LIGHTNING AND TREES

by George D. Freier

Many trees withstand the elements of nature for hundreds or even thousands of years and then have their existence terminated in a few millionths of a second when they receive a flash of lightning. Many of us have seen the results of lightning striking a tree even if we haven't seen the event happen. If one is close there is a blinding flash with instant thunder and many flying slivers. Many people have been too close and perhaps experienced nothing.

Under a tree
Is a poor place to be
During lightning and thunder.

The problem of lightning striking trees has been with us for a long time in that many of our forest fires are started in this way. Zeus has been revenged many times as a result of shooting his firey arrows at the Earth.

A more recent problem of concern is that more campers in our forests are getting killed by lightning bolts when lightning strikes a tree in the vicinity of the camper and does not strike the camper directly. As cities grow and suburban homes are built in wooded areas, many owners find that some of their favorite trees are lost to lightning and the owner becomes increasingly concerned about his safety and that of his home during thunderstorm periods. People starting new orchards will sometimes find that a lightning stroke to a single tree will kill several surrounding trees. Zeus is still shooting arrows and Thor's hammer still rings on his anvil as they keep finding more ways to remind us of nature's power to resist man's invasion.

Let us first consider the genesis of lightning. Most people think that thunderstorms "move in" but this is generally not the case. The thunderstorm cell grows pretty much in place, and the storm progression comes from a sequence of cells forming, one after the other, with new ones growing at the front of the storm and older cells dying as the storm passes in a sort of leap frog progression.

If the thunderstorm grows in place, it means the initial situation can be that of clear air with essentially no charge present. Where does the charge come from? As the air becomes unstable, moist air from near the surface of the earth moves upward and eventually starts condensing at cloud base level. As more and more condensation follows, there will be many more small droplets formed and these move upward to form the growing cloud as we see it, always bringing in more and more moist air from below. Eventually the cloud top is sufficiently high to reach temperatures where freezing takes place. As the drops grow by more condensation or by coalescence with other drops, some of them freeze and there will eventually be some drops of hail particles large enough to fall toward earth against the upward motion of the cloud air. As the downward moving larger drops interact with the smaller drops moving upward in the cloud region where the temperature is about zero degrees Celsius, there is charging from the water-ice interactions of the hydrometers. The larger falling drops become negatively charged and the smaller upward moving hydrometers become positively charged. The system starts with no charge and then separates equal amounts of positive and negative charge to form what is called a vertical dipole with positive charge above and negative charge below. As time goes on more and more positive charge moved upward and more and more negative charge moves downward with the region of charge generation and separation being the freezing level of the cloud.

The above separation is taking place over the reasonably good conducting earth, with the negative charge of the cloud being closest to the earth. This closer negative charge induces charge of the opposite polarity or positive charge on the surface of the earth. If a tree, a person, or a home is below the cloud it will carry a part of this induced charge, and the taller the object, the greater will be this fraction of induced charge. All of this buid-up of charge takes place quite slowly so that there is adequate time for most all objects including tall trees to become quite highly charged.

We started with no charge and the charging mechanisms have developed highly charged conditions. The negative charge at the base of the cloud is located between the positive charge at the top of the cloud and the positive charge induced on the ground. Since unlike charges attract each other, the negative charge may form a lightning discharge between itself and the top charge in which case we have a more or less harmless discharge, except if there is an airplane around, which is called a cloud flash. If, on the other hand, the discharge is between the negative charge and the induced charge on the ground, we then have a ground stroke which is what will concern us. On the average there are about four cloud strokes to one ground stroke, but this can vary much from storm to storm. If the cloud base is low, then the negative charge at the bottom of the cloud is closer to the positive induced charge on the ground and most of the lightning discharges may be between ground and the negative bottom of the cloud.

The tree can often sense the presence of these large charges before any lightning flash occurs. The leaves at the top go into what is called corona discharge which appears as St. Elmo's fire. The nature of this is shown in Figure 1 which is a bean plant in the proximity of a large charge in the laboratory. At the sharp edges of the leaves relatively few electrons will avalanche into the plant and cause air atoms on the way to emit light. This picture was made in a time exposure in a very dark laboratory. In the daytime, when this happens, the leaves will quiver quite noticeably at the top of the tree where the effect is greatest and can be observed best with binoculars. One should expect a close strike of lightning if he observes St. Elmo's fire. Excessive corona or St. Elmo's fire will burn the edges of the leaves where it takes place.

From here on let us be concerned with only the flash of lightning to ground which can damage the trees. The discharge could start at the cloud, as it does in most cases, which gives what is known as a D- stroke where the D implies downward motion of charge and the - sign indicates that it is

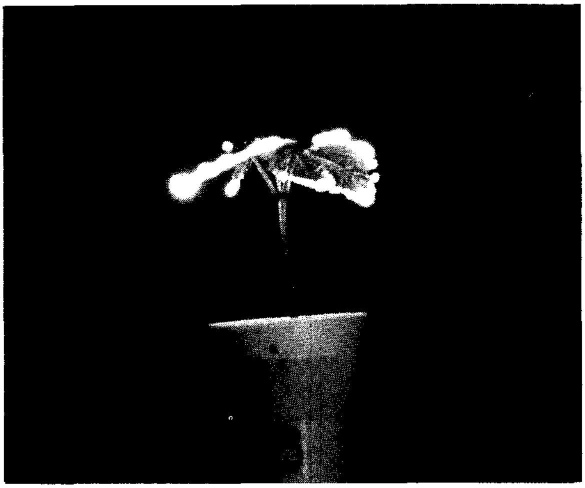

Figure 1. Time exposure of a bean plant in a strong electric field in a dark room. A second exposure shows the plant and vase. The St. Elmo's fire can be seen with a dark adapted eye.

a negative charge involved. If the ground discharge started at the ground, there would be a U+ stroke. Since most ground strokes are D-, we will further limit the discussion to them. Figure 2 and Figure 3 show laboratory sparks of the D- and U+ type. One can always tell the direction of a stroke by the direction of the lightning branches. If they point downward, we have a D stroke and if branches point upward, we have a U stroke. The direction of the stroke is quite easy to discern during a ground stroke.

Lightning processes take place very fast compared to the very long buildup time which we have described; in fact, the processes are so fast that the only thing that can transfer charges is the electron. All ions are much too massive to move very far in the time that a stroke takes place. The concept of transferring both positive and negative charges with only negative electrons is a little difficult. If a negative charge is moved during a discharge, the electrons are conveniently furnished by coming from negative ions of the charge center and then leaving the atoms as neutral particles. For a positive discharge the electrons must be "sucked into" the positive charge region from the surrounding neutral air and thus leave the air as a region of positive ions as the negative electrons move into the positive charge center and neutralize it.

Figure 2. A U+ stroke. The spark starts at the bottom smaller electrode and propagates upward to the larger electrode which acts as the negatively charged cloud. Note branching in direction of propagation.

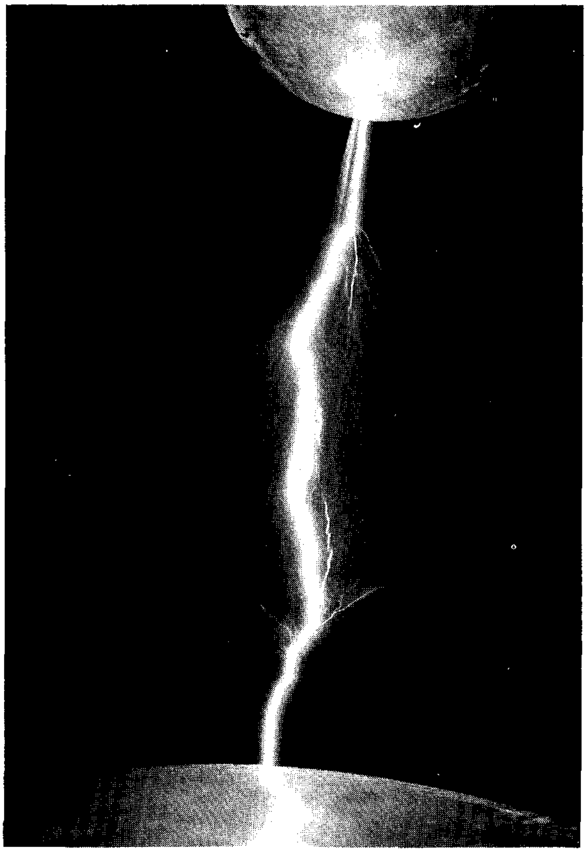

Figure 3. A D- stroke. The spark starts at the smaller top electrode which would be the cloud. Before the spark propagates all the way to the ground on the larger electrode, it is met by a return stroke.

When a U- ground stroke starts downward from the negative charge in the cloud base, it does not "know" where it will go. The electrons are repelled on ahead, sort of feeling their way to earth through much probing by branching. These branches face downward to form a D- stroke and many of the branches terminate before reaching ground. One of the many branches, however, will be successful in getting very close to earth. This process goes on in steps so that this initial part is called a stepped leader. The downward probing of the electrons with all the branching is bringing the negative charge of the cloud closer and closer to the ground and actually enhancing the amount of induced positive charge on objects on the ground. Higher objects such as trees usually get more than their share of induced positive charge because of their closer proximity to the downward moving charge. All of this downward branching of downward moving electrons takes place in a time of approximately fifty-thousandths of a second. Good conducting objects on the ground can collect more and more induced charge, even in this short time, while poor conductors, which probably includes trees, cannot add much induced positive charge while the negative charge from the cloud is descending. It is for this reason that good conductors are more likely to be struck. Trees are struck because, by being tall, they initially hold large amounts of induced charge.

When the downward moving negative charge is about one hundred and fifty feet above the earth, the taller objects on the earth have very large amounts of positive charge induced on them. The charge is so large that the air next to them breaks down by having electrons leave the air atoms and avalanche to the charged object. The avalanching then proceed upward to meet the downcoming branching stepped leaders and becomes the beginning of the return stroke which may carry ten thousand to one hundred thousand amperes of current as it drains the electrons from the branched leader channel and the cloud. This meeting of chàrges can be seen in Figure 3.

This process may be repeated several times separated in time about fifty-thousandths of a second. It is this repeated process that gives the flicker to lightning. We then say that the lightning flash consists of several strokes; each stroke yielding a large increase in the light intensity and the electric current. Each large pulse of current may flow for about fifty-millionths of a second. If the struck object is a tree, the tree must carry these large amounts of current to ground.

After a lightning stroke, the charges again build up in the cloud as before, and the process may be repeated, to give another flash very likely to some other point on the ground.

All of this description is to give the reader a time scale for the events during a flash. This time scale determines very much what happens under various conditions to be discussed later. The total duration of a flash is about four-tenths of a second.

The observer in a thunderstorm will then see flashes to ground at various points around him at intervals of every minute or several minutes depending on the severity of the storm. The heated lightning channel causes the thunder. The light from the channel comes to us almost instantly while the sound waves carrying the thunder noise come to us with a speed of about one mile every five seconds. One can quite easily determine the distance away that the flash struck by counting off seconds when one sees the light. Every five seconds correspond to one mile.

Observing the light and noise from a flash is much like observing a very long column of soldiers all firing their weapons at the same time on some visible command. We would see gun flashes from all soldiers simultaneously. The sound would arrive from the closest soldier first and if we measure the time interval between the flash and first sound, we would know the distance to the closest soldier. Sound will continue to come from the more distant soldiers for some time, which corresponds to the rumble of thunder. The crooked nature of the lightning channel makes the sound intensity vary and thus give a rumble.

When one observes a lightning flash, he should start one count of seconds when the light is seen and a second count of seconds when the first sound arrives. This second count gives some indication of the length of the lightning channel which may extend a great distance into the cloud beyond the visible cloud base. If the two counts were, say, ten seconds and forty seconds, one would know that the channel was about two miles away and was about eight miles long.

Occasionally, for a close flash, one may hear a sharp snap before the light is observed. This is caused by one of the unsuccessful branches overhead which was closer to you than the main channel. You should consider yourself lucky if you hear this snap before a flash.

During the flash you may observe the flicker at about twenty times per second as the successive pulses of intense current light up the channel for a total time of about one-half a second. Occasionally the channel glow may continue for over one second with a rather faint glow indicating much smaller amount of continuing current. Forest rangers differentiate these flashes from the shorter flashes by referring to it as hot lightning. The continuing current over relatively long times is the kind of flash which will start a forest fire. The bursts of much more intense current during each stroke of the flicker persist for such short times (50 microseconds) that they cannot transfer so much charge; and, although a tree is severely damaged by the intense current, it will not be ignited, hence called cold lightning.

The job of the discharge is to unite the negative charge at the cloud base, which may be several coulombs of charge spread over several square miles, with the induced positive charge on the ground which is an equal amount of charge also spread over several square miles. If the channel has struck a tree, this union of charge must all find a route through the tree. Since electrons are the only particles which can move sufficiently fast to carry out the processes, there will have to be a transfer of electrons from the cloud through the tree to the widespread positive charge on the ground.

Let us first consider what happens when a current of say 30,000 amperes flows along a tree trunk. The scars on the tree are along the surface and show a strip of wood and bark removed from the striking point to the ground rather meticulously following the grain of the wood. If the grain spirals around the tree, so does the scar. Larger current make deeper scars and may blow away half of the tree. There will be exceptions such as I experienced on our farm in earlier years. A heavy wire clothes line was strung between a box elder and an ash tree in the yard. Lightning struck the box elder and damaged it very much down to the clothes line. The current then moved across the line and blew away most of the ash on the remaining way to ground. We had an ash with a healthy top and box elder with a healthy bottom but both soon died.

Some studies of discharges following wood grain were made in our laboratory. The laboratory sparks have all the properties of lightning but we can control their size. The wood used was a piece of Sitka spruce with spring and summer wood well delineated. The wood had been cured well for musical instrument construction, and in this condition it would not conduct the sparks. The wood was then soaked in water until wet sparks would readily pass through the wood. The spark size was adjusted so that any one spark would not give excessive damage. Each spark chose to move through the darker *summer* wood and leave the lighter spring wood intact. After about fifty such sparks, the wood strip would turn into a bundle of light spring wood toothpicks. The results of such sparking are shown in Figure 4. The current prefers to follow the darker wood which thus guides it along the grain. Resistance measurements were made in all directions through the wood and showed no difference in value in any direction.

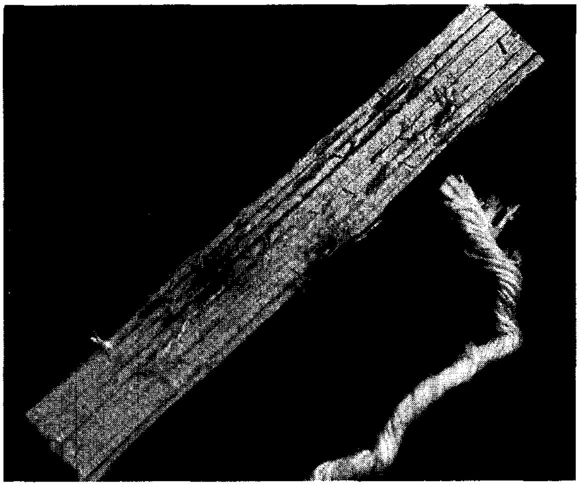

Figure 4. A piece of Sitka spruce wood after having many laboratory sparks pass through it. The summer wood is selectively removed by the spark channel. Only spring wood remains.

The preferential passage through dark wood was not a simple resistance phenomena. We then looked at the nature of the light emitted from the wood as the spark passed through the wood and this light was very red, being a characteristic color of hydrogen ions. This hydrogen may have been either in the wood or the water which made it wet. We decided that the current prefers to follow the darker wood and hence move along the grain, but we do not know why the spark prefers to move through darker wood. The fact that the wood must be wet would be consistent with the lightning scar being at the surface of the tree.

When the current flows from the base of the tree to ground, many different things can happen depending on the characteristics of the soil. I have found that a best way to think about what happens here is to consider characteristic times for things to happen. The lightning current is changing the amounts of charge in large amounts in the times of the order of microseconds. If the soil in which the tree is growing can respond sufficiently fast, it can carry electrons, by diffusion, to the positive charge which has been induced over a large area of the earth surrounding the tree before the stroke started. The current will move the electrons away from the tree base by any path which can handle the movement of charge in the fastest way. The rate of being able to distribute charge depends on the resistance of various paths; a high resistance results in a slow distribution so that charge will "pile up," while a very low resistance will correspond to a fast distribution of the charge to distant points without large amounts of charge build-up in any region around the base of the tree.

If the soil has a lower resistance than the root system of the tree, the currents distribute the charge rapidly through the soil. If the soil is dry and sandy, the distribution of charge can more easily be realized by having a current stay with the root system and thus damage the roots. Rocks have a very high resistance and cannot distribute the current at all. If the tree is in shallow soil over rocks, the entire spreading of the current will be in the shallow soil. If a person or animal is standing on this shallow soil, a lethal amount of current may flow up one leg and down the other. If a camper is nearby on rocky soil, a fraction of the current may be channeled through him and the zipper of his sleeping bag. The camper can protect himself by enclosing his sleeping

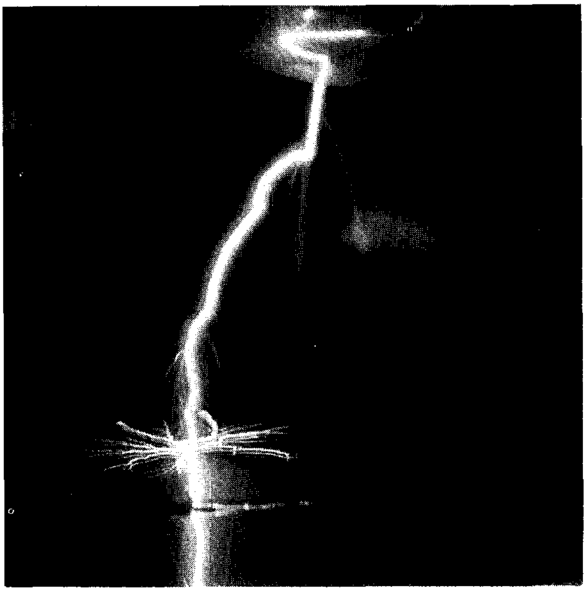

Figure 5. A spark to a shallow puddle of fresh water. The resistance of the water is sufficiently large so that electrical breakdown occurs horizontally over the surface of the water. A similar spark will penetrate salt water without spreading over the surface. Similar lateral spreading in shallow soil can be lethal to campers or animals in the proximity of the stroke.

area with a loop of wire on the ground surrounding his tent.

These concepts for spreading charge where tested in an experiment in which sparks were allowed to strike a surface of water. If the water is salt water, the resistance is low and the charge can be distributed through the water very fast. The spark will appear to go right into the water. If the water is fresh, the resistance is much higher and the water cannot distribute the charge sufficiently fast. Electrical breakdown then occurs over the surface of the water as shown in Figure 5. This is much like what happens when lightning strikes a tree in shallow soil over a rocky base. When lightning strikes a tree, it has been observed that some surrounding trees may also die. The damage is most likely to the roots from the spreading currents in shallow soil. Moses describes a situation something like this in Ex. 9:23.

Can one protect trees from lightning as one protects a home? The answer is yes, but other troubles may be invited that we do not want. I do not know of protection measures being taken anywhere but the protection would be mostly a matter of cost. A 3/8" stranded copper wire could be strung up the tree and connected to a very good ground such as a well. If a separate ground is to be provided it should to to a depth of 5 or 6 feet and be surrounded with some substance such as charcoal which, after becoming wet, can make a good contact with the earth. A ground wire must not make a sharp bend to some lateral point. All ground wires should be kept as straight as possible because kinks and bends add inductance which can lead to large voltages by magnetic induction. One should also have ground wires where people will not have to be near them during a thunderstorm.

If such a ground wire is used, the tree is likely to be struck more often. (There is no truth in the statement that lightning never strikes in the same place twice except when the object is destroyed in the first strike.) The tree may be used as a protective element for nearby objects. There is a rule of thumb which states that one can circumscribe about the base of any tall object a circle whose radius is equal to the height of the object, then everything in this circle is protected from lightning strikes. This is called a zone of protection, but is also is a zone of attraction for the tree. The rule simply implies that all the lightning strokes heading downward from the clouds and which would normally strike anywhere in the circle are attracted instead to the tall object. Tall objects then get struck more often.

Lightning is still as dangerous as ever and on the average kills more people each year than hurricanes and tornadoes; certainly it causes millions of dollars of damage. One should never seek shelter under a tree during a thunderstorm. If one is caught in an open area, he should squat as low as possible and always keep feet close together. Campers should surround their tents with a loop of wire and not have upward projecting metal tent poles; it would be far better to collapse the tent. Cabins should not be built on high rocky points unless they are very well protected with a lightning rod system. In urban quarters one should stay away from electrical appliances and telephones, and stay out of the bath tub during a thunderstorm. One should always stay off of open water because you become the highest object and will be more charged than the water surface. One could go on and on with many more specific rules but a little understanding of how lightning behaves allows for best reasoned judgment on what is best to do during a thunderstorm. If all necessary precautions have been taken, then simply sit back and enjoy the storm.

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PRINCIPLES OF EDUCATION IN ARBORICULTURE [1]

by Gordon King

Arboriculture, as defined in many dictionaries, is the culture of trees and shrubs. It is interrelated with horticulture, landscape architecture, forestry, pomology, agrostology, plant pathology, botany, and others. My comments will be confined primarily to Massachusetss; however, I will attempt to make observations that are common to other parts of the country.

It is best that we spend a few moments on the history of arboriculture, but not as complete as Dr. L.C. Chadwick's *3000 Years of Arboriculture — Past, Present and Future.* The knowledge of care and use of shade and ornamental trees probably arrived in this country with plantsmen who came in the 1600-1800's from Europe and Asia, and their information was passed on. There were many prominent educators and practitioners during the first 200 years, but Dr. George E. Stone, Head of the Botany Department at Massachusetts State Agriculture College certainly was one of the first and foremost. He did a great deal of research, extension, and teaching in shade tree management as early as the late 1800's. A formal course was devoted to shade tree management and some of his earliest pupils were founders of our largest private tree companies. Dr. Stone continued his interests long after leaving the state college.

We certainly must not forget Professor Karl Dressel with his Municipal and Recreational Forestry at Michigan State University. His program was diversified yet complete, since he relied on the teaching and research of many departments. Even as a student, I was aware of his struggle with the traditional forest service concept, which had no patience with what they now call "urban forestry."

At the same time many other schools, disciplines, and governmental agencies were focusing their attention on tree problems in the urban environment. Dr. L.C. Chadwick, Head of the Horticulture Department of Ohio State University contributed a great deal and still does. The entire hour could easily be devoted to those who have contributed and are contributing directly and indirectly to this field, but this is not my task.

However, I would like to mention that efforts are being made to catalog the contributions related to arboriculture in Canada, the British Isles, and the United States. The first effort is by J.W. Andreson, *Community and Urban Forestry, A Selected and Annotated Bibliography,* published by the U.S. Forest Service, Atlanta, Georgia.

At present, the Bureau of Outdoor Recreation, a federal agency, has directed a focus on the ur-

[1] Presented at The Annual Meeting of the International Society ot Arboriculture in St. Louis, Missouri in August of 1976.