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The Effect of
Air Currents
on
Electrostatic Discharge Distributions

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Summary

Using an apparatus to produce small-scale, safe lightning strikes using a standard static electricity generator, the effect of an artificially generated wind was measured.

With this knowledge of the effect of wind on lightning, it may be possible to compute the opposite, by deriving wind patterns through observations of natural lightning. If this is done, then the shape and locations of lightning strikes may provide important clues to possible storms, tornadoes, and other weather conditions.

Abstract

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Lightning is a form of electrostatic discharge which bears a very complex shape due to its high potential, long distance, and the presence of other meteorological factors. By isolating these factors, one may be able to determine their individual effects on either the shape of lightning, or the locations at which it strikes. This research used a Van de Graaff electrostatic generator to simulate lightning strikes on a flat metal surface and measured the effect of artificially-generated wind currents on the strike locations, finding that lightning tends to bend in the opposite direction as wind flow, possibly due to differences in pressure.

Experimental Report

Introduction

Current methods of developing lightning research involve a variety of methods of observing actual lightning. By launching rockets tied to thin metal wires upward, one may be able to trigger a lightning strike, which can be observed and measured with an apparatus set-up at the predetermined strike location. Satellites may be able to observe lightning and record data for storms, temperature fronts, and wind currents. However, as natural lightning and storms are extremely complex, there arise deficiencies with using these methods in meteorological research. Either one cannot observe *natural* lightning shapes or locations if it has been induced to strike with a human-made apparatus, or far too many variables are present to be able to perform an accurate study.

A solution to these problems can be provided by conducting research on a smaller, more manageable scale. By using an electrostatic source such as a Van de Graaff generator, it is possible to safely create a discharge similar in physical and electrical properties to natural lightning while maintaining a much more controlled environment. This also allows the elimination of additional variables resulting from the nature of weather itself (as potential effects on lightning can possibly come from wind speed, air pressure, temperature and temperature changes, cloud shapes and charge interactions between clouds, and rain properties).

Perhaps the most prominent and quickly changing property of weather is the wind speed at any given point. The following research was done by generating artificial wind with a fan while discharging a Van de Graff onto a metal plate. By tracking the locations of discharge through several hundred strikes with and without generated wind, the effects of the wind became isolated and experimentally visible.

Theoretical Predictions

The effect of air currents alone on electrostatic discharge can be observed by studying the physical and electrical properties of air.

Cloud-to-ground lightning, which results in a stream of electrons traveling downward from the clouds (which is most like the type of discharge considered in this experiment) occurs when negative charges build up on the lower region of a cloud. These force away the negative charges in the ground away from the surface. Then, a negatively charged stream of electrons (a negative *streamer*) builds downward from the clouds, as a positive streamer builds from the ground (unlike the negative streamer, the positive streamer from the ground is composed not of moving positive charges but rather a positive ionization of air particles). The two streamers, of opposite charges, attract; if they meet at a location, a conductive path will be temporarily formed, which will allow a flood of downward negative charges *(Source: Lightning Physics)*.

As lightning involves this creation of negative and positive streamers which ionize air particles, they may be affected by wind. As air moves across these building streamers, charged air particles may be moved, disrupting the streamer and shifting the location of discharge. This effect may occur if the streamer or cloud charges take a significant time to develop and wind speeds are high.

A second effect may occur due to wind. As wind currents develop, air pressure reduces as per Bernoulli's principle. The ideal gas law

$$PV = nRT \qquad \textit{(Equation 1)}$$

(P=pressure, V=volume, T=temperature, and *n* being the number of moles of gas present) requires that there be less air particles per unit of volume if there is a decrease in pressure. This will slightly change the dielectric constant of the given volume of moving air, bringing it slightly closer toward a value of 1. This may affect the capacitance of the gap as well as the dielectric breakdown constant of air from its standard of approximately 3 megavolts per meter.

Materials and Apparatus

A Van de Graaff generator was used to provide the negative potential necessary to trigger a discharge of the same properties as cloud-to-ground lightning. The negatively charged terminal (the upper sphere of a Van de Graaff) of the generator was connected to another sphere held stably inside a grounded frame; attached to the frame was a platform, kept 2.3 centimeters vertically downward from the second sphere. When in operation, dielectric breakdown of the air occurs frequently and miniature, controlled electrostatic bolts are created between the sphere and platform.

Since the property of interest is the probability distribution of strikes over the platform, the locations of discharge must be recorded. This was accomplished by stretching a sheet of carbon paper across the platform. When a discharge occurs, a tiny region of the carbon on the paper is fused together and remains distinctly visible. After data collection, the sheets of carbon paper were scanned into a computer for image enhancement and further statistical analysis.

A relatively powerful fan was situated near the apparatus and facing the discharge area in order to provide an artificial source of wind.

A diagram is shown below in Figure 0.1 (refer to Appendix A for photographs):

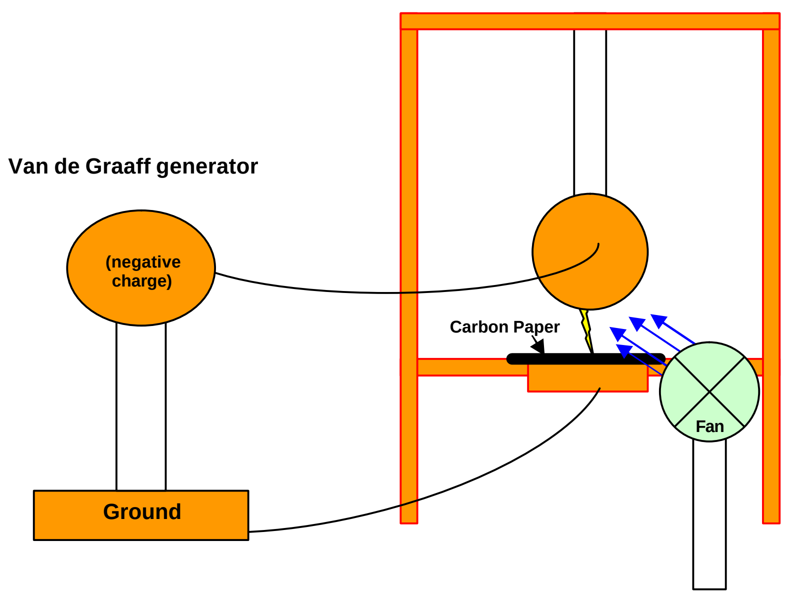


Figure 0-1: *The apparatus*

Method

The experiment was first conducted with the fan off. First, a sheet of carbon paper was securely attached to the grounded metal plate onto which the sphere discharges; the exact location of the carbon paper sheet was marked on the plate itself in order for each sheet to be accurately positioned. The Van de Graff generator was then switched on, which triggered a periodic discharge onto this surface, marking the carbon paper sheet.

400 strikes were counted before the generator was stopped, and the sheet taken to be scanned and enhanced through the computer.

The experiment was then conducted with the fan turned on with the power supply set at 6.3 volts each time. The experiment was then repeated and the data recorded on a sheet of carbon paper each time for 400 strikes.

Upon collection of 10 such sheets of data for each set (wind vs. no wind), they were all scanned and combined with the computer to obtain aggregate data for the total of 4000 strikes for each set. The effects of the wind could then be observed based on these images, as the density of strikes in any given location on the image is an indication of the probability of a lightning strike at that point.

A second, smaller investigation was also conducted. Without any recording of the locations of strikes, the Van de Graff was switched on—after reaching full speed, a stopwatch was used to time 100 discharges without the presence of wind, and then 100 discharges with the presence of wind. The Van de Graaff was *not* adjusted or switched off/on between trials in order to keep the rate of charge build-up constant. This was repeated six times to determine *if* wind had an effect not only on location, but on the frequency of strikes as well.

Statement of Results

After running the experiment as described in the *Method*, a distinct difference in the strike locations was visible when the generated wind was present. Through still air, the discharge locations formed a ring around the center of the sphere (likely caused by a structural screw hole that existed exactly in the bottom center of the discharging sphere; as it is the changes that are being noted, this should not affect the trend of the results). When the fan was switched on to generate wind parallel to the discharge surface, the locations of the discharges shifted towards only the wind side, leaving more of a semicircular shape in the pattern of discharges. 10 trials of 400 discharges each were run, after which the carbon paper sheets were scanned into a computer and enhanced to clearly outline strike locations. As the dimensions and conditions of the apparatus were kept the same through the 10 trials, all data was combined to create a composite image of all 4000 strikes, as shown below (refer to Appendix B for individual trial data).

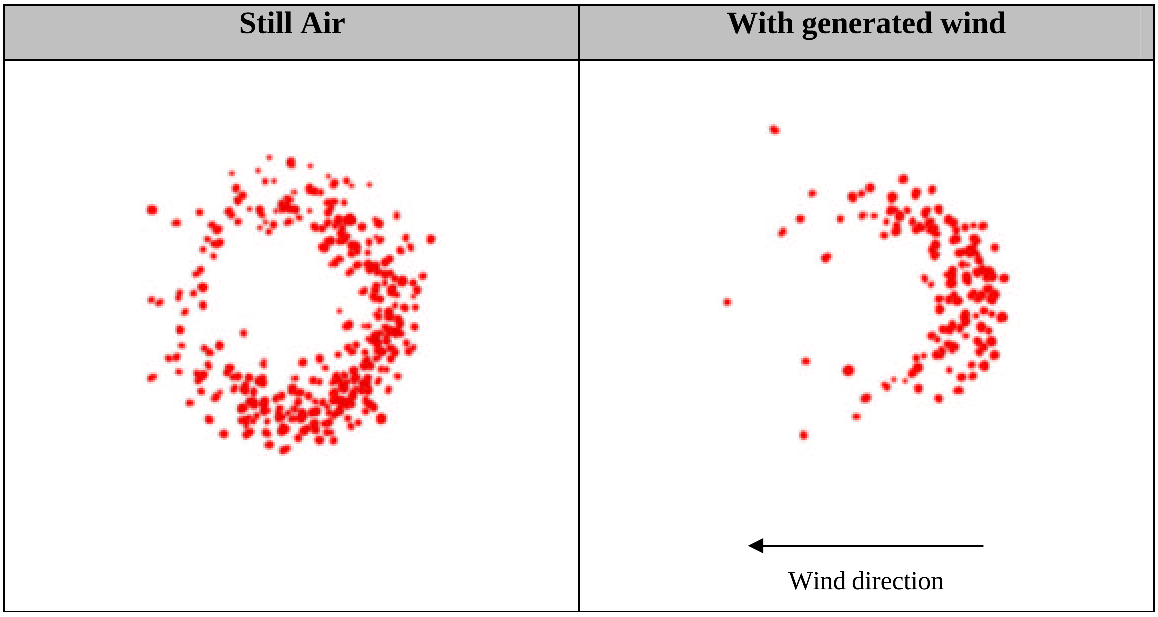


Figure 0-2: *Composite data for all 10 trials (refer to Appendix B for individual trial data)*

A timed test was also run to test the effect of the wind on the interval between discharges (which is dependent on the rate of electric field build-up between the discharging sphere and grounding plate). Six repetitions were done with 100 discharges each:

Still Air, time for 100 discharges	**Moving Air,** time for 100 discharges	**Percentage Increase** in time for moving air
30.75 s	30.25 s	-1.63%
30.47 s	30.25 s	-0.72%
29.12 s	29.79 s	+2.30%
28.31 s	28.94 s	+2.23%
27.87 s	28.12 s	+1.08%
28.94 s	28.47 s	-1.62%

Chart 0-3: *Table of results for timed discharges*

From this data, the percentage increases in time for moving air vary greatly, averaging a mere 0.27% increase in time for 400 discharges. This appears to be rather insignificant, indicating from these results that there may be no connection between the presence of wind and *time* taken to build an electric field or discharge. However, location appears to be significantly affected based on the results of the carbon paper tests.

Discussion of Results

As stated in the results, the location appears to be affected significantly by the presence of wind, biasing strikes towards the source of the wind (in other words, the strikes shift in a direction opposite the flow of wind). The second test suggested that there was no effect on the time required to discharge, due to the wind. In *Theoretical Predictions*, two possible sources of the change in properties were identified:

(1) Disruption of air particles during the formation of streamers or charged particles, or

(2) Change in air pressure due to movement as per Bernoulli's principle, consequently affecting the electrical properties of the air in general

Between these two hypotheses, the results suggest that (1) is likely not the case as any disruption in the formation of streamers would cause a change in the time required to discharge, as was not the case as demonstrated by the second test. (2) seems like a more valid explanation to the change in location, as the pressure may affect properties of air—the breakdown voltage in particular, which typically is approximately 3 million volts per meter. According to Paschen's Law, the breakdown voltage can be described as a function of the gap length and air pressure between the two terminals. For air, it is known to be roughly

$$V = (30pd + 1.35), \text{ kiloVolts}$$ *(Source: Lux)* *(Equation 2)*

where the pressure p is described in atmospheres and d in centimeters. If the pressure p reduces as one approaches the fan (as air velocities are higher towards the fan), then the breakdown voltage will consequently reduce as described by the above equation. With a lower breakdown voltage towards the lower-pressure region, a strike will occur there before a sufficient potential difference builds in the higher-pressure regions.

Conclusion

Using a method to perform lightning experiments on a small and controlled scale, a connection between the location of lightning strikes and the presence of wind appears to exist—lightning tends to be biased in the opposite direction as the air flow, possibly as a result of pressure differences resulting from wind, which alter the electrical properties of the atmosphere.

Given the shape of a much longer, natural lightning strike, the reverse may be possible to determine. If all other variables are constant, then a bend in the path of a lightning strike may be opposite the wind flow at that point—through a series of lightning strikes occurring in a region, the overall wind patterns can possibly be deduced. If a model of wind patterns can be generated on-the-fly during a storm, this type of prediction can be valuable in forecasting weather and providing warnings to occurrences such as tornadoes.

Overall, this research can be continued and extended in a variety of ways and provides a starting point for the development of new methods of weather forecasting and meteorology research.

Further Study

There are several opportunities for research in this field to expand upon this knowledge and develop the science of meteorology using methods similar to those in this experiment.

This experiment could be performed with a narrow stream of air through a tube from a high-quality air compressor instead of a fan. This would allow the air pressure an wind speed to be calculated. Also, an electrostatic source with known charge should be used; this type of apparatus will allow for collection of data for mathematical analysis which may lead to the finding of the equations involved in this effect. The change in the strike locations can be measured mathematically by computing the standard deviation of all strike distances from the center, *and* computing the standard deviation of all the directions of striking, specified in radians.

Other variables besides wind can also be researched, such as temperature and humidity differences, which may also be factors in determining the shape of a lightning strike. The effect of temperature can be measured by using a heater instead of a fan, with measured airflow if possible. As temperature also directly affects pressure (see Equation 1), it will affect the breakdown voltage as per Paschen's Law.

Satellite research to track lightning strikes and weather patterns to confirm the presence of these effects on a large scale. NASA has already collected various data of lightning strikes around tornadoes in storms, and found that lightning tends to circle updrafts *(Source: Lightning Position)*. If temperature and humidity data is collected, basic wind dynamics in a tornado may be simulated with a computer and the results of those experiments used to predict the lightning positions to see if lightning will follow the same circling pattern in the simulation. If this is successful, then the patterns of lightning should be collected by satellite and/or ground-based observation during a storm *over time* to see if the position of forming updrafts or tornadoes can be predicted in advance.

Acknowledgements

This research was done at Hunterdon Central Regional High School, Flemington, NJ, USA. Thanks to Mr. Sean Chappe, the teacher advisor for this experiment, as well as all other teachers and individuals who made this research possible.

Appendix A: Photographs

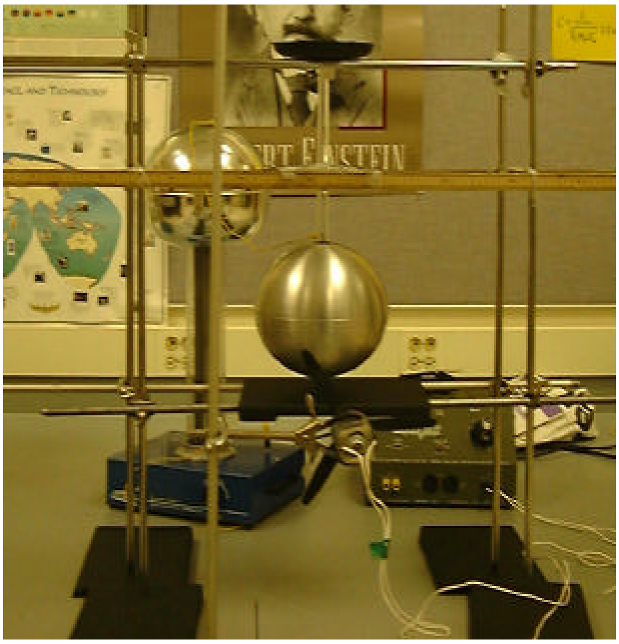
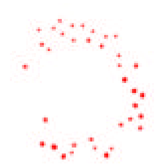
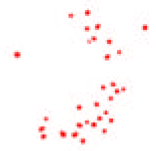
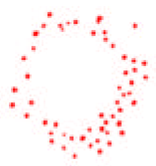
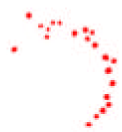
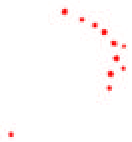
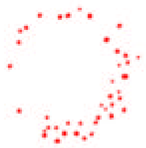
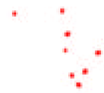
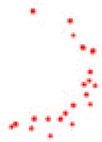
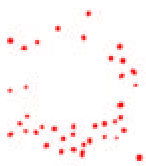
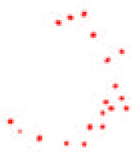
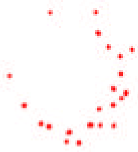
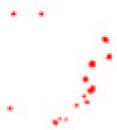
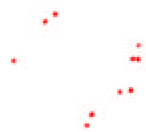


Figure 1-1: In the background towards the left is the Van de Graaff; it is connected to the discharging sphere in foreground. The carbon paper is securely attached to the black, grounded metal plate directly below the discharging sphere to record results.

Figure 1-2: The fan is visible towards the left. The entire frame of the apparatus is also grounded, in addition to the grounded metal plate to prevent unwanted charges from building up on the frame, biasing the results.

Appendix B: Individual Trial Data

Still Air		With generated wind	
 **Figure 2-1**	 **Figure 2-2**	 **Figure 3-1**	 **Figure 3-2**
 **Figure 2-3**	 **Figure 2-4**	 **Figure 3-3**	 **Figure 3-4**
 **Figure 2-5**	 **Figure 2-6**	 **Figure 3-5**	 **Figure 3-6**
 **Figure 2-7**	 **Figure 2-8**	 **Figure 3-7**	 **Figure 3-8**
 **Figure 2-9**	 **Figure 2-10**	 **Figure 3-9**	 **Figure 3-10**

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