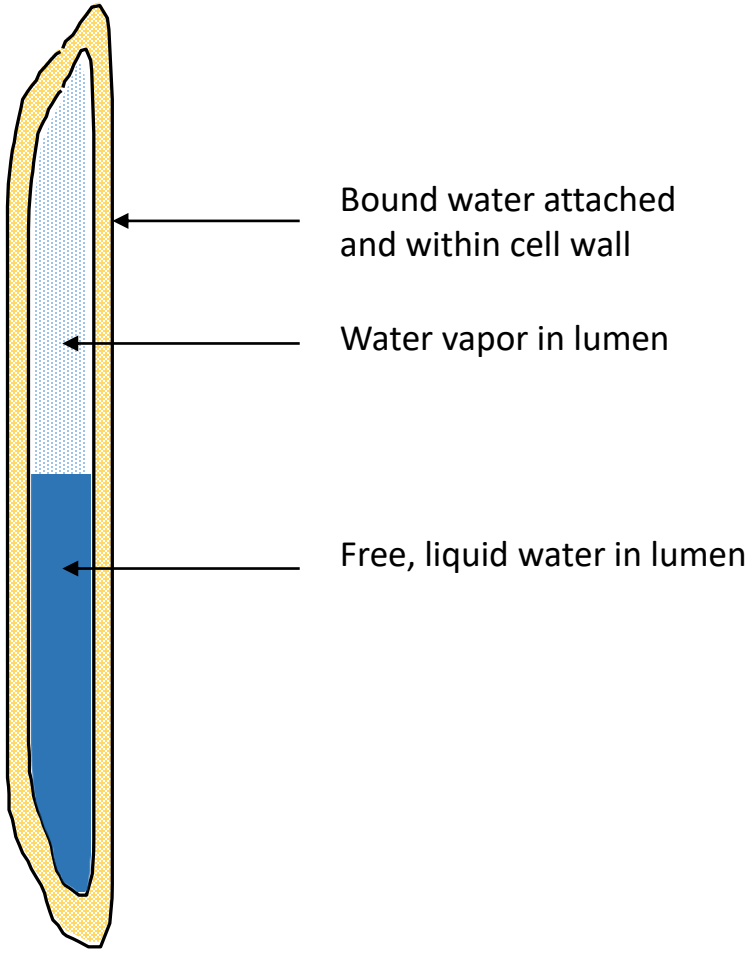
Wood cell wall and lumen



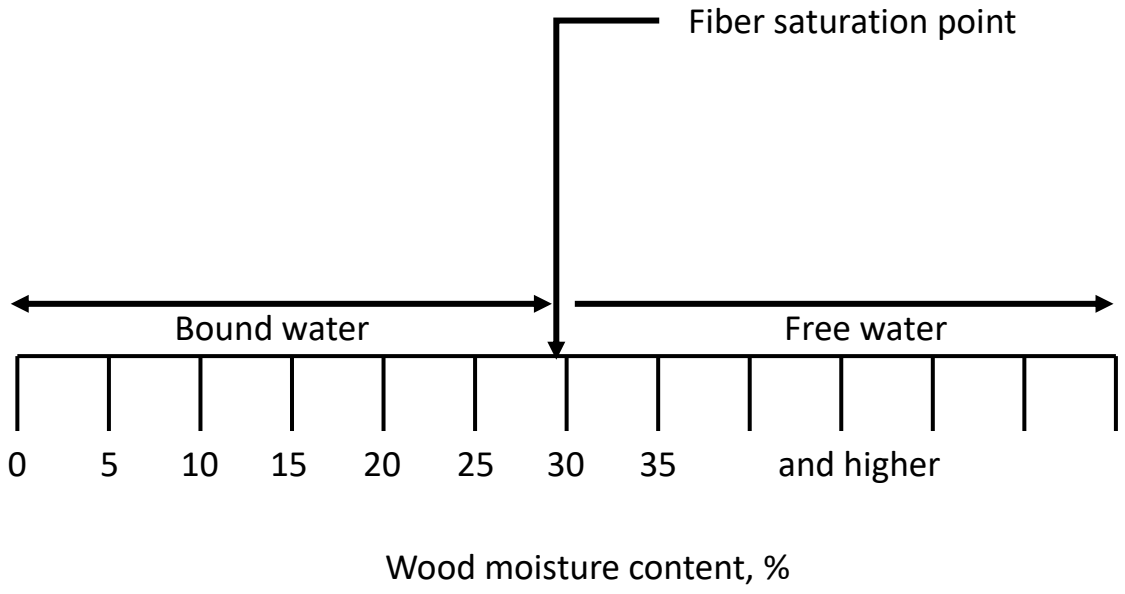
Source: Gambarelli & Bošnjak (2022), Research Outreach, University of Stuttgart

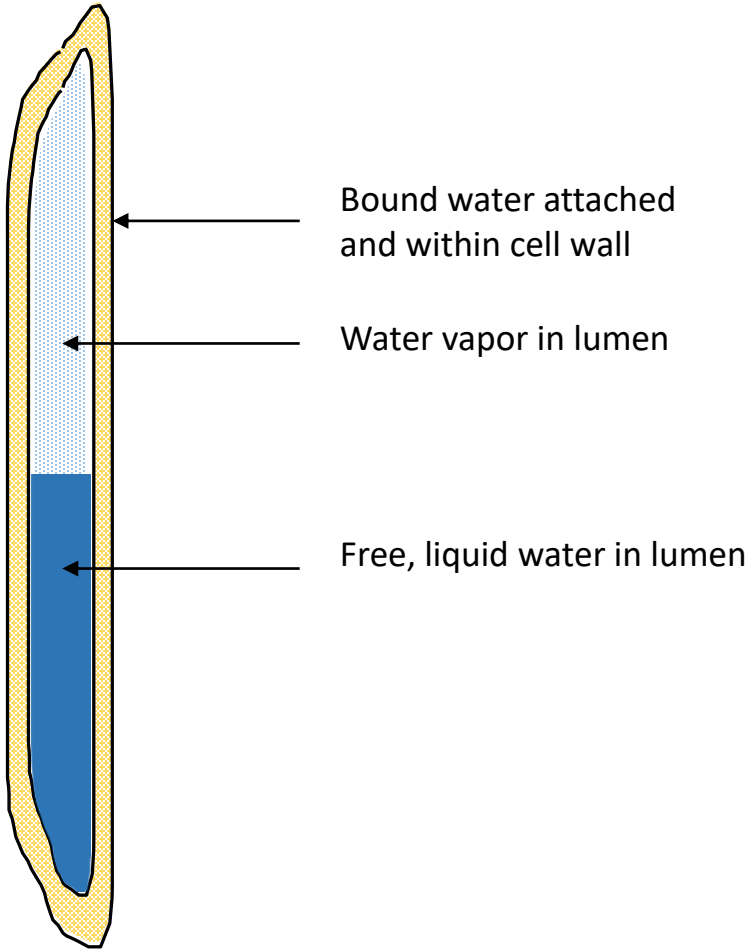
Types of water in wood

- Bound water
  - Attached to the cell wall
  - Difficult to remove – more energy
- Free water
  - In the cell lumen
- Vapor
  - In the cell lumen

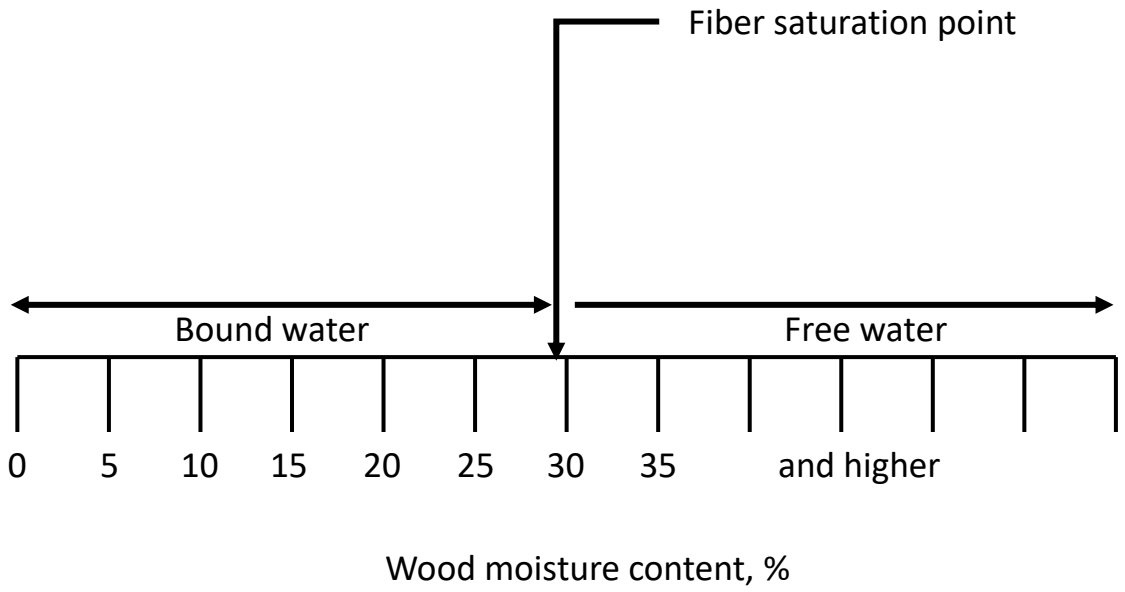


Fiber saturation point (FSB)





Factors affecting FSP



- Affected by
  - Species
  - Extractives
  - Density
  - Temperature
  - Heartwood/sapwood

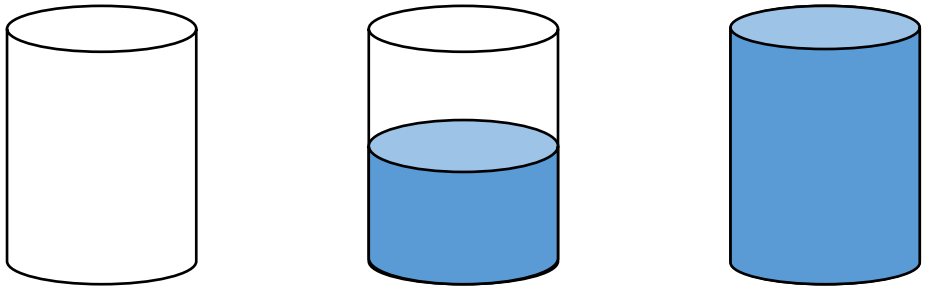
Absolute and relative humidity



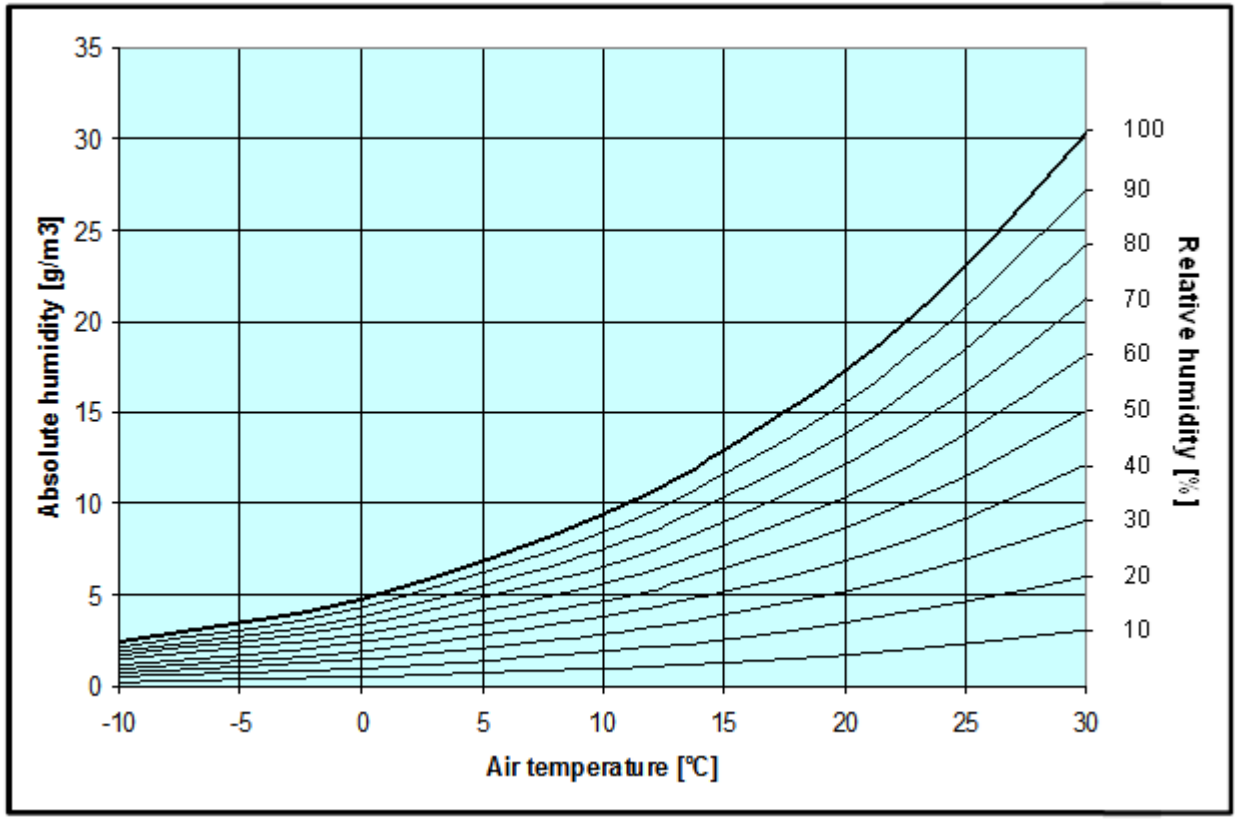
Source: Image: wirestock, Magnific.com

Relative humidity (RH)

- Ratio of the water in the air to how much it can hold
- 50 % RH means that the air has half as much water as possible
- 100 % RH air is saturated and that no drying can occur



Absolute and relative humidity



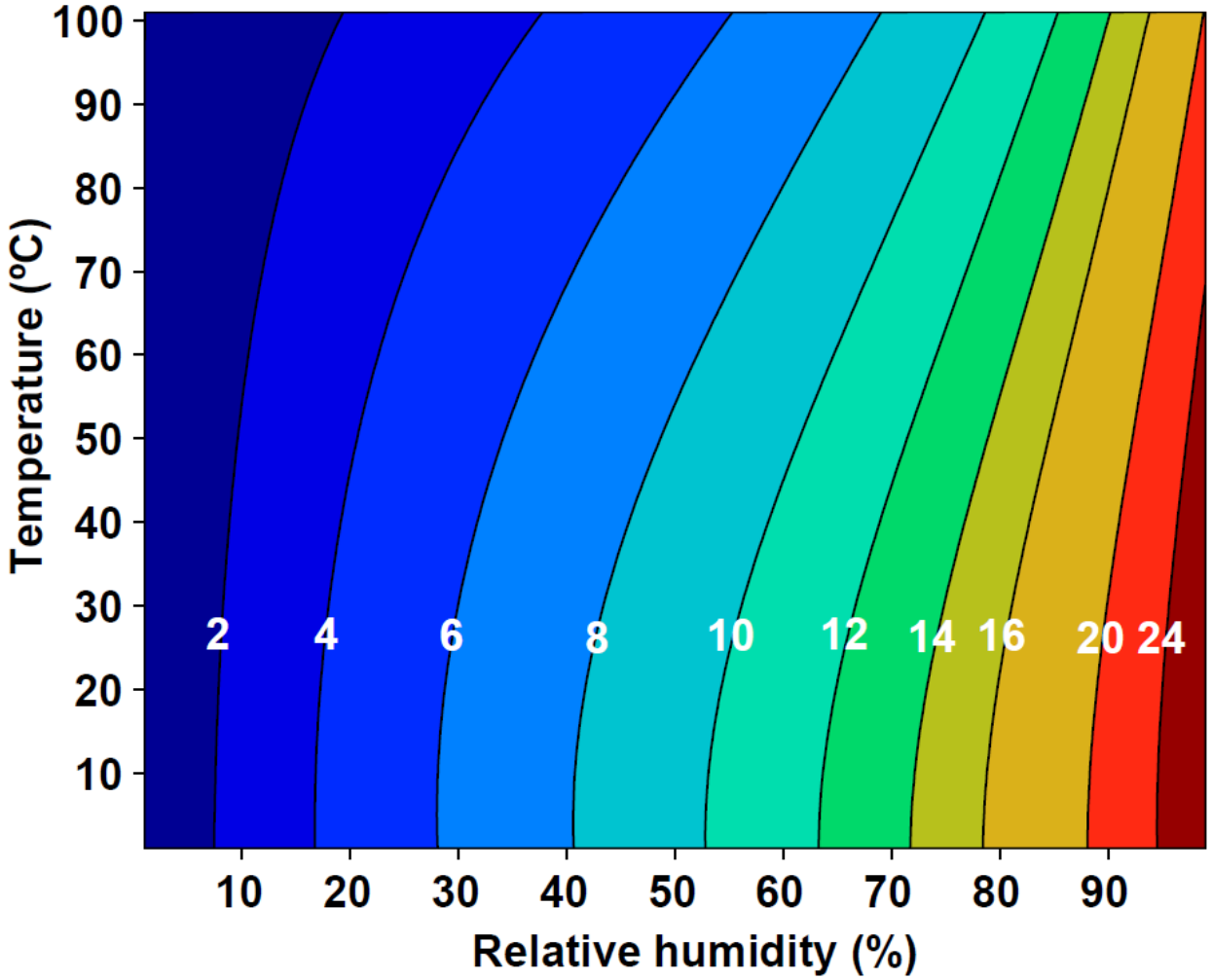
Source: Image: CTU Code, Annex 3, Fig. 3.1 (IMO/ILO/UNECE, 2014), wiki.unece.org

Equilibrium moisture content (EMC)

- Describes the air - not the wood
- The moisture content that wood eventually will reach in a given RH and temperature
- Variations from
  - Location
    - Indoor
    - Outdoor
  - Geographically
  - Time of year

EMC - RH

- 20 % EMC – 90 % RH (very humid)
- 12 % EMC – 65 % RH (standard room, semi-humid)
- 7-9 % EMC – 40-50 % RH (typical indoor)
- <5 % EMC - <30 % RH (uncomfortably dry)



Source: Forest Products Laboratory (2010), Wood Handbook

EMC table, Wood Handbook

Table 4–2. Moisture content of wood in equilibrium with stated temperature and relative humidity

Temperature		Moisture content (%) at various relative humidity values																	
(°C	(°F))	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
−1.1	(30)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
4.4	(40)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3
10.0	(50)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
15.6	(60)	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1
21.1	(70)	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
26.7	(80)	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6
32.2	(90)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
37.8	(100)	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9
43.3	(110)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
48.9	(120)	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0
54.4	(130)	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5
60.0	(140)	0.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0
65.6	(150)	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4
71.1	(160)	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9
76.7	(170)	0.7	1.5	2.3	3.0	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9.0	9.9	11.0	12.3	14.0	16.2	19.3
82.2	(180)	0.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6	9.5	10.5	11.8	13.5	15.7	18.7
87.8	(190)	0.6	1.3	1.9	2.6	3.2	3.8	4.4	5.0	5.5	6.1	6.8	7.5	8.2	9.1	10.1	11.4	13.0	15.1	18.1
93.3	(200)	0.5	1.1	1.7	2.4	3.0	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.7	9.7	10.9	12.5	14.6	17.5
98.9	(210)	0.5	1.0	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.7	7.4	8.3	9.2	10.4	12.0	14.0	16.9
104.4	(220)	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.5	5.0	5.6	6.3	7.0	7.8	8.8	9.9			
110.0	(230)	0.3	0.8	1.2	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.3	6.0	6.7						
115.6	(240)	0.3	0.6	0.9	1.3	1.7	2.1	2.6	3.1	3.5	4.1	4.6								
121.1	(250)	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	2.9										
126.7	(260)	0.2	0.3	0.5	0.7	0.9	1.1	1.4												
132.2	(270)	0.1	0.1	0.2	0.3	0.4	0.4													

Hysteresis

- At the same RH and temperature, wood that is **drying** has a **higher MC** than wood that is **wetting**
- Sigmoid (S-shaped):
  - steep start (water binds directly to the cell wall),
  - flatter middle (extra water layers),
  - steep end (swelling)
- Oscillating desorption: drying with fluctuating RH (real conditions)

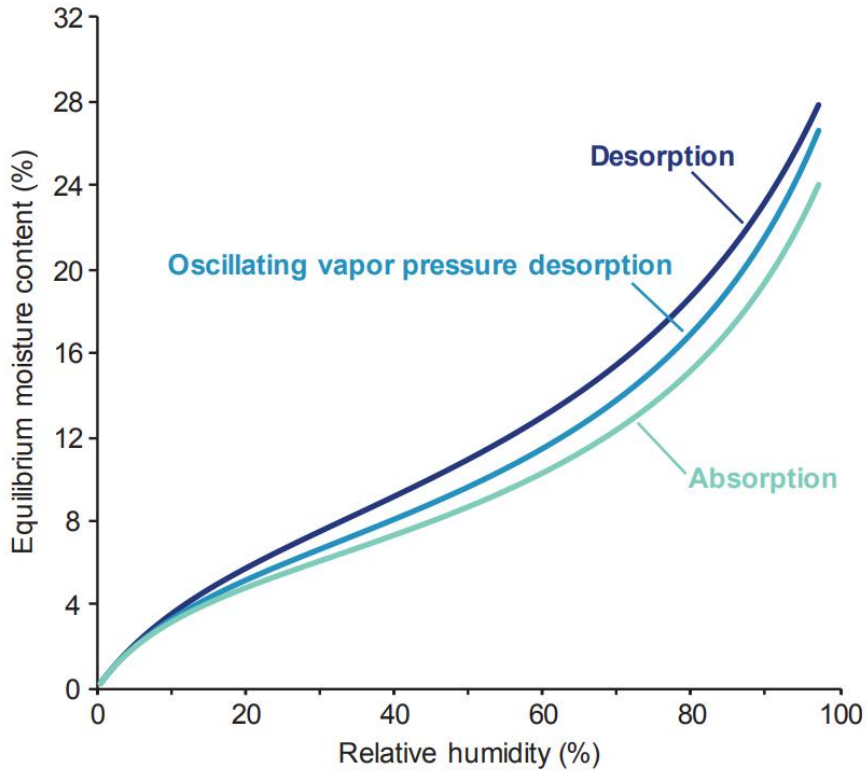


Figure 4–2. Moisture content–relative humidity relationship for wood under absorption and various desorption conditions.

Source: Forest Products Laboratory (2010), Wood Handbook

Common methods for measuring moisture content

- Gravimetric (Uses weight loss)
  - EN 13183-1 or ASTM D4442 – Direct moisture content measurement
    - Method A: convection oven-drying at 103 °C until “constant” weight achieved
- MC meters (MC correlated to some physical property)
  - ASTM D4444 - Use and calibration of hand-held moisture meters
  - EN 13183-2: resistance (pin) meters
  - EN 13183-3: capacitance (dielectric) meters
- Other methods
  - Near infrared spectroscopy (NIR), X-Ray, microwave

Gravimetric method

- Oven requirements
  - Large enough for samples
  - Ventilated
  - 103 °C
  - Forced air flow



Source: www.kambic.com

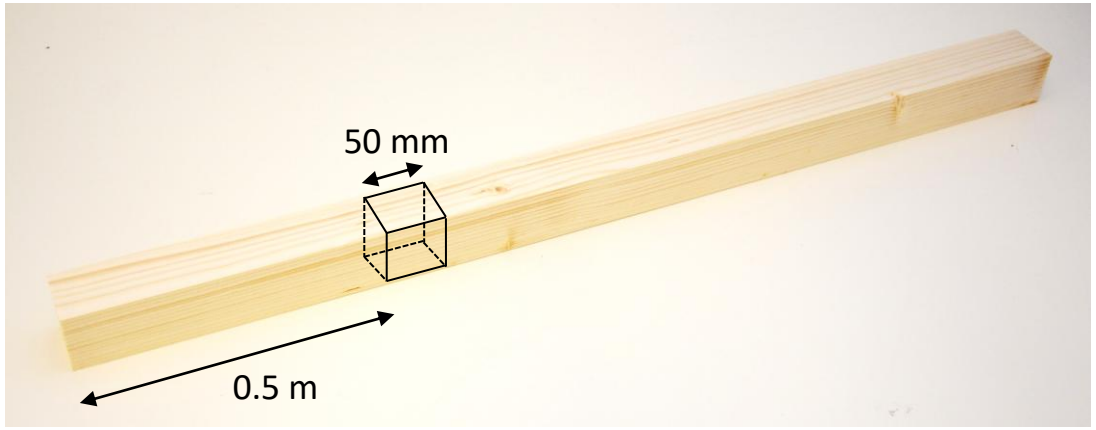
Scale requirements

- Scale requirements
  - Capacity/range
  - Precision
    - 1 part in 1000 gives ± 0.05% MC
    - 0.01 g resolution is okay for small specimens
    - 1 g resolution for specimens over 1 kg



Sample selection and cutting

- Representative of what you want to measure and account for variability
- For lumber: and least 0.5 m from the end of the board to avoid end effects
  - EN 13183-1: full cross-section, ≥ 20 mm along grain, ≥ 300 mm from end
- Not too small, not representative
- Weigh immediately after cutting or store in a bag to eliminate unwanted weight loss
- Initial weight
  - Write on the sample
  - Data sheet



Sample drying

- Dry at 103 °C
  - Temperature too low and not all water will be removed (MC calculation too low)
  - Temperature too high and some wood components will become volatile (MC calculation too high)
- Usually 24 hours is adequate for small samples
- Don’t mix wet and dry samples in the oven
- Don’t overload the oven
  - Longer drying time
  - Fire risk



Using a desiccator

- Oven-dry wood quickly absorbs moisture from the air, so cool samples in a desiccator
- The desiccant (e.g., silica gel) keeps the air inside dry
  - Replace or regenerate the desiccant when its color changes
- Useful for moving dry samples between labs, e.g., from the oven to the balance



Source: www.commons.wikimedia.org



Source: www.vwr.com

Gravimetric method

- Intuitive

$$MC = 100\ x \frac{Weight\ of\ water}{Weight\ of\ wood}$$

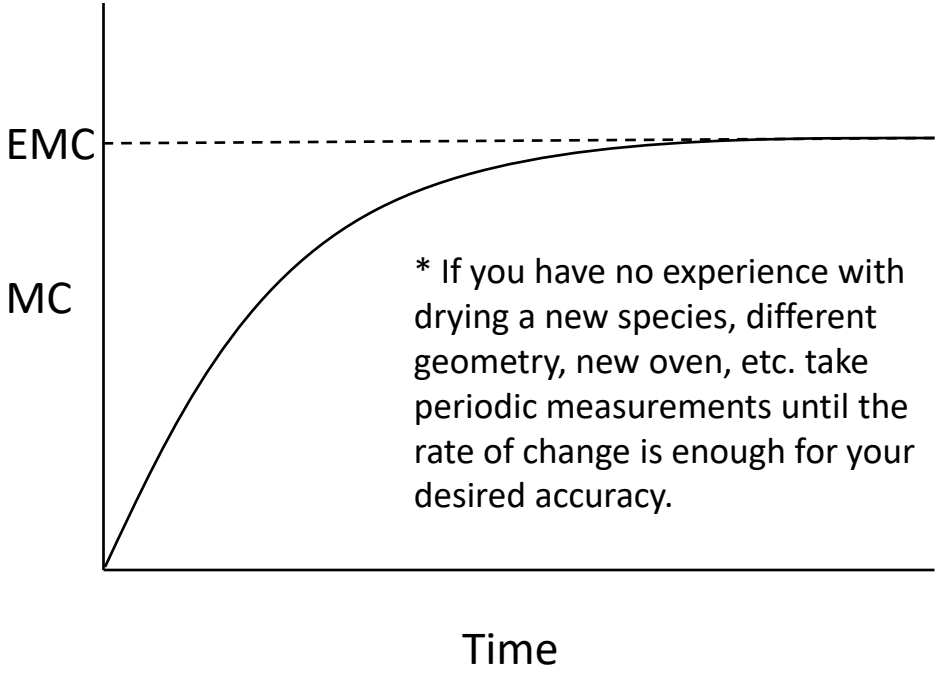
- Calculation

$$MC = 100\ x \frac{Wet\ weight\ of\ wood\ - Oven\ dry\ weight\ of\ wood}{Oven\ dry\ weight\ of\ wood}$$

- Oven dry: constant mass check
  - the difference in mass between two successive weighings (at least 2 hours apart) is less than 0.1%

Conditioning samples

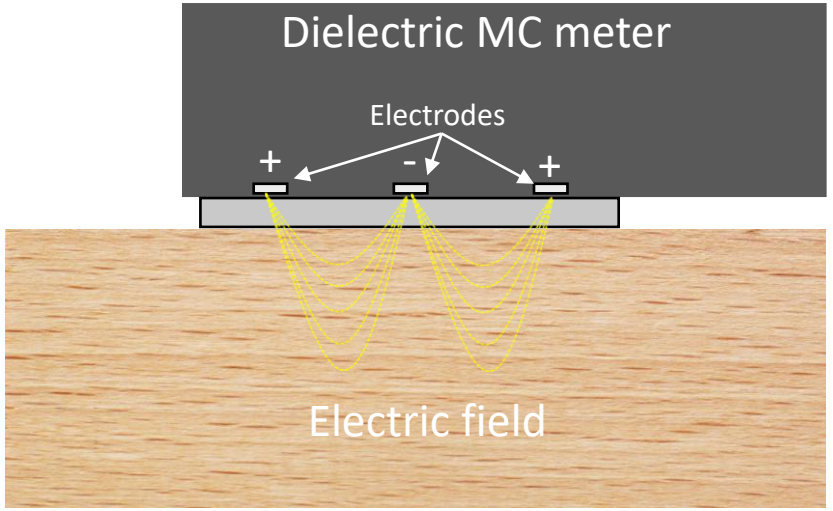
- Conditioning
  - Bringing all samples to the same equilibrium moisture content, “equilibrating”
  - EMC = equilibrium moisture content
- Considerations
  - Allow for variability
  - Conditioning room/chamber limitations
  - Airflow
  - Specimen size/geometry



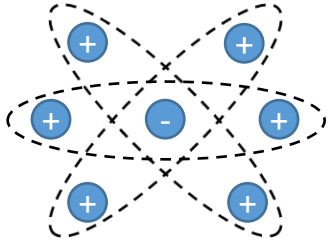
Measuring wood MC by electrical properties

- Dielectric – Ability of a material to store electrical energy
- Resistivity – How hard is it to have electricity pass through wood

Measuring wood MC by a dielectric (pinless) meter



- Average MC measurement with strongest influence from surface MC
- Useful range is 5 % to 25 %

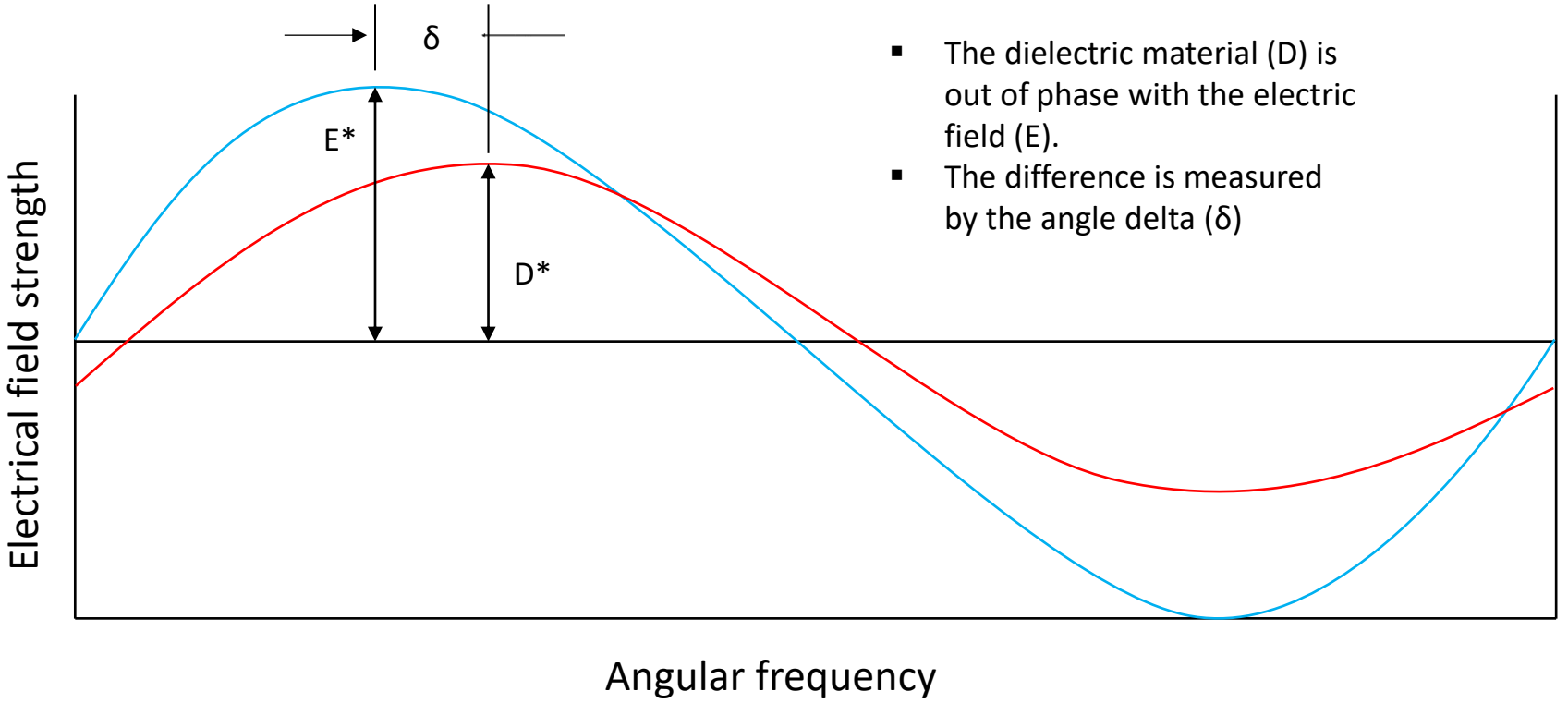


Electrode array layout (view from below)



Measuring wood MC by dielectric field

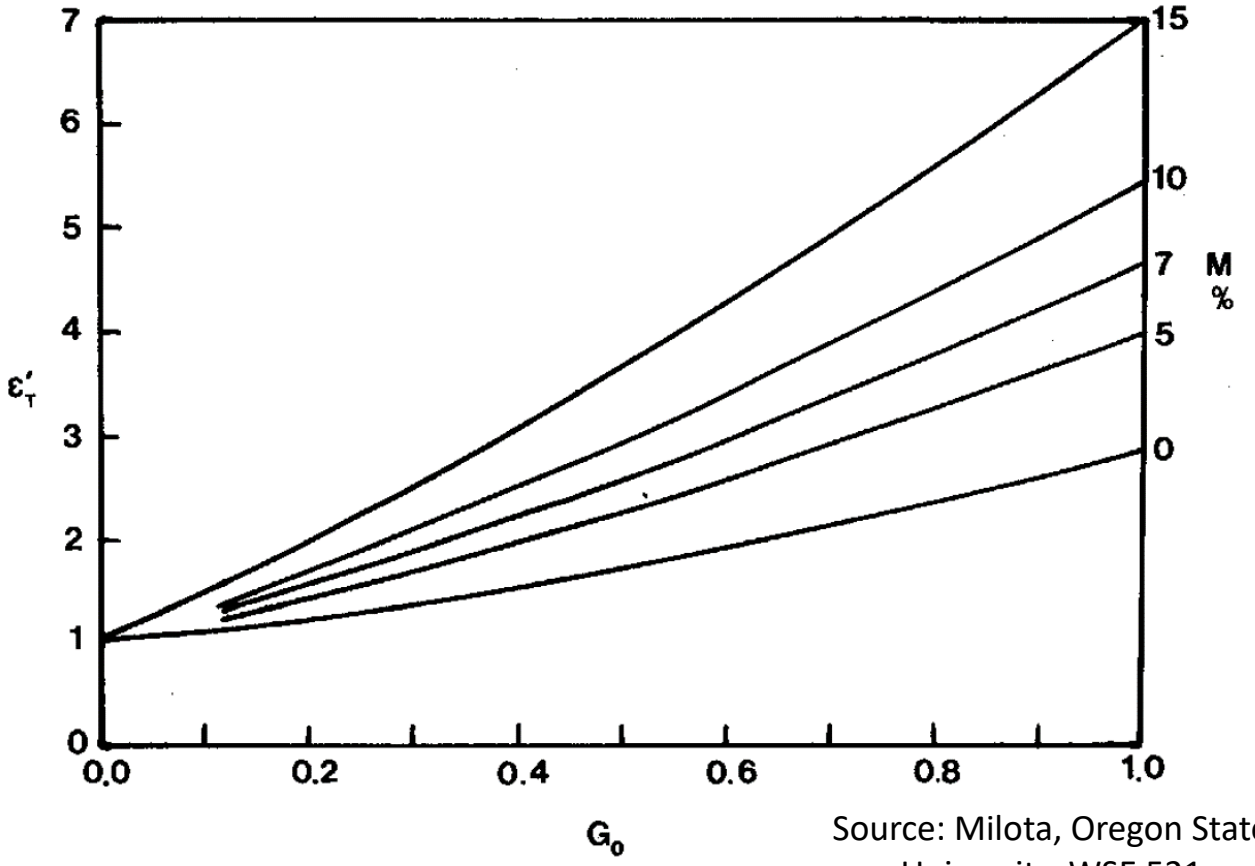
- The dielectric constant is a relative measure of the ability of a material to dissipate the energy of an electric field
- It is a measure of the polarization of atoms and molecules
- E* (blue): alternating electric field from the meter
- D* (red): wood's response
- δ: phase lag of the response, which represents energy lost as heat



- The dielectric material (D) is out of phase with the electric field (E).
- The difference is measured by the angle delta (δ)

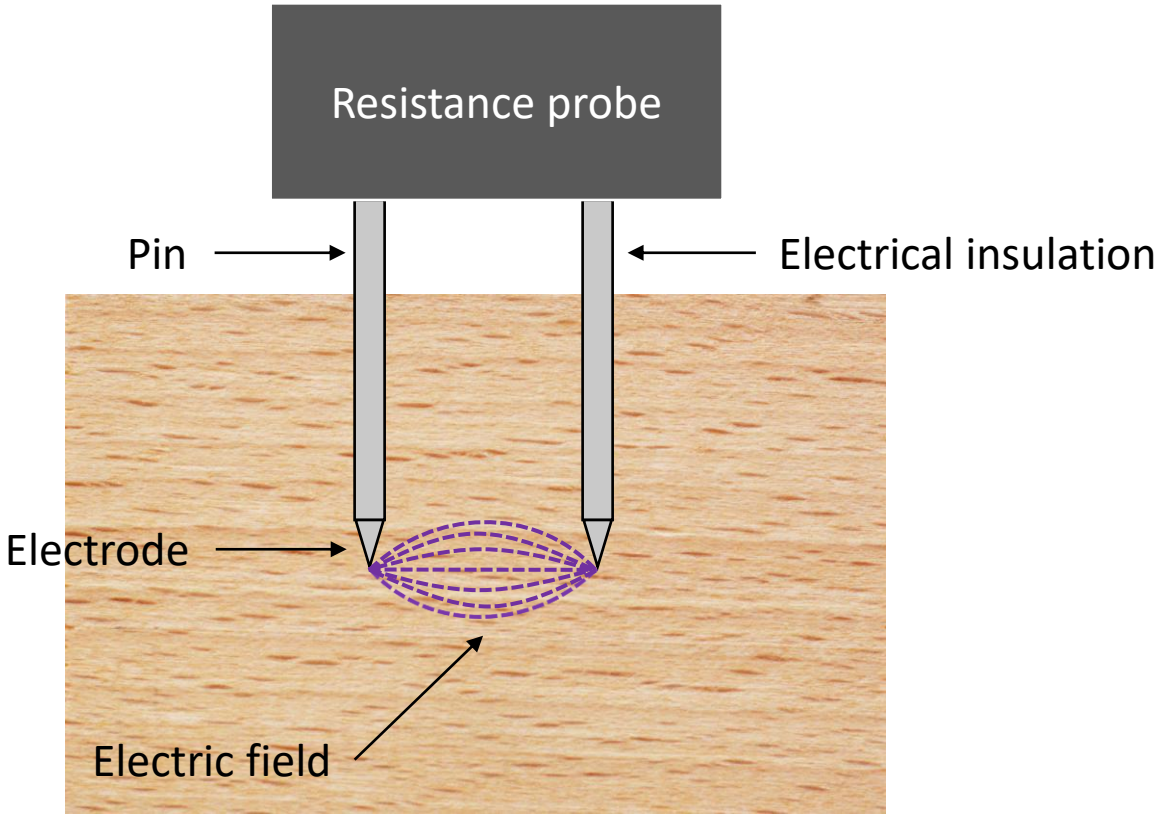
Measuring wood MC by dielectric field

- Transverse dielectric constant of wood vs. oven dry specific gravity at various moisture contents
- Meter must be calibrated to type of wood group to account for SG

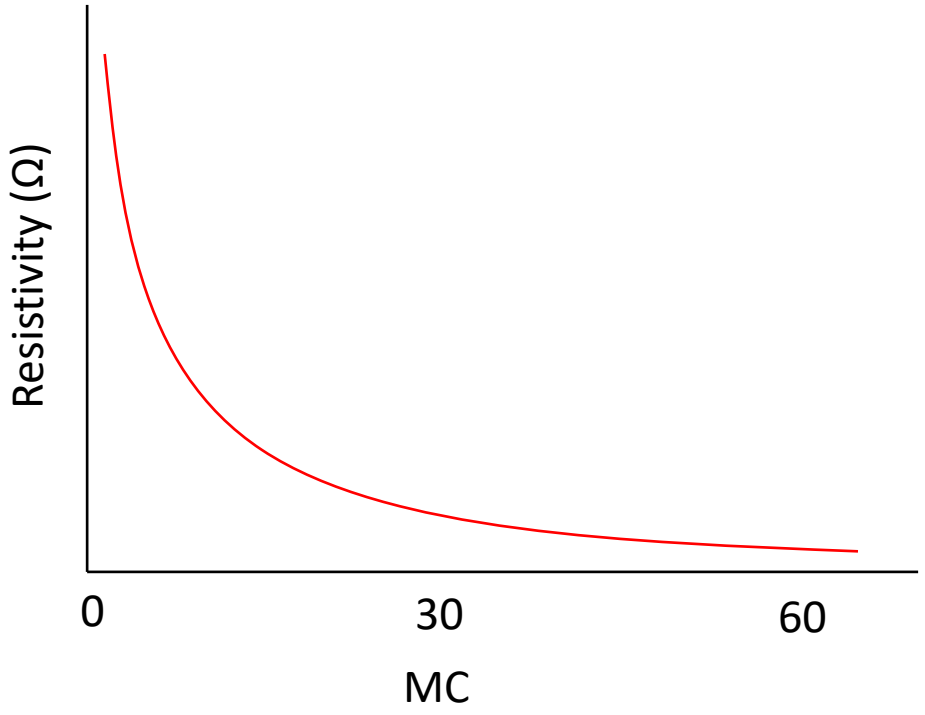


Source: Milota, Oregon State University, WSE 521

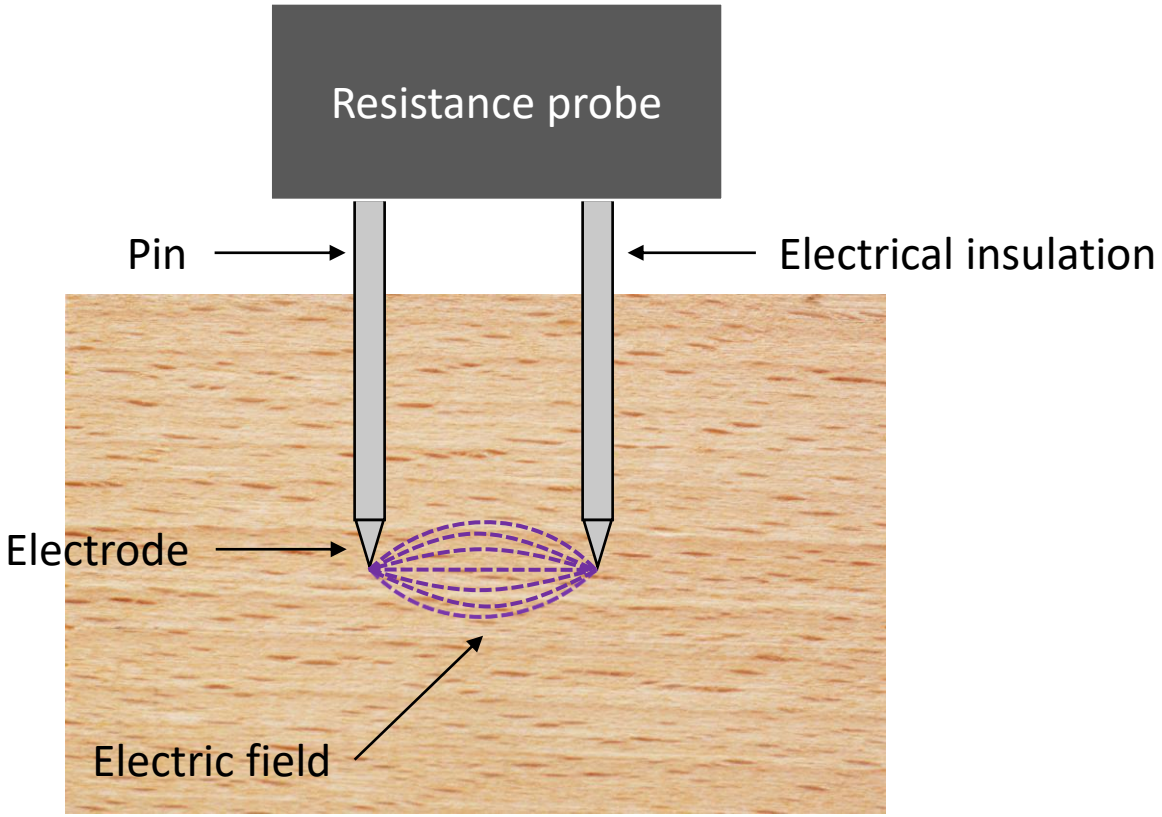
Measuring wood MC by electrical resistance



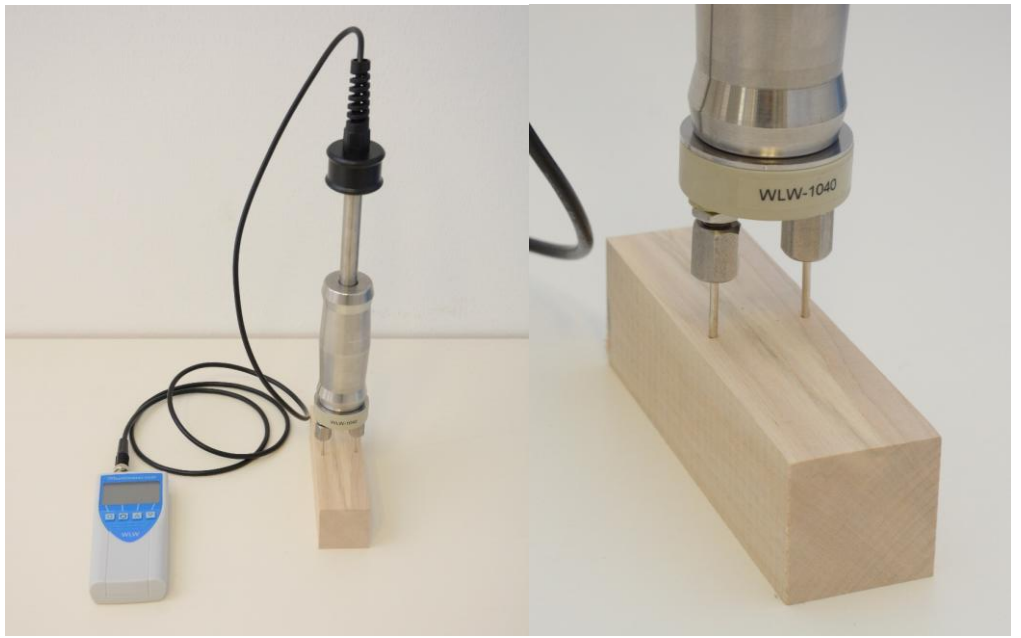
- Pin or conductance meter
- Point measure of MC
- Useful from 5 % to 25 % MC



Measuring wood MC by electrical resistance

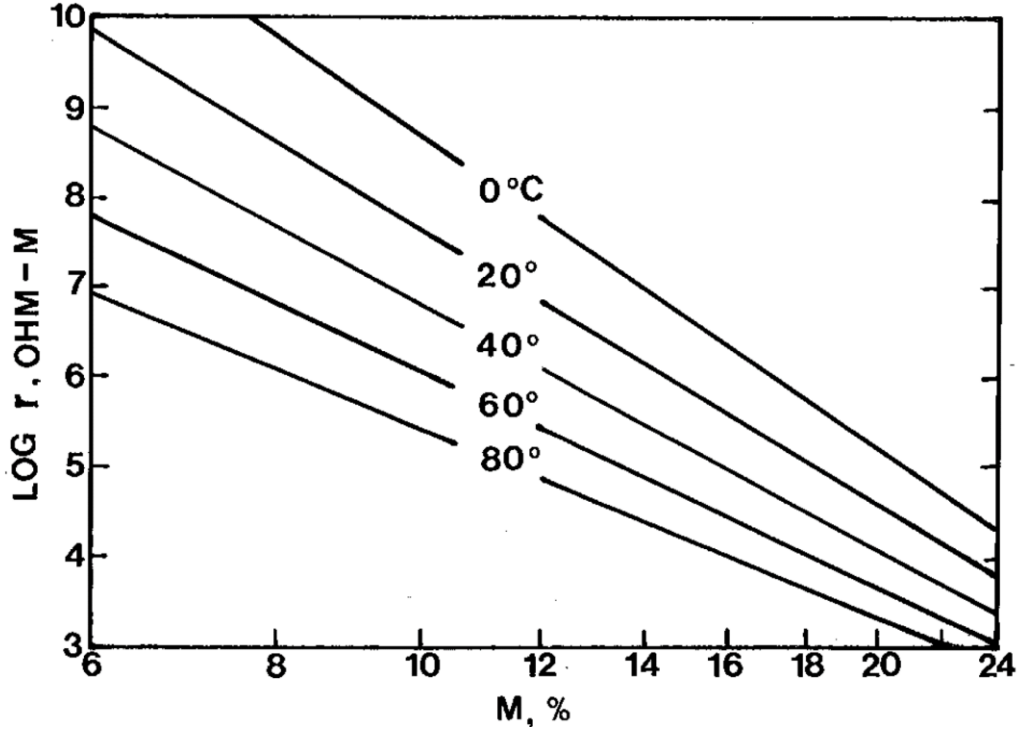


- Pin or conductance meter
- Point measure of MC
- Useful from 5 % to 25 % MC



Factors affecting MC readings

- Temperature must be accounted for in measurements with conductance meters
  - Resistivity drops by half for each 10°C rise
- Other factors
  - Grain direction
    - Longitudinal is ~ ½ of tangential
    - Radial is approx. 10 % less than tangential
  - Heartwood/sapwood
  - Chemicals/adhesives
    - Usually abnormally high readings



Source: Milota, Oregon State University, WSE 521

References

- Milota, M. 2010. Oregon State University. Wood Science and Engineering, WSE 521, Wood Science 1, Class Lectures.
- Forest Products Laboratory (2010) Wood Handbook: Wood as an Engineering Material. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory