Lightning Phenomenon – Introduction and Basic Information to Understand the Power of Nature

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This paper introduces the history of lightning researches, some hypothesis of lightning forming process, types of lightning and triggering ways.

I. Introduction

Benjamin Franklin (1706-1790)[1] endeavored to test the theory that sparks shared some similarity with lightning using a spire which was being erected in Philadelphia. While waiting for completion of the spire, he got the idea of instead using a flying object, such as a kite. During the next thunderstorm, which was in June 1752, it was reported that he raised a kite, 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.

Although experiments from the past 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. The impetus for new research came from the field of power engineering: as power transmission lines came into service, engineers needed to know much more about lightning in order to adequately protect lines and equipment.

Nowadays lightning is considered as an atmospheric discharge of electricity, which typically occurs during thunderstorms, and sometimes during volcanic eruptions or dust storms. In the atmospheric electrical discharge, a leader of a bolt of lightning can travel at speeds of 60,000 m/s (220,000 km/h), and can reach temperatures approaching 30,000 °C (54,000 °F), hot enough to fuse silica sand into petrified lightning, known scientifically as glass channels[2] or fulgurites which are normally hollow and can extend some distance into the ground. 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.

II. Forming Process[3]

1) Charge separation – the first process in the generation of lightning. There are two hypothesis describing the process:

– Polarization mechanism hypothesis

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

a) Falling droplets of ice and rain become electrically polarized as they fall through the atmosphere's natural electric field;
b) Colliding ice particles become charged by electrostatic induction.

Ice and super-cooled water are the keys to the process. Violent winds buffet tiny hailstones as they form, causing them to collide. When the hailstones hit ice crystals, some negative ions transfer from one particle to another. The smaller, lighter particles lose negative ions and become positive; the larger, more massive particles gain negative ions and become negative.

Figure 1. Lighting discharge.

– ELECTROSTATIC INDUCTION HYPOTHESIS

According to the electrostatic induction hypothesis charges are driven apart by as-yet uncertain processes. Charge separation appears to require strong updrafts which carry water droplets upward, super-cooling them to between -10 and -20 °C. These collide with ice crystals to form a soft ice-water mixture called graupel.[a] The collisions result in a slight positive charge being transferred to ice crystals, and a slight negative charge to the graupel. Updrafts drive lighter ice crystals upwards, causing the cloud top to accumulate increasing positive charge. The heavier negatively charged graupel falls towards 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 lightning discharges, which occurs when the gathering of positive and negative charges forms a sufficiently strong electric field.

There are several additional hypotheses for the origin of charge separation.

According to one such hypothesis, charge separation is initiated by the ionization of an air molecule by an incoming cosmic ray.

[a] snow pellets

2) Leader Formation

As a thundercloud moves over the Earth's surface, an equal but opposite charge is induced in the Earth below, and the induced ground charge follows the movement of the cloud.

An initial bipolar discharge, or path of ionized air, starts from a negatively charged mixed water and ice region in the thundercloud. The discharge ionized channels are called leaders. The negative charged leaders, called a "stepped leader", proceed generally downward in a number of quick jumps, each up to 50 meters long. Along the way, the stepped leader may branch into a number of paths as it continues to descend. 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 compared to the subsequent lightning channel.

When a stepped leader approaches the ground, the presence of opposite charges on the ground enhances the electric field. The electric field is highest on 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. Photographs have been taken on which non-connected streamers are clearly visible. When the two leaders meet, the electric current greatly increases. The region of high current propagates back up the positive stepped leader into the cloud with a "return stroke" that is the most luminous part of the lightning discharge.

3) 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.

a) Gurevich's runaway breakdown theory[4]

A theory of lightning initiation, known as the "runaway breakdown theory", proposed by Aleksandr Gurevich of the Lebedev Physical Institute in 1992 suggests that lightning strikes are triggered by cosmic rays which ionize atoms, releasing electrons that are accelerated by the electric fields, ionizing other air molecules and making the air conductive by a runaway breakdown, then "seeding" a lightning strike.

b) Gamma rays and the runaway breakdown theory

It has been discovered in the past 15 years that among the processes of lightning is some mechanism capable of generating gamma rays, which escape the atmosphere and are observed by orbiting spacecraft. Brought to light by NASA's Gerald Fishman in 1994 in an article in Science, these so-called Terrestrial Gamma-Ray Flashes (TGFs) were observed by accident, while he was documenting instances of extraterrestrial gamma ray bursts observed by the Compton Gamma Ray Observatory (CGRO). TGFs are much shorter in duration, however, lasting only about 1 ms.

Professor Umran Inan of Stanford University linked a TGF to an individual lightning stroke occurring within 1.5 ms of the TGF event, proving for the first time that the TGF was of atmospheric origin and associated with lightning strikes.

CGRO recorded only about 77 events in 10 years; however, more recently the RHESSI spacecraft, as reported by David Smith of UC Santa Cruz, has been observing TGFs at a much higher rate, indicating that these occur about 50 times per day globally (still a very small fraction of the total lightning on the planet). The voltage levels recorded exceed 20 MeV.

Scientists from Duke University have also been studying the link between certain lightning events and the mysterious gamma ray emissions that emanate from the Earth's own atmosphere, in light of newer observations of TGFs made by RHESSI. Their study suggests that this gamma radiation fountains upward from starting points at surprisingly low altitudes in thunderclouds.

Steven Cummer, from Duke University's Pratt School of Engineering, said, ‘These are higher energy gamma rays than come from the sun. And yet here they are coming from the kind of terrestrial thunderstorm that we see here all the time'.

Early hypotheses of this pointed to lightning generating high electric fields at altitudes well above the cloud, where the thin atmosphere allows gamma rays to easily escape into space, known as 'relativistic runaway breakdown', similar to the way sprites are generated. Subsequent evidence has cast doubt, though, and suggested instead that TGFs may be produced at the tops of high thunderclouds. Though hindered by atmospheric absorption of the escaping gamma rays, these theories do not require the exceptionally high electric fields that high altitude theories of TGF generation rely on.

The role of TGFs and their relationship to lightning remains a subject of ongoing scientific study.

4) Re-strike [5]

High speed videos (examined frame-by frame) show that most lightning strikes are made up of multiple individual strokes. A typical strike is made of 3 to 4 strokes. 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 again to, but weaker than, the initial stepped leader. The stroke usually re-uses the discharge channel taken by the previous stroke.

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.

III. Types of Lightning

Some lightning strikes take on particular characteristics; scientists and the public have given names to these various types of lightning. Most lightning is streak lightning. This is nothing more than the return stroke, the visible part of the lightning stroke. Because most of these strokes occur inside a cloud, we do not see many of the individual return strokes in a thunderstorm.

The return stroke of a lightning bolt, which is the visible bolt itself, follows a charge channel only about a half-inch (1.3 cm) wide. Most lightning bolts are about a mile (1.6 km) long[6].

– Cloud-to-Cloud Lightning

Lightning discharges may occur between areas of cloud having different potentials without contacting the ground. These are most common between the anvil 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 thunder. The "heat" portion of the term is a folk association between locally experienced warmth and the distant lightning flashes.

Figure 2. Cloud-to-cloud lighting.

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 witness. These are usually seen as a thunderstorm passes over you or begins to decay. The most vivid crawler behavior occurs in well developed thunderstorms that feature extensive rear anvil shearing.

– Dry Lightning[7]

Dry lightning is a term in 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.

– Rocket Lightning

It is a form of cloud discharge, generally horizontal and at cloud base, with a luminous channel appearing to advance through the air with visually resolvable speed, often intermittently. It is also one of the rarest of cloud discharges.

Figure 3. Multiple paths cloud-to-cloud lighting.

Figure 4. Lightning triggered by a volcanic materials thrust high into atmosphere.

– Cloud to Ground Lightning

Cloud-to-ground lightning is a great lightning discharge between a cumulonimbus cloud and the ground initiated by the downward-moving leader stroke. This is the second most common type of lightning, and poses the greatest threat to life and property of all known types.

– 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 fairly rare. One of theories is the observer sees portions of the lightning channel end on, and that these portions appear especially bright.

– 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.

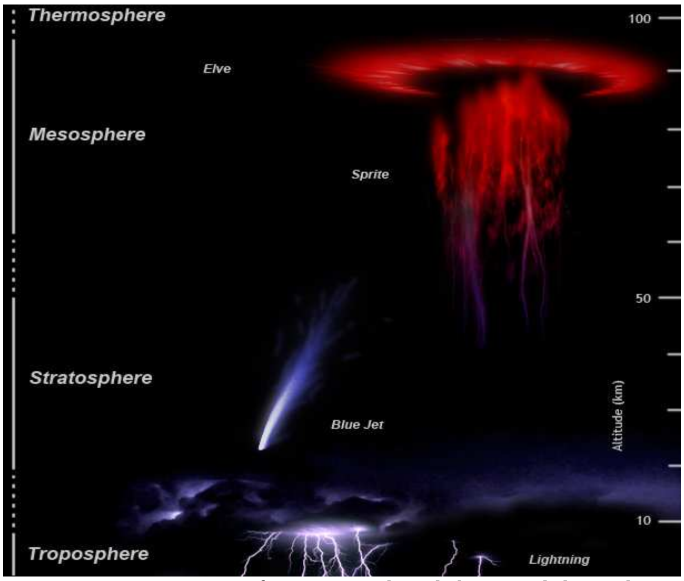

Figure 5. Representation of upper-atmospheric lightning and electrical-discharge phenomena.

– Ground-to-Cloud Lightning

Ground-to-cloud lightning is a lightning discharge between the ground and a cumulonimbus cloud from an upward-moving leader stroke.

– Ball Lightning[8]

Ball lightning is described as a floating, illuminated ball that occurs during thunderstorms. They can be fast moving, slow moving or nearly stationary. Some make hissing or crackling noises or no noise at all. Some have been known to pass through windows and even dissipate with a bang. Ball lightning has been described by eyewitnesses but rarely recorded by meteorologists.

– Upper-Atmospheric Lightning[9]

Reports by scientists of strange lightning phenomena above storms date back to at least 1886. However, it is only in recent years that fuller investigations have been made. This has sometimes been called mega-lightning.

IV. Triggering of Lightning

– Rocket-Triggered

Lightning has been triggered directly by human activity in several instances. Lightning struck Apollo 12 soon after takeoff. It has also been triggered by launching lightning rockets carrying spools of wire into thunderstorms. The wire unwinds as the rocket ascends, providing a path for lightning. These bolts are very straight due to the path created by the wire.

– Volcanically Triggered[10]

Extremely large volcanic eruptions, which eject gases and material high into the atmosphere, can trigger lightning. This phenomenon was documented by Pliny The Elder during the AD79 eruption of Vesuvius, in which he perished.

– Laser Triggered[11]

Since the 1970s, researchers have attempted to trigger lightning strikes on demand. Such triggered lightning is intended to protect rocket launching pads, electric power facilities, and other sensitive targets.

Researchers generated filaments[b] that lived too short a period to trigger a real lightning strike. Nevertheless, a boost in electrical activity within the clouds was registered.

[b] channel of ionized molecules

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