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Evapotranspiration: Gravity Defying Water

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I teach Phy-Chem and AP Biology in an urban magnet high school. Phy-Chem is understood to be a freshmen general science class with an emphasis on physics and chemistry. AP Biology is a high school biology class that uses a college curriculum provided by the College Board. At my school AP Biology's, like all AP classes, enrollment is an open-door policy wherein students can choose to take the class and do not have to meet any requirements to enter. The Phy-Chem curriculum is structured around 21 Next Generation Science Standards (NGSS). These standards are drawn from both the physical and environmental science standards as well as engineering standards.

This high school is a performing arts magnet school drawing students from within New Haven as well as the surrounding districts. There are approximately 650 students all of which are focused on an art for their four-year high school enrollment. We utilize a block schedule wherein classes are 85 minutes long and repeat every other day. This presents many challenges concerning homework and turn-around time for feedback on in class work because of the long gaps between class meetings. Conversely it does allow for long class periods that lend themselves to activities that utilize multiple modalities.

The content of this unit is applicable in both a biology class and an earth science class. Thought it might lean heavier towards biology with the flow of water through plants the importance of water cycle in general and the relevance of the properties of water are of top priority in any earth science curriculum. I would expect a student in biology to have a working knowledge of the properties of water so that the when presented with the phenomenon of water flowing against gravity through plant life the focus can be on the plant structures more so than on the water.

The phenomenon, or hook, for this unit is the movement of water against the pull of gravity, in particular to the top of our giant trees such as the *Sequioa semperivens* (giant redwood) which reach heights of over 300 feet. Teaching around a phenomenon is the current trend with the States adoption of the Next Generation Science Standards (NGSS). I will note the standards applicable to this unit in the appendix. The use of water transport in plants is an effective phenomenon because not only is easy for students to grasp the oddity of water moving against gravity but also because the understanding of this action requires students to grasp scientific concepts from multiple disciplines. Though not immediately exciting to think about, it is easy to find ways to draw students in, for example one can dissect a plant and find that there are no organs or obvious machinery present to pump water against the pull of gravity. There are also multiple hands-on activities concerning the properties of water that will help to keep students engaged as they anchor scientific principles to the phenomenon.

For one to effectively teach about water transport in plants I believe it is necessary to first consider the need for teaching for understanding. One needs to consider the over whelming evidence of the importance of understanding over the memorization of facts. Understanding a concept allows one to apply their understandings to other situations impacting their ability to learn new concepts. Taking the approach that understanding is the goal of teaching a teacher can revisit their teaching methods and adjust them with that goal in mind. Assessing understanding can be difficult because it does not always lend itself to the typical assessment task such as a paper and pencil test. Different methods of assessment will be discussed.

Relevance of Teaching for Understanding

Teaching for understanding is about the pursuit of science literacy for our students. This is embedded in critical literacy. A scientifically literate person is perceptive about the world around them and also empowered to make decisions. If you consider that education has the broad purpose of producing an educated populous to govern and lead a country the need to pursue scientific literacy is apparent and urgent. Our students cannot be effective stewards of this planet if they do not have to the tools to engage with the knowledge that is available to them. They must be able to think critically about the issues that shape our planet, such as climate change, disease, and technology to name a few.

Maria Grant and Diane Lapp offer four actions to foster critical thinking in the classroom (Grant & Lapp, Teaching Science Literacy, 2011). Grant and Lapp argue that teachers must identify science topics of interest, engage students in reading the research, teach students to read like scientists, and guide learners to evaluate data.

Teaching Through Topics of Interest

Teaching through topics of interest is about captivating students' attention by delivering necessary standards through application of those standards within the context of a relevant issue or phenomenon. If students are interested in the issue the relevance of the content and skills associated with understanding the issue are important to the student. Increased interest in a topic will inherently interest classroom engagement. Often we struggle with students that think that science has nothing to do with their everyday lives when the truth is there are connections with almost everything. We are also confronted with students that feel as if science involves some sort of unobtainable un-accessible skill set, when the truth couldn't be further from this belief. Science is merely the pursuit of answers, driven by curiosity or necessity. The problem for our students is that the skills to effectively discover answers are skills that need to be directly taught. These skills can seem daunting but the trepidation that students have can be overcome when they realize that the skills used allow them to answer the questions that they have.

Evapotranspiration is the process in which water is transferred to the atmosphere via evaporation from soil and surfaces as well as through plant transpiration. Plants acquire water through their root systems and release water through their leaves. The openings on the leaves are called stomata. Stomates open in order to let carbon dioxide (CO_2) in for primary production. When they do this the plant loses water twenty times faster than they gain CO_2. This is a major dilemma for plants. A significant amount of rainfall that hits soil is absorbed by roots and ultimately transferred back to the atmosphere due to this high demand of water by plants. This is achieved through both biological and physical properties. This unit will focus on the role of plants in evapotranspiration. The information in this unit may be used in a physical science curriculum to add a little life to the teaching of the water cycle. It is also pertinent to a biology curriculum. In this unit you will find descriptions of the physical properties of water that allow it both change phase and move against the gravitational pull of the earth. You will also find information about the structure and function of particular plant anatomy. Lastly, there is a section of this unit that covers the role of evapotranspiration in the water cycle. I use this unit in both my physical chemistry class and biology class, there are some easy to do labs in the activity section as well.

Engaging Students in the Research

Students require a base of knowledge to understand a concept effectively. It is important that students understand that research is always necessary to understand a concept. The issue is that science textbooks, and of course journal articles, are laden with vocabulary that our students are not normally exposed to. The vocabulary is often content specific and cannot be unmarried from the literature if descriptions are going to be left intact and complete. The necessary texts are flush with “multisyllabic words and sentences that require extensive background knowledge.” We must be conscious of the barrier vocabulary may present and utilize appropriate level texts while teaching students how to approach a reading that has new words. We must also take into consideration the amount of new words needed to understand a concept and keep it to a manageable level. Using articles focused on relevant ideas is helpful because students will want to understand the new words.

Students Reading Like Scientists

It is not enough to just offer or assign readings. To help students become scientifically literate we must instruct them on how to read like a scientist. If a student is to be learning while reading a science textbook they must know that thinking while reading is key. Direct instruction may be necessary for our students wherein the teacher can model the method. If a scientist is reading a text he/she is constantly trying to connect the new information with previous information. He/she is also trying to understand every graph, image, or table by using clues in the images and text. Furthermore, he/she will check for understanding by forming statements and arguments in thought.

Evaluating Data

Generating conclusions is pivotal to science and students need help understanding what a conclusion in science is. Nuanced within the formation of a conclusion is the correct evaluation of data. Scientific study offers seemingly endless ways to label and quantify data. It is important that teachers do not overlook all the labels and units that may be relevant to data that we use during lessons. In order for our students to make accurate conclusions they need to understand the meaning and relevance of the data presented. For example many of my freshmen struggle with the concept of concentration or that of rate. I find that I have to intentionally teach what I assume is background knowledge, but if not addressed their ability to formulate an accurate conclusion is hampered.

Evapotranspiration

When plants transpire, which is the release of water vapor through the stomata, this is considered evapotranspiration because water is essentially traveling from the land to the atmosphere. The cumulative evapotranspiration of plants has an effect on global climate as it impacts the amount of moisture in the air.

Acquisition of Water by Plants

Water is absorbed by terrestrial plants through their root systems. Within this water there will be beneficial nutrients dissolved, but the focus of this unit is solely on the transport of water through a plant. Plants do not have any organs to "drink" water and rely on the surface tension of water to move it through and into the tissue. This action relies on the cohesive and adhesive properties of water as well as the phenomenon of water potential. These properties of water result from the polar nature of the water molecule. Following is a discussion about the emergent properties of water. The specifics of water movement into the root system will be covered further in this unit.

Water

Fundamental understandings of phase and phase change are important in the pursuit of the bigger understanding of the importance of the properties of water. Water is so ubiquitous that it is often overlooked in the class room. Water has properties that help to explain why it is paramount to life on Earth. Connecting the concepts of phase will help students to form connections between the properties of water and its connection to life.

Water has four properties, known as emergent properties, these properties are due to the polar nature of the water molecule. Water consists of two hydrogens and one oxygen covalently bonded in a "V" shape with oxygen at the apex. The oxygen is more electronegative than the hydrogens and the electrons of the hydrogens spend more time closer to the oxygen. This structure results in a polar molecule wherein the oxygen has a slightly negative charge and the hydrogens a slightly positive charge (see figure 1). This polarity allows water molecules to interact with each forming weak hydrogen bonds between two opposite charges of adjacent molecules (see figure 2). Through this polarity and resulting hydrogen bonding, water gains four important properties: cohesive behavior, ability to moderate temperature, expansion upon freezing, and versatility as a solvent.

Figure 1:

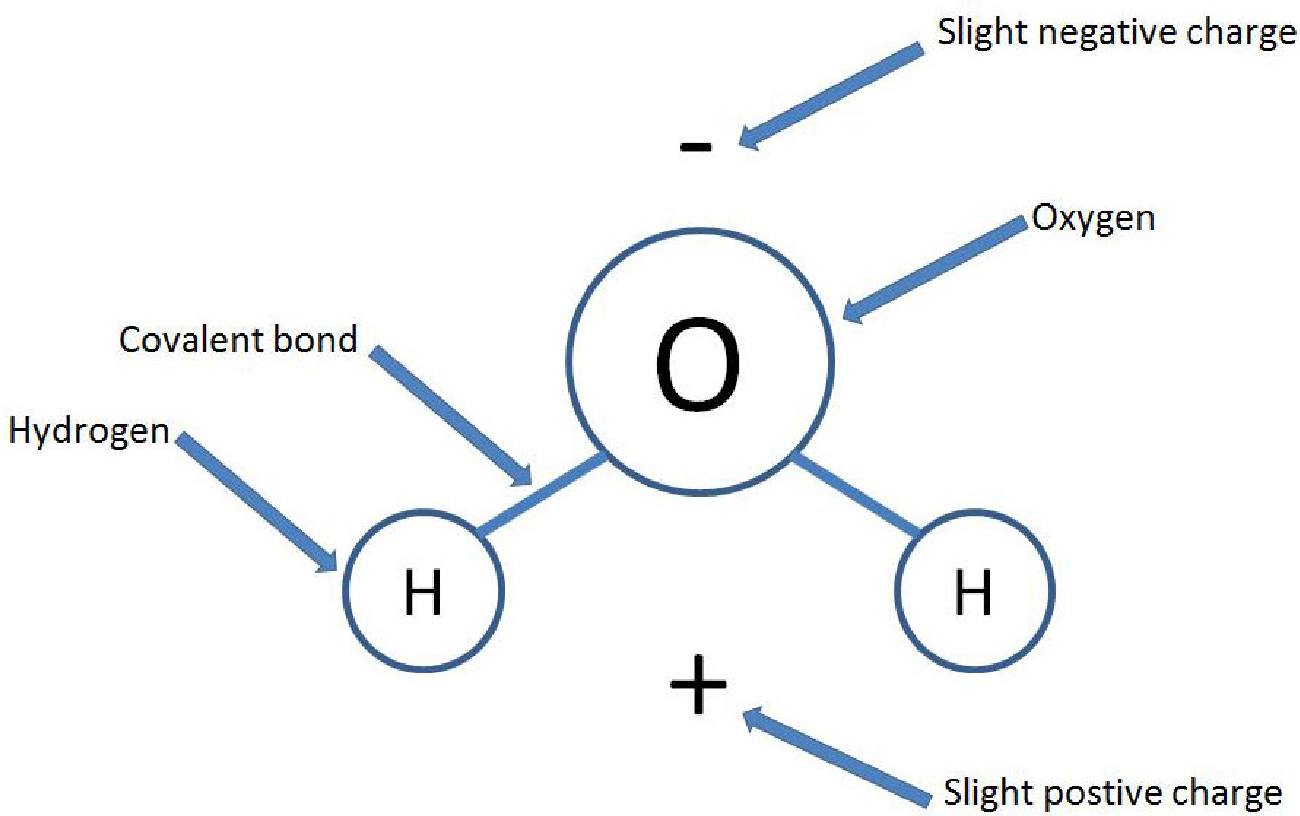
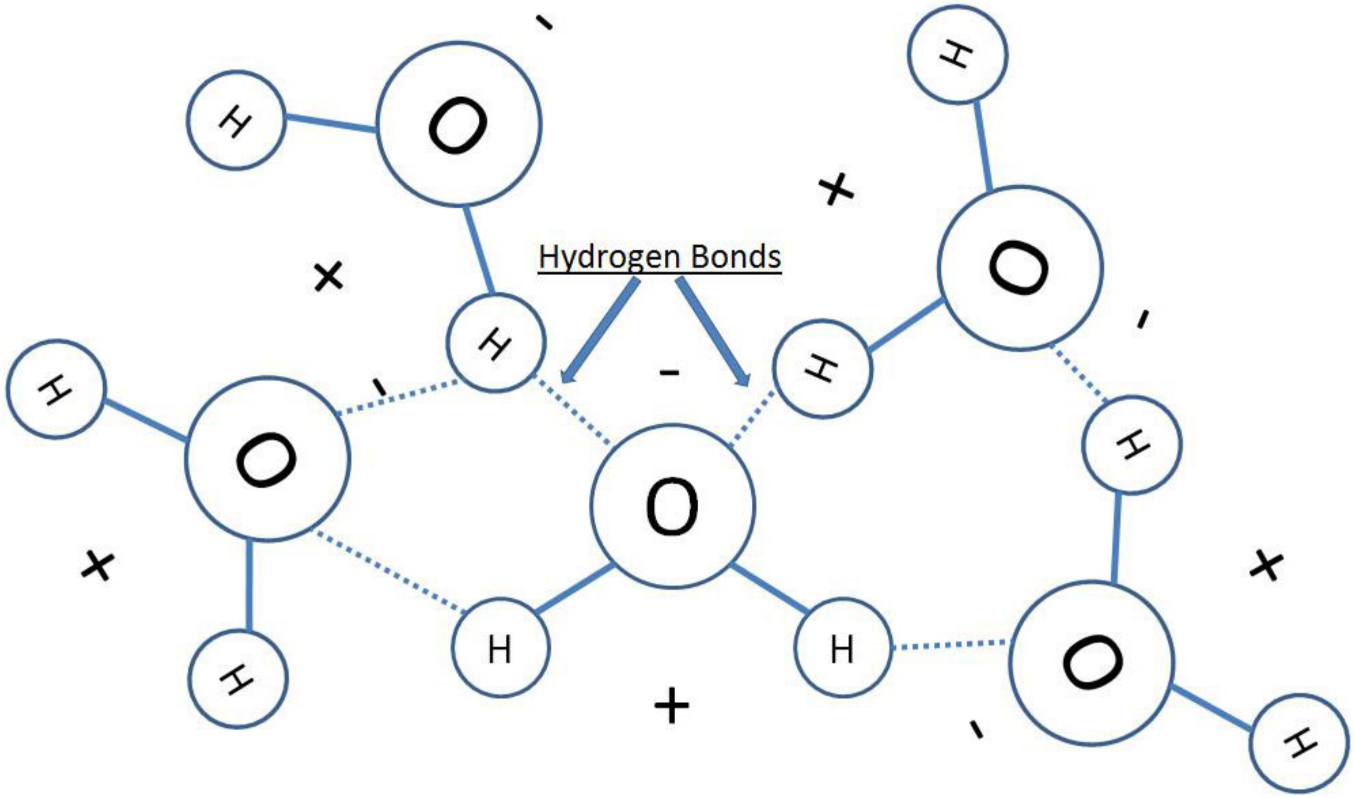

Slight negative charge
-
Oxygen
O
Covalent bond
Hydrogen
H
H
+
Slight postive charge

Figure 2:



Cohesion

How does a tree transport water against the force of gravity? Cohesion is the attractive force between two like molecules. Simply put, water sticks to water. This is because water is a polar molecule allowing for interactions of opposing charges when surrounded by other water molecules. Adhesion is the attraction of water to other surfaces that have charged particles. These properties allow terrestrial plants to transport water throughout their structures through specialized networks of water conducting cells. Contained within the water are vital nutrients and minerals as well.

Cohesion and adhesion can be demonstrated in the classroom with capillary tubing. This is thin glass tubing that will draw water up, against gravity. The polar water molecules will interact with ions in the glass, bonding with the glass. The water that is bonding with the glass will also continue to be bonded with other water molecules. As molecules are attracted higher and higher up the tube they will drag behind them more water. This is similar to how water is transported within a plant and can be used for visualization. The water leaves the stomates when they open to acquire CO_2. Due to this "unbroken chain" of water through the plants, when water leaves the stomates, water is drawn water from the roots upward. This upward movement is caused by the adhesive and cohesive nature of the water. This unbroken chain of water can be broken if the water freezes or an embolism forms due to a compromise of the xylem. This can threaten the fitness of the plant.

Moderation of Temperature

Why does our planet have such a relatively constant temperature? Water has a high specific heat. It takes one calorie of energy to raise 1 gram of water by 1˚C. Conversely as water cools, a calorie is lost for every gram of water that drops 1˚C in temperature. Water is held together by its hydrogen bonds, though weak in comparison to a covalent bond, they still require significant energy to overcome. This allows water to absorb heat without changing temperature rapidly in comparison to many other liquids. Heat is a measure of kinetic energy, a given volume of water's total heat is a measure of its total kinetic energy. Temperature is a measure of the average kinetic energy of the molecules that make up the matter. Thus it is important to note that heat and temperature are not interchangeable. Students can struggle with this concept and it may help to have them consider that a boiling cup of water has a higher temperature than a swimming pool, but the swimming pool has more heat.

Earth's temperature is relatively constant, in part, because of the water that covers 70% of its surface. This water absorbs heat during the day and summertime and releases this heat slowly at night and during winter months. The resistance of water to rapid temperature changes allows it to absorb and release massive amounts of heat while maintaining a relatively stable temperature. This has allowed for the persistence of life in our oceans as well because flora and fauna are subjected to major temperature swings. The movement of water among the oceans helps to distribute heat to areas of the world. For example, the Gulf Stream delivers heat to the west coast of Europe.

Most organisms are primarily water by mass. Considering the high specific heat of water one can realize that this allows organisms to avoid rapid temperature changes due to environmental conditions. Furthermore, many organisms utilize evaporative cooling. In the same note that it takes an energy investment to increase the temperature of water, recall that it also requires an energy investment to cause a phase transition of water from liquid to gas. Water on the surface of an organism will absorb heat from the body as well as the surroundings and when this water evaporates, it takes energy. The net effect is that the molecules left behind have less energy. This is a repetitive process that helps organism to maintain their temperature by essentially passing excess energy to water molecules to cause evaporation. This process of evaporative cooling also aids lakes and ponds in maintaining their temperature.

Expansion Upon Freezing

Very few substances are less dense as a solid than a liquid, water is one of them. Ice is about 10% less dense than liquid water causing it to float. This is due to the crystalline lattice structure formed when water freezes. Because of the polar nature of the water molecule and its "V" shape it is arranged in a crystal that has spaces when solid. This ice creates an insulating layer over lakes and ponds in the winter months. The ice allows liquid water to persist below it, a necessary medium for the flora and fauna to persist. If ice were denser than water our lakes and ponds would freeze from the bottom up completely changing the survival strategy of organisms.

This property of expansion upon freezing also helps to shape our planet. As water seeps into crevices and cracks of rocks and is then caused to freeze and expand it widens those openings. Over time this property contributes to the weathering and erosion of rocks. Not to mention the creation of obnoxious pot holes on our roads.

Versatile Solvent

The polarity of water causes it to dissolve substances that are polar, ionic, or have polar or ionic regions in their molecules. This allows for water to be a wonderful biological medium in cells. Dissolving many substances readily makes for easy transportation of substances within cells and between cells. This property allows plants to acquire nutrients effectively through water intake.

Water Potential

Water moves across membranes because of differences in water potential. Water will move from areas of higher water potential to areas of lower water potential. Water potential is a measure of potential energy between a given sample of water and pure water. There are four factors that impact water potential: solute potential; pressure potential (turgor in plants); gravity potential; and matric potential. Each of these factors either increases or decreases the potential energy of a sample of water in comparison to another sample of water.

You can think of water molecules as having a given amount of energy. Considering a sample of water with a solute dissolved within, the water molecules of that sample have less potential energy overall because they are interacting with the solute. This is the basics of the effect of solute concentration on water potential. Given two samples of water, one with a solute and the other pure water, the pure water will have more potential energy. This is assuming all other factors are the same. Now assume that you have these two samples separated by a barrier that is permeable to water and not the solute. There will be a net movement of water molecules from the side with pure water because of its relative greater potential energy. You can do a simple demonstration in the class room with two sticks of celery. Place one in a cup with pure water and the second in a cup with salt water. After some time the stalk in pure water will be rigid and the one in salt water will be flaccid. This happens because of water potential. The stick in fresh water was immersed in an environment with a higher water potential than its cells. The result is that cells take in water to their capacity, now full there is pressure exerted on their cell walls and the entire structure is rigid. In contrast the stalk in salt water was immersed in an environment with lower water potential than its cells. In this case water moved out of the cells and into the environment leaving the structure as a whole more flexible.

Pressure as it pertains to water potential is a more straight forward concept to understand. If two identical samples of water are separated by a semipermeable the sample with greater pressure will have more potential and there will be a net movement of water towards the side with less pressure. In plants the pressure of interest is turgor pressure. Turgor is developed within a plant cell through the control of ion concentrations and the central vacuole. This is unique to plant cells as they have rigid cell walls that which can withstand pressure. For example, the central vacuole can be expanded with fluid thus taking up more space in the space within the cell. Since the cell wall is ridged, space is finite, thus pressure can generated that impedes the flow of water into the cell. Imagine you and some friends are trying to get into a room that is 10’ x 10’. There is a balloon with a 10’ diameter in the center of the room. If that balloon is fully inflated it will severely limit how many people fit in the room and if it is deflated it will not have such a big impact.

Gravity is a factor when it comes to water potential but is often of no consequence as the interface between two fluid containing bodies is just that, an interface, thus they are exposed to the same gravitational forces by default. Of note though, is the fact that trees that are transporting water hundreds of feet from the ground and therefore the effect of gravity cannot be overlooked. That being said, we must leave it as just a thing of note when considering that the water potential within the root system must be less than that of the surrounding soil. A tree of any significant height must have a strategy to compensate for the increase of water potential caused by the elevation of the water within the vessels and trachea of the xylem. The gravitational pull on this continuous column of water from root to tree top will increase the energy potential.

Matric potential is similar to solute potential, but in this case the water molecules are interacting with surfaces. This interaction is adhesion. Plant cells have walls made of cellulose, a material that is highly hydrophilic, as in water has and affinity for it. Cellulose fibers are arranged in a matrix, thus the designation of a matric potential. The impact of this is important because it results in a lower water potential within the plant when compared to the environment, assuming other factors are equivalent to each other. When a plant is fully saturated its matric potential is zero. This is because all cellulose is associated with water. In contrast if the plant is not saturated, the matric potential creates significant negative water potential for the plant, encouraging water to be drawn into the root fibers. Matric potential is an important factor for water uptake by roots from soil. Soils can have a high matric potential as well because of the composition and shapes of soil particles. Particles of soil are irregular and full of tiny crevices that increase their surface area. Water acquisition by plants must overcome this attractive force between water and soils. This will be discussed in further along in this unit as surface tension in the xylem of the plant stem is addressed.

Roots: Water Absorption

The roots of a plant terminate in thin tubular extensions of root epidermal cells. These are referred to as root hairs. These hair-like extensions are the water collecting structures of the plant. They increase the surface area of the roots enormously, allowing for efficient water collection from the soil. In addition to these plant structures most plants have a mutualistic association with fungi that aid in water absorption. These fungal associations are called mycorrhizae and they further increase the surface area available for water collection with their fibrous hair like extensions. Ultimately water moves from soil to root because of water potential. A successful plant maintains water potential lower than that of the soil it is anchored in, thus facilitating the flow of water from soil to plant via osmosis. This is driven by evaporative loss of water at the leaves, the terminus of the plant’s water column.

Stems: Water Transport

The stems of a plant have tubular cells referred to as xylem. Xylem is responsible for the vertical movement of water up a plant. There are many features of xylem that allow it to defy gravity and many other physical properties. The method employed is to utilize the surface tension of water to maintain a negative pressure environment. Recall that water will flow from areas of high pressure to areas of low pressure due to water potential. How this is achieved within the plant stem I cannot fully explain but I will share the main ideas as well as adaptations that plants have evolved to combat forces that would compromise the goal of moving water.

Tension is the force that moves water up through a plant to the leaves. This tension is the result of cohesive and adhesive forces of water. The end product is a pressure differential between the column of water in the xylem of a plant and the surrounding environment. The water is essentially in a negative pressure state. When a stomate is opened the water escapes as vapor and replacement water is pulled up from the root system at the base of the plant because the water column within the plant is in low pressure, contrast to the higher pressure at the root system. The issue is that gas bubbles, or embolisms, can easily form when water is in low pressure. Particularly when gas has dissolved in water of higher pressure than it is later subjected to, think of a can of soda being opened. The column of water within the xylem may be at a pressure equivalent to -20 atmospheres.

Gas bubbles, or embolisms, do not regularly form though in the column of water, gases stay in solution because of the surface tension of water and the lack of any sights for nucleation. The low pressure of the water column cannot support a gas bubble because the surface tension of water is a greater force. The walls of the xylem vessels are sufficiently smooth as to not support sites of nucleation or cavitation events. There are no areas for a bubble to be shielded from the surface tension forces of the fluid. A nucleation site can also occur at any microscopic area that is hydrophobic, giving a gas a sort of starting point. With the lack of any area to start a bubble, bubbles do not regularly form in the column of water within a plant. In fact bubbles do not normally form without a nucleation site. Consider that water can be super-heated and then explosively boil, well after it has reached the boiling temperature. This can occur in the home with a brand new pot or piece of glassware. The new material has the potential to be so smooth that there are no nucleation sites for a bubble to form. Often the mistake is that once a utensil is immersed in the super-heated water it instantly boils as the utensil has sites for nucleation.

The instance of embolism formation under regular circumstances is limited by the negative pressure and lack of nucleation sites, but it can happen. There are also structures that prevent a gas bubble from expanding and migrating should one form in the first place. There are perforation plates that separate xylem vessels vertically. Between a two sections of xylem vessels there are these barriers that all fluid must pass through to reach the next higher section of the column. These perforation plates limit the growth and propagation of embolisms by forcing the fluid through small holes in the perforation plate. These serve to decrease the size of any possible embolism and as the size of the bubble is decreased its ability to expand decreases as the effect of surface tension on the bubble is compounded. The smaller the bubble the more surface tension force there is on it because of its decreased surface area to volume ratio, thus the less likely it is to expand and grow.

There are also passageways between adjacent xylem vessels, these allow for the flow of water to continue upwards should a vessel be interrupted by damage or embolism. These are again minute passage ways that limit the ability for an embolism to pass through thus isolating the embolism in one vessel or vessel section.

Lastly, the interface between the column of water and the outside environment, at the terminus of the column in the leaf, must be addressed. Surely this could be an area with rapid evaporation as the water in the column is at such low pressure that it is essentially ready to boil out as vapor. The fact is though that the end of the column is not an opening equal in diameter to the tube itself. The end is layered with a matrix of cell wall material, creating an almost felt-like structure. Within this structure there are countless interfaces between water in the column and air. Each opening is so small though that the surface tension is strong enough to hold the water molecules in the liquid state, to a point. Picture how water forms a meniscus in a glass graduated cylinder, this curvature is formed by the attraction of water to the class and the surface tension. You can imagine that these tiny curves exist at each tiny interface as water has a high affinity for the cellulose in the cell wall. There exists a massive pressure difference between the water at these interfaces, because of small size, and the atmosphere. The difference is so great that it causes the water to curve in significantly. Water is of course lost or passed on to the environment from these points, but at a somewhat controlled rate. When the stomates of a plant open, the air from inside the leaf, containing water vapor is passed out as CO_2 is passed in.

This brings us to the end of the transport of water up through a tree, drawn in through the roots, transported vertically through xylem, and released through the stomatal openings. These openings are controlled by guard cells. The stomates are often large enough to be visible on the leaf. They are typically located on the underside of the leaf so as not to be subjected to direct sunlight when opening. They are moveable structure that are controlled hormonally, by environmental stimuli (light), atmospheric CO_2 concentration, humidity, and abiotic and biotic factors. The mechanisms are not fully understood, but the action is clear, opening allows for the influx of CO_2 to drive primary production and results in a loss of water as transpiration.

To sum things up, water movement up and through a tree has not been mimicked by any man-made invention. Trees achieve this feet without any direct energy input, relying solely on the properties of water. There are variations among plants, with some moving more water faster than others, as plants have evolved, filling ecological niches.

Activities

Activity: Cohesive Nature of Water

This is a modeling activity. You want to begin by discussing and drawing the water molecule. Noting and labeling the polar nature of the molecule. The two hydrogens are bonded to the oxygen in the middle at an angle of 104˚. The hydrogen end has a slight positive charge and the oxygen end has a slight negative charge. This occurs because the oxygen is more electronegative and is able to pull the electrons shared in each of two covalent bonds with the hydrogens closer to itself. These electrons being more closely associated with the oxygen thus results in the oxygen having a slightly negative charge the polarity of the molecule. Students should not that opposites attract and adjacent water molecules will bond to each other via the slight negative charge of one end and the slight positively charged hydrogen of another molecule. Because of the bond angle within water this can result in a very complex three dimensional bond structure in ice called the crystalline lattice. Once the students have an understanding of how water molecules bond to each other you want to have them apply this to situations.

You can have the students apply their understanding of how water bonds to water with a simple activity involving a penny and a pipette or dropper. Have the students place the penny on the lab bench and begin adding water to the penny one drop at a time. Instruct them stop once a bubble is formed. Up to 40 drops of water may accumulate, creating a convex shape, like a dome. The students then have to determine how the dome shape is achieved by the water. This is because the water drops have a higher affinity for each other than other surfaces. The attractive force of other water molecules keeps the molecules stuck together despite the force of gravity and the attractive forces of surrounding materials. Instruct the students to draw what they think the molecules of water look like and how they must be arranged.

Cohesive and adhesive behavior can also be modeled in the hallways and stairwells of the building. With each student acting as water molecule you begin at the bottom the stairs. A student climbs the stairs with one hand on the hand rail and the other holding the shirt of another student behind them. Their hands represent hydrogen atoms and their bodies are oxygen atoms. This patter can be repeated. As they climb the stairs in a sort of chain they are modeling the movement of water through a plant, against the opposing force of gravity. The adhesive and cohesive attractive forces are greater than that of the pull of gravity.

Activity: Water Potential

A water potential lab is easy to do with some dialysis tubing and common chemicals. The dialysis tubing will allow for the passage of water molecules as well as ions, but will not allow for large molecules such as sucrose to diffuse through. This is a semi-permeable membrane that will allow your students to experiment with water potential.

What you need are some solution options and about 30cm of dialysis tubing per student group. The solution options are: distilled water; 1M NaCl solution; 1M glucose solution; and 1M sucrose solution. There are other options as well, but these are the ones that I use in my class because of ease of accessibility and safety. The students work with 10cm sections of tubing, having been pre-soaked in distilled water they tie off one end, fill the tubing with a solution and tie off the other end, creating something similar to a sausage. This is then massed and immersed in a beaker of different solution for about 30 minutes. The final mass is then taken and a percent change in mass is calculated. The students will determine that because of water potential and the semi-permeable membrane, water, as indicated by a mass change, is diffusing through the membrane. For example, a dialysis tubing unit filled with distilled water that is immersed in a beaker of 1M glucose solution will lose mass over time as water moves out of the tubing unit and into the glucose solution. This happens because the water in the tubing has higher water potential than the water in solution surrounding it.

This simple activity is good practice for students not only in experimental design but also with mathematical calculations. This also provides them with a tangible example of water potential in action.

Activity: Viewing Stomata / Stomata Impression

You can easily have students create an impression of the underside of a leaf in order to more easily view the guard cells of stomates with a microscope. Stomates are the plant structure that allows for the movement of water out of a plant and the intake of carbon dioxide. The guard cells of stomates open and close in response to light, circadian rhythm, abiotic factors, biotic factors, and hormones. Terrestrial plants will have stomates located on the underside of their leaves.

This activity is a simple hands-on activity that will help garner interest in the students for plant life. Most students will not have thought about a plant having active structures on their leaves. Looking at stomates is also important because they are represent the end of the unbroken chain of water that is present within a plant. This is a common and simple activity that uses clear nail polish, tape, microscopes, and glass slides. You can find numerous iterations of the activity on the internet. I will provide the basics in the next paragraph.

You begin by asking students to select and bring a leaf from three different plants to class. This will provide students with the chance to compare stomate density among plants. On the underside of the leaf, using clear nail polish, create a thick layer of nail polish in an area about equivalent to a square centimeter. Allow the nail polish to dry completely and use a piece of clear scotch tape to remove the impression from the leaf. You do this by applying the sticky side of the tape to the area with nail polish. Peal the tape off and the nail polish impression will come with the tape. The waxy layer on the leaf surface helps prevent the nail polish from adhering to the leaf. Next lay this tape and impression on a clean slide and use a microscope at 400X to view the impression. Have students select an area of the impression that has visible stomates and count them. They can repeat the procedure with different leaf types and compare the stomate densities among them. To determine the number of stomates per mm^2 multiply the number of stomates found within a viewing area by eight. This will provide the stomate density per mm^2.

Resources

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Appendix

Implementing District Standards

My district, like many across this country, has adopted the Next Generation Science Standards (NGSS) to guide science curriculum. This unit seeks to address standard HS-PE-ESS2-5: Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. Like many of the standards, though they appear concise, once you read them and un-pack the ideas within you realize how complex they really are. You also realize how broad you may go in teaching for each specific performance expectation. With this unit one may address the properties of water within the context of living organisms, trees, while weaving in the overall effect of water movement through our forests and back into the atmosphere. This unit focuses primarily on the need to understand the properties of water to fully grapple with the phenomenon of water evapotranspiration by plants.