Thunderstorms and its relationship with Electrical Discharge

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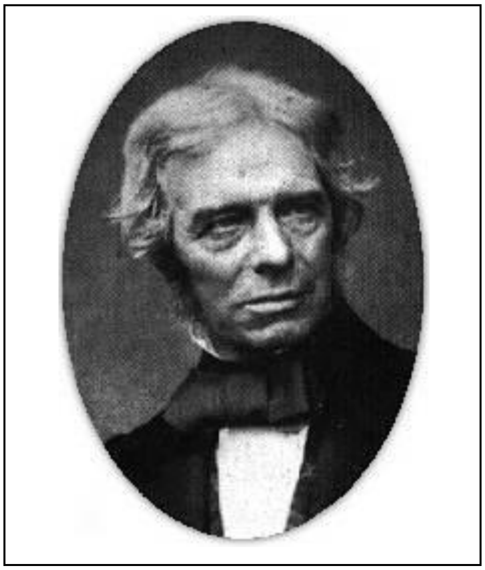
Introduction

Many scientists believe that thunderstorms are essential for creating organic compounds, without thunderstorms, living organisms wouldn't exist. One of the most important factors of thunderstorm is lightning. Lightning is powerful, beautiful, yet deadly. "You see lightning during thunderstorms" is a common phrase many have heard of. Everyone knows what thunderstorms are; however, many understand little about the electrical discharge in the atmosphere as lightning appears and the loud thunder follows after. Moreover, is there more than one type of thunderstorms? What causes lightning and thunder? How are charges involved in the production of lightning? What are the processes of electrical discharge during lightning? And last but not least, what are the effects of lightning on our lives and how do we stay safe during a thunderstorm? The effect that lightning's mysteries do not need to be unknown, as we understand lightning, it remains less mysterious yet still dangerous and unpredictable.

Biography of Michael Faraday

Before we begin, let's learn more about Michael Faraday – physicist who discovered electrical discharge and many more topics that benefit the physics world greatly. Faraday was born on September 22th, 1791 in Newington Butt, England. Faraday's father was a blacksmith, and Faraday spent his early career as an apprentice of a bookbinder. In 1812, Faraday attended a series of four lectures by Sir Humphry Davy with Mr. Dance. Afterwards, Faraway wrote to Sir Davy along with the notes Faraday took during the lecture. Because of the connection with Sir Davy and his recommendation, Faraday was appointed to be the laboratory assistant of the Royal Institution of Great Britain in 1813, and then was promoted to be the director years later.

Faraday worked at the same institution for over fifty-four years, and died on the 25th of August, 1867.



Faraday's path to this early career was first opened by Davy. Throughout his life, Faraday contributed many discoveries to the chemistry field, such as the new chloride of carbon, his experiment with gas diffusion, liquefaction of gases, and many more. Although that is the case, Faraday's most well known contribution to the physical world is the electrical diffusion and induction (Michael Faraday).

Retrieved from: http://www.scienceshorts.com/MichaelFaraday.jpg

Formation of Clouds

Now, let us start with the very basics: formation of clouds. Everyone knows that water can exist in three different states: gas, liquid, and solid (from the hottest temperature to the lowest). On the earth surface, millions of water particles in the state of gas go through evaporation from the ground to the atmosphere every day. As sun rises, heat from the sun heats up the earth surface; therefore, cause the water in the soil to heat up as well. When the temperature reaches a certain point, water in the liquid state will transform to vapors due to high temperature as well as increase in kinetic energy. The warm vapors from the earth rise higher and higher in to atmosphere, and as it rises to higher altitudes, the temperature begins to drop. Eventually, the vapors are being cooled enough where they will condense into water droplets, creating the cloud we see in the sky.

Types of lightning atmosphere discharge

While lightning is a common phenomenon of thunderstorms, many don't know that there are different types of lighting. In total, there are four different types of lightning discharges: downward negative lightning, upward negative lightning, downward positive lightning, and upward positive lightning. Out of these four types of lightning discharges, over ninety-percent of all lightning are cause by the downward negative lightning flashes, the rest ten percent are made up by the other three types of discharges (Vladimir). Photo below shows the four types of lightning discharges.

Figure 1

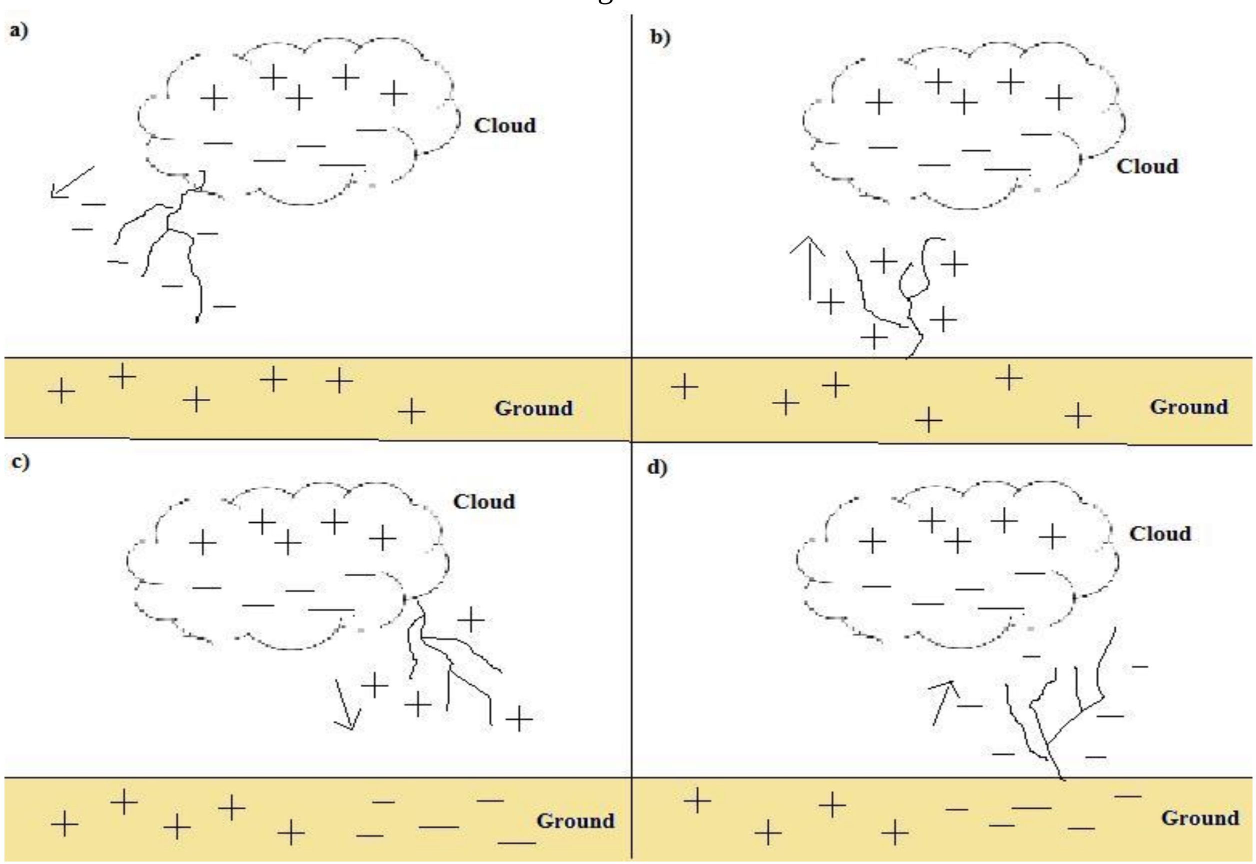


Figure 1 shows the four different types of lightning discharges. a)Downward negative lightning; b) Upward negative lightning; c) Downward positive lightning; d) Upward positive lightning.

Important Process before Electrical Discharge

Now, let continue with the formation of clouds from where we left off. As clouds move higher in the atmosphere, the conductivity in the atmosphere also changes. According to Rakov, "the atmosphere below about 50 km is conducting, owing to the presence of ions created by both cosmic rays and the natural radioactivity of the Earth[…] small ions are the primary contributors to the conductivity of the lower atmosphere" (Vladimir A.Rakov). However, above altitude of 60 km, the main atmosphere conductivity is contributed by electrons. Since the main contributor of the atmosphere conductivity is by free electrons, it is also called electrosphere; moreover, under a static condition, the region is known as the equipotential region.

The temperature also gradually drops as the cloud rises higher, and ice begins to form (usually between -10C to -40C). Once the temperature is cold enough, a thin layer of ice will form around the water particle, while inside of this thin layer of ice, water remains in its liquid state. At this point, all positive charges migrate toward the outer shell where ice located, leaving the liquid state to have a net negative of charge. The reason why protons migrate to the ice particles is that the scientists believe the mobility of protons in ice is much greater than water (about two orders of magnitude larger or 100 times greater). Scientists have found that as temperature decreases, the rate of proton transfer increases. In ice, all water molecules are neatly ordered in a lattice. The formation of the ice lattice allows the protons to "jump" from one proton acceptor to another through the hydrogen bonding in ice. In this case, the protons are being transferred both as a wave as well as a particle; therefore, the transfers of protons are much rapid paced process in a high ordered formation (C. H. Bamford).

While the separation of charges keeps on taking place within the water particles, the clouds are still moving up into higher atmosphere. The rising of clouds will create instability, and the movements will cause the half freezing ice bump into each other. As they bump into each other, the outer icy shell breaks, and since ice has a lighter density compare to water, all ice particles (which carries a net positive charge) migrate to the top part of the cloud, leaving denser, liquid form of water at the bottom of the cloud with the net negative charge. Over time, there are more and more electric charges differences being released into the cloud, creating an electric field. Eventually the electric field charges will build up so big, that the result of that is a step leader coming down to the earth (but we'll talk about that in a little bit)

A potential difference is also being developed between the clouds and earth. Now, we already know that each object (the cloud and the earth) contains both positive and negative charges. Due to the net negative charge at the bottom of the cloud, positive charges will gather at the surface of the earth in that specific region. In other words, the net negative charges from the cloud will induce a positive charge at the surface of the earth. (The end of positive potential is called an anode, and the lower potential end is known as the cathode. Conductors are presents at the two ends of conductors, also known as the electrodes.)

The Lightning Process and its Electrical Discharge

Electrical discharge happens everywhere in our daily lives from switching on the light to the lightning we see during thunderstorms, but what is exactly an electrical discharge? An electrical discharge is created when conduction two different electrical potential through a medium. The medium is usually neutral in charge (which also serves as an insulator); in addition, it is usually in a gas form – the atmosphere. The natural radio activity on the earth surface will release small amount of charges (usually electrons) as well as other ions in to the atmosphere, which gives the medium some form of conductivity. During the electrical discharge, there is usually a transfer of matter. Matter can be anything from electrons to actual molecules or ions;

however, due to the fact that electrons are smaller and lighter in weight, it is easier to be moved; therefore, the matter that's transferred during the electrical discharge is usually electrons (J. B. Calvert). Lightning is the charges traveling through air were they transfer these charges to other media including the earth, these static charges require to be discharged and earth is best place. To put simply, lighting is merely the separation of charges.

The development of the potential difference in the cloud and the ground was the first phase of the lightning creation, after a great potential difference within the cloud was created, it enters a second phase. This time, it involves the actually process of lightning.

There are two main parts for the process of second phase. The first part is called a step leader, which is the very initial electrical discharge in the cloud. This is often referred as the "preliminary breakdown" (Vladimir). The electrons in the cloud moves toward the ground in a series of steps at the speed of approximately 50m/μs (like going down stairs). The step leader is very faint to the human eye, under many circumstances; we do not even see it. The step leader's main purpose is to ionize the air as it "steps" down toward the ground. The ionization of the air will allow the charges flow more easily. Meaning, it makes the lightning we see later on stronger, and easier to see. At the same time, positive charge on the ground travels up any conductor to reach the step leader (some of the examples can be trees building, or even humans). This process of moving positive charges is also known as the streamers. As the step leader travel further down to the ground and the positive charges travels up the conductor, the distance between two charges are decreasing. Eventually, the distance between two charges will be small enough, and the attraction between them is strong enough to cause the positive charges "jump" up to meet with the step leader (keep in mind that like charges repel and opposite charges attract). After the two charges meet, pulses of energies will flow to both ends (cloud and earth) through the already ionized path. The pulse of energy will cause a “return stroke”, which is the flash of light we usually see. The return strike is usually travelling in the opposite direction (from the ground to the cloud). However, since the process of returning strike happens so fast, common eyes cannot tell that the return strike actually occurs from bottom up.

Moreover, under common circumstances, we see a series of lightning. Instead of just one flash, we see several flashes in one setting. The reason for that is because the potential difference is still great in the cloud, and it will take a series of electrical discharge to discharge the charges within the cloud. The lighting we see after the step leader is called the “dart leader”. This also involves the electrons travel down toward the ground; however, since the step leader had already ionized the air, the electrons can travel at a faster speed and in greater quantity. This time when the dart leader meets the streamers, it results in several return strokes (usually four or five times), which results in several flashes of light we see. After several flashes of light, the potential difference won’t be as great since most of electrons have been discharged into earth, and there won’t be any more electrical discharges until enough electrical charge potential difference have build up again.

During the electrical discharge interactions, the two charges heats up the air around it to about 30,000 Celsius (more than five times hotter than the surface of the sun). The high temperature at such a short amount of time causes air particles to expand rapidly and emit light. At the same time of air expansion, a loud sound wave (also known as the shock wave) was also created as a phenomenon of heating the air in a short amount of time, which is known as the thunder. Thunder is a type of sound wave and since sound waves travels much slower than light, we see lightning before hearing the thunder. Light travels approximately 3E8 m/s while thunder (the sound wave) only travels around 300m/s.

Figure 2 below sum up the basic steps of lightning and its electric discharge.

Figure 2

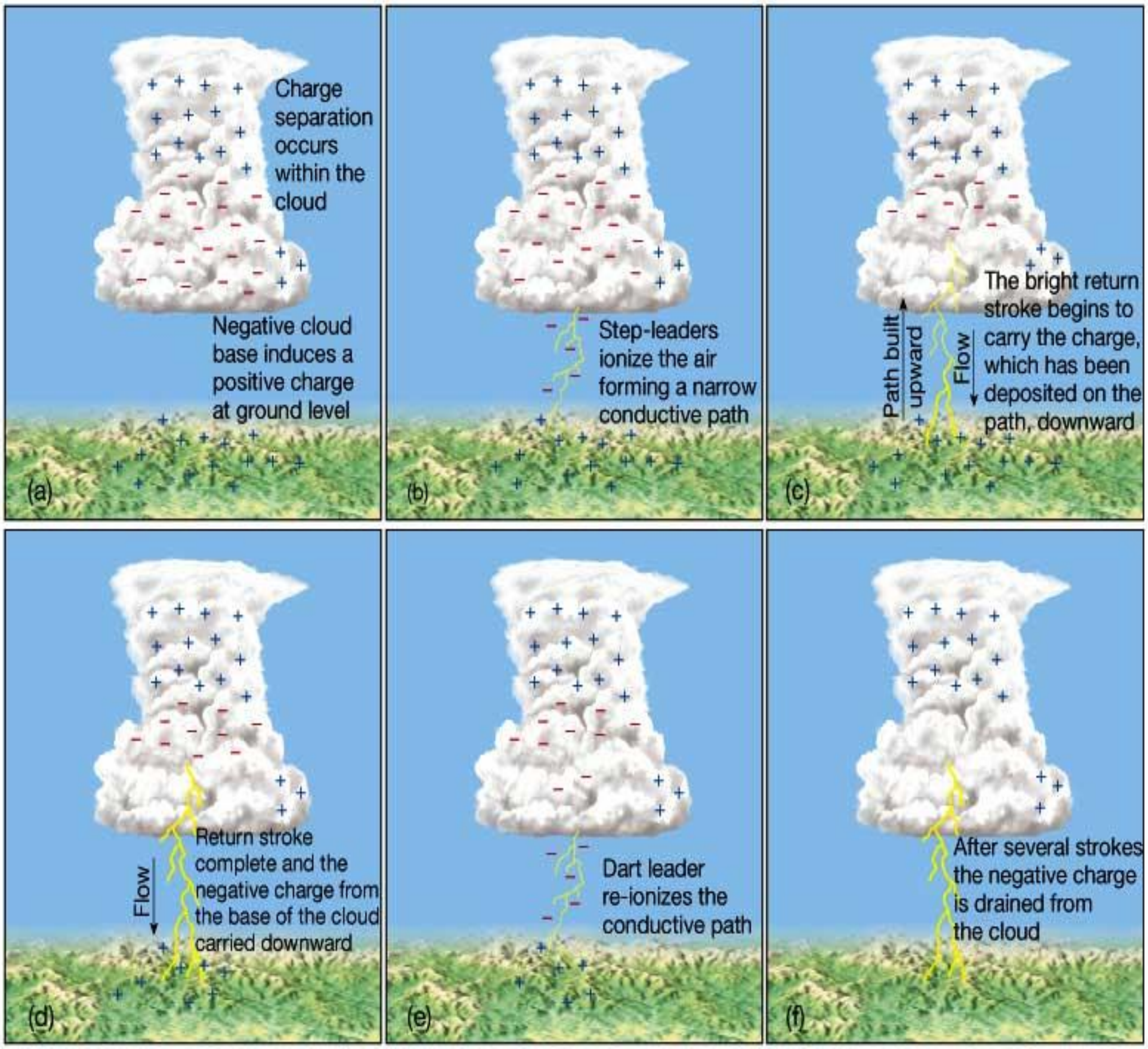


Figure above shows the basic steps of lightning and its electric discharge.
Retrieved from: http://www.ux1.eiu.edu/~cfjps/1400/shockinglecture.html

Again, thunder is usually the after effect of a lightning flash. “Thunder can be defined as the acoustic emission associated with a lightning discharge” (Vladimir). During the electrical discharge, the flow of electricity along the discharge path ionizes the gases of the air and produces great heat. The gases expand violently and rapidly, causing compression waves that travel outward at the speed of sound. These compression waves produce audible sound waves. On average, thunder have an average power flux between 0.17*10^-3 to 19.3 * 10^-3 J/m^2s, and the pressure of an average thunder ranges between 0.22 to 2.4 N/m^2 (Vladimir).

Generally speaking, thunder can be divided into two main categories. The first one is the audible (acoustic energy) that we hear, while the second one I the infrasonic (acoustic energy) that we cannot hear due to the low frequency (below 20Hz). Since human ears cannot hear the infrasonic sound produced by thunder, we’ll focus more on the audible sound human ears can hear. The audible sound is produced when air is heated rapidly in several microseconds or less, this causes an overpressure in the channel the electrons just traveled through. The overpressure results in the shock wave that we hear travels in supersonic speed. The initial speed of thunder will travel approximately ten times of the speed of the sound; however, this speed decreases rapidly due to the fact most of the energy will transfer into the surrounding atmosphere within the first few meters it travels (Vladimir).

Why Do We Care?

Now it all comes done to the question, “Why do we care?” It’s nice to learn about the thunderstorms, but in what way does it impact human lives? The answer is quite complicated. According to National Severe Weather Laboratory, lightning is responsible for 4-5 billions of dollars of damage per year. Moreover, it is responsible for about 60 deaths, and over 300 injuries per year. The electricity and current from the lightning may affects the electrochemical system of the body. When large amount of electrical current is being passed onto human body, there will be a large amount of energy released in a short amount of time: electrical, mechanical, and thermal. Injuries caused by electrical energy are the most common and severe of all.

The electrical injury is caused when several thousand or several hundred thousand of amps are flowing into the human body. The degree of damage varies depends on the flow of path of the current. When human skin is wet, the resistance is around 1000 ohms; when human skin is dry, the resistance can go up to 1 million ohms. When the skin is dry, lightning is more likely to travel deeper into the body, which can cause damages to vascular system, the nervous system, and muscles. When the skin is wet, lightning is more likely to travel over the human body, which can cause severe burns on the surface of the body. With all the interior damages lightning can cause, the nervous cells are more prone to lightning damage. Many people who were struck by lightning suffer nerve damage, memory loss, seizure, brain malfunction, and emotional problems. The duration of lightning damage may be temporary; however, many also find themselves suffer from lightning damages for the rest of their lives (Thunderbolt International).

Despite how dangerous lightning is, staying safe under the thunderstorm is moderately easy. During a thunderstorm, one should seek for shelter immediately such as your home, store buildings, or cars. Remove all metal objects since mental objects serve as good electrical conductors. If no shelter is around, one should curl into a ball and become the smallest target as possible to avoid the chances of being struck by lightning.

Figure 3

Figure 3 shows a lady smiling to the camera for a photo shot. Notice her hair is standing up, which means there are electrical charges traveling up her body from bottom up (earth to her head). She is serving as a conductor for streamers, which increases her change of being struck by lightning.
Image retrieved from: http://www.nssl.noaa.gov/primer/lightning/images/knipp.jpg

Although thunderstorms are essential to all living organism, the lightning that occurs along with the thunderstorm is beautiful yet fatal. It is important to understand the process and the production of lightning; however, it is also important to know the how dangerous thunderstorms are. Understanding how a lightning and thunder works can help a person respect this magnificent work of nature as well as staying safe during the thunderstorm.

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