Humidity’s Effect on the Permittivity of Space: The Effects of Water Vapor on Lightning

Dylan Jones and Sam Clark

University Physics II

Section 2H

Humidity's Effect on the Permittivity of Space: The Effects of Water Vapor on Lightning

INTRODUCTION

Lightning has always intrigued mankind. From early childhood on to old age, it can fascinate the population with its devastating power and shocking beauty.

Scientists began experiments with lightning dating almost 300 years ago. The most well known initial lightning experiment came with the "kite" experiment, originally performed by Thomas-Francois Dalibard. Benjamin Franklin and many other notable scientists of the age hypothesized at the many different possible causes of lightning, but the kite experiment gave some of the first scientific findings that related lightning to electricity. It wasn't until 1916 when Charles Steinmetz created artificial lightning that lightning was truly thought of as a giant electric spark.

The actual cause of lightning is still under debate. There are two main theories pertaining to the creation of lightning: 1) the Electrostatic Induction Hypothesis and 2) the Polarization Mechanism Hypothesis.

The Electrostatic Induction Hypothesis does not have an adequate reason for why there is an initial charge separation, but it covers the reason behind the collection of charge in the cloud. This hypothesis first requires there to be an updraft within the storm cloud that drives water droplets high into the system where they are super-cooled. This super-cooled water then collides with ice crystals to form an ice/water mixture called "graupel." This collision causes a slight positive charge to be applied to the crystals, which there in turn applies a negative charge to the graupel. With the constant updraft, the "lighter" ice is taken back up to the top of the cloud while the graupel accumulates in the middle and bottom portions. Since the graupel is negatively charged, there is a collection of negative charge at the bottom of the cloud and a positive charge at the top of the cloud.

The Polarization Mechanism Hypothesis, in essence, is the same as the Electrostatic Induction Hypothesis, but it has a possible reason for the original charge separation. Its explanation for the charge separation is that the ice and water droplets become polarized in the Earth's natural magnetic field.

Since the clouds have a collection of negative charge in the lower portion of the cloud, there is an induced charge on the surface of the Earth. With the constant growing charge in the cloud, the induced charge on the Earth grows as well. And with this growing potential difference, the air between the ground and cloud begins to ionize and it creates a path between the cloud and earth with the lowest amount of resistance. This is the path that the bolt of lightning follows.

Another, slightly more imaginative, theory for the formation of lightning comes from Aleksandr Gurevich in 1992. His theory states that cosmic rays cause the ionization of atoms in the air. This ionization releases electrons, which are accelerated by the Earth's magnetic field. The accelerating electrons then ionize other atoms, which cause a lightning strike by a "runaway breakdown." This gives it its name: The Gurevich Runaway Breakdown Theory.

PURPOSE

This project looks not into the causes of lightning, but the different effects that humidity as an environmental factor can have on the stroke of lightning of itself. It is our intention to take the two main elements of a thunderstorm, water and lightning, and explore them together in a controlled environment. In this experiment, the main factor in question is, of course, humidity. How will it affect an electric spark, if at all? Once we understand how humidity affects the discharge of energy over a distance, we can apply our findings to help us develop a better understanding of the behavior of lightning in thunderstorms.

HYPOTHESIS

With increasing humidity, the distance an electric spark can spark through will decrease. The amount of charge then required to create an electric shock over the same distance will increase.

In applying this hypothesis to lightning in thunderstorms, we believe that a much larger charge difference must accumulate between the earth and the clouds to get a lightning bolt to strike during a thunderstorm, which obviously has a very high humidity, than it would if it was a beautiful, dry day. We do not have to worry about a lightning bolt striking on a beautiful, dry day, however, because there is not enough charge being separated in the sky on these days.

PROCEDURE

This project will make use of a device called a “Wimshurst Machine,” which is a

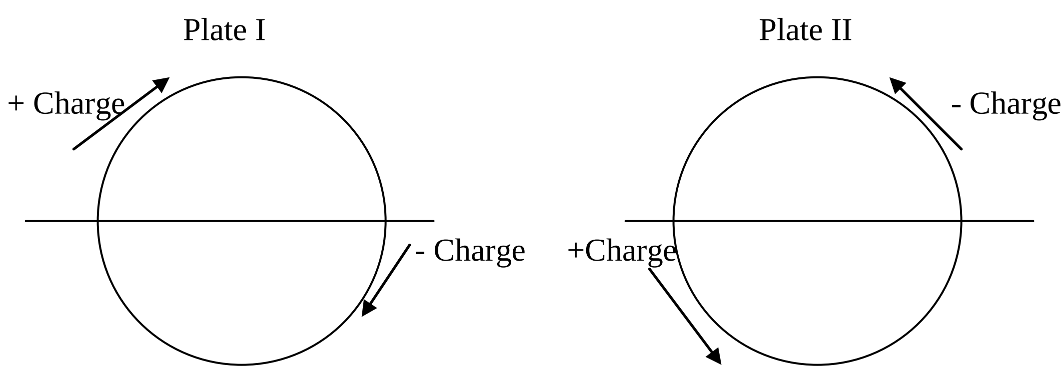
QuickTime™ and a
decompressor
are needed to see this picture.

device that can create an electric charge, that predates the Van De Graf Generator.

The way this machine is constructed is it has two circular glass plates that are set up parallel to one another. On one side of the plates (the back-side in the image) there is a small crank that turns one direction clockwise, and the other plate counter-clockwise. On these plates, there are small metal sections (usually copper for its conductivity) placed radially around both plates at equal distances between each other; both plates are set up with these metal sections at the same locations on the plates. Along with this, there are two parallel, double-ended brushes (at right angles to each other) on opposite sides of the plates that touch the plate on their respective sides.

Parallel to the ground, there are metal “collection combs” on the left and right sides of the plates that are on both sides of the plates. From these combs, there is a bar that travels to a large conductor (two on each side, one for each mesh). From this conductor, another bar travels to spherical nodes that can be positioned at different distance from each other.

The way the machine generates a spark is a rather simple principle. If a small positive charge is on one of the sections and the crank of the machine is turned, the positive charge is then moved around the plate. When the metal section that has the charge comes in contact with the bristle on its respective side, it causes a negative charge to be generated in the metal section on the opposite side of the plate. On the opposite plate, whenever the positive metal section passes by a neutral section on the other side, the negative charges of the neutral section are pulled to the inner surface and the positive charges are pushed to the outer surface. Once this section of separated charge reaches the metal brush on its side, the positive charge then moves through the brush to the opposite side of the plate. So, in essence:



In the images above, on either side of the plates, where the lines cross them, is where the collection combs are located. Notice that on both plates, the positive charges are both traveling to the right side and the negatives are traveling to the left. At these combs, the excess positive and negative charges are collected and are sent to the conductors. Over time, enough charge is developed in the conductors that at the nodes of the machine, the change in potential becomes so strong that a spark occurs to lower the difference.

The actual experimental procedure will be done as follows. First we have to gather all the tools and materials we need for the experiment. This consists of the Wimshurst machine, a humidifier, a stopwatch, a pencil and paper, and water. Now we can set up the experiment. It is important to run this experiment in a small room, so the moister from the humidifier would have as high of a concentration as we could get, which would hopefully give us more visible results.

The first task to be done once we have the Wimshurst machine set up in a small room is to do a control run to collect the control data. The data we will be collecting is the number of sparks created over a 10 second time interval at different rotational velocities. We will count the number of discharges over a 1.8cm distance between the rods of the Wimshurst machine. The variable to be changed is the amount of humidity in the air. The first trial, the control, will be done with no additional humidity to the room. Dylan will hold the stopwatch and turn the machine, and Sam will focus on counting the number of sparks. The different velocities to be tested were 1 rotation every 4 seconds, 1rotation every 6 seconds, 1 rotation every 8 seconds, and 1 rotation every 10 seconds. (We decided not to test 1 rotation every 2 seconds because the rate of discharge was too high for a person to keep up with counting.)

The next step is to set up the humidifier and let it run in the room for 30 minutes. Once this is done, it is time run the Wimshurst machine again at the same rotational velocities and count the discharges. Once this data has been collected, turn the humidifier on for an additional 30 minutes, totaling one hour of humidifying time. Once the additional 30 minutes has elapsed, we run the third data collecting trial with the same rotational speeds. Once this is completed, the humidifier is turned back on for another 30 minutes. Once this is completed, the fourth trial is to be done.

The last thing to explore is to see the affects created when the humidifier was placed right next to the Wimshurst machine, positioned so that the stream of moister would rise right up between the two discharge nodes. Once the two machines are set up this way, the fifth and final trial is to be completed.

DATA

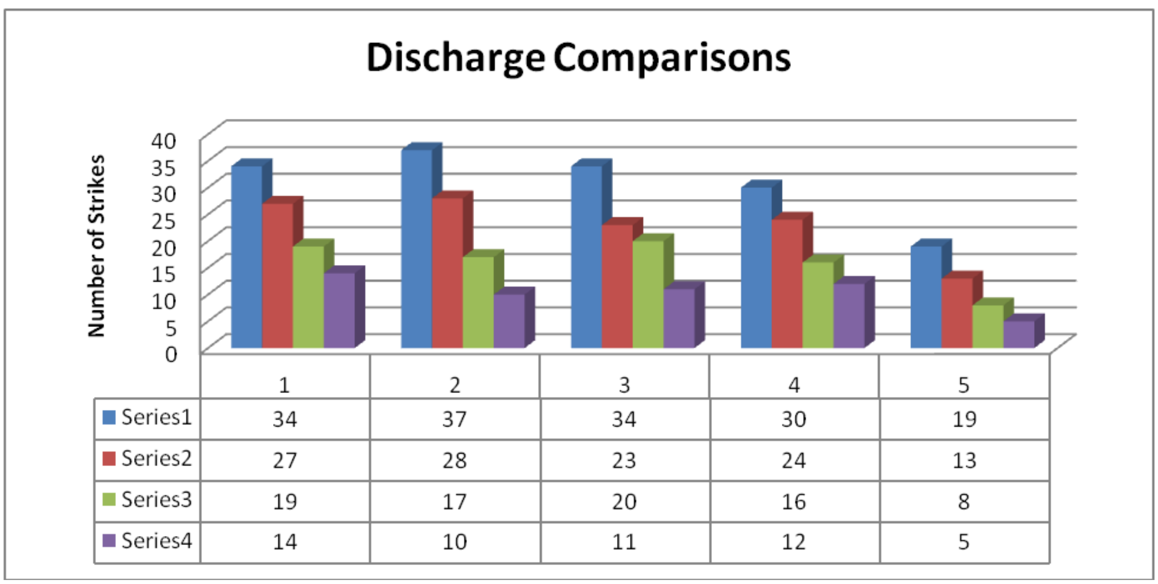
No Humidity	
Seconds per Rotation	Number of Sparks
4	34
6	27
8	19
10	14

30 Minutes of Humidity	
Seconds per Rotation	Number of Sparks
4	37
6	28
8	17
10	10

60 Minutes of Humidity	
Seconds per Rotation	Number of Sparks
4	34
6	23
8	20
10	11

90 Minutes of Humidity	
Seconds per Rotation	Number of Sparks
4	30
6	24
8	16
10	12

Humidifier Stream between Rods	
Seconds per Rotation	Number of Sparks
4	19
6	13
8	8
10	5



Group 1 = No Humidity
Group 2 = 30 Minutes of Humidifier
Group 3= 60 Minutes of Humidifier
Group 4 = 90 Minutes of Humidifier
Group 5 = Direct Stream of Humidity

Series 1 = 1 Rotation every 4 seconds
Series 2 = 1 Rotation every 6 seconds
Series 3 = 1 Rotation every 8 seconds
Series 4 = 1 Rotation every 10 seconds

RESULTS

We were not able to see any distinct difference in the different humidity level trials. In theory, we were suppose to see a decrease in the number of discharges as the concentration of moister in the air increased, but this was not the case. This does not rule out the idea that moister levels can affect the permittivity of free space, it just means that our experiment did not work out to show this outcome.

The fact that we were not able to see any distinct difference in each trail is probably due to the fact that any change in the velocity has a direct affect on the number of discharges, and that there wasn't a very accurate way of regulating the machine angular velocity; there is no way to make sure that the rotation velocity for 1 rotation every four seconds was the same in each trial without having a motor do the rotations.

It was revealed in the trial where there was a direct stream of moister flowing through the space between the rods, however, that there can be an affect on the permittivity of air by water. The problem in the other trials is that the concentration of humidity in the air between the two rods just wasn't significant enough to affect the permiability of the air on such a "large" scale. Not enough, at least, to affect it more than the inconsistency with the rotational velocities.

ERROR ANALYSIS

The experiment did not work out as planned. The fact that the humidifier was not strong enough to significantly affect the dampness of the air, coupled with the fact that it is impossible to rotate the Wimshurst handle at a consistant velocity for each trial, laid the foundation for an unsuccessful experiment. If we had done counted the number of strikes for each trial more than a couple of times, recorded all of them, and then averaged them, we probably would have gotten slightly better data.

Conclusion

First and foremost, the experimental portion of this project did not turn out the way we had anticipated. We did not understand the large quantity of error that was going to occur as a result of trying to count so many discharges over such a small period of time. Also, not being able to find a motor that would rotate the Wimshurst machine's handle at a consistent velocity introduced a lot of error. Leaving that up to a person guaruntees significant error.

After this experiment, possible continuations would be to test the same aspect of the weather, but much more accurately and with better equipment. We could find a means of figuring how much charge is being produced and then we could relate that to the discharges. Another continuation that is possible is testing more than just humidity; other testing possibilities include temperature, wind speed, lighting conditions, etc.

The natural devastation that can come from a storm will always fascinate the world, and we have yet to examine every reason for what occurs. This project was meant to answer a question, but it only creates new ones as well as deepens the current one.

Works Cited

Benjamin Franklin. (n.d.). In *APS Physics | APS Home*. Retrieved March 14, 2009, from http://www.aps.org/programs/outreach/history/historicsites/franklin.cfm

Christian, H. J., & McCook, M. A. (n.d.). A Lightning Primer. In G. P. Miller & M. W. McCook (Eds.), *Lightning and Atmospheric Elelectricity Research at GHCC*. Retrieved March 15, 2009, from http://thunder.nsstc.nasa.gov/primer/primer2.html

Phillips, T. (n.d.). NASA - Electric Ice. In *NASA - Science@NASA*. Retrieved March 5, 2009, from http://science.nasa.gov/headlines/y2006/13sep_electricice.htm

Thomas-François Dalibard. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved March 12, 2009, from http://en.wikipedia.org/wiki/Thomas-Francois_Dalibard