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МОЛНИЯ: ГИПОТЕЗЫ ОБРАЗОВАНИЯ, ВИДЫ МОЛНИЙ
PHENOMENON OF LIGHTNING: NATURE, FORMATION AND TYPES

Historical significance of lightning and of the lightning research Mankind has always been fascinated by lightning. In ancient times thunder and lightning were connected with various religious and mythical concepts.

Lightning was viewed as part of a deity or a deity in of itself. For example, the Ancient Greeks believe, that lightning is a weapon of Zeus. In Norse mythology, Thor is the god of thunder and the sound of thunder comes from the chariot he rides across the sky. The lightning comes from his hammer Mjölnir. In Slavic mythology the highest god of the pantheon is Perun, the god of thunder and lightning.

On the other hand, death by lightning was regarded in ancient Rome as unclean, and victims were buried without any ceremony. Fear of lightning soon developed into a search for protection against this terrifying and unfathomable natural phenomenon. Already in early history, various remedies were thought to appease or avoid the consequences of lightning.

Today, scientists established lightning is an atmospheric electrostatic discharge (spark) accompanied by thunder, which typically occurs during thunderstorms, and sometimes during volcanic eruptions or dust storms. There are some 16 million lightning storms in the world every year.

How lightning initially forms is still a matter of debate. Scientists have studied root causes ranging from atmospheric perturbations (wind, humidity, friction, and atmospheric pressure) to the impact of solar wind and accumulation of charged solar particles. Ice inside a cloud is thought to be a key element in lightning development, and may cause a forcible separation of positive and negative charges within the cloud, thus assisting in the formation of lightning.

History of lightning research

It is necessary to disclose the history of lightning research that is associated with the name of a leading scientist of the United States, Benjamin Franklin (1706–1790). As a scientist, he was a major figure in the American Enlightenment and the history of physics for his discoveries and theories regarding electricity.

B. Franklin endeavored to test the theory that sparks shared some similarity with lightning by using a spire which was being erected in Philadelphia, United States. While waiting for completion of the spire, he got the idea to use a flying object such as a kite. During the next thunderstorm, which was in June 1752, it was reported that he raised a kite. He was accompanied by his son as an assistant. On his end of the string he attached a key, and he tied it to a post with a silk thread. As time passed, Franklin noticed the loose fibers on the string stretching out; he then brought his hand close to the key and a spark jumped the gap. The rain which had fallen during the storm had soaked the line and made it conductive [1].

Thomas-François Dalibard and De Lors conducted it at Marly-la-Ville in France, a few weeks before Franklin's experiment. In his autobiography Franklin clearly states that he performed this experiment after those in France, which occurred weeks before his own experiment, without his prior knowledge as of 1752.

Although experiments from the time of Benjamin Franklin showed that lightning was a discharge of static electricity, there was little improvement in theoretical understanding of lightning (in particular how it was generated) for more than 150 years.

In 1900, Nikola Tesla generated artificial lightning by using a large Tesla coil, enabling the generation of enormously high voltages sufficient to create lightning.

Properties

Lightning can occur with both positive and negative polarity. An average bolt of negative lightning carries an electric current of 30,000 amperes (30 kA), and transfers fifteen coulombs of electric charge and 500 megajoules of energy. Large bolts of lightning can carry up to 120 kA and 350 coulombs. An average bolt of positive lightning carries an electric current of about 300 kA — about 10 times that of negative lightning.

The voltage involved for both is proportional to the length of the bolt. However, lightning leader development is not just a matter of the electrical breakdown of air, which occurs at a voltage gradient of about 1 megavolts per metre (MV/m). The ambient electric fields required for lightning leader propagation can be one or two orders of magnitude (10−2) less than the electrical breakdown strength. The potential ("voltage") gradient inside a well-developed return-stroke channel is on the order of hundreds of volts per metre (V/m) due to intense channel ionization, resulting in a true power output on the order of one megawatt per meter (MW/m) for a vigorous return stroke current of 100 kA. The average peak power output of a single lightning stroke is about one trillion watts — one terawatt (1012 W), and the stroke lasts for about 30 millionths of a second — 30 microseconds.

Lightning rapidly heats the air in its immediate vicinity to about 20,000 °C (36,000 °F) — about three times the temperature of the surface of the Sun. The sudden heating effect and the expansion of heated air gives rise to a supersonic shock wave in the surrounding clear air. It is this shock wave, once it decays to an acoustic wave, that is heard as thunder.

Different locations have different potentials and currents for an average lightning strike. In the United States, for example, Florida experiences the largest number of recorded strikes in a given period during the summer season, has very sandy soils in some areas, and electrically conductive water-saturated soils in others. As much of Florida lies on a peninsula, it is bordered by the ocean on three sides. The result is the daily development of sea and lake breeze boundaries that collide and produce thunderstorms.

Formation

Cloud particle collision hypothesis

According to this cloud particle charging hypothesis, charges are separated when ice crystals rebound off graupel. Charge separation appears to require strong updrafts which carry water droplets upward, supercooling them to between -10 and -40 °C. These water droplets collide with ice crystals to form a soft ice-water mixture called graupel. Collisions between ice crystals and graupel pellets usually results in positive charge being transferred to the ice crystals, and negative charge to the graupel. Updrafts drive the less heavy ice crystals upwards, causing the cloud top to accumulate increasing positive charge. Gravity causes the heavier negatively charged graupel to fall toward the middle and lower portions of the cloud, building up an increasing negative charge. Charge separation and accumulation continue until the electrical potential becomes sufficient to initiate a lightning discharge, which occurs when the distribution of positive and negative charges forms a sufficiently strong electric field.

Polarization mechanism hypothesis

The mechanism by which charge separation happens is still the subject of research. Another hypothesis is the polarization mechanism, which has two components:

Falling droplets of ice and rain become electrically polarized as they fall through the Earth's natural electric field;

Colliding/rebounding cloud particles become oppositely charged.

There are several hypotheses for the origin of charge separation.

Lightning initiation

Even assuming an electric field has been established, the mechanism by which the lightning discharge begins is not well known. Electric field measurements in thunderclouds are typically not large enough to directly initiate a discharge. Many hypotheses have been proposed, ranging from including runaway breakdown to locally enhanced electric fields near elongated water droplets or ice crystals. Percolation theory, especially for the case of biased percolation, describe random connectivity phenomena, which produce an evolution of connected structures similar to that of lightning strikes.

Leader formation and the return stroke

As a thundercloud moves over the surface of the Earth, an electric charge equal to but opposite the charge of the base of the thundercloud is induced in the Earth below the cloud. The induced ground charge follows the movement of the cloud, remaining underneath it.

An initial bipolar discharge, or path of ionized air, starts from a negatively charged region of mixed water and ice in the thundercloud. Discharge ionized channels are known as leaders. The positive and negative charged leaders, generally a "stepped leader", proceed in opposite directions. The negatively-charged one proceeds downward in a number of quick jumps (steps). 90 percent of the leaders exceed 45 m (148 ft) in length, with most in the order of 50 to 100 m (164 to 492 feet). As it continues to descend, the stepped leader may branch into a number of paths. The progression of stepped leaders takes a comparatively long time (hundreds of milliseconds) to approach the ground. This initial phase involves a relatively small electric current (tens or hundreds of amperes), and the leader is almost invisible when compared with the subsequent lightning channel.

When a stepped leader approaches the ground, the presence of opposite charges on the ground enhances the strength of the electric field. The electric field is strongest on ground-connected objects whose tops are closest to the base of the thundercloud, such as trees and tall buildings. If the electric field is strong enough, a conductive discharge (called a positive streamer) can develop from these points. This was first theorized by Heinz Kasemir. As the field increases, the positive streamer may evolve into a hotter, higher current leader which eventually connects to the descending stepped leader from the cloud. It is also possible for many streamers to develop from many different objects simultaneously, with only one connecting with the leader and forming the main discharge path.

Once a channel of ionized air is established between the cloud and ground this becomes a path of least resistance and allows for a much greater current to propagate from the Earth back up the leader into the cloud. This is the return stroke and it is the most luminous and noticeable part of the lightning discharge.

Discharge

When the electric field becomes strong enough, an electrical discharge (the bolt of lightning) occurs within clouds or between clouds and the ground. During the strike, successive portions of air become a conductive discharge channel as the electrons and positive ions of air molecules are pulled away from each other and forced to flow in opposite directions.

The electrical discharge rapidly superheats the discharge channel, causing the air to expand rapidly and produce a shock wave heard as thunder. The rolling and gradually dissipating rumble of thunder is caused by the time delay of sound coming from different portions of a long stroke.

Re-strike

High speed videos show that most lightning strikes are made up of multiple individual strokes. A typical strike is made of 3 or 4 strokes, though there may be more.

Each re-strike is separated by a relatively large amount of time, typically 40 to 50 milliseconds. Re-strikes can cause a noticeable "strobe light" effect.

Each successive stroke is preceded by intermediate dart leader strokes akin to, but weaker than, the initial stepped leader.

The variations in successive discharges are the result of smaller regions of charge within the cloud being depleted by successive strokes. The sound of thunder from a lightning strike is prolonged by successive strokes.

Types

Some lightning strikes exhibit particular characteristics; scientists and the general public have given names to these various types of lightning. The lightning that is most-commonly observed is streak lightning. This is nothing more than the return stroke, the visible part of the lightning stroke. The majority of strokes occur inside a cloud so we do not see most of the individual return strokes during a thunderstorm.

Cloud-to-ground lightning

This is the best known and second most common type of lightning. Of all the different types of lightning, it poses the greatest threat to life and property since it strikes the ground. Cloud-to-ground (CG) lightning is a lightning discharge between a cumulonimbus cloud and the ground. It is initiated by a leader stroke moving down from the cloud.

Bead lightning

Bead lightning is a type of cloud-to-ground lightning which appears to break up into a string of short, bright sections, which last longer than the usual discharge channel. It is relatively rare. Several theories have been proposed to explain it; one is that the observer sees portions of the lightning channel end on, and that these portions appear especially bright. Another is that, in bead lightning, the width of the lightning channel varies; as the lightning channel cools and fades, the wider sections cool more slowly and remain visible longer, appearing as a string of beads.

Ribbon lightning

Ribbon lightning occurs in thunderstorms with high cross winds and multiple return strokes. The wind will blow each successive return stroke slightly to one side of the previous return stroke, causing a ribbon effect.

Staccato lightning

Staccato lightning is a cloud-to-ground lightning (CG) strike which is a short-duration stroke that (often but not always) appears as a single very bright flash and often has considerable branching. These are often found in the visual vault area near the mesocyclone of rotating thunderstorms and coincides with intensification of thunderstorm updrafts. A similar cloud-to-cloud strike consisting of a brief flash over a small area, also occurs in a similar area of rotating updrafts.

Ground-to-cloud lightning

Ground-to-cloud lightning is a lightning discharge between the ground and a cumulonimbus cloud initiated by an upward-moving leader stroke. This type of lightning forms when negatively charged ions called the stepped leader rise up from the ground and meet the positively charged ions in a cumulonimbus cloud. Then the strike goes back to the ground as the return stroke. This is also called positive lightning.

Cloud-to-cloud lightning

Lightning discharges may occur between areas of cloud without contacting the ground. When it occurs between two separate clouds and when it occurs between areas of differing electric potential within a single cloud it is known as intra-cloud lightning. Intra-cloud lightning is the most frequently occurring type.

These are most common between the upper anvil portion and lower reaches of a given thunderstorm. This lightning can sometimes be observed at great distances at night as so-called "heat lightning". In such instances, the observer may see only a flash of light without hearing any thunder.

Another terminology used for cloud–cloud or cloud–cloud–ground lightning is "Anvil Crawler", due to the habit of the charge typically originating from beneath or within the anvil and scrambling through the upper cloud layers of a thunderstorm, normally generating multiple branch strokes which are dramatic to witnesses.

Dry lightning

Dry lightning is a term in Canada and the United States for lightning that occurs with no precipitation at the surface. This type of lightning is the most common natural cause of wildfires. Pyrocumulus clouds produce lightning for the same reason that it is produced by cumulonimbus clouds. When the higher levels of the atmosphere are cooler, and the surface is warmed to extreme temperatures due to a wildfire, volcano, etc., convection will occur, and the convection produces lightning.

Ball lightning

Ball lightning may be an atmospheric electrical phenomenon, the physical nature of which is still controversial. The term refers to reports of luminous, usually spherical objects which vary from pea-sized to several metres in diameter. It is sometimes associated with thunderstorms, but unlike lightning flashes, which last only a fraction of a second, ball lightning reportedly lasts many seconds. Ball lightning has been described by eyewitnesses but rarely recorded by meteorologists.

Laboratory experiments have produced effects that are visually similar to reports of ball lightning, but at present, it is unknown whether these are actually related to any naturally occurring phenomenon. One theory is that ball lightning may be created when lightning strikes silicon in soil, a phenomenon which has been duplicated in laboratory testing. Given inconsistencies and the lack of reliable data and completely contradicting and unpredictable behavior, the true nature of ball lightning is still unknown and was often regarded as a fantasy or a hoax. Reports of the phenomenon were dismissed for lack of physical evidence, and were often regarded the same way as UFO sightings. Severely contradicting descriptions of ball lightning makes it impossible even to create plausible hypothesis that will take into account described behavior.

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