LIGHTNING

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Section H2

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Lightning

Since the beginning of what is known as "history," lightning has inhabited and occurred on the planet Earth. This phenomenon has inflicted curiosity into minds of everyone throughout time. Artifacts from ancient times have shown images of lightning in various settings with several symbolic meanings. "A lightning flash was one of the chief signs of the displeasure of Zeus in ancient Greece" (Rakov, 2006) depicts one of many viewpoints of what lightning was. It was believed to have been a godly power or sign, but as the wheels of time have progressed so has the knowledge of lightning. Lightning, in a modern scientific aspect, is the discharge of atmospheric electricity.

At a Glance

Lightning occurs at instances that last microseconds, but despite this short time frame they should not be underestimated. An average bolt of lightning can hold anywhere from 30 kiloamperes to 300 kiloamperes of current. (Lightning wiki, 2009) That's thousands of times more current than is needed to be lethal to the human body, considering it doesn't even take 1 amp to be fatal. Similarly, the charge of lightning bolts range from 5 coulombs to 350 coulombs depending on the type. Along with high current and voltage lightning heats the surrounding air 10,000^{o}C to 30,000^{o}C. (Rakov, 2006) The surface of the sun actually contains less heat than a bolt of lightning. This can be understood by referring to the fact that in the visibility spectrum of heat, white-blue is hotter than yellow-orange.

Another more uncommon property of lightning is its power spatial characteristics. In 2008 measurements for the power spatial characteristics of electromagnetic fields were made possible by scientist from the Russian Academy of Science. These scientists analyzed the electric and magnetic field from a region that had

numerous lightning discharges. Using Earth's conductivity properties, Maxwell's equations, and fractional geometry methods they theoretically established power indices. "One of the parameters (Δ) characterized the tortuosity of lightning discharge, while (D) describes the fractional dimension of distribution of conducting region on Earth's surface." (Balkhanov, 2009)

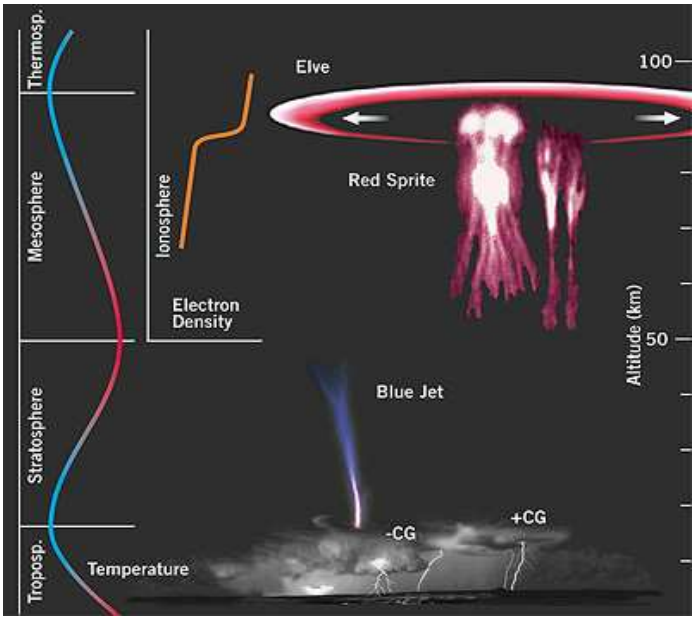
Process

Although an understanding of why lightning discharge happens is unclear, how it happens can be explained. There are numerous types of lightning and the formation of each is slightly different. The general pattern happens to be ionization, current path formation, and discharge. It begins with storm clouds separating charge. The top of cloud separates into positive charge, and the bottom of the cloud will be opposite in charge. This charge separation creates high intensity electric fields that, once built up enough, need to be discharged. Naturally the cloud will look for a conductor to discharge, relieve itself of energy. The Earth, other clouds, and the region known as the electrosphere are the cloud's conductive options. "The majority of lightning discharges, probably three-quarters, do not involve ground"(Rakov, 2006) which leaves discharge to occur in the air, within clouds, or the electrosphere. The surrounding air ionizes into plasma due to high electric field. This ionized air creates a path for the cloud to discharge to the Earth. The ionization process is similar to having a road built so cars (lightning) can follow. With a path, clouds are able to discharge and the luminosity that is associated as a "lightning flash" occurs.

The luminosity is generally observed is leaders, streamers, and return strokes. Step leaders form from the clouds and advance toward the ground at intervals of 15 meters to 50 meters, branching off into different paths. Their visibility and current is

low in comparison to the return stroke. As the leader descends, the electric field at the ground increases. When the ground has strong enough electric field it wants to discharge, opposite in charge compared to the step leader. The streamer and leader will often meet creating a greater path. This larger path allows for more current to flow, which is the reason why return stokes are more powerful. A return stoke is the discharge from the ground back to the clouds; a return stroke's purpose is to neutralize the leader charge. Being the most damaging and optically brightest portion of the lightning discharge process, the return stroke is also the most studied lightning process.

Types



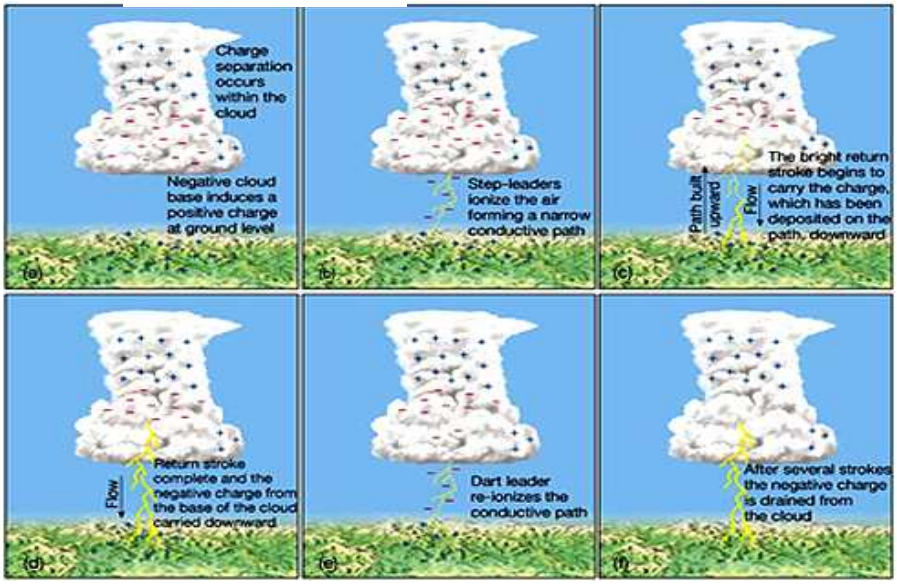
(A space station view on giant lighting,2005)

Earth has four atmospheric levels, in ascending order: troposphere, stratosphere, mesosphere, and thermosphere. Each level has its own type of lightning discharge and uniqueness. The upper atmospheres include unique types of lightning often referred to as "megalighting" or "giant lightning" do to their size. These types of lightning however are rare and harder to observe compared to the troposphere's discharge types. The

troposphere is lowest atmosphere and its numerous variations have been divided into categories.

The CG, cloud-to-ground, discharge is one of the most common and familiar forms of lightning in the troposphere. Sometimes referred to as fork lightning, cloud-to-ground lightning can be positive or negative. Electrical storm clouds will separate into positive charge in the upper region and negative charge in the lower region. The discharge will usually be negative occupying 90% (Rakov, 2006) of all cloud-to-ground discharges, but can occasionally be positive. Negative discharge will attract a positive streamer discharge and both act to transfer negative charge from the cloud to ground. If a cloud needs to discharge after the step leader, the discharge is called darts. Darts simply follow the same channel that the leaders created. Negative CG discharge is relatively easy to observe. It tends to appear from the bottom of cumulonimbus fork, or branch out, downwards to the ground. Little is known about positive lightning discharge due to its infrequent occurrences. Observations have brought together five situations that appear to relate to positive discharge: dissipating thunderstorms, winter thunderstorms, shallow clouds, severe storms, and thunderclouds contaminated by smoke. Due to its massive current and comparatively long time span, positive discharge has spawned a great deal of

(Short, 2005)



attention. These discharges are the highest measured currents of troposphere lightning, carrying near 300 kiloamperes and lasting for approximately 10 microseconds. Potential difference in positive CG lightning is also much greater than negative CG lightning, because the increased distance positive discharge has to travel from the cloud to the ground. The well- known type of positive CG discharge is the anvil-to ground. The bolts hover horizontally through the top of the cloud then arcs downward toward the ground. Other aesthetic based classifications of CG lightning include bead, ribbon, and staccato; each of which appear as named.

Ground-to-cloud lightning, both negative and positive, occur due to similar reasons. Tall structures in flat terrain or structures on mountain tops discharge upward and can be followed by return-strokes. Differentiating between ground-to-cloud lightning based on names can be slightly misleading. Upward negative lightning initiates with upward positive leaders, while upward positive lightning discharges begin by upward negative leaders.

Two extraordinary types of lightning that have heavily theorized causes would be the ball lighting and the bead lighting. The ball lighting unfortunately has little recordings but enough reports to cause curiosity. Most witness reports say that ball lighting appears after a lighting flash in a spherical form lasting for a few seconds. Characteristics that define ball lightning theory include: association with storms, its commonly reported physical appearance, its occurrence spaces, and its motion is inconsistent with the conceived behavior of a hot gas. In contrast bead lighting, is well-documented and described as disrupted or fragmented lightning bolts. A number of hypotheses bring up the thought that bead lightning could be optical illusions. “Bead lightning arises because the observer views portions of the lightning channel coming

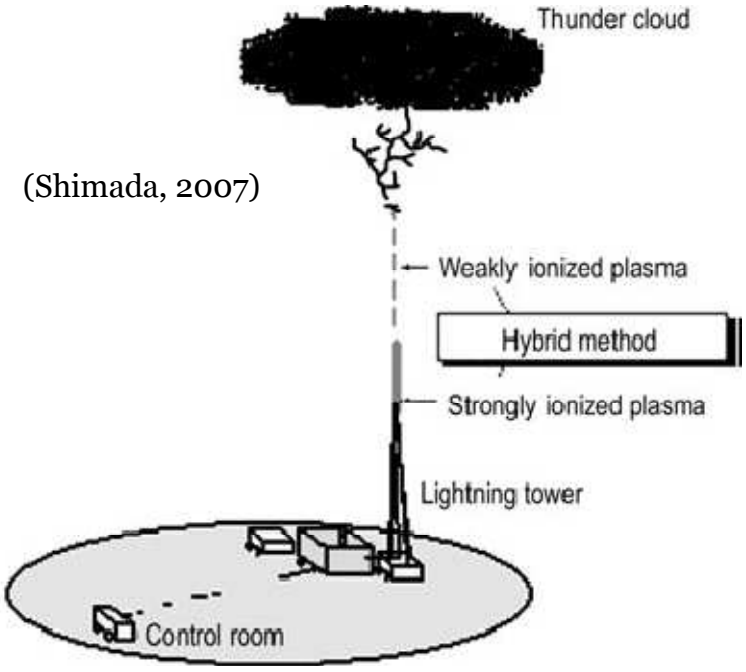
toward or away from the observer creating thinning affects the bolt line." (Rakov, 2006) Another theory presents that bead lightning is due to channel kinks or bends from large radius lightning channels. If cooling rates for channels are proportional to radius, it is possible that varying bolt radii occurs because of different cooling rates in the channel.

Upper atmosphere lightning is a relatively new study that has advanced since 1990. The three observed types are elves, sprites, and blue jets. Blue jets occur in the stratosphere, altitudes 10-50km above Earth's surface. They project from top of cumulonimbus clouds a concentrated white and then project upwards while fading to a blue hue. In 1994, blue jets were finally caught on tape from research aircrafts "56 blue jets were located by triangulation in the 1994 Arkansas storm." (Rakov, 2006) In the mesosphere, the phenomenon known as sprites transpire. Sprites have been reported to have red or blue coloring in the shape of a carrot with tendrils dangling down. They almost always exist in clusters and last milliseconds, but are difficult to see with optical intensities of .1 to 10 rayleigh. To put the unit of rayleigh, the unit for brightness in a square meter in one second in a better perspective, the night sky is about 250 rayleigh. Theories behind sprites are extensive using conventional-breakdown and runaway-electron theories to explain the event. Elves, an acronym for Emissions of Light and Very Low Frequency Perturbations from Electromagnetic Pulse Sources, occur in the lower thermosphere. Described as a halo shape, elves expand from 200-700km in less than a millisecond. They are caused by acceleration of electrons by high-current fields growing out radially. In attempts to model jets, sprites, and elves it is established that all three need very large source currents and charges.

Cloud discharges denote intracloud, intercloud, and air discharges consume the majority of lightning discharges. Rather than discharging over long distances from

ground-to-cloud, clouds will discharge to objects nearby. During intracloud discharge negative bolts from the bottom of the cloud and positive bolts from the top of the cloud with connect. In the case of intercloud lighting, discharging will be between two separate clouds. Sometimes the air is enough of a conductor to discharge; there may not be enough field intensity for the bolt to reach the ground or objects.

Lightning does not only occur in thunderstorms, it can be triggered in a number of ways. Humans have triggered lightning with rockets and lasers for research. One reason for triggering lightning is because "lightning poses several dangers and threats therefore scientist have tried to develop diversion techniques." (Khan, 2002) The concept behind triggered lightning is to provide a path for charged clouds to discharge, whether it is a rocket with wire or ionized laser. Although rocket-triggered lightning is well established there are new pushes for the unconventional laser triggering. Laser triggered diversions would be able to discharge clouds to a single point. This is would be slightly superior to rocket triggering, because rocket triggering doesn't discharge to a designated spot which can strike surrounding structures or systems. It has also been documented that large volcano eruptions, earthquakes, and thermonuclear explosions may produce



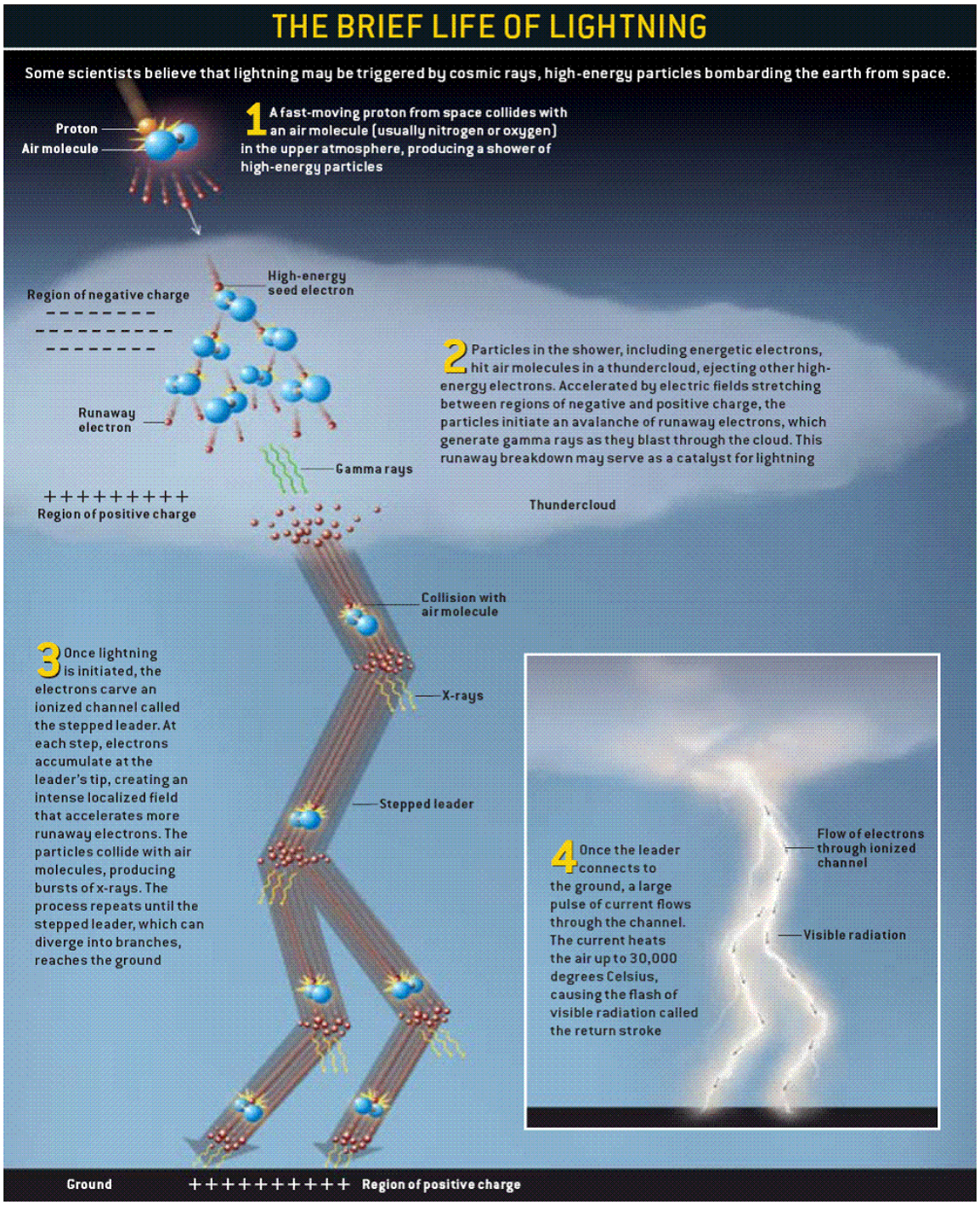
(Shimada, 2007)

lightning discharge. Attribution to these phenomena comprise of increased field by volcanic cloud composition, electric field constructed by seismic strain, and charged atmosphere after a nuclear explosion.

Theories

Despite the amount of knowledge on how lightning discharge occurs, there is an absence of a solid explanation on why and how clouds accumulate and separate charge. Purposed explanations consist of the global circuit theory, Gurevich's runaway breakdown theory, induction hypotheses, and the polar mechanism hypothesis. The global circuit theory believes that lightning is a necessary natural event. The theory views the Earth as a giant spherical circuit with two shells. The inner shell is Earth and the outer shell is the electrosphere. Earth's surface carries a net negative charge of magnitude 5×10^5 Coulombs, while equal positive charge is distributed throughout the atmosphere. (Rakov, 2006) The theory states that the planet stays charged; therefore, there must be some act that recharges the Earth. Thunderclouds are the mechanism responsible for the recharge. Lightning discharge replenishes the Earth with negative charges, while positive charges come from clouds. Positive charges may be released from the clouds, or perhaps in the form of precipitation falling to Earth's surface. There a number of induction hypotheses that attempt to explain the separating of charge in storm clouds. The common theme in these hypotheses is particle collisions that result in charges. Updrafts cause rain particles to collide and cause either charge separation or charge transfers. Gravity finishes the separation job and when enough charge separation is built up, discharge occurs. In 1992, Aleksandr Gurevich purposed that atoms become ionized and separate because of cosmic rays. He's theory is called Gurevich's Runaway Breakdown theory, because a significant part of it is due to

(Dwyer, 2005)



runaway breakdown of electrons. A good explanation of how cosmic rays affect molecules and stimulates the discharge is provided in the figure above. For additional clarification, runaway breakdown can be described as generation of new high accelerated electrons due to runaway particles. The polar mechanism hypothesis is very

similar to the previous theories; it contains two parts. Drops of precipitation become polarized by Earth's electric field. Then the colliding drops become charged by the electrostatic induction processes. As research continues, one of these theories/hypotheses may become a law, but until then cloud charge and separation is still an inquisition.

Conclusion

Back in the 1700's Benjamin Franklin toyed around with lightning in his kite experiment. He used a kite, silk thread, and a key in his experiment to attract lightning discharge. Benjamin Franklin was not the first or only person to do this. Lightning has fascinated people through the ages. From some of these fascinated minds, research and a better understanding of lightning discharge has resulted. Observations and studies have given explanation to the cause of discharging. The potential between separated charges in clouds gets to an intensity that requires discharge. The reason for clouds obtaining and separating charge include many theories and hypotheses. Lightning is a phenomenon to many people because of its unique luminosity. The frequently seen discharge occurs in the troposphere shaped like zig zag branches, but there are other brilliant forms of lightning. These unique forms of lightning discharge include blue jets, elves, and sprites. Lightning doesn't only occur on planet Earth, extraterrestrial forms have been observed. Observed discharge on other planets could help the understanding of lightning on this planet. Once a godly sign, lightning is now just one of nature's events with deep scientific curiosity. The flashes that last less than a microsecond contain ages of history and depth.

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