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WATER (H2O) – TREE ESSENTIAL ELEMENT

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Life on Earth is a function of water, geology, atmosphere, and genetics. Life extracts materials in many forms from the Earth system and generates more complex materials using energy derived from chemical transformations and sunlight. Past and current success in material accumulation and concentration, plus failure of any life-generated materials to be instantly decomposed, provide the basis for many trophic levels of life to exist. The foundation of Earth's ecology rests primarily with sunlight-capturing and material-extracting green plants.

Green plants use fabricated organic materials, with associated inorganic elements, to capture light within narrow wavelength windows. This light energy is momentarily held within specialized compounds which allow time for chemical reactions to transfer energy away into other materials. Energy dense materials help generate a series of mass and energy exchanges, and build and maintain concentration gradients within biological membranes. Energy extracted from light is used to perform work in a cell and is transported using organic compounds to other cells within an organism. Trees do all of this energy capture and organic building, plus transport materials long distances and live many years.

Components

Eighty percent (80%) of all materials in a living tree is water taken from soil, with minute amounts taken directly from the atmosphere and precipitation. Of the remaining materials seen as a tree, roughly 19% are three elements derived from water and carbon-dioxide gas. These elements (i.e. carbon ©, hydrogen (H), and oxygen (O)) are chemically combined and boosted to a higher energy level (i.e. reduced) and visible as all tree parts. The remaining ~1% of tree material is composed of essential elements removed from soil, although small amounts of some essential elements (i.e. sulfur (S) and chlorine (Cl)) can be extracted from the atmosphere. Figure 1.

The sunlight powered synthesis process of a tree leads to other organisms consuming tree materials in some form, whether herbivores, parasites, scavengers, or symbionts. All organisms deriving life energy from this process generate waste, shed parts, and die. Synthesized materials outside living membranes decompose into simpler components, finally releasing all essential elements to the environment. These essential elements are usually reprocessed by other local organisms, chemically held within the soil, or eroded / leached away from the site.

Elements Of Life

Trees utilize 19 elements for life processes. Many more elements can be found inside a tree, but their concentrations are related to their concentrations in the environment. Figure 2. All elements essential for tree life are varied in chemistry and provide varied biochemical services within a tree. Some are used in only one or two processes (i.e. molybdenum (Mo)), while others are used to swaddle everything else (i.e. potassium (K)) within a water bath. Understanding tree essential elements help tree health care providers better manage trees and sites.

Life's Catalyst

A critical inorganic component of tree life is water. Roughly 80% of all variation in tree growth is water related, either through water concentration in soil, aeration interactions, and/or drainage in soil. Water is an essential "element" of trees. Although it is composed of two essential elements, it functions as a critical feature of everything living. Water dissolves, surrounds, transports, and buffers essential elements. The essential element bath and coating for tree life is provided by water.

Water is the catalyst of life. When water availability is constrained at minute levels, life slows, declines, and fails. Properties of water make it both unusual chemically and critical biologically. Water is relatively tiny as a compound, but acts large because of its electro-chemistry. Pure water in small portions is clear and colorless. Tree water is a solution of resources and living processes.

Essentially Wet!

Water is essential to tree life as well as its most limiting resource. 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 systems which sustain trees. Within each living tree cell is a water-based solution which contains, supports and dissolves a variety of elements, materials and molecules responsible for life. For example, water is the starting point for photosynthesis capturing energy from the sun, a hydraulic fluid, a transport stream, and solvent.

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 and 1 or 2 neutrons. The third atom in water is a massive oxygen which has an atomic structure which easily captures and holds up to two negatively charged electrons. These electron sharing 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, molecular weight 18 amu. The heavier isotopes of naturally occurring water (molecular weights = 19-22) may not be as biologically active as light water and are extremely rare. Figure 2.

Charge Exposure

In binding with oxygen, hydrogens tend to loose their negatively charged electrons 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. The 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. Figure 3. At a neutral pH (pH = 7), one in 10 million water molecules are ionized. As pH becomes lower (more acidic), more H^+ ions exist per liter of water. A pH of 4 means the concentration of H^+ is one in 10,000. Water molecules generally stay in one molecular piece, unequally sharing hydrogen electrons.

Sticky Shapes

The shape of a water molecule impacts its electro-chemistry and interactions with other water molecules. There are many ways to envision three atoms in water attaching to each other. Water molecules are not straight or in a 90^o L-shaped. Oxygen has four possible attachment points for hydrogens — 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 $\sim 105^o$ (104.5^o) angle away from each other around a much larger and massive oxygen atom. At this angle, each hydrogen presents a partial positive charge to other water molecules and materials. Oxygen presents two variable partial negative charges to other molecules. Figure 5.

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 can also 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 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, more molecules escape from liquid into a gas form (water vapor) with increasing temperature.

Hydrogen bonding occurs when hydrogen is positioned between two strongly electronegative atoms. Oxygen (O), fluorine (F), nitrogen (N), and chlorine (Cl) can participate in compounds with hydrogen bonding. Both oxygen (O) and nitrogen (N) form hydrogen bonds which can positively influence the shape or conformation of biological molecules. Both chlorine (Cl) and fluorine (F) pull apart and disrupt biologics.

Complex Structures

Water should not be viewed as a host of individual molecules interacting. Because of hydrogen bonding, water develops complex geometric relationships with surrounding water molecules, which exist in few other materials. The 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 semi-crystalline form in a liquid state. This semi-structure confers stability which makes water unique. Water is dominated by this stable semi-crystalline structure up to about 105oF (40.5oC). At this temperature the 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 (and negatively) 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 40oF (4oC) when water is at its densest. As liquid water continues to cool, hydrogen bonding of cold water begins to reorganize into larger areas of crystalline-like structures. As energy content in liquid water declines to 32oF (0oC), hydrogen bonds set-up a liquid crystal structure made of many tetrahedron shapes.

As water freezes, tetrahedron bonds are set into true crystal forms. This water crystal formation is a solid which is less dense than the liquid from which it formed. 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 its liquid form. Ice floats because it is less dense than liquid water. The lower density tetrahedron structure of solid water allows ice to float, and provides the basic building blocks and shapes found in snowflakes and frost.

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 demonstrating properties expected of a much different, much heavier and larger compound. Water interacts with any material having small irregularities in electronic composition. Water will adhere to many surfaces which have many forms of partial charges and ionic terminals.

Water forms a thin film around most soil and biological materials. For example, a landscape soil under drought conditions contains a relatively large concentration of water. This water content is sticking to, and surrounding, organic matter and clay particles, as well as filling small gaps or pores between particles. By placing soil in an oven at 212oF (100oC), 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.

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 water molecule 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 7. 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 their electrostatic charges and cohesion forces, helping these large molecules dissolve in water.

Electric Shells

Many tree essential elements dissolve readily in water and form ions, either positively charged "cations" or negatively charged "anions." Ions come from the disassociation or separation of a molecule. Table salt easily ionizes into the positive cation sodium (Na^+) and negative anion chlorine (Cl^-) when stirred into water. The full charges on the ions cause the partially charged water molecules to line-up and surround each in a hydration sphere or layer. Ions then tend to behave as much larger molecules because they are blanketed with many water molecules attracted to their charge. Figure 8 lists tree essential element ions as used by trees.

In soil, most essential element atoms 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. 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. This physical property helps water dissolve many things. Water infiltrates and coats life and its resources.

Biology

Water provides a solution and climate for specific biochemical reactions to occur. The structure or configuration of enzymes depend upon structural support of water. 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 oxygen in O_2 gas released in photosynthesis is derived from water. The hydrogens and electrons from water are used for chemical reduction of CO_2 captured from the atmosphere. Water provides electrons, hydrogens, and oxygen to capture light energy, make tree food, and produce oxygen gas! Water is a tree essential "element." Figure 9.

Conclusion

Water is an universal elixir of tree life. 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, aeration, and drainage in the soil. Water is critical to trees!

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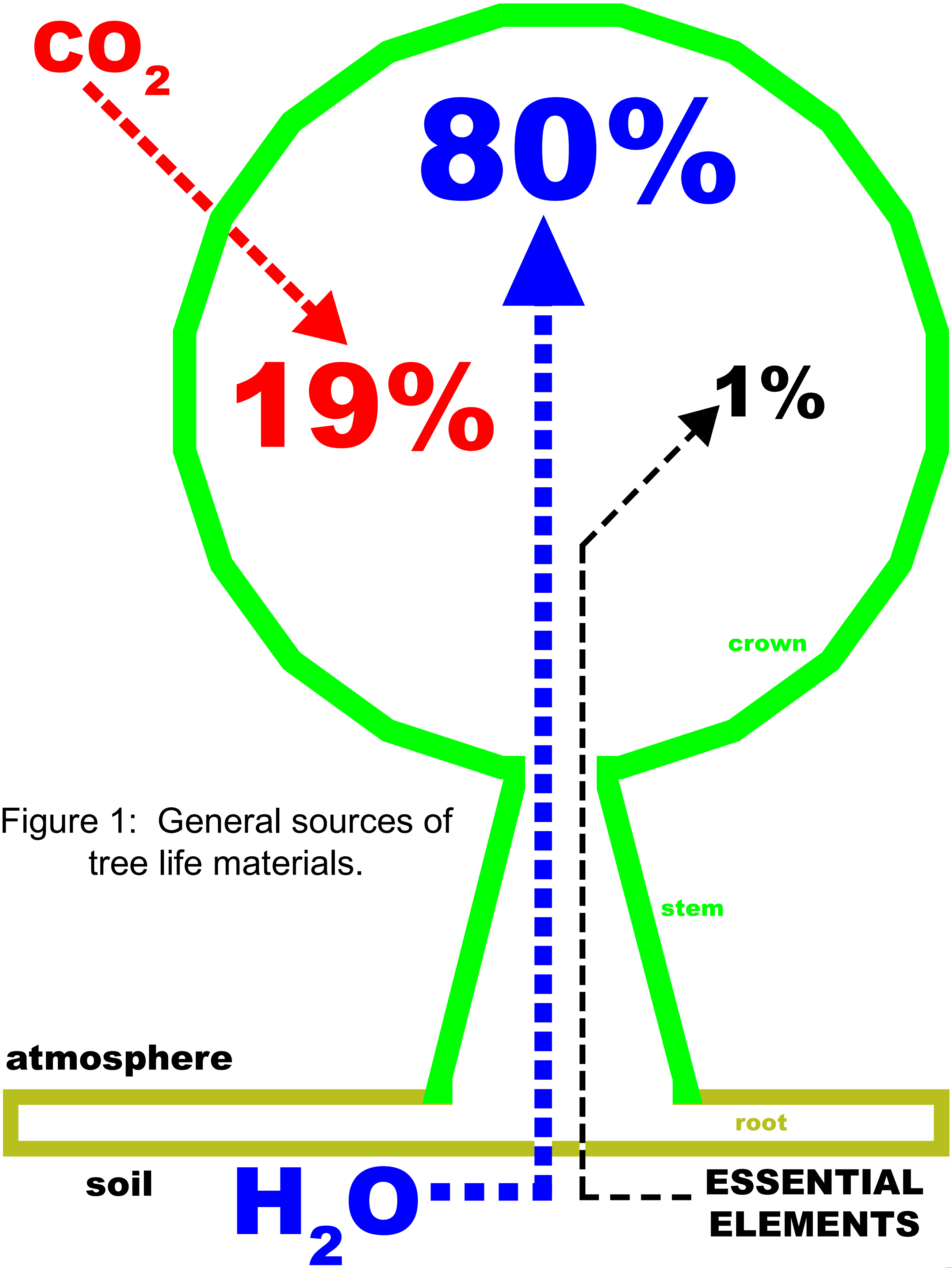

Figure 1: General sources of tree life materials.

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%

Figure 2: Percent of the nine (9) naturally occurring water molecule forms in the atmosphere.
(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.

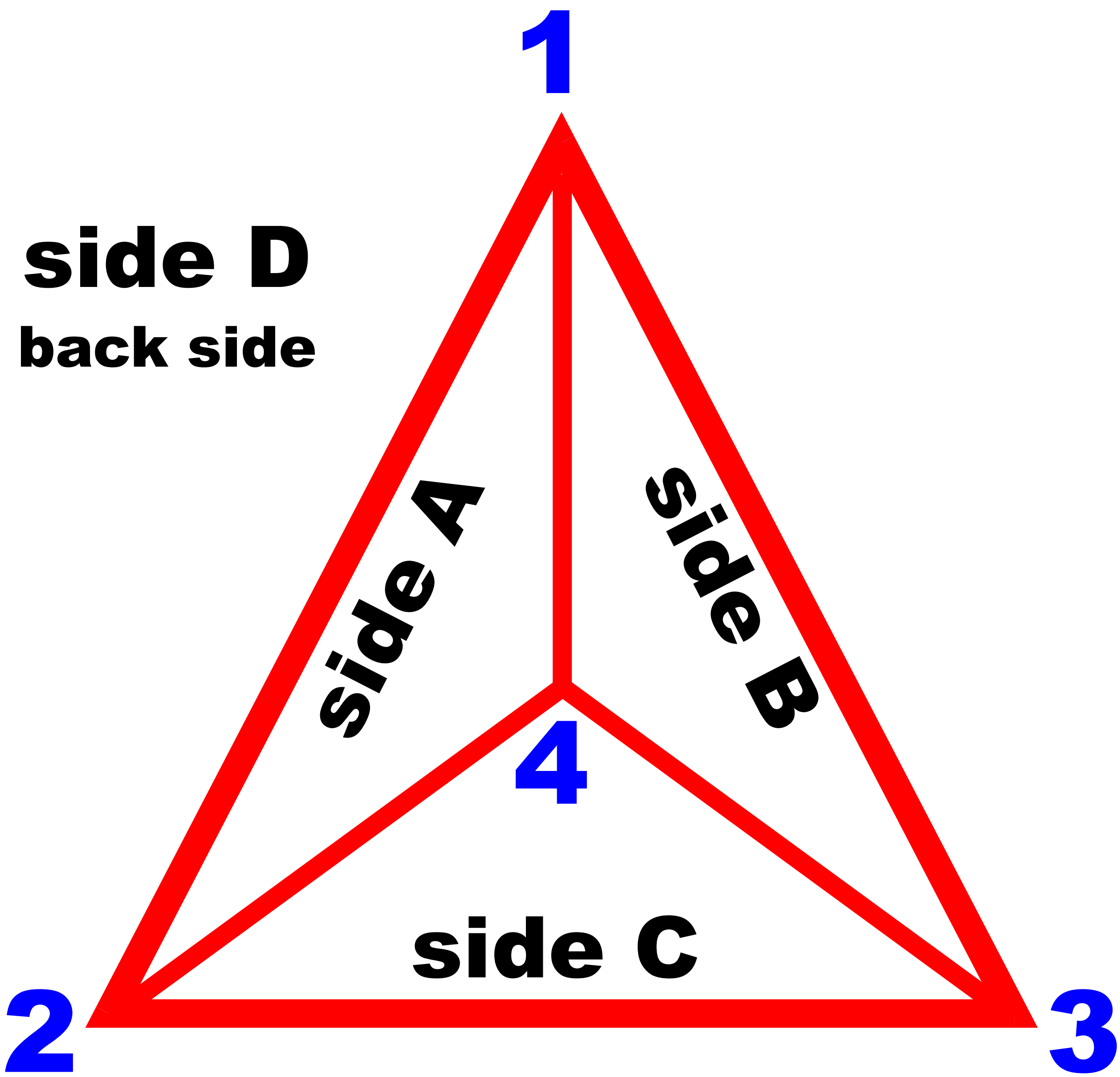

Figure 4: Oxygen bond attachment geometry is in the form of a tetrahedron with four corners (1-4) and four sides (A-D), only two corners can be used to bond with hydrogens.

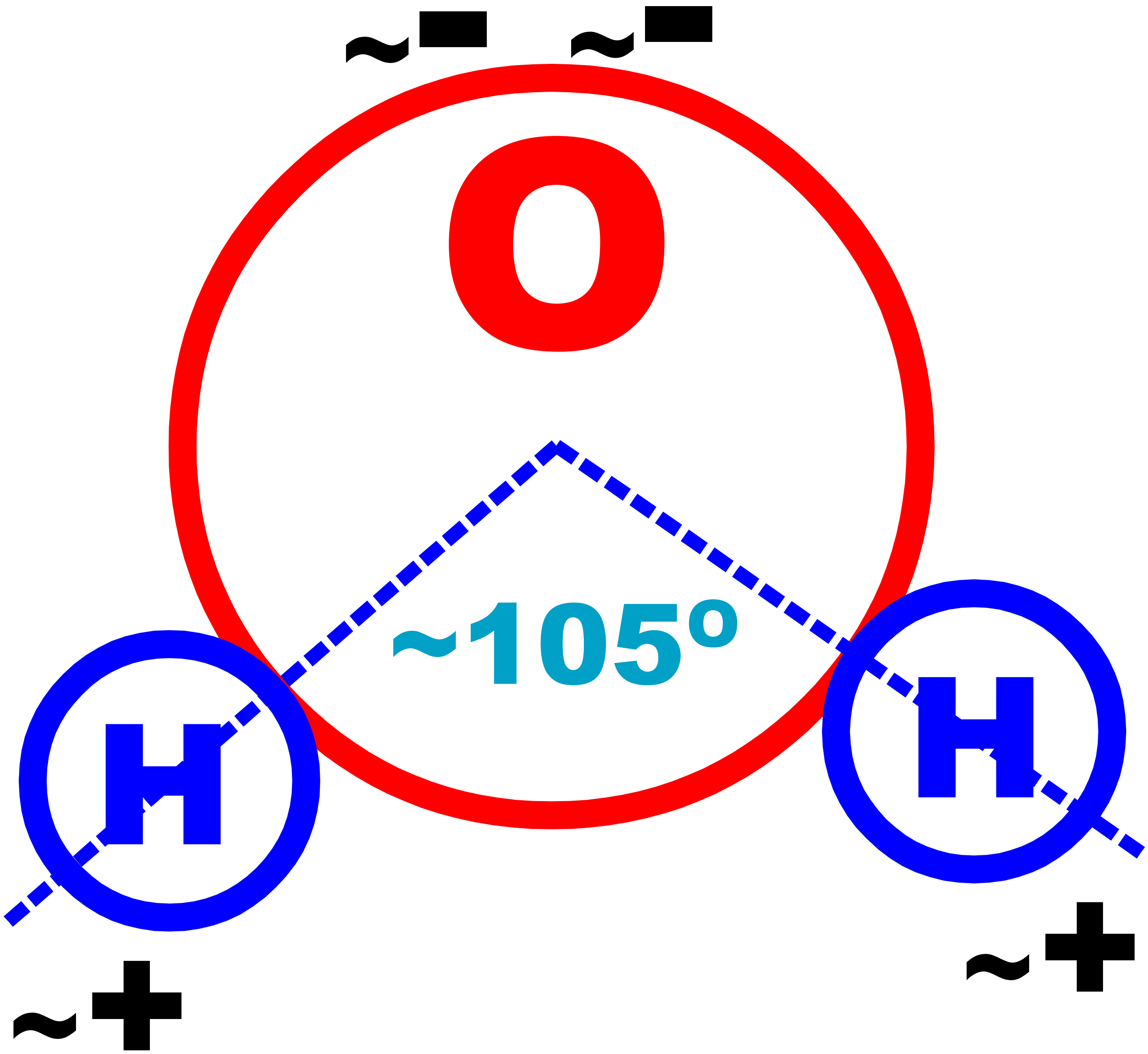

Figure 5: Diagram of water molecule with oxygen (O) and two hydrogen (H) atoms. Hdrogen atoms are always separated by ~105º (104.5º) as they glide around the oxygen's perimeter, never on opposite sides.

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.

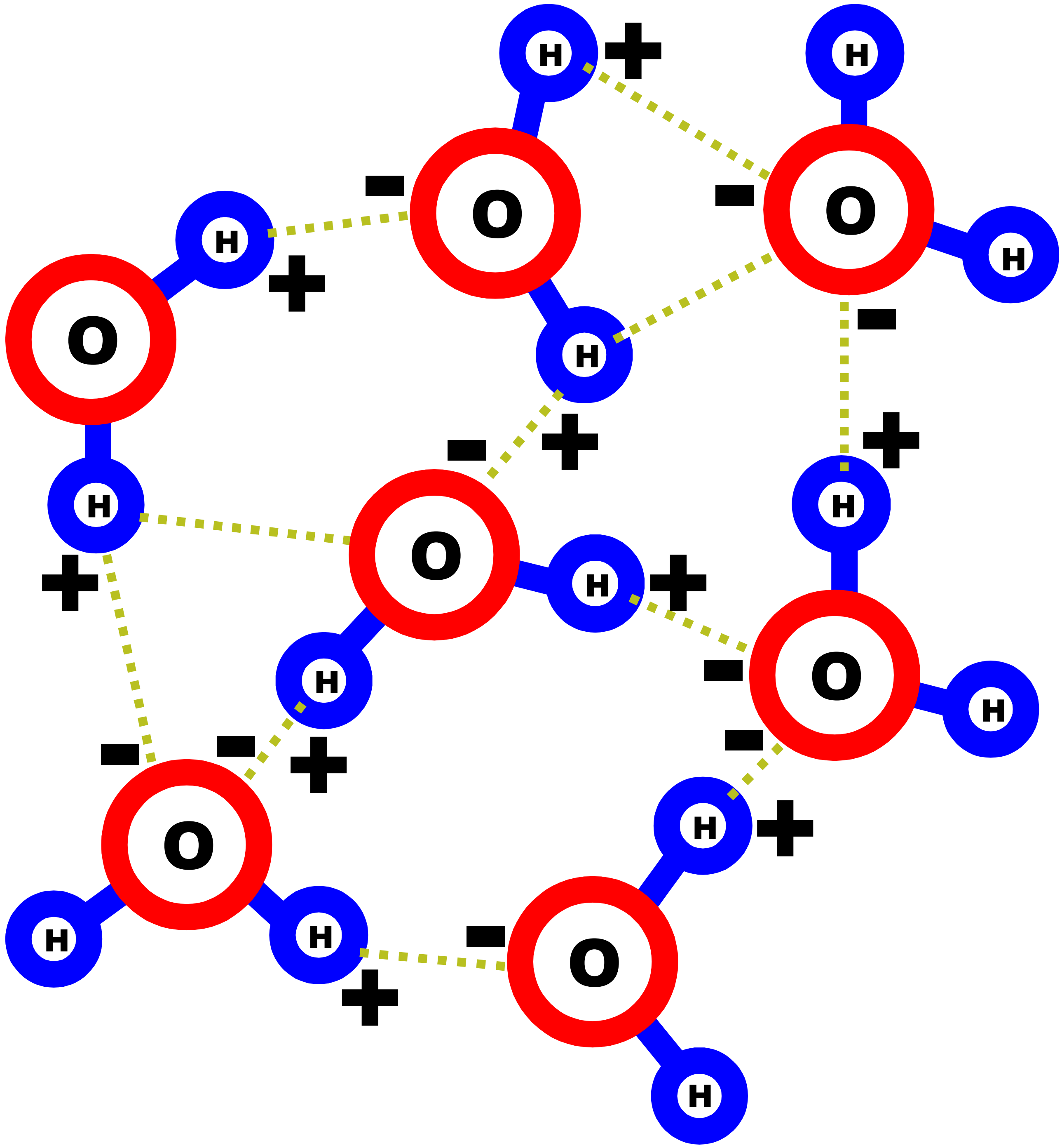

Figure 6: Diagram of seven water molecules interacting with each other due to partial electrostatic charges and associated 0 to 4 hydrogen bonds per molecule.

The dotted lines represent hydrogen bonds. Remember, this is a simple two dimensional diagram, while water molecules are in a four dimensional framework of constantly changing hydrogen bonds.

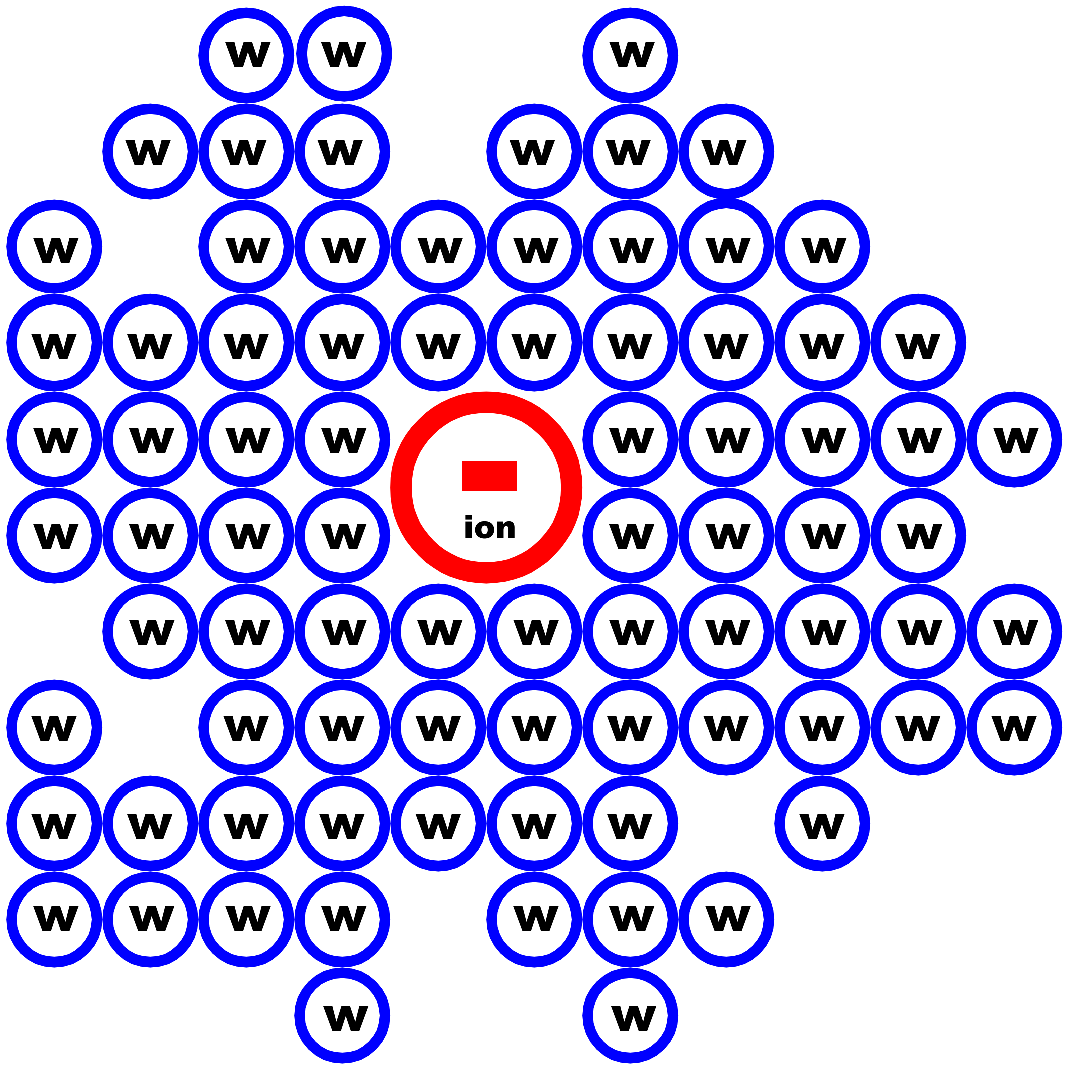

Figure 7: Two-dimensional diagram of water (w) molecules surrounding an ion with a negative charge, generating a hydration sphere, effectively increasing ionic size and blanketing full ionic charge. The partial positive charges on water molecules surround the negative ion. A hydration sphere is actually four dimensional, and under constant change.

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 a neutral molecule

Figure 8: Tree essential element ionic uptake forms which are surrounded by a water hydration sphere.

Figure 9: Coder Spiral of Tree Essential Elements, all contained within water shells and moved in a water bath.