Lightning

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Lightning flashes during a thunderstorm

High-speed, slow-motion lightning video captured at 6,200 frames per second.

Lightning is a sudden electrostatic discharge that occurs during an electrical storm. This discharge occurs between electrically charged regions of a cloud (called intra-cloud lightning or IC), between two clouds (CC lightning), or between a cloud and the ground (CG lightning). The charged regions in the atmosphere temporarily equalize themselves through this discharge referred to as a *strike* if it hits an object on the ground, and a **flash**, if it occurs within a cloud. Lightning causes light in the form of plasma, and sound in the form of thunder. Lightning may be seen and not heard when it occurs at a distance too great for the sound to carry as far as the light from the strike or flash.

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Lightning electrification

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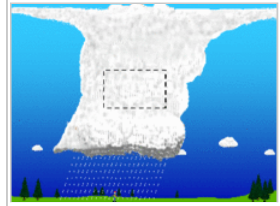
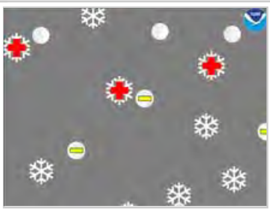


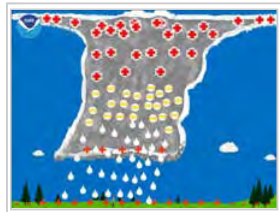
The main charging area in a thunderstorm occurs in the central part of the storm where air is moving upward rapidly (updraft) and temperatures range from -15 to -25 Celsius

The details of the charging process are still being studied by scientists, but there is general agreement on some of the basic concepts of thunderstorm electrification. The main charging area in a thunderstorm occurs in the central part of the storm where air is moving upward rapidly (updraft) and temperatures range from -15 to -25 Celsius, see figure to the right. At that place, the combination of temperature and rapid upward air movement produces a mixture of super-cooled cloud droplets (small water droplets below freezing), small ice crystals, and soft hail (graupel). The updraft carries the super-cooled cloud droplets and very small ice crystals upward. At the same time, the graupel, which is considerably larger and denser, tends to fall or be suspended in the rising air.[1]



When the rising ice crystals collide with graupel (soft hail), the ice crystals become positively charged and the graupel becomes negatively charged.

The differences in the movement of the precipitation cause collisions to occur. When the rising ice crystals collide with graupel (soft hail), the ice crystals become positively charged and the graupel becomes negatively charged. See figure to the left. The updraft carries the positively charged ice crystals upward toward the top of the storm cloud. The larger and denser graupel is either suspended in the middle of the thunderstorm cloud or falls toward the lower part of the storm.[1]



The upper part of the thunderstorm cloud becomes positively charged while the middle to lower part of the thunderstorm cloud becomes negatively charged.

The result is that the upper part of the thunderstorm cloud becomes positively charged while the middle to lower part of the thunderstorm cloud becomes negatively charged.[1]

The upward motions within the storm and winds at higher levels in the atmosphere tend to cause the small ice crystals (and positive charge) in the upper part of the thunderstorm cloud to spread out horizontally some distance from thunderstorm cloud base. This part of the thunderstorm cloud is called the anvil. While this is the main charging process for the thunderstorm cloud, some of these charges can be redistributed by air movements within the storm (updrafts and downdrafts). In addition, there is a small but important positive charge buildup near the bottom of the thunderstorm cloud due to the precipitation and warmer temperatures.[1]

General considerations

Four-second video of a lightning strike, Island in the Sky, Canyonlands National Park, Utah, United States.

On Earth, the lightning frequency is approximately 40–50 times a second or nearly 1.4 billion flashes per year[2] and the average duration is 0.2 seconds made up from a number of much shorter flashes (strokes) of around 30 microseconds.[3]

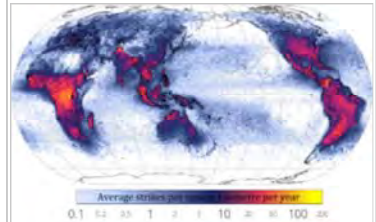
Many factors affect the frequency, distribution, strength and physical properties of a typical lightning flash in a particular region of the world. These factors include ground elevation, latitude, prevailing wind currents, relative humidity, proximity to warm and cold bodies of water, etc. To a certain degree, the ratio between IC, CC and CG lightning may also vary by season in middle latitudes. Because human beings are terrestrial and most of their possessions are on the Earth where lightning can damage or destroy them, CG lightning is the most studied and best understood of the three types, even though IC and CC are more common types of lightning. Lightning's relative unpredictability limits a complete explanation of how or why it occurs, even after hundreds of years of scientific investigation.

A typical cloud to ground lightning flash culminates in the formation of an electrically conducting plasma channel through the air in excess of 5 kilometres (3.1 mi) tall, from within the cloud to the ground's surface. The actual discharge is the final stage of a very complex process.[4] At its peak, a typical thunderstorm produces three or more *strikes* to the Earth per minute.[5] Lightning primarily occurs when warm air is mixed with colder air masses, resulting in atmospheric disturbances necessary for polarizing the atmosphere. However, it can also occur during dust storms, forest fires, tornadoes, volcanic eruptions, and even in the cold of winter, where the lightning is known as thundersnow.[6][7] Hurricanes typically generate some lightning, mainly in the rainbands as much as 160 kilometres (99 mi) from the center.[8][9][10]

The science of lightning is called *fulminology*, and the fear of lightning is called *astraphobia*.

Frequency

Lightning is not distributed evenly around the planet, as shown in the map.



World map showing frequency of lightning strikes, in flashes per km² per year (equal-area projection), from combined 1995–2003 data from the Optical Transient Detector and 1998–2003 data from the Lightning Imaging Sensor.

About 70% of lightning occurs over land in the tropics where atmospheric convection is the greatest. This occurs from both the mixture of warmer and colder air masses, as well as differences in moisture concentrations, and it generally happens at the boundaries between them. The flow of warm ocean currents past drier land masses, such as the Gulf Stream, partially explains the elevated frequency of lightning in the Southeast United States. Because the influence of small or absent land masses in the vast stretches of the world's oceans limits the differences between these variants in the atmosphere, lightning is notably less frequent there than over larger landforms. The North and South Poles are limited in their coverage of thunderstorms and therefore result in areas with the least amount of lightning.

In general, cloud-to-ground (CG) lightning flashes account for only 25% of all total lightning flashes worldwide. Since the base of a thunderstorm is usually negatively charged, this is where most CG lightning originates. This region is typically at the elevation where freezing occurs within the cloud. Freezing, combined with collisions between ice and water, appears to be a critical part of the initial charge development and separation process. During wind-driven collisions, ice crystals tend to develop a positive charge, while a heavier, slushy mixture of ice and water (called graupel) develops a negative charge. Updrafts within a storm cloud separate the lighter ice crystals from the heavier graupel, causing the top region of the cloud to accumulate a positive space charge while the lower level accumulates a negative space charge.


Lightning in Belfort, France

Because the concentrated charge within the cloud must exceed the insulating properties of air, and this increases proportionally to the distance between the cloud and the ground, the proportion of CG strikes (versus cloud-to-cloud (CC) or in-cloud (IC) discharges) becomes greater when the cloud is closer to the ground. In the tropics, where the freezing level is generally higher in the atmosphere, only 10% of lightning flashes are CG. At the latitude of Norway (around 60° North latitude), where the freezing elevation is lower, 50% of lightning is CG.[11][12]

Lightning is usually produced by cumulonimbus clouds, which have bases that are typically 1–2 km (0.6-1.25 miles) above the ground and tops up to 15 km (9.3 mi) in height.

Lightning hotspots: The place on Earth where lightning occurs most often is near the small village of Kifuka in the mountains of the eastern Democratic Republic of the Congo,[13] where the elevation is around 975 m (3,200 ft). On average, this region receives 158 lightning strikes per 1 square kilometer (0.39 sq mi) per year.[14] Lake Maracaibo in Venezuela averages 297 days per year with lightning activity.[15] Other lightning hotspots include Catatumbo in Venezuela, Singapore,[16] Teresina in northern Brazil,[17] and Lightning Alley in Central Florida.[18][19]

Necessary conditions

0:00 MENU
Sound of a thunderstorm

In order for an electrostatic discharge to occur, two preconditions are necessary: (1) a sufficiently high electric potential between two regions of space must exist; and (2) a high-resistance medium must obstruct the free, unimpeded equalization of the opposite charges.

It is well understood that during a thunderstorm there is charge separation and aggregation in certain regions of the cloud; however the exact processes by which this occurs are not fully understood.[20]

The atmosphere provides the electrical insulation, or barrier, that prevents free equalization between charged regions of opposite polarity. This is overcome by "lightning", a complex process referred to as the lightning "flash".

Electrical field generation

View of lightning from an airplane flying above a system.

As a thundercloud moves over the surface of the Earth, an equal electric charge, but of opposite polarity, is induced on the Earth's surface underneath the cloud. The induced positive surface charge, when measured against a fixed point, will be small as the thundercloud approaches, increasing as the center of the storm arrives and dropping as the thundercloud passes. The referential value of the induced surface charge could be roughly represented as a bell curve.

The oppositely charged regions create an electric field within the air between them. This electric field varies in relation to the strength of the surface charge on the base of the thundercloud – the greater the accumulated charge, the higher the electrical field.

Flashes and strikes

The best studied and understood form of lightning is cloud to ground (CG). Although more common, intracloud (IC) and cloud to cloud (CC) flashes are very difficult to study given there are no "physical" points to monitor inside the clouds. Also, given the very low probability lightning will strike the same point repeatedly and consistently, scientific inquiry is difficult at best even in the areas of high CG frequency. As such, knowing flash propagation is similar amongst all forms of lightning, the best means to describe the process is through an examination of the most studied form, cloud to ground.

Downward leaders

A lightning strike from **cloud to ground** in the California, Mojave Desert

In a process not well understood, a channel of ionized air, called a "leader", is initiated from a charged region in the thundercloud. Leaders are electrically conductive channels of partially ionized gas that travel away from a region of dense charge. Negative leaders propagate away from densely charged regions of negative charge, and positive leaders propagate from positively charged regions.

The positively and negatively charged leaders proceed in opposite directions, positive upwards within the cloud and negative towards the earth. Both ionic channels proceed, in their respective directions, in a number of successive spurts. Each leader "pools" ions at the leading tips, shooting out one or more new leaders, momentarily pooling again to concentrate charged ions, then shooting out another leader.

An **intracloud** flash. A lightning flash within the cloud, illuminates the entire blanket.

Leaders often split, forming branches in a tree-like pattern.[21] In addition, negative leaders travel in a discontinuous fashion. The resulting jerky movement of these "stepped leader(s)" can be readily observed in slow-motion videos of negative leaders as they head toward ground prior to a negative CG lightning strike. The negative leaders continue to propagate and split as they head downward, often speeding up as they get closer to the Earth's surface.

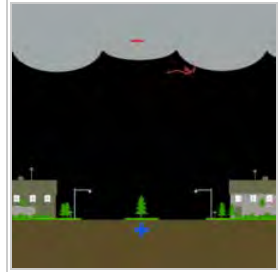
About 90% of ionic channel lengths between "pools" are approximately 45 m (148 ft) in length.[22] The establishment of the ionic channel takes a comparatively long amount of time (hundreds of milliseconds) in comparison to the resulting discharge, which occurs within a few microseconds. The electric current needed to establish the channel, measured in the tens or hundreds of amperes, is dwarfed by subsequent currents during the actual discharge.

A downward leader travels towards earth, branching as it goes.

Initiation of the outward leaders is not well understood. The electric field strength within the thundercloud is not typically large enough to initiate this process by itself.[23] Many hypotheses have been proposed. One theory postulates that showers of relativistic electrons are created by cosmic rays and are then accelerated to higher velocities via a process called runaway breakdown. As these relativistic electrons collide and ionize neutral air molecules, they initiate leader formation. Another theory invokes locally enhanced electric fields being formed near elongated water droplets or ice crystals.[24] Percolation theory, especially for the case of biased percolation,[25] describes random connectivity phenomena, which produce an evolution of connected structures similar to that of lightning strikes.

Upward streamers

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 grounded 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 positively charged ionic channel, called a positive or upward streamer, can develop from these points. This was first theorized by Heinz Kasemir.[26][27]


Lightning strike caused by the connection of two leaders, positive shown in blue and negative in red

As negatively charged leaders approach, increasing the localized electric field strength, grounded objects already experiencing corona discharge exceed a threshold and form upward streamers.

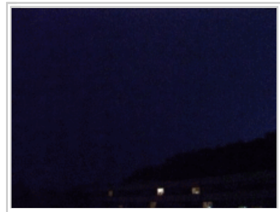
Attachment

Once a downward leader connects to an available upward leader, a process referred to as attachment, a low-resistance path is formed and discharge may occur. Photographs have been taken on which unattached streamers are clearly visible. The unattached downward leaders are also visible in branched lightning, none of which are connected to the earth, although it may appear they are.

Discharge

Return stroke

Once a conductive channel bridges the air gap between the negative charge excess in the cloud and the positive surface charge excess below, a massive electrical discharge follows. This is the 'return stroke' and it is the most luminous and noticeable part of the lightning discharge.


High-speed photography showing different parts of a lightning flash during the discharge process as seen in Toulouse, France.

A large electric current flows along the plasma channel from the cloud to the ground, neutralising the positive ground charge as electrons flow away from the strike point to the surrounding area. This huge surge of current creates large radial voltage differences along the surface of the ground. Called step potentials, they are responsible for more injuries and deaths than the strike itself. Electricity takes every path available to it.[28] A portion of the return stroke current will often preferentially flow through one leg and out another, electrocuting an unlucky human or animal standing near the point where the lightning strikes.

The electric current of the return stroke averages 30 kiloamperes for a typical negative CG flash, often referred to as "negative CG" lightning. In some cases, a positive ground to cloud (GC) lightning flash may originate from a positively charged region on the ground below a storm. These discharges normally originate from the tops of very tall structures, such as communications antennas. The rate at which the return stroke current travels has been found to be around 1×10^8 m/s.[29]

The massive flow of electric current occurring during the return stroke combined with the rate at which it occurs (measured in microseconds) rapidly superheats the completed leader channel, forming a highly electrically conductive plasma channel. The core temperature of the plasma during the return stroke may exceed 50,000 K, causing it to brilliantly radiate with a blue-white color. Once the electric current stops flowing, the channel cools and dissipates over tens or hundreds of milliseconds, often disappearing as fragmented patches of glowing gas. The nearly instantaneous heating during the return stroke causes the air to expand explosively, producing a powerful shock wave which is heard as thunder.

Re-strike

High-speed videos (examined frame-by-frame) show that most negative CG lightning flashes are made up of 3 or 4 individual strokes, though there may be as many as 30.[30]

Each re-strike is separated by a relatively large amount of time, typically 40 to 50 milliseconds, as other charged regions in the cloud are discharged in subsequent strokes. Re-strikes often cause a noticeable "strobe light" effect.[31]

Each successive stroke is preceded by intermediate dart leader strokes that have a faster rise time but lower amplitude than the initial return stroke. Each subsequent stroke usually re-uses the discharge channel taken by the previous one, but the channel may be offset from its previous position as wind displaces the hot channel.[32]

Transient currents during flash

The electric current within a typical negative CG lightning discharge rises very quickly to its peak value in 1–10 microseconds, then decays more slowly over 50–200 microseconds. The transient nature of the current within a lightning flash results in several phenomena that need to be addressed in the effective protection of ground-based structures. Rapidly changing currents tend to travel on the surface of a conductor, in what is called the skin effect, unlike direct currents, which "flow through" the entire conductor like water through a hose. Hence, conductors used in the protection of facilities tend to be multi-stranded, with small wires woven together. This increases the total bundle surface area in inverse proportion to the individual strand radius, for a fixed total cross-sectional area.

The rapidly changing currents also create electromagnetic pulses (EMPs) that radiate outward from the ionic channel. This is a characteristic of all electrical discharges. The radiated pulses rapidly weaken as their distance from the origin increases. However, if they pass over conductive elements such as power lines, communication lines, or metallic pipes, they may induce a current which travels outward to its termination. This is the "surge" that, more often than not, results in the destruction of delicate electronics, electrical appliances, or electric motors. Devices known as surge protectors (SPD) or transient voltage surge suppressors (TVSS) attached in parallel with these lines can detect the lightning flash's transient irregular current, and, through an alteration of its physical properties, route the spike to an attached earthing ground, thereby protecting the equipment from damage.

Types

There are three primary types of lightning, defined by what is at the "ends" of a flash channel. They are intracloud (IC), which occurs within a single thundercloud unit; cloud to cloud (CC), which starts and ends between two different "functional" thundercloud units; and cloud to ground (CG), that primarily originates in the thundercloud and terminates on an Earth surface, but may also occur in the reverse direction, that is ground to cloud. There are variations of each type, such as "positive" versus "negative" CG flashes, that have different physical characteristics common to each which can be measured. Different common names used to describe a particular lightning event may be attributed to the same or different events.

Cloud to ground (CG)

Cloud-to-ground is the best known and third most common type of lightning. It is the best understood of all forms because it allows for scientific study given it terminates on a physical object, namely the Earth, and lends itself to being measured by instruments. Of the three primary types of lightning, it poses the greatest threat to life and property since it terminates or "strikes" the Earth. Cloud-to-ground (CG) lightning is a lightning discharge between a thundercloud and the ground. It is usually negative in polarity and is usually initiated by a stepped leader moving down from the cloud.

Positive and negative lightning

CG lightning can occur with both positive and negative polarity. The polarity is that of the charge in the region that originated the lightning leaders. An average bolt of negative lightning carries an electric current of 30,000 amperes (30 kA), and transfers 15 coulombs of electric charge and 500 megajoules of energy. Large bolts of lightning can carry up to 120 kA and 350 coulombs.[33]

Unlike the far more common "negative" lightning, positive lightning originates from the positively charged top of the clouds (generally anvil clouds) rather than the lower portion of the storm. Leaders form in the anvil of the cumulonimbus and may travel horizontally for several kilometers before veering towards the ground. A positive lightning bolt can strike anywhere within several kilometers of the anvil of the thunderstorm, often in areas experiencing clear or only slightly cloudy skies; they are also known as "bolts from the blue" for this reason. Positive lightning typically makes up less than 5% of all lightning strikes.[34]


Anvil-to-ground *(Bolt from the blue)* lightning strike initiates from the clear, but turbulent sky above the anvil cloud, then drives a bolt of plasma through the cloud directly to the ground.

Because of the much greater distance to ground, the positively charged region can develop considerably larger levels of charge and voltages than the negative charge regions in the lower part of the cloud. Positive lightning bolts are considerably hotter and longer than negative lightning. They can develop six to ten times the amount of charge and voltage of a negative bolt and the discharge current may last ten times longer.[35] A bolt of positive lightning may carry an electric current of 300 kA and the potential at the top of the cloud may exceed a billion volts — about 10 times that of negative lightning.[36] During a positive lightning strike, huge quantities of extremely low frequency (ELF) and very low frequency (VLF) radio waves are generated.[37]

As a result of their greater power, as well as lack of warning, positive lightning strikes are considerably more dangerous. At the present time, aircraft are not designed to withstand such strikes, since their existence was unknown at the time standards were set, and the dangers unappreciated until the destruction of a glider in 1999.[38] The standard in force at the time of the crash, Advisory Circular AC 20-53A, was replaced by Advisory Circular AC 20-53B in 2006,[39] however it is unclear whether adequate protection against positive lightning was incorporated.[40][41]

Aircraft operating in U.S. airspace have been required to be equipped with static discharge wicks. Although their primary function is to mitigate radio interference due to static buildup through friction with the air, in the event of a lightning strike, a plane is designed to conduct the excess electricity through its skin and structure to the wicks to be safely discharged back into the atmosphere. These measures, however, may be insufficient for positive lightning.[42]

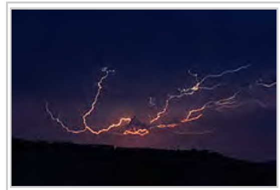
Positive lightning has also been shown to trigger the occurrence of Upper-atmospheric lightning between the tops of clouds and the ionosphere. Positive lightning tends to occur more frequently in winter storms, as with thundersnow, during intense tornadoes [43] and in the dissipation stage of a thunderstorm.[44]

Cloud to cloud (CC) and intra-cloud (IC)

Lightning discharges may occur between areas of cloud without contacting the ground. When it occurs between two separate clouds it is known as *inter-cloud lightning*, 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.[44]


Branching of cloud to cloud lightning, New Delhi, India

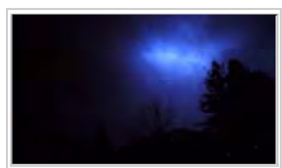
Intra-cloud lightning most commonly occurs between the upper anvil portion and lower reaches of a given thunderstorm. This lightning can sometimes be observed at great distances at night as so-called "heat lightning". In such instances, the observer may see only a flash of light without hearing any thunder.


Multiple paths of cloud-to-cloud lightning, Swifts Creek, Australia.

Another term used for cloud–cloud or cloud–cloud–ground lightning is "Anvil Crawler", due to the habit of charge, typically originating beneath or within the anvil and scrambling through the upper cloud layers of a thunderstorm, often generating dramatic multiple branch strokes. These are usually seen as a thunderstorm passes over the observer or begins to decay. The most vivid crawler behavior occurs in well developed thunderstorms that feature extensive rear anvil shearing.

Observational variations


Cloud-to-cloud lightning, Victoria, Australia.


Cloud-to-cloud lightning seen in Gresham, Oregon.

- **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 meters in diameter.[45] 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.[46][47] Scientific data on natural ball lightning is scarce owing to its infrequency and unpredictability. The presumption of its existence is based on reported public sightings, and has therefore produced somewhat inconsistent findings. Brett Porter,[48] wildlife ranger, reported having taken a photo at Queensland of Australia in 1987.
- **Bead lightning** is the decaying stage of a lightning channel in which the luminosity of the channel breaks up into segments. Nearly every lightning discharge will exhibit *beading* as the channel cools immediately after a return stroke, sometimes referred to as the lightning's 'bead-out' stage. 'Bead lightning' is more properly a stage of a normal lightning discharge rather than a type of lightning in itself. Beading of a lightning channel is usually a small-scale feature, and therefore is often only apparent when the observer/camera is close to the lightning.[49]
- **Dry lightning** is used in Australia, 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.[50] Pyrocumulus clouds produce lightning for the same reason that it is produced by cumulonimbus clouds.
- **Forked lightning** is cloud-to-ground lightning that exhibits branching of its path.
- **Heat lightning** is a lightning flash that appears to produce no discernible thunder because it occurs too far away for the thunder to be heard. The sound waves dissipate before they reach the observer.[51]

- **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.
- **Rocket lightning** 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.[52]
- **Sheet lightning** is cloud-to-cloud lightning that exhibits a diffuse brightening of the surface of a cloud, caused by the actual discharge path being hidden or too far away. The lightning itself cannot be seen by the spectator, so it appears as only a flash, or a sheet of light. The lightning may be too far away to discern individual flashes.
- **Smooth Channel lightning** are positive cloud to ground lightning strikes where the forward stroke originates from the ground upwards to the cloud. The smooth channel is in the lower section of the lightning channel but should branch higher up (not visible as the "branching" is inside the cloud). Large supercells generate tremendous areas of positively charged cloud material (thick anvil) and wind shear prevents excessive negative strokes as with "normal" thunderstorms. Downdrafts, such as the forward flank downdraft (FFD), bring the positively charged cloud material closer to the ground, where such lightning occurs.
- **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.[53] 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, appearing like a blip, also occurs in a similar area of rotating updrafts.[54]

Anvil Crawler over Lake Wright Patman south of Redwater, Texas on the backside of a large area of rain associated with a cold-front

- **Superbolts** are bolts of lightning around a hundred times brighter than normal. On Earth, one in a million lightning strikes is a superbolt.[55][56]
- **Sympathetic lightning** is the tendency of lightning to be loosely coordinated across long distances. Discharges can appear in clusters when viewed from space.
- **Clear-air lightning** describes lightning that occurs with no apparent cloud close enough to have produced it. In the U.S. and Canadian Rockies, a thunderstorm can be in an adjacent valley and not observable from the valley where the lightning bolt strikes, either visually or audibly. European and Asian mountainous areas experience similar events. Also in areas such as sounds, large lakes or open plains, when the storm cell is on the near horizon (within 26 kilometres (16 mi)) there may be some distant activity, a strike can occur and as the storm is so far away, the strike is referred to as **a bolt from the blue**.[57] In fact, it actually originates from the anvil cloud atop a thunderstorm which may be as far as 35 kilometers away.[58] It carries around ten times the current of an ordinary bolt of lightning and has a positive charge while most other lightning has a negative one. This commonly is known as positive lightning. .[59]

This CG was of very short duration, exhibited highly branched channels and was very bright indicating that it was staccato lightning near New Boston, Texas.

Effects

Lightning strike

Objects struck by lightning experience heat and magnetic forces of great magnitude. The heat created by lightning currents traveling through a tree may vaporize its sap, causing a steam explosion that bursts the trunk. As lightning travels through sandy soil, the soil surrounding the plasma channel may melt, forming tubular structures called fulgurites. Even though roughly 90 percent of people struck by lightning survive,[60] humans or animals struck by lightning may suffer severe injury due to internal organ and nervous system damage. Buildings or tall structures hit by lightning may be damaged as the lightning seeks unintended paths to ground. By safely conducting a lightning strike to ground, a lightning protection system can greatly reduce the probability of severe property damage. Lightning also serves an important role in the nitrogen cycle by oxidizing diatomic nitrogen in the air into nitrates which are deposited by rain and can fertilize the growth of plants and other organisms.[61][62]

Thunder

Because the electrostatic discharge of terrestrial lightning superheats the air to plasma temperatures along the length of the discharge channel in a short duration, kinetic theory dictates gaseous molecules undergo a rapid increase in pressure and thus expand outward from the lightning creating a shock wave audible as thunder. Since the sound waves propagate not from a single point source but along the length of the lightning's path, the sound origin's varying distances from the observer can generate a rolling or rumbling effect. Perception of the sonic characteristics is further complicated by factors such as the irregular and possibly branching geometry of the lightning channel, by acoustic echoing from terrain, and by the typically multiple-stroke characteristic of the lightning strike.

Light travels at about 300,000,000 m/s, and sound travels through air at about 340 m/s. An observer can approximate the distance to the strike by timing the interval between the visible lightning and the audible thunder it generates. A lightning flash preceding its thunder by one second would be approximately 350 metres (0.22 mi) in distance; a delay of three seconds would indicate a distance of about one kilometer (0.62 mi) (3×340 m). A flash preceding thunder by five seconds would indicate a distance of approximately one mile (1.6 km) (5×340 m). Consequently, a lightning strike observed at a very close distance will be accompanied by a sudden clap of thunder, with almost no perceptible time lapse, possibly accompanied by the smell of ozone (O_3).

High-energy radiation

The production of X-rays by a bolt of lightning was theoretically predicted as early as 1925[63] but no evidence was found until 2001/2002,[64][65][66] when researchers at the New Mexico Institute of Mining and Technology detected X-ray emissions from an induced lightning strike along a grounded wire trailed behind a rocket shot into a storm cloud. In the same year University of Florida and Florida Tech researchers used an array of electric field and X-ray detectors at a lightning research facility in North Florida to confirm that natural lightning makes X-rays in large quantities during the propagation of stepped leaders. The cause of the X-ray emissions is still a matter for research, as the temperature of lightning is too low to account for the X-rays observed.[67][68]

A number of observations by space-based telescopes have revealed even higher energy gamma ray emissions, the so-called terrestrial gamma-ray flashes (TGFs). These observations pose a challenge to current theories of lightning, especially with the recent discovery of the clear signatures of antimatter produced in lightning.[69]

Volcanic

Volcanic activity produces lightning-friendly conditions in multiple ways. The enormous quantity of pulverized material and gases explosively ejected into the atmosphere creates a dense plume of particles. The ash density and constant motion within the volcanic plume produces charge by frictional interactions (triboelectrification), resulting in very powerful and very frequent flashes as the cloud attempts to neutralize itself. Due to the extensive solid material (ash) content, unlike the water rich charge generating zones of a normal thundercloud, it is often called a dirty thunderstorm.

Volcanic material thrust high into the atmosphere can trigger lightning.

- Powerful and frequent flashes have been witnessed in the volcanic plume as far back as the 79 AD eruption of Vesuvius by Pliny The Younger.[70]
- Likewise, vapors and ash originating from vents on the volcano's flanks may produce more localized and smaller flashes upwards of 2.9 km long.
- Small, short duration sparks, recently documented near newly extruded magma, attest to the material being highly charged prior to even entering the atmosphere.[71]

Extraterrestrial

Lightning has been observed within the atmospheres of other planets, such as Jupiter and Saturn. Although in the minority on Earth, superbolts appear to be common on Jupiter.

Lightning on Venus has been a controversial subject after decades of study. During the Soviet Venera and U.S. Pioneer missions of the 1970s and 1980s, signals suggesting lightning may be present in the upper atmosphere were detected.[72] Although the Cassini–Huygens mission fly-by of Venus in 1999 detected no signs of lightning, the observation window lasted mere hours. Radio pulses recorded by the spacecraft Venus Express (which began orbiting Venus in April 2006) may originate from lightning on Venus.

Human-related phenomena

- **Airplane contrails** have also been observed to influence lightning to a small degree. The water vapor-dense contrails of airplanes may provide a lower resistance pathway through the atmosphere having some influence upon the establishment of an ionic pathway for a lightning flash to follow.[73]
- **Rocket exhaust plumes** provided a pathway for lightning when it was witnessed striking the Apollo 12 rocket shortly after takeoff.
- **Thermonuclear explosions** by providing extra material for electrical conduction and a very turbulent localized atmosphere, have been seen triggering lightning flashes within the mushroom cloud. In addition, intense gamma radiation from large nuclear explosions may develop intensely charged regions in the surrounding air through Compton scattering. The intensely charged space charge regions create multiple clear-air lightning discharges shortly after the device detonates.[74]

Scientific study

Properties

Thunder is heard as a rolling, gradually dissipating rumble because the sound from different portions of a long stroke arrives at slightly different times.[75]

When the local electric field exceeds the dielectric strength of damp air (about 3 million volts per meter), electrical discharge results in a *strike*, often followed by commensurate discharges branching from the same path. (See image, right.) Mechanisms that cause the charges to build up to lightning are still a matter of scientific investigation.[76][77] New study confirming dielectric breakdown is involved. Rison 2016 (http://www.nature.com/ncomms/2016/160215/ncomms10721/full/ncomms10721.html?WT.ec_id=NCOMMS-20160217&spMailingID=50715003&spUserID=MTc3MDUyNjcxMjY1S0&spJobID=862105978&spReportId=ODYyMTA1OTc Lightning may be caused by the circulation of warm moisture-filled air through electric fields.[78] Ice or water particles then accumulate charge as in a Van de Graaff generator.[79]

Researchers at the University of Florida found that the final one-dimensional speeds of 10 flashes observed were between 1.0×10^5 and 1.4×10^6 m/s, with an average of 4.4×10^5 m/s.[80]

Detection and monitoring

Lightning strike counter in a museum

The earliest detector invented to warn of the approach of a thunder storm was the lightning bell. Benjamin Franklin installed one such device in his house.[81] [82] The detector was based on an electrostatic device called the 'electric chimes' invented by Andrew Gordon in 1742.

Lightning discharges generate a wide range of electromagnetic radiations, including radio-frequency pulses. The times at which a pulse from a given lightning discharge arrives at several receivers can be used to locate the source of the discharge. The United States federal government has constructed a nationwide grid of such lightning detectors, allowing lightning discharges to be tracked in real time throughout the continental U.S.[83][84]

The Earth-ionosphere waveguide traps electromagnetic VLF- and ELF waves. Electromagnetic pulses transmitted by lightning strikes propagate within that waveguide. The waveguide is dispersive, which means that their group velocity depends on frequency. The difference of the group time delay of a lightning pulse at adjacent frequencies is proportional to the distance between transmitter and receiver. Together with direction finding methods, this allows to locate lightning strikes up to distances of 10,000 km from their origin. Moreover, the eigenfrequencies of the Earth-ionospheric waveguide, the Schumann resonances at about 7.5 Hz, are used to determine the global thunderstorm activity.[85]

In addition to ground-based lightning detection, several instruments aboard satellites have been constructed to observe lightning distribution. These include the Optical Transient Detector (OTD), aboard the OrbView-1 satellite launched on April 3, 1995, and the subsequent Lightning Imaging Sensor (LIS) aboard TRMM launched on November 28, 1997.[86][87][88]

Artificially triggered

- **Rocket-triggered lightning** can be "triggered" by launching specially designed rockets trailing spools of wire into thunderstorms. The wire unwinds as the rocket ascends, creating an elevated ground that can attract descending leaders. If a leader attaches, the wire provides a low-resistance pathway for a lightning flash to occur. The wire is vaporized by the return current flow, creating a straight lightning plasma channel in its place. This method allows for scientific research of lightning to occur under a more controlled and predictable manner.[89]

The International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, Florida typically uses rocket triggered lightning in their research studies.

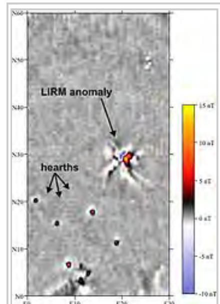
- **Laser-triggered**

  Since the 1970s,[90][91][92][93][94][95] researchers have attempted to trigger lightning strikes by means of infrared or ultraviolet lasers, which create a channel of ionized gas through which the lightning would be conducted to ground. Such triggering of lightning is intended to protect rocket launching pads, electric power facilities, and other sensitive targets.[96][97][98][99][100]

  In New Mexico, U.S., scientists tested a new terawatt laser which provoked lightning. Scientists fired ultra-fast pulses from an extremely powerful laser thus sending several terawatts into the clouds to call down electrical discharges in storm clouds over the region. The laser beams sent from the laser make channels of ionized molecules known as "**filaments**". Before the lightning strikes earth, the filaments lead electricity through the clouds, playing the role of lightning rods. Researchers generated filaments that lived a period too short to trigger a real lightning strike. Nevertheless, a boost in electrical activity within the clouds was registered. According to the French and German scientists who ran the experiment, the fast pulses sent from the laser will be able to provoke lightning strikes on demand.[101] Statistical analysis showed that their laser pulses indeed enhanced the electrical activity in the thundercloud where it was aimed—in effect they generated small local discharges located at the position of the plasma channels.[102]

Physical manifestations

Magnetism



Lightning-induced remanent magnetization (LIRM) mapped during a magnetic field gradient survey of an archaeological site located in Wyoming, United States.

The movement of electrical charges produces a magnetic field (see electromagnetism). The intense currents of a lightning discharge create a fleeting but very strong magnetic field. Where the lightning current path passes through rock, soil, or metal these materials can become permanently magnetized. This effect is known as lightning-induced remanent magnetism, or LIRM. These currents follow the least resistive path, often horizontally near the surface[103][104] but sometimes vertically, where faults, ore bodies, or ground water offers a less resistive path.[105] One theory suggests that lodestones, natural magnets encountered in ancient times, were created in this manner.[106]

Lightning-induced magnetic anomalies can be mapped in the ground,[107][108] and analysis of magnetized materials can confirm lightning was the source of the magnetization[109] and provide an estimate of the peak current of the lightning discharge.[110]

Solar wind and cosmic rays

Some high energy cosmic rays produced by supernovas as well as solar particles from the solar wind, enter the atmosphere and electrify the air, which may create pathways for lightning bolts.[111]

In culture and religion


Lightning by Mikalojus Konstantinas Ciurlionis (1909)

In many cultures, lightning has been viewed as part of a deity or a deity in and of itself. These include the Greek god Zeus, the Aztec god Tlaloc, the Mayan God K, Slavic mythology's Perun, the Baltic Pērkons/Perkūnas, Thor in Norse mythology, Ukko in Finnish mythology, the Hindu god Indra, and the Shinto god Raijin.[112] In the traditional religion of the African Bantu tribes, lightning is a sign of the ire of the gods. Verses in the Jewish religion and in Islam also ascribe supernatural importance to lightning. In Christianity, the Second Coming of Jesus is compared to lightning.[Matthew 24:27][Luke 17:24]

The expression "Lightning never strikes twice (in the same place)" is similar to "Opportunity never knocks twice" in the vein of a "once in a lifetime" opportunity, *i.e.*, something that is generally considered improbable. Lightning occurs frequently and more so in specific areas. Since various factors alter the probability of strikes at any given location, repeat lightning strikes have a very low probability (but are not impossible).[113][114] Similarly, "A bolt from the blue" refers to something totally unexpected.

Some political parties use lightning flashes as a symbol of power, such as the People's Action Party in Singapore, the British Union of Fascists during the 1930s, and the National States' Rights Party in the United States during the 1950s.[115] The Schutzstaffel, the paramilitary wing of the Nazi Party, used the Sig rune in their logo which symbolizes lightning. The German word Blitzkrieg, which means "lightning war", was a major offensive strategy of the German army during World War II.

In French and Italian, the expression for "Love at first sight" is *coup de foudre* and *colpo di fulmine*, respectively, which literally translated means "lightning strike". Some European languages have a separate word for lightning which strikes the ground (as opposed to lightning in general); often it is a cognate of the English word "rays". The name of New Zealand's most celebrated thoroughbred horse, Phar Lap, derives from the shared Zhuang and Thai word for lightning.[116]

The bolt of lightning in heraldry is called a thunderbolt and is shown as a zigzag with non-pointed ends. This symbol usually represents power and speed.

The lightning bolt is used to represent the instantaneous communication capabilities of electrically powered telegraphs and radios. It was a commonly used motif in Art Deco design, especially the zig-zag Art Deco design of the late 1920s.[117] The lightning bolt is a common insignia for military communications units throughout the world. A lightning bolt is also the NATO symbol for a signal asset.

The Unicode symbol for lightning is ☇ U+2607

See also

Dinosaur-shaped lightning bolt at Petrified Forest National Park, USA

- Atmospheric convection
- Dark lightning
- Dry thunderstorm
- Harvesting lightning energy
- Keraunomedicine – the medical study of lightning casualties
- Lichtenberg figure
- Lightning safety
- Lightning-prediction system
- Paleolightning
- Radio atmospheric
- St. Elmo's fire
- Sprites
- Upper-atmospheric lightning
- Vela satellites – satellites which could record lightning *superbolts*
- Whistler (radio)
- Lightning strike
- Lightning rod

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External links

- How Lightning Works (http://science.howstuffworks.com/nature/natural-disasters/lightning.htm) at HowStuffWorks
- Thunderstorms and Lightning (https://www.dmoz.org/Science/Earth_Sciences/Atmospheric_Sciences/Meteorology/Weather_Phenomena/Thunderstorms_an at DMOZ
- NOAA Lightning research (http://www.nssl.noaa.gov/research/lightning/)
- European Cooperation for Lightning Detection (http://www.euclid.org/)
- WWLLN (http://wwlln.net/) World Wide Lightning Location Network
- Bibliography of Fulgurites (http://www.lbk.ars.usda.gov/wewc/bof/fulgurites.htm)
- Image of lightning within a volcanic ash cloud (http://imgur.com/HMPBICj)

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