How Does Lightning Work

A Better Description of Electrical Discharge

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What makes lightning so fascinating? Lightning is one of the most underestimated natural disasters that cause death. Cooper &Andrews states, **“In the United States, the average annual numbers of deaths from lightning exceeds the number from other natural disasters (e.g., earthquakes, tornadoes, and blizzards)” (1995)**. Studies showed, despite the fact that the probability of people being struck is minimal, once a person is struck, injuries are serious. That does not mean everyone struck by lightning dies. The consequences of being struck by lightning include **“neurologic and neuropsychologic disorders, seizures, brain injury, spinal artery syndrome, blindness, amnesia, anxiety attacks, and peripheral nerve damage”** (Cooper, 1995). Until this day, scientists are trying to figure out where could lightning strike next.

This paper will discuss how charge is formed in the clouds and what major aspects play an important role in the polarization act. Also, the paper will discuss how important it is to realize that the ground plays a vital role on how lightning works. Consequently, previous literature described how non uniform field lines lead the lightning to follow a non-straight path, and it illustrated that lightning can strike in other areas besides the ground and the clouds. Subsequently, this essay will elaborate on how the “Universe is not very cooperative” in lightning’s bolt behavior (Stewart, 2012), before finally explaining the phenomenon behind how lightning works (if existent) in other planets, such as Saturn.

According to Vladmir A. Rakov and Martin A. Uman “ Wilson was the first to observe, from ground-based measurements, systematic variations in the polarity of both relatively steady electric fields of thunderclouds and transient electric field changes due to the lightning” (2007, 73). Wilson established that positive charges tend to move upwards in the cloud, and that negative charges move downwards (**Vladmir A. Rakov and Martin A. Uman).** Thunder clouds can be very tall, several miles high. Weather inside the cloud, the movement of air up and down, can cause movement of charge, which will cause buildup of charge. Positive charges will form at the top of the cloud and negative charges at the bottom of the cloud. The cloud basically becomes polarized due to buildup of these charges.

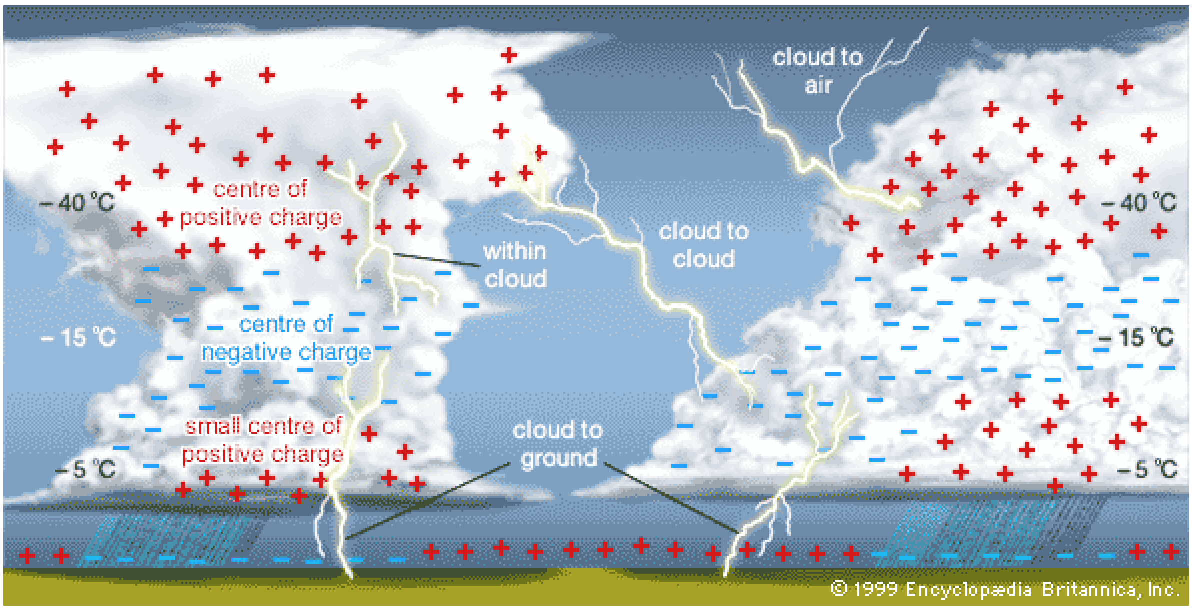
A thunder cloud develops from a small cloud called cumulus. Two important characteristics play a major role in the polarization act. Within the clouds, moving ice particles are moving in a raging manner. The water cycle plays an important role in triggering the evaporation of water in the form of gas which undergoes condensation by interacting with ice particles and water droplets present in the cloud. The interaction prompts an electron removal from the water evaporated. Hence, charge separation takes place.

The other important characteristic that takes place which aids in the polarization of a storm cloud involves the glacial process. As the evaporated water rises, colder weather is present at higher altitudes. The cold temperature causes the gathered water particles to freeze. As particles freeze, they tend to bind closer to each other. The evaporated water, which is frozen within the clouds, develops a negative charge and the particles that are not of the grouped particles develop a positive charge. This leaves the frozen negatively charged particles to fall down to the bottom of the storm cloud and the positively charged portion to rise to the top of the cloud by the air current. Negative charges at the bottom of the clouds have an effect on the ground beneath it. This is where charging by induction occurs.

It is important to realize that the ground plays a role on how lightning works. In the ground, there are positive charges and negative charges. The positive charges are from protons which are stuck in the nuclei of the atoms. The negative charges are from electrons but are easier to move, and they are repelled by the negative charges on the clouds. Therefore, the ground beneath it is charged by induction and develops a net positive charge. When something is charged, the charge tends to concentrate on the corner and pointy parts of an object **(Stewart, John and Gay Stewart)**. Anything sticking up relative to its surrounding will be more strongly charged. The negative charges developed at the clouds are attracted by anything that holds a net positive charge. Before a lightning path is created, separate paths of ionized air are descended from the cloud. These are known as step leaders. This is quite a phenomenon because when these step leaders are attracted to earth's ground, they must go through stages, which may or may not be in a straight line. The ionized air is dispersed in different directions, which will lead to an unequal lightning strike in different locations. Any object can cause air to break down in one direction over the other. Hence, that makes the step leader try to reach earth's ground faster.

Lightning bolts' direction can be counter intuitive. Flux lines have an impact on the lightning bolts' direction. What are flux lines? Dr. Stewart stated flux lines "radiate" perpendicularly from the charge surface moving towards its opposite charge. Therefore if a surface of any cloud is not straight then there exist lines that are what we called in class "non uniform." The non uniform lines cause the step leaders to follow a path other than straight lines. It is very important to understand that step leaders follow a path with less resistance so that the most current can run through. It can be thought of as a circuit, where bulbs light brighter if more current runs through the circuit, but bulbs go dimmer when resistance is increased because less current will flow through. A straight line may or may not contain the least resistance; therefore step leaders can take routes that are not straight. If the force of attraction between the step leader and the ground is strong enough, electrons will jump across a gap and a lightning bolt is developed.

Lightning can travel from ground to cloud as well as cloud to ground. It can also travel from one cloud to the other if a positive charged region is developed on the other cloud. The concept where opposites attract/likes repel plays a role here as well. Again, the negative charges from the first cloud will repel the negative charges from the other cloud causing charge by induction. Hence, lightning strikes occur between two different clouds. A lightning strike can also occur within the same cloud with the same phenomenon explained.

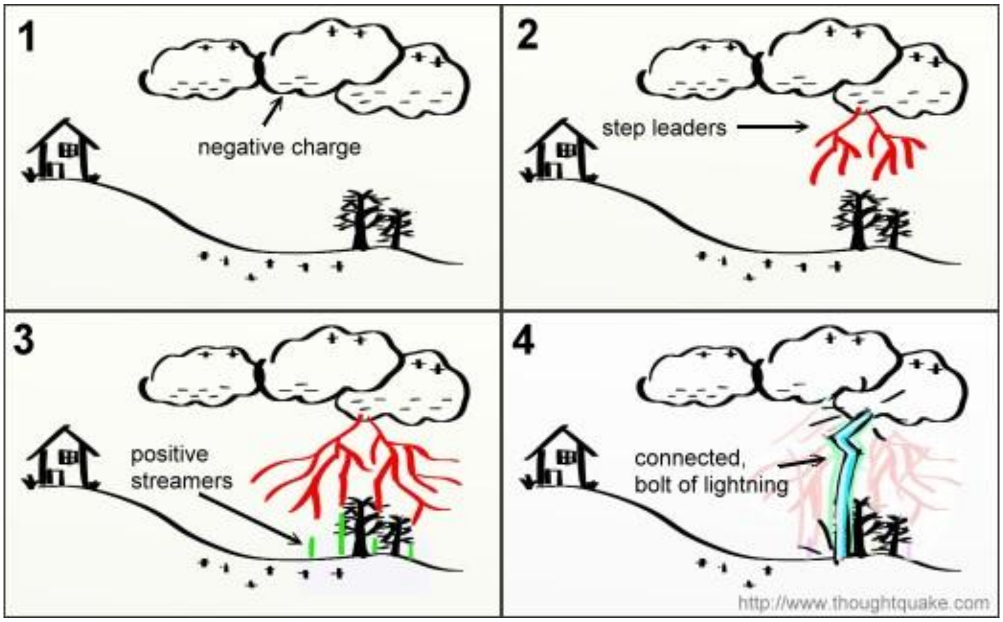


http://whyfiles.org/2011/nothing-light-about-lightning/

Detailed figure on how charge is separated within clouds, revealing that lightning strikes between clouds, within clouds and between clouds and the ground

How do objects get an “electric shock?” Objects such as people, trees, cars, houses etc… start responding to strong fields as step leaders approach earth. Positive streamers reach out to the step leaders. Once both the positive streamer and step leader meet, the plasma leaves the conductive surrounding air in the cloud to reach the earth. To neutralize charge separation, current flows between earth and the cloud. Heat is associated with electrical current is a result of the contact between the step leader and the positive streamer. According to **Zavisa, John, "In fact, a bolt of lightning is hotter than the surface of the sun" (2012).** The explosion heard when lightning strikes is due to the large electrical current generated when the step leader and positive streamer meet along with the heat. Moreover, **"Physics teaches us that sound travels much slower than light, so we see the flash before we hear the thunder. In air, sound travels roughly 1 mile every 4.5 seconds. Light travels at a blazing 186,000 miles (299,000 kilometers) per second" (Zayisa, John, 2012).**

Dielectrics and conductors were important topics in Dr. Stewart's lecture. Dr. Stewart explained how charges can move within a conductor and how in dielectrics charges can only move within an atom of a scale. Furthermore, Dr. Stewart discussed how air is an insulator, to an extent. He further illustrated how air can become a conductor when strong electric fields in clouds are strong enough to exceed its threshold value. In lightning, strong fields that surround the cloud ionize the air, which makes it more of a conductor. When strong fields break the threshold of air and convert it to a conductor, charge transfer occurs where charge moves the clouds to the ground, or within or between the clouds. **(Stewart John and Stewart Gay, 2011).**



http://www.thoughtquake.com

The figure shows the stages on how the positive streamers connect with the leaders to establish lightning.

When lightning strikes it tries to find the easiest way to the ground. So why does lightning strike a tree despite the wood being a horrible conductor? Well, wood is a better conductor than air, so instead of lightning striking the "empty sides" next to the tree, its easiest route to the ground is through the tree. This will cause the negative charges from the clouds to disperse in the ground and neutralize the positive charges. Furthermore, if a person is standing outside during a thunderstorm, the person is also a better conductor than air, and the person has already developed net positive charge from the ground. Therefore, the easiest route for lightning to reach the ground is through the person.

Scientists worked, and are still working, on how they can trigger lightning. As mentioned, lightning tries to find its easiest way to the ground. Scientists are able to do this by setting up a rocket which has a tiny wire attached to it that is on the ground. The rocket shoots up into the cloud with its trailing wire behind it. Once the rocket hits up into the cloud it provides a new conducting path for lightning to flow, and that will trigger a lightning strike. Lightning does not have an erratic path to ground; it comes straight through the wire. Scientists utilize this strategy to be able to study lightning in ways such as measuring its voltage.

Scientists invented ways to discharge lightning. Benjamin Franklin invented the lightning rod that helped scientists understand how lightning works. A lightning rod is a metal pole that is placed at the corner top of the house and it causes a large concentration of charge on the pole, so lightning becomes more likely to strike that pole. It can be a common misconception that people believe that placing a rod on top of the house is bad because it will prompt the strike of lightning there. However, a metal cable is run down from the pole. This cable runs down to the ground. Since it is a good conductor and because it is the pointy thing at the roof of the house, that is where lightning will hit. This metal cable provides a path for lightning, which goes into the ground and disperses and leaves the house unharmed. The metal pole attracts lightning towards it and deters it. The pole makes sure it provides a path where lightning will strike without causing any damage. Subsequently, sailboats are other objects that are prone to lightning because of what they are made up of. Whether they are made of aluminum (which is a very good conductor) or wood (which is a better conductor than air) sailboats are prone to be struck by lightning. From a relatively flat ocean/sea, the only thing that is pointy is the boat. For larger sailboats however, they might be grounded by having a cable that runs down the mast and through the boat and along the bottom of the boat. This provides a path for the lightning to discharge into the water.

It is important to understand that lightning is a huge electrical discharge and generates a lot of heat. Therefore, the air within the vicinity of a lightning bolt gets extremely heated up and it expands so fast that it creates sound waves. Sound waves create a crack and that is when people hear the thunder. Lightning as mentioned before is made up of segments. Each segment makes its own crack. For example, a person standing on the ground will hear the sound that comes out of a lightning bolt once it hits the metal rod. This is because the person is closer to the end of the lightning bolt. Also, the segments that are closer to the clouds will cause the sound to be heard by the person later. Scientists were able to figure a way to measure how far away a lightning bolt is. Light travels at a tremendous speed of $3*10^8$ m/s, this means when a bolt strikes, it reaches the eyes almost immediately, and hence the time taken for light to reach the viewer is negligible. On the other hand, sound travels at a speed much slower than light; it travels at a speed of about 340 m/s. So, to measure how far away a lightning bolt is, scientists mentioned that once a flash is seen, count the number of seconds until thunder is heard and divide the number of seconds by five. The result of this approximation gives people the estimate of how far away the lightning bolt is. For example, when someone sees a lightning bolt and after 10 seconds the sound (also known as the thunder) is generated, and then divide 10 seconds by 5, that means the lightning bolt is about 3.6 miles away or 6 kilometers away. Furthermore, an alternative way to make another approximation of how far away a lightning bolt is from the viewer is by multiplying the number of seconds counted after the flash is visible times 340 m/s.

Lightning possesses several strange properties. During a thunderstorm, it is safer to be inside a car than outside. Conventional wisdom teaches us that rubber tires act like an insulator; however, that is not the major reason. When lightning strikes the ceiling of the car, which is a conductor, the electricity generated within the metal will again go through the path where it is easiest to reach the ground and that is through the exterior metal parts of the car, leaving the interior part of the car untouched. As stated before, lightning may strike in branches, and the current flows to neutralize the charge separation. Dr. Stewart's famous statement on how "the

Universe is not very cooperative, we would like it to be, but it is not," (Stewart, 2012) illustrates vital concepts that many might take for granted. The word "cooperative" can be understood in many different ways; one of the ways is not everything your eyes see is true. If one strike is generated, multiple others can follow up. The strikes following the main one occur while the main strike is still visible, making the viewer believe that the lightning seen lasted longer than usual.

Lightning can be found in planets other than Earth. One of the most intriguing planets is Saturn. Until this day, it is not certain that lightning occurs in Saturn. Saturn, unlike Jupiter, Neptune and Uranus has features that scientists could not understand and still do not understand. Despite possessing similar features to Jupiter, there is still controversy about whether or not the electrostatic discharges in Saturn's atmosphere cause lightning.

Saturn is the 6th planet from the sun; it is 60268km in radius and is surrounded by rocks and ice and largely surrounded by liquid metallic hydrogen. Its outer layer consists of helium, molecular hydrogen, water, methane and ammonia. Unlike most planets, Saturn has no detainable surface, and there is a gradual transition from a gaseous atmosphere to a liquid interior (**Vladmir A. Rakov and Martin A. Uman).** Furthermore, Vladmir A. Rakov and Martin A. Uman stated that **"Saturn has a magnetic field whose strength at the equator is of the same order of magnitude as that at the Earth's surface" (2007, 543).** Similar to Jupiter, Saturn's clouds consist of three main layers; the first layer consists of ammonia, the second layer consists of ammonium hydrosulfide and finally the third layer is just an ordinary water cloud. Saturn's clouds are thick, which is due to its extended atmosphere via low gravity (**Vladmir A. Rakov and Martin A. Uman).** In the early 1980's Voyager 1 and Voyager 2 flybys of Saturn found possible evidence of lightning. The planetary radio-astronomy instrument of each of the

Voyagers detected a frequency range that caused curiosity. However, despite Saturn having similar characteristics as Jupiter, it turned out that the bursts of radio emission from Saturn are different than that of Jupiter. It was surprising to find out that the emissions detected occurred with a repetition of 10 hours, and "**the episode of electrostatic discharges for one episode was about seven hours" (Vladmir A. Rakov and Martin A. Uman, 2007, 543).** It is important to realize that the features observed by both Voyagers on the electrostatic discharges were almost the same. However, the strength was less when the second Voyager was there. The argument made against the existence of lightning on Saturn's atmosphere is that Saturn's electrostatic discharges do not originate from lightning. The absence of the electrostatic discharges that are signaled in Earth are different from those at Saturn. In addition, the interpretation of how the Saturn electrostatic discharges originated from the atmosphere is hugely controversial. It is argued on how the lower end of the Saturn electrostatic discharges frequency spectrum can move through an ionosphere, which normally it should **"reflect downward all radiowaves with frequencies lower than the plasma frequency" (Vladmir A. Rakov and Martin A. Uman, 2007, 544).** It is important to understand that the ionosphere should not transmit signals that are anything below 200kHz, while the planetary radio astronomy instrument detected radio sound in the frequency range from 20 kHz-40kHz **(Vladmir A. Rakov and Martin A. Uman).** It is believed that the ionosphere could have absorbed these frequencies due to its shielding. This data is conclusive that lightning does not occur in Saturn's atmosphere.

In conclusion, in Earth, charge formation in the clouds is very important. The buildup of positive charges at the top of the cloud and the negative charges at bottom of the cloud causes the cloud to be polarized. Furthermore, the concept of polarization emphasizes on how lightning works; both charge separation and the glacial process are vital characteristics for the initiation of lightning. Consequently, it was further discussed how lightning bolts follow the shortest path to reach the ground for electric discharge, noting the fact that the shortest path is not necessarily a straight line. The shortest path for a lightning bolt is the path with least resistance. Subsequently, it is possible to calculate the distance of how far a lightning bolt is away from a person after witnessing the lightning bolt and hearing the thunder. Moreover, utilizing scientific understanding on how lightning works helps avoid death and serious injuries. Finally, there is controversy about the existence of lightning in Saturn, and how Saturn electrostatic discharges intrigued many scientists to question how lightning works in Saturn.

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