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Tree-Sustaining Attributes of Water

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Trees act as conduits through which water passes. Instead of water evaporating at the soil surface, a tree provides an elevated surface for water evaporation. A tree can be visualized as a water fountain lifting and evaporating water from its leaves. The water interface between tree and atmosphere (i.e. the leaf) is the major biological control point for water movement in a tree, and for water conservation.

Water is the catalyst of life. When water availability is constrained, life slows, declines, and fails. Drought forces trees to make many genetically based, resource decisions in order to survive. Tree health professionals must understand water and its many impacts on trees.

Most Valuable Resource (MVR)

Water is essential to tree life as well as the most limiting resource. Trees have developed specialized organs, processes, and surfaces to carefully use and conserve water. The value of water lies with its chemical properties, physical reactions, and biological uses. Water is the single most important molecule in trees, as well as the ecological system which sustain trees. Water is a starting point for photosynthesis capturing energy from the sun, a hydraulic fluid, a transport stream, and a solvent. Water comprises 80% of tree mass on average.

Within each living tree cell is a water-based solution which contains, supports and dissolves a variety of materials and molecules responsible for life. This water solution of life is called “cytoplasm” or “cytosol.” A tree is genetically programmed to maintain water contents in cytoplasm allowing food production, energy use, and protein synthesis to occur. To keep the inside of living cells bathed in water, trees horde water from a dry environment. Trees are a standing pipe of soil water held against gravity and the dryness of the atmosphere.

Water Everywhere?

Approximately 97% of all water on our planet is in oceans. Ocean water contains about 35,000 parts per million (ppm) dissolved materials, comprised of more than 80 elements. Fresh water (less than 1000 ppm dissolved materials) represents the remaining 3% of water on Earth, 2/3’s of which is snow and ice in glaciers and polar ice caps. Water in the atmosphere, ground water, lakes, and streams comprise the remaining 1/3 of one percent of Earth’s fresh water. Liquid and solid water cover roughly three-quarters of Earth’s surface area.

Because of water’s properties, it can absorb or release more heat than most other substances for each temperature degree of change. Water buffers extreme temperature fluctuations, acting as a heat reservoir, heat exchanger, cooling system, and protection for life. The changing states of water (and the energy released) power thunderstorms and hurricanes. Water's changing states help dissipate sun energy and buffer rapid climatic changes across the globe. World wide and continental water cycles generate deserts and rainforests, depending upon ratios of evaporation and precipitation. Attributes of water make it the driving force of small scale and large scale climate.

Water As Life

Water is an unique substance. Pure water in small portions is clear and colorless with no taste or odor. It is easily tainted with all kinds of other materials. Properties of water make it both unusual chemically and critical biologically. The most basic of its interactions with other water molecules, and other materials, are associated with its electronic properties. Water is a perfect platform to build and sustain life.

Water State

At a growing tree's temperature, water exists as a gas and as a liquid. As temperature changes, relative proportions of water in its primary states change. More energy propels water molecules at a faster rate, and by definition, temperature increases. As energy is reduced in water, temperatures decline, with water eventually freezing to a solid. Pure water freezes at 32^{o}F (0^{o}C) and boils at 212^{o}F (100^{o}C), under one atmosphere of air pressure. Our temperature scales are set by these properties of water.

Water in the gas phase surrounds us in the atmosphere. The most simple weather descriptions usually include a relative humidity measure. On a large scale, water vapor blankets Earth and acts as a greenhouse gas, keeping heat from escaping into space. Water in its solid phase drags other water molecules to its crystal surface. Growing ice crystals can act like daggers to living cells. Depending upon its molecular energy level and environment, it is possible to have individual water molecules in a continuous exchange between all three physical states. Figure 1.

Molecular Form

A water molecule -- the most basic unit -- is composed of three atoms covalently bonded together. These bonds involve sharing electrons between atoms. Two of the three atoms are small hydrogens, each with a single negatively charged electron surrounding a positive charged proton with various numbers of neutrons. The third atom in water is a massive oxygen which has an atomic structure that easily captures and holds up to two negatively charged electrons. These covalent bonds between atoms in a water molecule are strong.

There are many kinds of water. Water can exist in nine (9) different forms (isotope combinations). There are two (2) types of naturally occurring hydrogen available for use which vary in their nuclear components. There are three (3) naturally occurring oxygen types available. The lightest form of water is by far the most common -- H2O molecular weight = 18. The heavier isotope combinations of naturally occurring water (molecular weights = 19-22) are extremely rare and may not be as biologically active as standard water. Figure 2.

Charge Exposure

In binding with oxygen, hydrogens tend to loose their negative electron charges for most of the time. The almost continuous loss of negatively charged electrons from both hydrogens partially exposes their positively charged proton centers. The capture of two extra negatively charged electrons for most of the time by oxygen, adds a partial negative charge to oxygen. The ability of oxygen to steal electrons (unequal sharing) from its hydrogen partners generate a partial charge separation within water molecules. Partial positive and negative charges balance out within one water molecule leaving no net charge.

Individual molecules of water have a slight tendency to completely ionize or disassociate. Chemically two water molecules can break apart into one H_3O+ ion and one OH- ion, or an average disassociation of one H+ (proton) and one OH- (hydroxy group). A chemical balance exists between water molecules in ionized and non-ionized states, with most in a non-ionized form. At a neutral pH (pH=7), one in 10 million water molecules are ionized. As pH becomes lower (more acidic), more H+ ions exist. A pH of 4 means the concentration of H+ is one in 10,000. Figure 3. Water molecules generally stay in one molecular piece, unequally sharing hydrogen's electrons.

Sticky Shapes

Part of understanding partial charge attraction is examining the shape of water molecules. There are many ways to envision three atoms in water attaching to each other. Atoms in water molecules are not straight or in a 90^o L-shaped. Oxygen has four possible attachment points for hydrogens, representing the corners of a tetrahedron, but can only bond with two hydrogens. Figure 4. The two hydrogens can only be attached to a single oxygen in one way. Hydrogens are always at a ~105^o angle from each other over the surface of the much larger and massive oxygen atom. At this angle, each hydrogen presents a partial positive charge to other water molecules and materials. Oxygen presents a variable partial negative charge to other molecules. Figure 5.

The interactions between water molecules involve partial negative charges attracting partial positive charges among all other water molecules. This partial charge attraction is called "hydrogen bonding." Hydrogen bonding is not as strong as a covalent bond between atoms, but is strong enough to require some energy to break (i.e. 4.8 kilocalorie/mole). Hydrogen bonding also can occur over longer distances (1.8X longer) than short covalent bonds between atoms in a water molecule.

H-Bonds

As a liquid, every water molecule is surrounded with other water molecules except those at an edge or on the surface. Within liquid water, each molecule is held within an ephemeral framework of 0-4 hydrogen bonds from all directions. Figure 6. The mutual attraction between water molecules is called "cohesion." Even though one hydrogen bond slips to another molecule, the average number of these bonds per water molecule remains roughly the same for each energy level. As temperatures climb, more hydrogen bonds break. At the liquid water surface, molecules can escape from liquid into a gas form.

Hydrogen bonding occurs when hydrogen is positioned between two strongly electronegative atoms. Oxygen, fluorine, nitrogen and chlorine can participate in compounds with hydrogen bonding. Oxygen in one water molecule can form a hydrogen bond with a hydrogen on another water molecule. Both oxygen and nitrogen form hydrogen bonds that can positively influence the shape or conformation of biological molecules. Both chlorine and fluorine pull apart and disrupt biologics.

Complex Structures

Water is simply not a host of individual molecules interacting. Because of hydrogen bonding, water develops complex structural and geometric relationships with surrounding water molecules which exist in few other materials. Remember, potential for a maximum of four hydrogen bonds coming from a single water molecule allows water to mimic a four-sided, three dimensional structure called a tetrahedron, rather than a flat, two-dimensional triangle. As these tetrahedrons stack-up, they form small areas of structure which approximate a crystalline form.

As more crystalline areas develop and line-up with each other, water can be described as having a semicrystalline form in a liquid state. This semi-structure confers stability which makes water unique. Water is dominated by this stable semicrystalline structure up to about 105°F (40.5°C). At this temperature, energy within water is great enough to prevent most large structural areas of hydrogen bonding from occurring. This stability temperature is biologically significant because water which surrounds, supports, and interfaces with many tree enzymes and molecular conformations begin to subtly change properties above this temperature.

Ice Floats

As liquid water cools, more and more hydrogen bonds are formed and maintained. This increased attraction with decreasing temperature continues until 40°F (4°C) when water is at its densest. As liquid water continues to cool, hydrogen bonding of cold water begins to reorganize into large areas of crystalline-like structures. As energy content in liquid water declines to 32°F (0°C), hydrogen bonds setup a liquid crystal structure made of tetrahedron shapes packed together.

As water freezes, the tetrahedrons are set into true crystal forms. This water crystal formation is a solid which is less dense than the liquid it formed from. The four hydrogen bonds and the packing density of tetrahedron crystals formed at freezing separates individual water molecules by more space than is present between water molecules in a liquid form. Ice floats because it is less dense than liquid water. The lower density tetrahedron structure of solid water allows ice to float in liquid water, and provides the basic building blocks and shapes found in snowflakes and frost.

Being Dense

Water's greatest density is at 40°F (4°C). Water volumes nearing 40°F (4°C) will sink. Moving water temperature from 40°F (4°C) down to 32°F (0°C), causes water to internally restructure and it rises to float on the surface. Water is least dense at 32°F (0°C). Within an 8°F (4°C) temperature range, water is found at its densest and lightest.

The characteristic of a solid form being less dense than a liquid form is rare. This feature allows lakes to freeze from the top downward in Winter, and completely thaw in Spring, protecting the water column and lake floor ecological systems from freezing damage. Liquid water density differences help propel water column mixing rates, as well as providing environmental stimuli to a number of water creatures and processes.

Changes

As energy is added to liquid water, more molecular movement occurs with greater intensity, breaking more hydrogen bonds. Within liquid water, there are several energy states where water molecule interactions undergo significant changes. The molecular interconnections shift and slide to maintain the lowest energy level and/or simplest structure possible.

To review, the ice-to-liquid state change is clearly an important event for the biological use of water. At 40°F (4°C), when water is at its densest, is an important structural change point. The internal structural connectivity of liquid water shifts with every 18°F (10°C) increase above 40°F (4°C). There is also a structural phase change at approximately 105°F (40.5°C) where lower energy semicrystalline patchwork of water molecules grades into fields of more energetic and less interactive water molecules. Some biological materials and processes become much less efficient beyond this point because of water properties, as well as associated temperature effects.

Little Big Size

The most abundant form of water has the smallest molecular weight of 18 mass units with 16 mass units coming from a single oxygen. Other molecules similar to the mass and size of water molecules quickly evaporate and exist as a gas at tree growth temperatures. Because of hydrogen bonding, water molecules are "sticky," attracting each other and generating properties expected of a much different, much heavier and larger compound. Water interacts with any material having at least small irregularities in their electronic composition. Water will adhere to many surfaces which have partial charges and ionic terminals.

Water forms a thin film around most soil and biological materials. For example, a landscape soil under increasing drought conditions still contains a relatively large concentration of water. This water content is sticking to and surrounding organic matter and clay particles, and filling small gaps or pores between particles. By placing soil in an oven at 212°F (100°C), most water can be driven off, although some still will remain closely bound to various surfaces and within crystal structures. Adding water to a soil allows surface films of water to enlarge, filling ever larger soil pores. Any added water becomes part of a water matrix already in soil which sticks together, and a portion of which can be dragged into a tree.

Electric Shells

Many tree essential elements dissolve readily in water and form ions, either positively charged "cations" or negatively charged "anions." Figure 7. Ions come from disassociation or separation of a neutral molecule. Table salt easily ionizes into positive cation sodium ($Na+$) and negative anion chlorine ($Cl-$) when stirred into water. The full charges on ions cause the partially charged water molecules to line-up and surround each in a hydration sphere or layer. Ions with hydration spheres tend to behave as much larger molecules because they are blanketed with many water molecules attracted by their charge.

In soil, most essential elements are not dissolved in solution, but held within organic materials or mineral compounds. There are always a small portion of these elements dissolved in water and attracted to various charges on soil particles. The small water molecule charges, in-mass, tug at any surface materials and surround them (dissolve them). An individual water molecule is very small compared to most other materials and can be drawn into the smallest of pores or spaces. Water's physical and chemical properties help dissolve many things. Water infiltrates and coats life and its resources.

Polar Blankets

Water is generally a highly stable, non-ionized, polar molecule that acts as a nearly universal solvent. Wherever water flows through soil or over tree surfaces, it dissolves and carries along valuable materials. Because of its small size and polar nature, water dissolves many materials, more than any other liquid. Water can fit into small surface faults and between other molecules which helps dissolve materials.

Water is considered a polar substance because of its unique hydrogen bonds caused by partial electronic charges. In terms of kitchen chemistry, polar substances like water dissolve or attract other polar materials. Water can not influence non-polar materials like oils, thus oil and water do not completely mix but separate. Adding a soap or detergent to an oil-water mixture puts a charged "handle" on the oil and then water can dissolve it away.

Wet Sphere

Materials that are ionic or polar can be pulled into water and surrounded by a shell of many water molecules hiding or covering (neutralizing) any charge. Many acids, bases and salts ionize easily in a water solution and are immediately surrounded by a hydration layer or shell. A hydration shell of water surrounding polar or charged materials makes these materials behave as if they were larger compounds and modify their physical properties. Figure 8. Some relatively large (at the molecular scale), but highly charged materials like clay colloids, can be suspended in water. Large molecules with many atoms can be surrounded by water minimizing any electrostatic charges and cohesion forces, helping these large molecules dissolve in water.

Surface Tension

Water molecules within liquid water are pulled equally (on average) from all sides by hydrogen bonding. Water molecules at the surface are pulled only on one side into the water mass. Without attraction from the air above, surface water molecules are held and pulled inward toward other water molecules. "Surface tension" is the result of a force generated by hydrogen bonding pulling together water molecules. Surface tension allows small items which are more dense than water to be held on the surface of water. "Water strider" insects use water surface tension as a means of transportation. Water has a strong surface tension force, like a cloth stretched across a drum head. The only other common liquid with a stronger surface tension is the liquid metal mercury.

Without gravity or a surface to adhere to, large groups of water molecules are pulled by surface tension into a round ball to minimize surface area per unit volume. In gravity, tear-drop-shaped droplets are formed as water falls. Liquid water on surfaces to which it does not adhere well (like a waxy surface) will "bead-up." Water would rather stick to itself than to many surfaces. The surface tension of water allows wind to push against it, generating waves in large water bodies. Detergent helps reduce surface tension of water (by as much as 70%) and allows water to spread out over a surface.

Capillary Movement

There are some surfaces to which water is attracted or adheres well. These wettable surfaces cause a film of water to partially pull away from other water molecules and cling to the wettable surface. As one molecule moves forward and adheres to a surface, it pulls on other water molecules behind. Over time a layer of water will be pulled out and over a wettable surface. If a small diameter tube is made of a wettable surface material, water will be pulled against gravity, and other forces, into the tube. This characteristic of water is called "capillary movement."

Capillary movement involves three primary forces generated in liquid water by hydrogen bonding -- adhesion, cohesion, and surface tension. Adhesion is attraction of water for a wettable surface. Cohesion is attraction of one water molecule for another water molecule. Surface tension minimizes surface area. Inside a small diameter tube, water is attracted along the walls by adhesive forces. As water is pulled along the tube surface by adhesive forces, surface tension and cohesion drag more water molecules along behind. When cohesive forces of water, tube size resistance to movement, and gravity become too great, (or surface tension is reduced) water movement in a capillary stops.

Tubular Water

One way to envision water pulled into and up a capillary tube is to use a suspension bridge model. A column of water is suspended against gravity by adhering to tube walls (bridge uprights). Adhesive forces on tube walls allow cohesion forces among the rest of the water molecules to be pulled up and supported like spanning cables between bridge uprights carrying the weight. Cohesive forces keep all the water molecules together, reaching a minimum surface area for the diameter of the tube (distance between bridge uprights). The smaller the diameter of tube, the greater the adhesive / cohesive forces pulling-up on the water column for the same mass suspended behind. Extremely small diameter tubes, soil pores, or intercellular spaces can attract water, allowing it to move a relatively long way (many inches).

Capillary movement components can be seen where liquid water touches the side of a glass. The water surface is not flat or evenly suspended, but is drawn slightly up the sides of a glass. This raised rim is called a "meniscus." A meniscus is the visible sign of adhesive forces between the glass and water.

Capillary movement is responsible for some within- and between-cell water movement in trees, and small pore space movements in soils. Cell wall spaces are extremely small (interfibril) and can slowly "wick-up" water. Water conducting tissues of trees (xylem), does NOT utilize capillary movement for water transport. If xylem columns were open at the top, a maximum capillary rise of 2-3 feet could be obtained. Xylem transport is by mass movement of water not capillary action. Capillary movement is a matter of inches, not dragging water to the top of a 300 feet tall tree.

Specific Heat

As energy is added to water, the molecules tend to increase vibration and movement. The more movement, the more hydrogen bonds break. Many hydrogen bonds must be broken before the average movement of an individual molecule is affected (i.e. water temperature increases). Because of the massive number of hydrogen bonds in water, it requires a lot of energy to record even a small change in water temperature. Water can absorb a great deal of energy tied up in breaking hydrogen bonds but does not lead to measurable temperature increases.

This property of absorbing significant energy before showing temperature change is a measure called "specific heat." Having a high specific heat means water is well suited for cooling machines and buffering temperature changes. A high specific heat also means, as water finally does change states, a lot of energy is involved. For example, in a moist soil system, water present can absorb more than five times the amount of energy (heat) compared with soil materials present to reach the same change in temperature.

Evaporation

As water temperature is raised more and more hydrogen bonds are broken. From the surface, as select water molecules are untethered from all hydrogen bonds, they escape into the atmosphere as water vapor. This process occurs at all temperatures, but is maximized at near boiling when almost all hydrogen bonds are broken and water vaporizes (changes states). The amount of energy required for changing liquid water into a gas (boiling or vaporization) is large for such a small molecule because of the cohesion (hydrogen bonding) between molecules.

Throughout liquid water, the average attractive forces between molecules is dependent upon temperature. But each separate molecule can have a higher or lower energy level than average. Surface water molecules with higher than average energy levels can overcome shifting hydrogen bonds and break away. This is called evaporation when a water molecule from a liquid mass escapes into a gas phase. Because the escaping molecule had a higher than average energy level, it leaves the liquid cooler (lower average energy) upon evaporation, which is called evaporative cooling or heat dissipation. As temperature of the water increases, evaporation accelerates.

At tree growth temperatures, energy required to evaporate water is the highest for any liquid. Most of this energy is used to break hydrogen bonds. Biologically, the significance of this high heat of vaporization means when water evaporates from a leaf, a large amount of energy is needed and a large amount of evaporative cooling takes place. Alternatively, water buffers rapid changes in temperature through its resistance to temperature change.

Vapor Pressure

Humidity is the amount of water vapor in the air. At a given atmospheric pressure, there is only a specific amount of water vapor which can be a constituent of air (partial gas pressure). For example, water molecules under saturated conditions comprise a maximum of less than 1% at 40°F, up to 9% at 112°F of air. The maximum amount of water vapor which could be in air is called the "saturated vapor pressure." Rarely is water vapor in air at saturation.

Any amount of water vapor less than saturation can be represented by a percent of full saturation or relative humidity. At any relative humidity less than 100% (saturation), water molecules on a liquid surface would be evaporating faster than those being captured from the gas phase. The lower the relative humidity (farther from saturation vapor pressure), the faster evaporation from a water surface. This can be thought of as a vapor pressure deficit or "dryness" of the atmosphere.

For example from Figure 9, saturated vapor pressure of water (100% relative humidity) is given. Also shown are 90% and 70% relative humidity (RH). These relative humidity values less than 100% represent a vapor pressure deficit in air of -142 bars and -482 bars of water potential tension, respectfully.

Drying Force

The rate water molecules evaporate for each temperature is a unique "vapor pressure." When the vapor pressure of liquid water equals the air pressure over it, water boils. The standard boiling temperature of pure water is 212°F (100°C) at one atmosphere of pressure (or ~1 bar or ~1,000 millibars). Changing air pressure will change the boiling temperature (equilibrium between vapor pressure and air pressure). Temperature and air pressure are key components governing water evaporation and boiling.

Water moves from areas of high concentrations to areas of low concentrations -- from more moist to less moist. In a tree, water evaporates from moist inner leaf surfaces, and escapes from stomates and tree surfaces into dry air. Even at very high relative humidity levels in the atmosphere, trees lose water because the atmosphere is chemically dry. For example, air at 98% relative humidity has a water potential which is more than 100 times drier than internal leaf surfaces. Except under fog conditions (100% relative humidity), trees are always losing water to a dry atmosphere. Figure 10. As temperatures increase during the day, relative humidity plummets making the drying force of the atmosphere much greater. Figure 11.

Tensile Strength

Water is strong under tension (not to be confused with surface tension!). The force needed to pull water apart is substantial (theoretically pure water can sustain -300 bars of tension). Water in small tubes can sustain tension forces approaching 8% the tensile strength of aluminum or copper wire. Maximum tensile forces applied to water show up to 30% of the hydrogen bonds are positioned and participate in tension loading. Unfortunately, many things negatively impact the tensile strength of water.

In trees, cell wall materials, diameter of the xylem water column, amount and types of dissolved materials present, and discontinuities in the semicrystalline structure of water around H+ and OH- groups will all lower tensile strength in a water column. Water from soil will have dissolved materials which will affect tensile strength. Dissolved gases, when put under a negative pressure (tension in a water column), can come out of solution and form a bubble. Once a bubble is formed, it can expand and contract eliminating tensile strength in a water column.

Tiny Bubbles

Gas bubble formation in tree xylem water columns is called cavitation. As temperatures rise and tension in a water column increases, more gases will fall out of solution and form small bubbles. These tiny bubbles may gather and coalesce, "snapping" a water column in two. As temperatures decrease, water can hold more dissolved gasses until it freezes. Freezing allows gases to escape, potentially cavitating water conducting tissue when thawed. Trees have some limited means to reduce these cavitation faults.

Energy Changes

The "heat of fusion" is the energy required to change an amount of solid water into liquid water at its melting point. Water's heat of fusion is 80 calories per gram. This energy does not change temperature of water but breaks approximately 15% of the hydrogen bonds in the crystalline ice which then melts into liquid water. The transition from ice at 32^{o}F (0^{o}C) to liquid at 32^{o}F (0^{o}C) requires the addition of 80 calories of heat and initiates a decrease in volume and an increase in density of about 9%.

The "heat of vaporization" is the energy required to change an amount of liquid water into a gas at its boiling point. Water's heat of vaporization is 540 calories per gram (5.4 times the energy needed to raise water temperature from 32^{o}F to 212^{o}F (0^{o}C to 100^{o}C)). There is no change in water temperature as this vaporization energy is absorbed because it is overcoming the hydrogen bonding in liquid water to generate vapor (steam). At 212^{o}F (100^{o}C), water in both liquid and gas phases exist. Steam is more reactive and energetic than liquid water because of the additional energy (5.4X more energy) accumulated by the molecules for vaporization. Figure 12.

Just Heat

Water is very stable as it is heated past its boiling temperature. Bonds between atoms in pure water can remain intact beyond 3,630^{o}F (2,000^{o}C). Water can be decomposed into its component gases by adding small amounts of acid (H+) or base (OH-), and then running an electric current through the liquid. Pure water at a neutral pH (pH=7) does not conduct electricity significantly. It is impurities and ionization which allow water to be conductive.

On The Move

Water movement and its transportation of materials is essential to tree life. The three major forms of water transport are driven by diffusion, mass flow, and osmosis forces:

Diffusion – Diffusion operates over cell distances. Diffusion is the movement of dissolved materials from high concentration areas to low concentration areas. Diffusion can move a dissolved molecule in water across a cell in a few seconds. Diffusion does not operate biologically over larger distances. It would take decades to diffuse a molecule across a distance of one yard.

Mass Flow – Most water movements we visualize are due to mass flow caused by pressure differences. Wind, gravity, and transpiration forces initiate and sustain small differences in water pressure. These small differences drive water and its dissolved load of materials in many different directions. Because pressure is the driving force in mass flow, (not concentration differences as in diffusion), size of the conduit is critical to flow rates. If the radius of the conduit is doubled, volume flow increases to the fourth power (X^4) of the size increase. For example, if the conduit radius doubles, the flow rate increases by 16 times.

Osmosis – Osmosis is the movement of water across a membrane. Membranes in living tree cells separate and protect different processes and cellular parts. Membranes act as selective filters, preventing materials with large hydration spheres from passing through. Small, uncharged materials may pass freely. The driving force to move materials in osmosis is a combination of pressure and concentration forces, depending upon membrane constituents.

Biology

Water provides a solution and internal climate for specific biochemical reactions to occur. The structure or configuration of enzymes depend upon water's structural support. In addition, many reactions and their associated biological catalysts are temperature sensitive. Water provides a constant temperature bath and a stable environment for life-functions. Water is also a component or product of some biological reactions.

For example, the photosynthetic system in a tree depends upon oxidation of water to provide electron resources needed for capturing light energy. The oxygens in O2 gas released in photosynthesis are derived from water. The hydrogens (protons) concentrated from water are used as an energy source to capture carbon dioxide to make carbohydrates. Water provides electrons, hydrogens, and oxygen to capture light energy, make tree food, and release oxygen!

Pump-Up Cells

Water is a good hydraulic fluid. It is non-compressible and low viscosity. Water is used to expand and hold tree cells rigid and erect (turgor pressure). Cell divisions generate individual units for expansion. Water pressure generated through osmotic changes in cells is used to push against the cell wall and expand cell dimensions (growth). Water expands and holds a cell at its new dimensions until cell wall fibers and lignification constrain expansion. Visible wilting and petiole drooping in trees during drought periods are derived from loss of cellular pressure because of water loss.

Conclusion

Water is the universal elixur of tree life. The attributes of water conspire to generate a molecule essential to all things "tree." Across the Sunbelt 80% of all variation in tree growth is associated with water: availability, aearation, and drainage in the soil. Water is great!

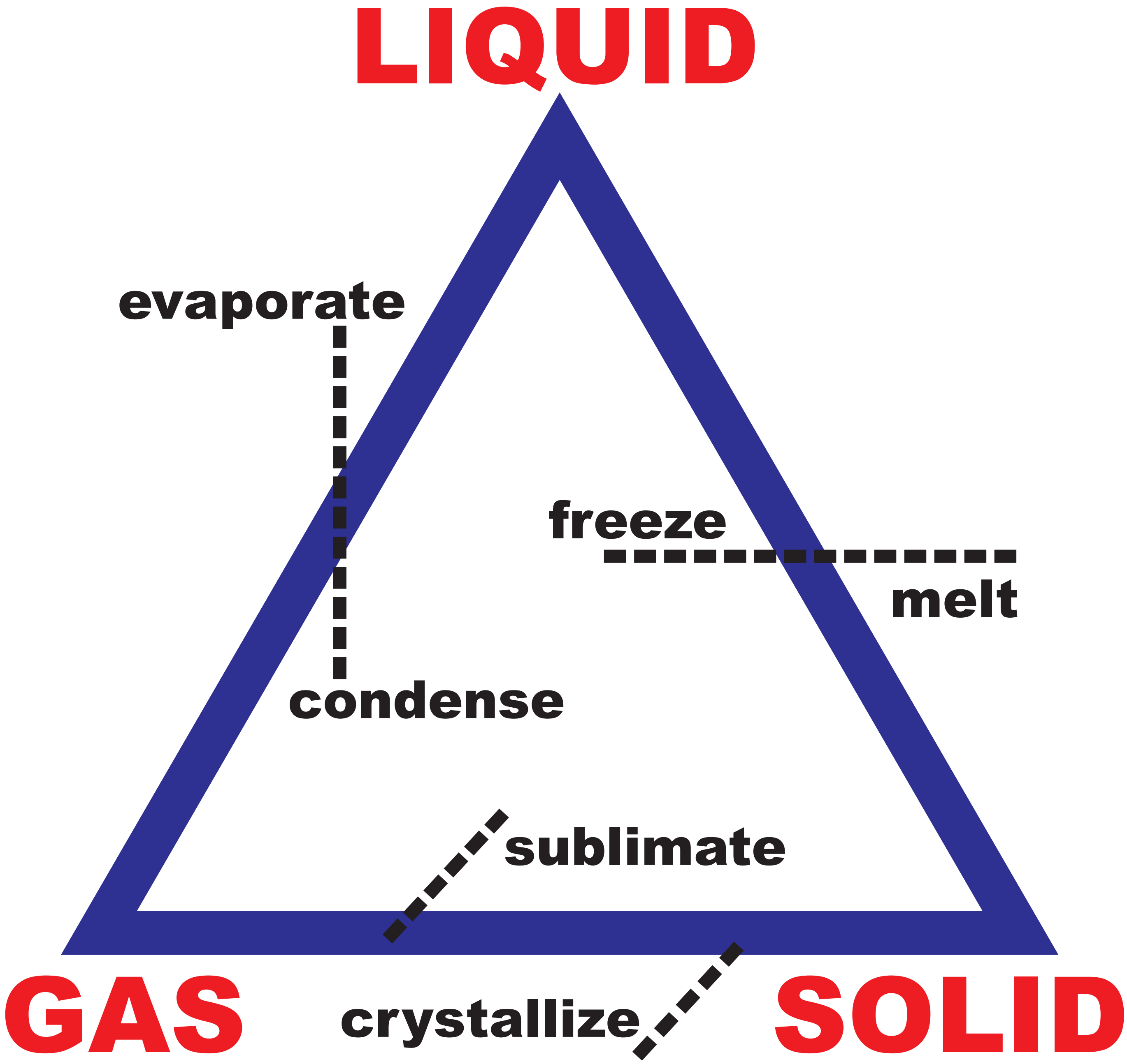

Figure 1: Diagram showing states of water and names of transitions between states.

total hydrogen mass	oxygen mass	percent water form on Earth
2 (^1H,^1H)	16	99.74 %
2	17	0.04 %
2	18	0.20 %
3 (^2H,^1H)	16	0.01 %
3	17	0.000004 %
3	18	0.00002 %
4 (^2H,^2H)	16	0.000001 %
4	17	(4×10^{-10}) %
4	18	(2×10^{-9}) %
		100%

^3H is a synthesized radioactive hydrogen with a ~12.3 year half-life.
The rest of synthesized hydrogens & oxygens have short half-lifes (< few seconds).

Figure 2: Percent of the nine (9) naturally occurring water molecule forms.
(Note percents are NOT in decimal form).

pH	ionized water proportion
2	1: 100
3	1: 1,000
4	1: 10,000
5	1: 100,000
6	1: 1 million
7	1: 10 million
8	1: 100 million
9	1: 1 billion

Figure 3: Ionic proportions of water at various pH levels.

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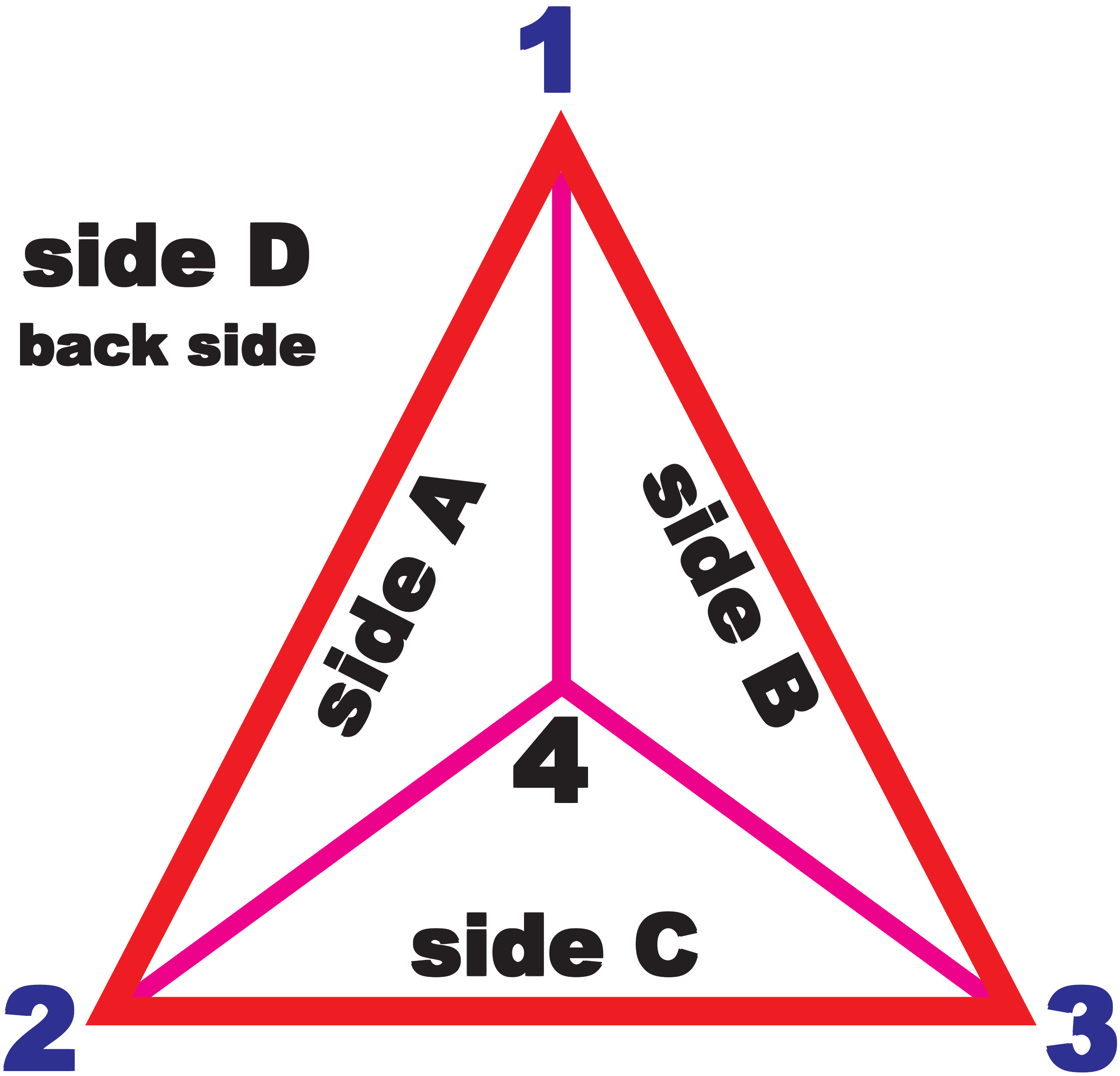

Figure 4: Oxygen bond attachment geometry is in the form of a tetrahedron with four corners (1-4) and four sides (A-D), only two corners can be filled with hydrogens.

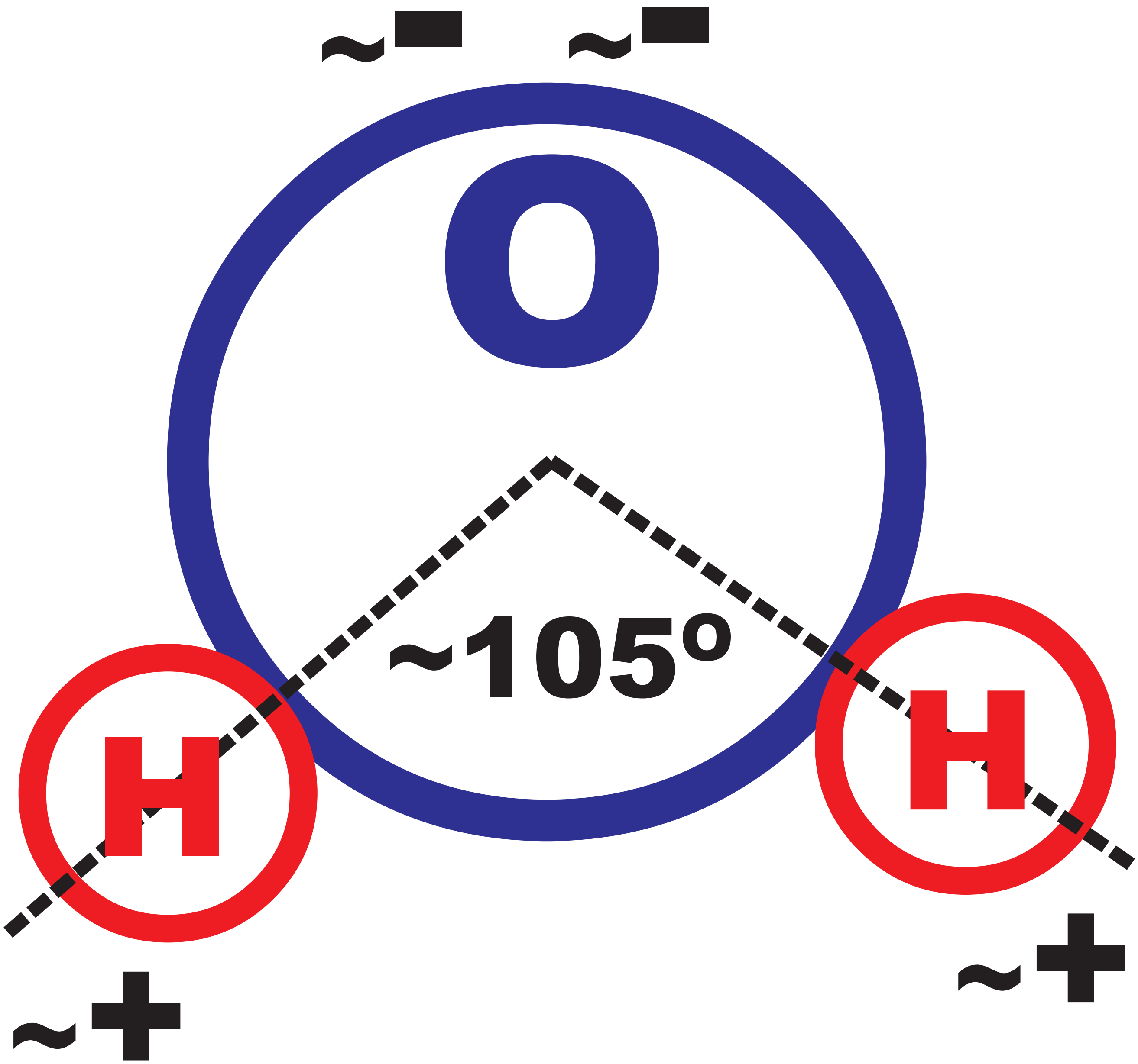

Figure 5: Diagram of water molecule with oxygen (O) and two hydrogen (H) atoms. Hydrogen atoms are always separated by ~105° as they glide over the oxygen perimeter, never on opposite sides. Oxygen draws electrons away from hydrogens generating a polar molecule with partial negative charges (~**-**) on the oxygen side and partial positive charges (~**+**) on the hydrogen side.

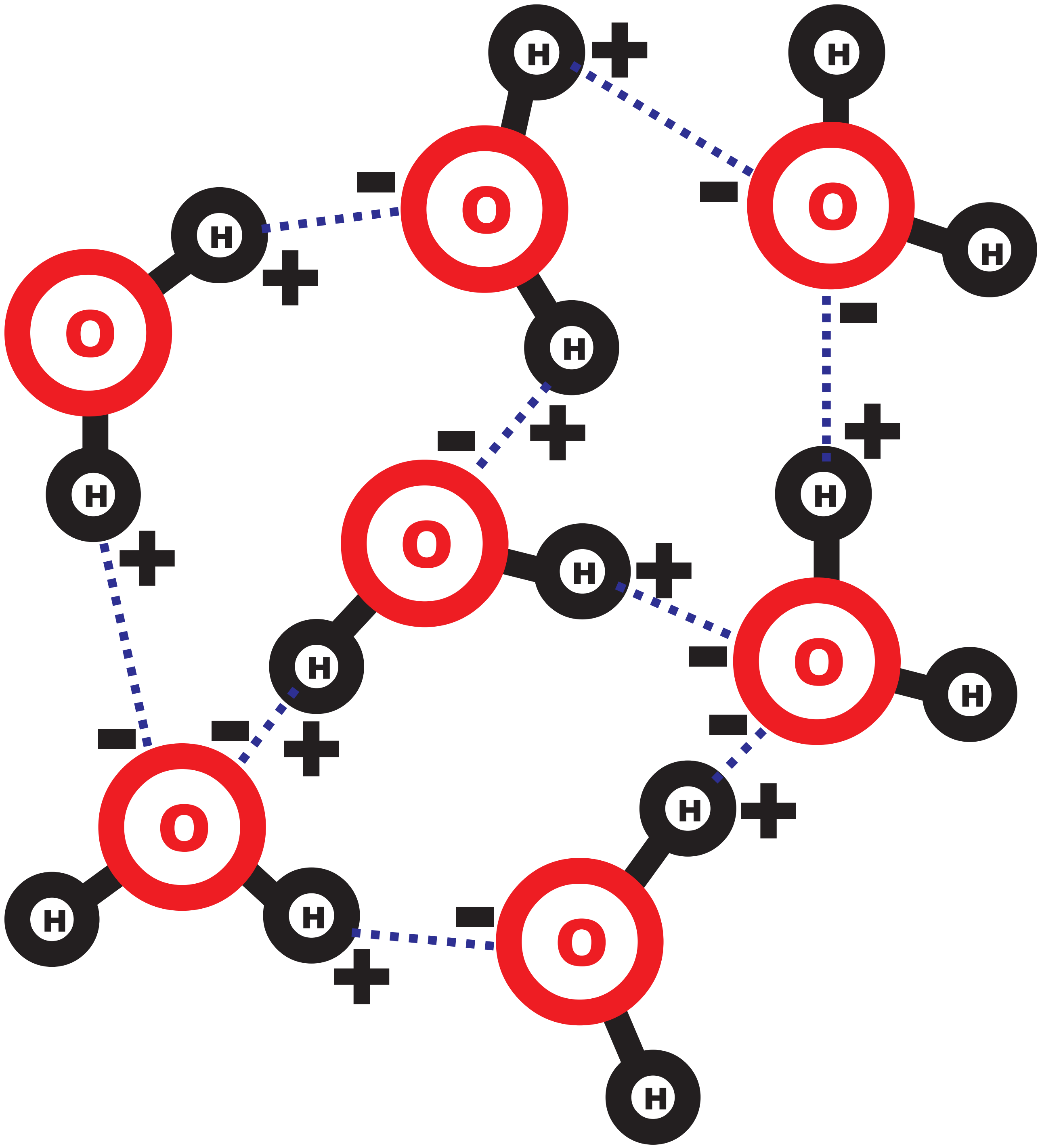

Figure 6: Diagram of seven water molecules interacting with each other due to partial electrostatic charges associated with 0 to 4 hydrogen bonds. Dotted lines represent hydrogen bonds. Remember, this is a simple two dimensional diagram, while water molecules are in a four dimensional framework of constantly shifting hydrogen bonds.

element name	element symbol	most common form(s) available for tree		
carbon*	C	HCO_3^-	CO_2	
oxygen*	O	O_2	H_2O	
hydrogen*	H	H_2O		
nitrogen*	N	NO_3^-	NH_4^+	$CO(NH_2)_2$
potassium	K	K^+		
calcium	Ca	Ca^{+2}		
magnesium	Mg	Mg^{+2}		
phosphorus	P	$H_2PO_4^-$	HPO_4^{-2}	
sulfur*	S	SO_4^{-2}	SO_2	
chlorine*	Cl	Cl^-	Cl_2	ClO_3^-
iron	Fe	Fe^{+2}	Fe^{+3}	
manganese	Mn	Mn^{+2}	Mn^{+4}	
zinc	Zn	Zn^{+2}		
boron*	B	H_3BO_3		
copper	Cu	Cu^+	Cu^{+2}	
silicon*	Si	H_4SiO_4		
molybdenum	Mo	MoO_4^{-2}		
nickel	Ni	Ni^{+2}	Ni^{+3}	
cobalt	Co	Co^{+2}	Co^{+3}	

* = trees can take up element as neutral molecule

Figure 7: Tree essential elements ionic uptake forms.

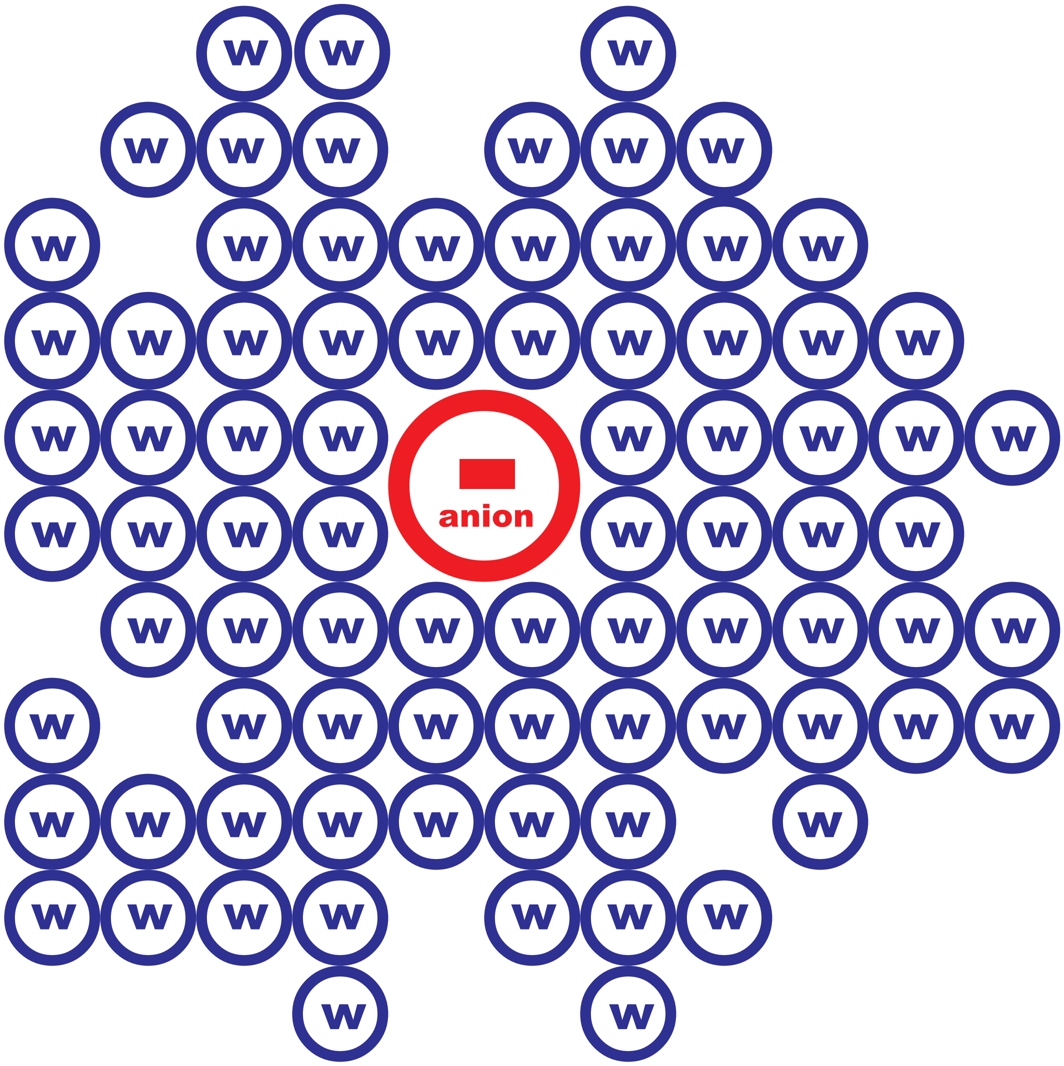

Figure 8: Two-dimensional diagram of water molecules surrounding an ion with a negative charge generating a hydration sphere effectively increasing ionic size. The partial positive charges on the water molecules line-up facing toward the negative ion.

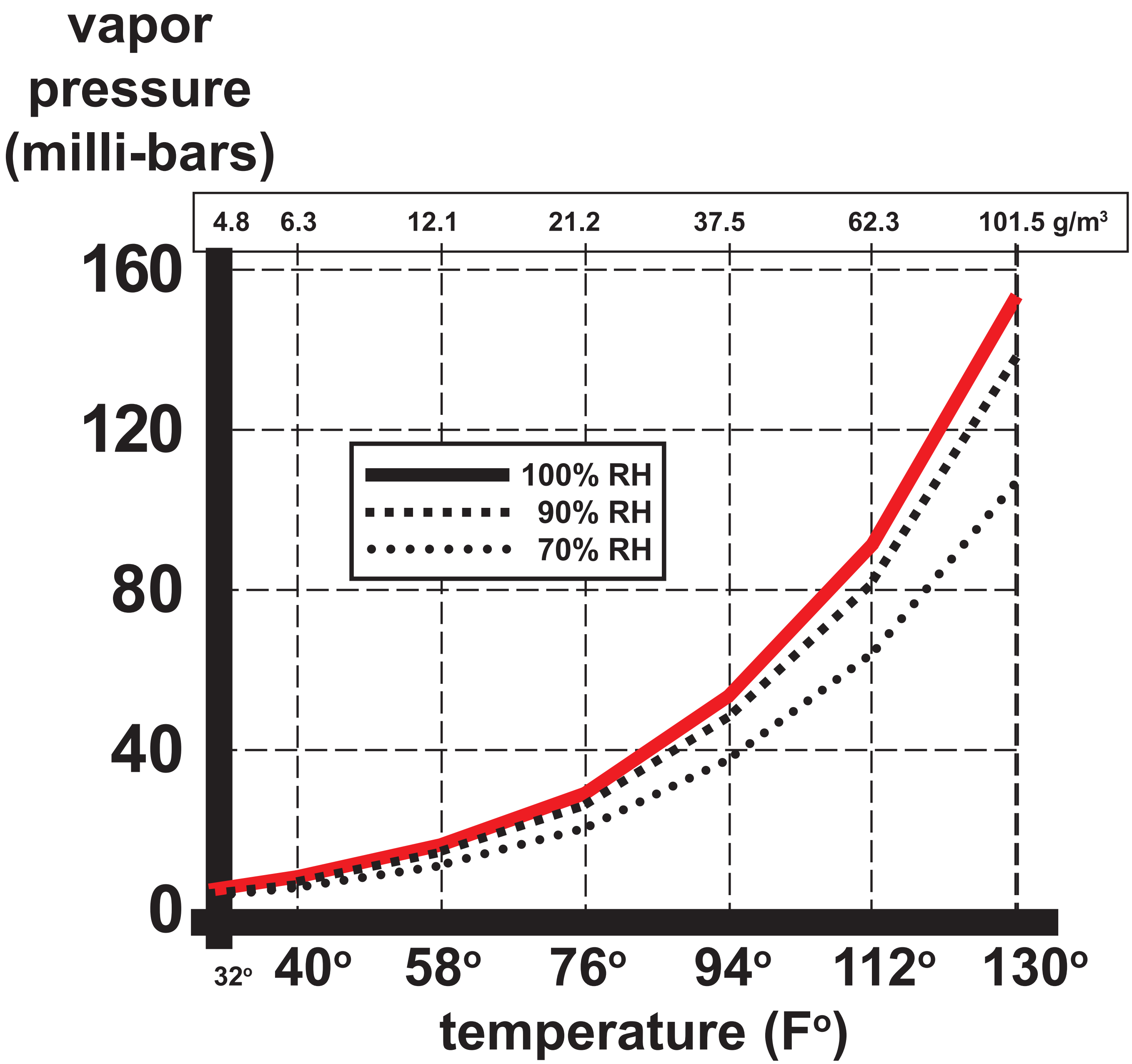

Figure 9: Saturated vapor pressure of water in atmosphere (100% relative humidity), the most water vapor normally found in air above liquid water. Also shown are 90% and 70% relative humidity (RH). The box over the graph contains the actual amount of water (vapor density in grams per cubic meter) in air for each temperature.
(value approximations derived from Tabata, 1973)

relative humidity (%)	air temperature (F°)				
	50°	60°	70°	80°	90°
100	0	0	0	0	0
99	-13	-13	-14	-14	-14
98	-26	-27	-27	-28	-28
95	-67	-68	-70	-71	-72
90	-138	-140	-143	-145	-148
70	-466	-475	-483	-492	-500
50	-905	-922	-939	-956	-971
30	-1,572	-1,602	-1,631	-1,660	-1.687
10	-3,006	-3,064	-3,119	-3,175	-3,226

Figure 10: Estimated water potential (bars) of air for various relative humidity values (percent) and temperatures (F°).

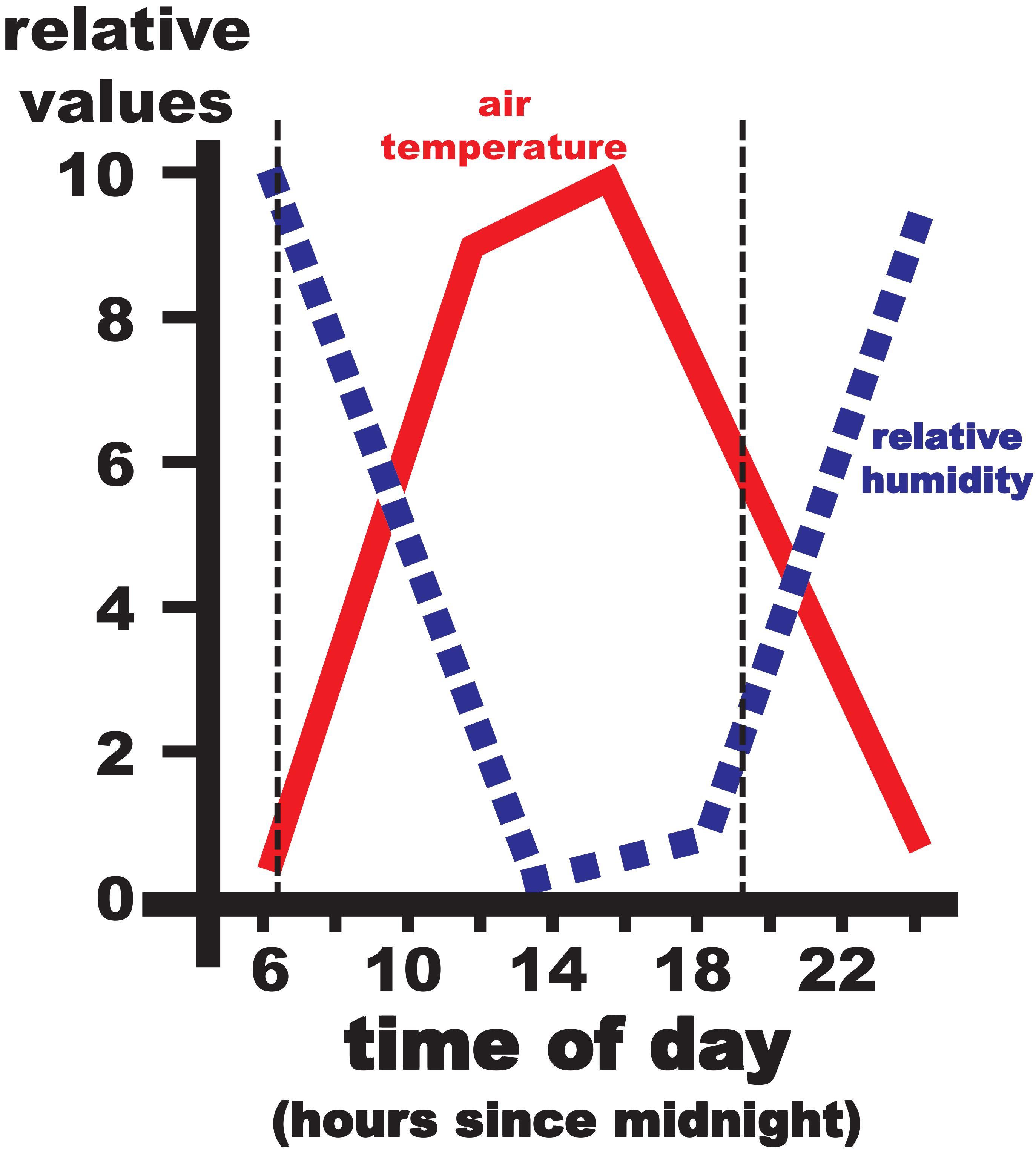

Figure 11: Relative value or measurement throughout a day for relative humidity and air temperature. Note the inverse relationship between temperature and relative humidity.

ICE (32°F) + 80 cal. = LIQUID (32°F)
LIQUID (32°F) + 100 cal. = LIQUID (212°F)
LIQUID (212°F) + 540 cal. = GAS (212°F)

Figure 12: Water physical state changes with energy added (cal. = calories).

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