Lightning

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Lightning strikes during a thunderstorm

Sound of a thunderstorm

Lightning is a massive electrostatic discharge caused by unbalanced electric charge in the atmosphere. Lightning can be either inside clouds (IC), cloud to cloud (CC) or cloud to ground (CG) and is accompanied by the loud sound of thunder. Because the speed of sound in air (~340 m/s) is so much slower than the speed of light (300,000,000 m/s) from the lightning flash the distance to a lightning strike can be closely approximated by dividing the flash-thunder interval, T (sec) by 3--T(sec)/3 = km distance or T(sec)/5 = mile distance. Thunder often lasts several seconds because the sounds from different parts of the lightning strike arrive at different times.

A typical cloud to ground lightning strike is often over 5-6 km (3-4 mi) long[1] but may be many kilometers longer. A typical thunderstorm may have three or more strikes per minute at its peak.[2] Lightning is usually associated with and produced by cumulonimbus clouds which may reach up to 15 km high (10 mi) high and often have a base 5-6 km (3-4 mi) above the ground. The sun heats the earth and water causing massive up-drafts of warm moisture-filled air to rise like a giant hot air balloon that go through different temperature zones and electric fields typical of a thunderstorm formation. Once the moisture in the air cools and condenses into rain droplets or ice crystals it falls in massive turbulent down drafts typical of rain storms. The temperature of the moisture filled air typically falls about 6° C (11° F) for each 1,000 metres (3,300 ft) of higher elevations causing much of the water vapor to freeze into ice crystals or super cooled water droplets at higher elevations.[3]

As the ice crystals, graupel or water droplet laden masses of air rise or fall they tend to either accumulate or get rid of electrons depending on the type of ice or water particles in the air and the electric fields and temperatures they are rising or falling through. The rising and falling particles in the air acts like a massive Van de Graaf generator belt that is used to separate the negatively charge electrons and positively charged molecules missing electrons. These accumulations of charge of different signs generate large powerful electric fields in the clouds and between the clouds and ground much like what would occur in a massive parallel plate capacitor. Strong electric fields between clouds with too many or not enough electrons or clouds and the ground accelerate these electrons towards areas deficient in electrons.[4]

The turbulent airflow typical of clouds may move different charged parts of clouds into different locations. If the local electric field is strong enough to exceed the dielectric strength of moisture filled air (about 3 million Volts/m) there will be a massive flow of electrons away from where there are too many electrons (negative charge) towards places where there are not enough electrons (positive charge). There are local variations in dielectric strength and charge distributions that cause the lightning charge flows to follow a tortuous path through the atmosphere. These powerful electric fields also accelerate the molecules deficient in electrons but since they typically weigh at least 30,000 times more than electrons they are much harder to move in air.

Massive amounts of unbalanced charge can accumulate in different areas of the clouds or between the clouds and the ground. Observation by satellite show that about 75% of all lightning strikes are from regions inside clouds or from cloud to cloud with only about 25% reaching the ground. When the electric fields are strong enough these massive charge imbalances are discharged as electrons flow towards areas deficient in electrons. A lightning strike reestablishes a local charge equilibrium. Once a lightning strike has established a low resistance path to an unbalanced charge region there are usually three or more return strokes following the same ionized lightning channel that drain other adjacent volumes of unbalanced charge a few milliseconds later.

Lightning may also occur during snow storms (thundersnow), volcanic eruptions, dust storms, forest fires or tornadoes which all have large flows of rising particles in the atmosphere which can and do accumulate massive amounts of differing charge in different locations and conditions inside clouds of rising and falling snow, dust, volcanic or smoke particles and dissipate these charge accumulations with lightning strikes.[5] [6] Hurricanes typically generate some lightning in the hurricane eyewall and inner and outer rainbands circling the hurricane center. The rainbands in a strong hurricane can be as much as 160 km (100 mi) from the center and typically contains the majority of the lightning strikes.[7]

Very strong tropical cyclones (hurricanes) generate more lightning activity near the eyewall of the hurricane; but the total number of lightning strikes in the rainbands remains even higher. Hurricane lightning strikes are at a low level when the hurricane is over the ocean and their number increases as the hurricane makes land fall.[8] Lightning in hurricanes is now studied by data obtained from the **Long Range Lightning Detection Network (LLCN)** which can detect lightning up to 2000 km (1200 mi) from their detector stations.[9]

The complicated details of the mechanisms that cause lightning are still a matter of scientific investigation.[10] The rise and fall of water droplets, ice crystals (graupel, etc.) inside a cloud as they are carried aloft through different temperature zones and electric fields in updrafts or down in downdrafts are thought to be a key elements in lightning development, and may cause a forcible separation of positive and negative charges which are transferred by collisions within the cloud, thus assisting in the formation of the large charge differences in the atmosphere that cause lightning. The "typical" thunderstorm cloud accumulates positive charge in the colder upper part of the cloud, negative charge in the middle and lower parts and possibly a small positive charge at the base of the cloud. Collisions of moving water droplets, ice particles and smoke or dust particles, which are bipolar in charge distribution, in the presence of a strong electric fields are thought to possibly enhance charge buildup of different polarity.[11]

The fear of lightning (and thunder) is called astraphobia. Because of the severe danger of a close lightning strike this fear may be appropriate. The study or science of lightning is called **fulminology**, and someone who studies lightning is referred to as a **fulminologist**.[12]

Contents

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

A typical lightning strike

Animation, based on high speed photography, depicting cloud to cloud lightning in Toulouse, France.

The turbulent rising moist warm air flow combined with rain drops and ice crystals rising and falling though different temperature zones and electrical fields typical of cumulonimbus clouds may cause different parts of the cloud to accumulate an excess of positive or negative charge. Usually the top of the cloud which may be as cold as -40°C (-40°F) is composed of small ice crystals charged positively with the middle of the cloud charged negative with a possible small zone at the base of the cloud of positive charge. A large accumulation of charge gives rise to strong electrical fields in the clouds and induces fields on the ground of the opposite polarity. Electric fields accelerate charged particles.

Air is a great insulator but when this potential difference between either parts of a cloud charged differently or the cloud and ground exceed the local dielectric strength of air (about 2 to 3,000,000 volts/m (2 to 3 MV/m) a inside cloud (IC), cloud to cloud (CC), or cloud to ground (CG), a massive flow of electrons in a lightning stroke may be initiated. Paths in the air with higher electric fields or lower dielectric strength cause the electrons in a lightning strike to go though a tortuous path in the air, changing directions slightly or significantly every few centimeters or inches.

Each major stroke of a lightning strike is usually about 50 m (150 ft) long and lasts about 1 to 2 microseconds with a pause of about 50 microseconds as more charge is accumulated before resuming another stroke in a slightly or significantly different direction. The front of a lightning strike is called a *stepped leader* and may split into many different paths--not all of them reach the ground giving rise to the phrase: *forked lightning*. The part of the stroke that reaches the ground nearly always carries most of the charge and is seen as the lightning bolt as electrons rush to the newly found highly conductive ionized air and low resistance path. In a typical cloud-to-ground strike, electrons descend from cloud base to ground.

Just before the strike leader reaches the ground, the charge in the step leader induces a huge electric potential in objects connected to the ground (some 10's of million volts), that brings up spikes of positive charge flow from high sharp objects, lightning rods, people, trees, etc., connected to the ground or water. After the descending and rising charge paths meet, massive amounts of charge flow in the 1 to 4 cm (.5 to 1.5 in) thick ionized channel of air centered in a lightning bolt channel—this massive flow of charged particles heats the air and gives the brightest part of a lightning strike. The stepped *leader* of a bolt of lightning may take on average about 20 milliseconds to reach the ground. Occasionally much longer lightning strokes occur which take more time. Once the downward and upward current flow impulses meet—a few metres or tens of metres above earth—a much more conductive connection is established between the cloud and the ground and the front edge of the return stroke electrons zip from the cloud at about 0.3-0.5 times the speed of light, c, on the highly ionized lightning stepped *leader* stroke path. Return currents may continue for several microseconds with three or more repeat strokes common. Subsequent lightning strokes following the ionized lightning channel are initiated by *dart* leaders.[13]

The return stroke with its much larger current flow produces the highly visible intense main lightning strike as it heats and ionizes the surrounding air in the lightning channel to about 30,000 degrees C (54,000 degrees F). This fast and massively heated ionized air in the lightning channel "explodes" creating the shock waves that within a few yards decay to loud sound waves we hear as thunder. Thunder, under ideal conditions, can be heard from over 20 km or 12 miles away. The relatively slow speed of sound (~340 m/s) and the extended length (5-6 km) of a typical lightning strike extends the sound of thunder over several seconds.

Multiple return strokes over the highly conductive ionized channel to different local charge locations about 0.5 km (0.3 mi) away from the original sources in the cloud may be needed to establish a larger volume of charge equilibrium. Sometimes return strokes take long enough to recur that they cause the lightning to flicker. A typical lightning flash has four return strokes spaced a few tens of milliseconds apart but over 30 return strokes have been observed. Although resolvable with high speed photography and other instruments a typical lightning strike occurs much faster than the human eye can see it so it appears as a single bright flash of lightning lasting a few tenths of a second.[14]

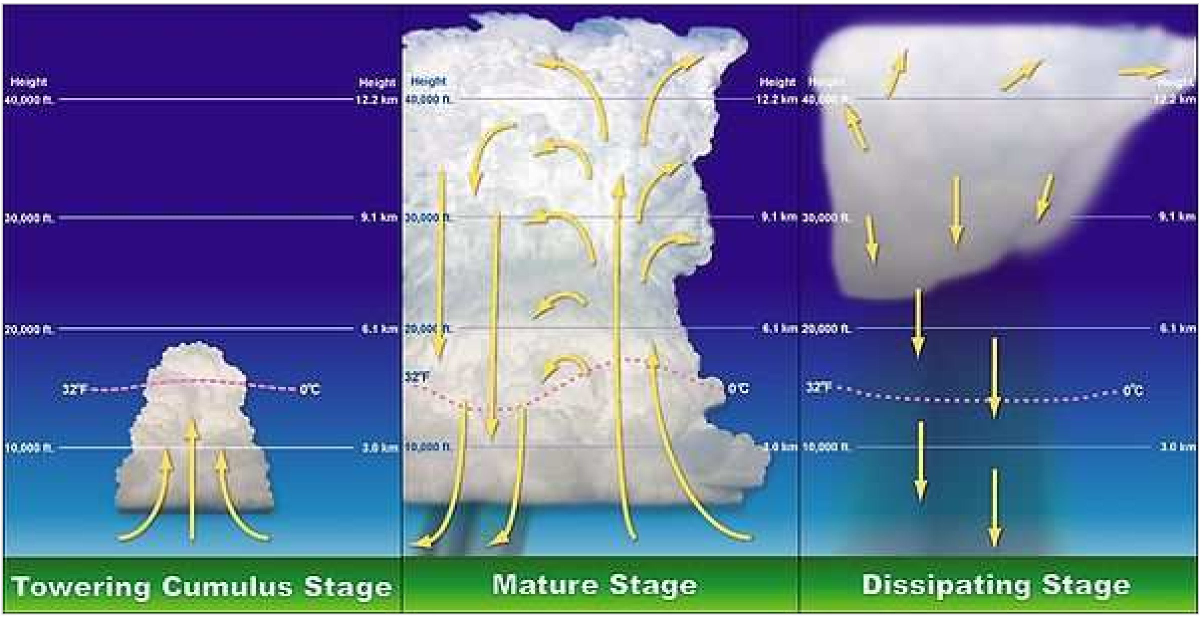
Dependent on the location and time of year about 5 to 10% of lightning is *positive lightning* that originates mainly in the "anvil" of cumulonimbus clouds near the top of the typical thunderstorm, where a high positive charge (electron deficient) often resides. "Positive lightning" that forms in this region has a descending stepped leader that will carry an apparent positive charge as electrons rush to the top of the cloud leaving positive charged molecules behind. When this "positive pulse" reaches the ground electrons will flow from the ground to cloud—the opposite of the usual electron flow. Positive lightning is particularly dangerous since it originates in the upper levels of a storm cloud several kilometers higher than a typical lightning strike.[15]

The amount of air the strike must "burn through" to reach the ground requires a much stronger electric field. The current flow is typically much stronger than a negative strike. Its flash duration is longer, and its peak charge and potential can be ten times greater than a negative strike; as much as 300,000 amperes and well over several billion volts. Positive lightning, though typically rarer, can be the dominate type of cloud-to-ground (CG) lightning during the winter months and in the last stages of a thunderstorm. Positive lightning typically strikes at the edge of a storm but can strike up to 10 km (6 mi) from a storm. The positively charged upper parts of the cumulonimbus cloud has been identified as a major source of the recently discovered *sprites*, *elves*, *blue flashes* and other lightning like phenomena observed well above the clouds, 30 to 95 km (20 to 60 mi) in altitude, well above the parent thunderstorm clouds which typically stop at about 15 km.

High speed photographs of a lightning storm show the step wise development of lightning strikes.[16]

An average bolt of negative lightning carries an electric current of about 30,000 to 100,000 amperes (30-100 kA) at a voltage of over a billion volts.

The current in a lightning strike can raise the temperature of sand high enough to fuse the silica in it into glass channels known as fulgurites, which are normally hollow and can sometimes extend as much as several meters into the ground. Water in trees can be heated enough to cause them to explode and/or set the tree on fire--a leading cause of forest fires.[17][18]



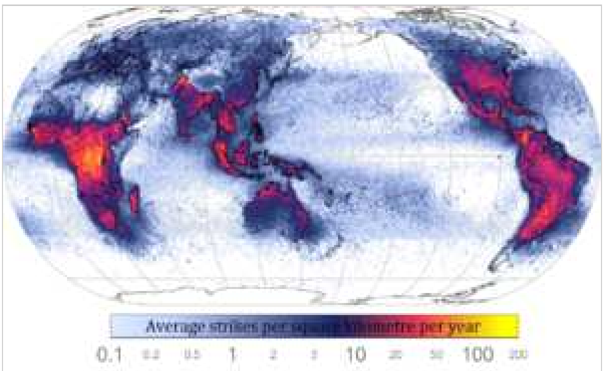
Stages of a thunderstorm's life. Most lightning usually occurs in the mature stage with *positive lightning* possible in the dissipating stage.

The most lightning deaths occur to people exposed in an open field or on water where they are the highest local object and most likely to attract a lightning strike. Lightning hitting a tree with people under it is the second leading cause of lightning deaths. Isolated trees are typically the highest object around and attract lightning--the danger in a forest of trees is reduced. The safest places to be if lightning threatens are inside a building with metal plumbing and wiring which conduct the electricity away from you, or inside a metal-bodied and metal-roofed vehicle which acts as a faraday cage. Cars are usually safe because lightning induced current and voltage stay outside the metal surrounding the typical passenger compartment and do not penetrate inside--the skin effect that makes Faraday cages work. The rubber tires on a motorcycle, etc. or the fabric topped convertible offer no protection. If *Lightning Roars Stay Indoors*.[19]

The average *peak* power output of a single lightning stroke is about one trillion watts — one terawatt (10^{12} W), and the stroke lasts for about 30 to 90 microseconds. Most of the energy is dissipated in creating the ionized air channel and thunder.[20]

Frequency and distribution

Main article: Distribution of lightning



World map of frequency of lightning strikes, in flashes per square kilometer per year

Lightning strikes 40–50 times a second worldwide, for a total of nearly 1.4 billion flashes per year.[21]

Cloud-to-ground (CG) lightning accounts for 25% of lightning globally. The base of the negative region in a cloud is typically at the elevation where freezing occurs. The closer this region is to the ground, the more likely cloud-to-ground strikes are. In the tropics, where the freeze zone is higher, 10% of lightning is CG. At the latitude of Norway (60° lat.) where the freezing elevation is lower, 50% of lightning is CG.[22][23]

Lightning is not distributed evenly around the planet.[24] About 70% of lightning occurs on land in the tropics, where most thunderstorms occur. The north and south poles and the areas over the oceans have the fewest lightning strikes. The place where lightning occurs most often is near the small village of Kifuka in the mountains of eastern Democratic Republic of the Congo,[25] where the elevation is around 975 metres (3,200 ft). On average this region receives 158 lightning strikes per 1 square kilometer (0.39 sq mi) a year.[26] Other hotspots include Catatumbo lightning in Venezuela, Singapore[27], Teresina in northern Brazil[28] and "Lightning Alley" in Central Florida.[29][30]

Formation

Cloud particle collision hypothesis

View of lightning from an airplane flying above a system.

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 (14 and -40 °F). These water droplets collide with ice crystals to form a soft ice-water mixture called graupel. Collisions between ice crystals and graupel pellets usually result in positive charge being transferred to the ice crystals, and negative charge to the graupel.[20]

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.[20]

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:[31]

1. Falling droplets of ice and rain become electrically polarized as they fall through the earth's magnetic field;
2. Colliding/rebounding cloud particles become oppositely charged.

There are several hypotheses for the origin of charge separation.[32][33][34]

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.[35] Many hypotheses have been proposed, ranging from including runaway breakdown to locally enhanced electric fields near elongated water droplets or ice crystals.[36] Percolation theory, especially for the case of biased percolation,[37] 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. Ionized channels of the discharge 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). About 90% of the leaders exceed 45 m (148 ft) in length, with most in the order of 50 to 100 m (164 to 328 ft).[38]

Illustration of a negative streamer (blue) meeting a positive counterpart (red) and the return stroke. Click to watch the animation.

As it continues to descend, the stepped leader may branch into a number of paths.[39] 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.[40][41]

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.[42]

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.[43]

Re-strike

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 or 4 strokes, though there may be more.[44]

Lightning is a highly visible form of

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.[43]

Each successive stroke is preceded by intermediate dart leader strokes akin to, but weaker than, the initial stepped leader. The stroke usually re-uses the discharge channel taken by the previous stroke.[45]

energy transfer.

The variations in successive discharges are the result of smaller regions of charge within the cloud being depleted by successive strokes.[*citation needed*]

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.[*citation needed*]


Cloud-to-ground lightning

Cloud-to-ground

Cloud-to-ground 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 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*.[46][47]

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.[*citation needed*]

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.[48] 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.[*citation needed*]

Forked lightning is a name, not in formal usage, for cloud-to-ground lightning that exhibits branching of its path.

Positive lightning

Local variations in cloud formations can cause the bottom of a cloud to accumulate a positive charge which will induce a negative charge on the ground. 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 15 coulombs of electric charge and 500 megajoules of energy. Large bolts of lightning can carry up to 120 kA and 350 coulombs.[49] An average bolt of positive lightning carries an electric current of about 300 kA — about 10 times that of negative lightning.[50]

Unlike the far more common "negative" lightning, positive lightning occurs when a positive charge is carried by the top of the clouds (generally anvil clouds) rather than the ground. Generally, this causes the leader arc to form in the anvil of the cumulonimbus and travel horizontally for several miles before veering down to meet the negatively charged streamer rising from the ground. The bolt can strike anywhere within several miles 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 makes up less than 5% of all lightning strikes.[51]


Anvil-to-ground *(Bolt from the blue)* lightning strike.

Because of the much greater distance they must travel before discharging, positive lightning strikes typically carry six to ten times the charge and voltage difference of a negative bolt and last around ten times longer.[52] During a positive lightning strike, huge quantities of ELF and VLF radio waves are generated.[53]

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.[54] 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,[55] however it is unclear whether adequate protection against positive lightning was incorporated.[56][57]

Positive lightning is also now believed to have been responsible for the 1963 in-flight explosion and subsequent crash of Pan Am Flight 214, a Boeing 707.[58] Due to the dangers of lightning, aircraft operating in U.S. airspace have been required to have static discharge wicks to reduce the possibility of attracting a lightning strike, as well as to mitigate radio interference due to static buildup through friction with the air, but these measures may be insufficient for positive lightning.[59]

Positive lightning has also been shown to trigger the occurrence of upper atmosphere lightning. It tends to occur more frequently in winter storms, as with thundersnow, and at the end of a thunderstorm.[20]

Dry lightning

Main article: 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.[60] Pyrocumulus clouds produce lightning for the same reason that it is produced by cumulonimbus clouds.

Rocket lightning

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.[61]

Cloud-to-cloud


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


Cloud-to-cloud lightning, Victoria, Australia.

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.[20]

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. The "heat" portion of the term is a folk association between locally experienced warmth and the distant lightning flashes.

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 the observer or begins to decay. The most vivid crawler behavior occurs in well developed thunderstorms that feature extensive rear anvil shearing.

Sheet lightning is an informal name for 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.

Heat lightning is a common name for a lightning flash that appears to produce no discernable thunder because it occurs too far away for the thunder to be heard. The sound waves dissipate before they reach the observer.[62]

Triggered lightning

Rocket-triggered

Lightning has been triggered by launching lightning rockets carrying trailing spools of wire into thunderstorms. The wire unwinds as the rocket ascends, providing a path for lightning. These bolts are typically very straight due to the straight path created by the wire.[63]

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

Lightning has also been triggered directly by other human activities: Flying aircraft can trigger lightning.[64] Furthermore, lightning struck Apollo 12 soon after takeoff, and has struck soon after thermonuclear explosions.[65]

Volcanically triggered

See also: Dirty thunderstorm

There are three types of volcanic lightning:

- 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 79 AD eruption of Vesuvius, in which he perished.[66]
- An intermediate type which comes from a volcano's vents, sometimes 2.9 km long.
- Small spark-type lightning about .91 meters long lasting a few milliseconds.[67]


Volcanic material thrust high into the atmosphere can trigger lightning.

Laser-triggered

Since the 1970s,[68][69][70][71][72][73] 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.[74][75][76][77][78]

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 too short a period 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.[79] 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.[80]

Extraterrestrial lightning

Lightning has been observed within the atmospheres of other planets, such as Venus, Jupiter and Saturn. Lightning on Venus is still a controversial subject after decades of study. During the Soviet Venera and U.S. Pioneer missions of the 1970s and '80s, signals suggesting lightning may be present in the upper atmosphere were detected.[81] However, the Cassini–Huygens mission fly-by of Venus in 1999 detected no signs of lightning at all. Despite this, it has been suggested that radio pulses recorded by the spacecraft Venus Express (which began orbiting Venus in April 2006) may originate from lightning on Venus.[82]

Physical effects

Thunder

Main article: 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. 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 five seconds would be about one mile (1.6 km) (5x340 m) distant. A flash preceding thunder by three seconds is about one kilometer (0.62 mi) (3x340 m) distant. 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, and the smell of ozone (O_3).

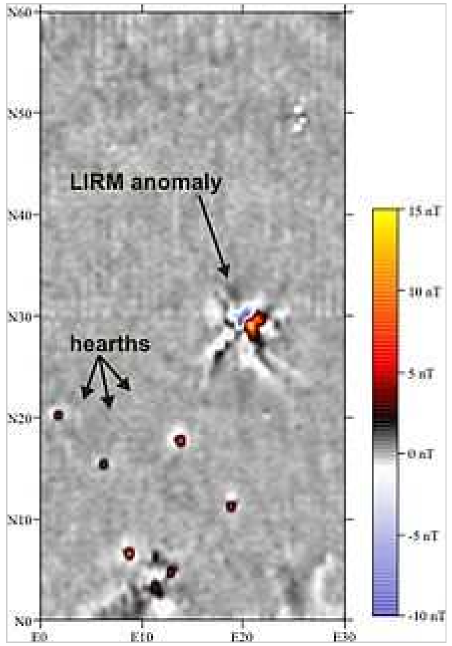
High energy radiation

The production of X-rays by a bolt of lightning was theoretically predicted as early as 1925[83] but no evidence was found until 2001/2002,[84] when researchers at the New Mexico Institute of Mining and Technology detected X-ray emissions from an induced lightning strike along a 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. 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.[85]

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 discovery of the clear signatures of antimatter produced in lightning.[86]

Lightning-induced magnetism

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[87][88] but sometimes vertically, where faults, ore bodies, or ground water offers a less resistive path.[89] One theory suggests that lodestones, natural magnets encountered in ancient times, were created in this manner.[90]



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

Lightning-induced magnetic anomalies can be mapped in the ground,[91][92] and analysis of magnetized materials can confirm lightning was the source of the magnetization[93] and provide an estimate of the peak current of the lightning discharge.[94]

Human factors

Detection

Main article: Lightning detection

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.[95] 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 arrive at several receivers can be used to locate the source of the discharge. The United States federal government has constructed a nation-wide grid of such lightning detectors, allowing lightning discharges to be tracked in real time throughout the continental U.S.[96][97]

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 10000 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.[98]

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.[99][100][101]

Harvesting lightning energy

Main article: Harvesting lightning energy

Since the late 1980s, there have been several attempts to investigate the possibility of harvesting energy from lightning. While a single bolt of lightning carries a relatively large amount of energy (approximately 5 billion joules[102]), this energy is concentrated in a small location and is passed during an extremely short period of time (milliseconds); therefore, extremely high electrical power is involved.[103] It has been proposed that the energy contained in lightning be used to generate hydrogen from water, or to harness the energy from rapid heating of water due to lightning.[104]

A technology capable of harvesting lightning energy would need to be able to rapidly capture the high power involved in a lightning bolt. The ever-changing energy involved in each lightning bolt is a problem. Additionally, lightning is sporadic, and therefore energy would have to be collected and stored; it is difficult to convert high-voltage electrical power to the lower-voltage power that can be stored.[104] Another major challenge when attempting to harvest energy from lightning is the impossibility of predicting when and where thunderstorms will occur. Even during a storm, it is very difficult to tell where exactly lightning will strike.[102]

In culture

Further information: Lightning in religion

In many cultures, lightning has been viewed as part of a deity or a deity in of itself. These include the Greek god Zeus, the Aztec god Tlaloc, the Mayas' 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. 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.

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).[105][106] 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 and the British Union of Fascists during the 1930s. The Schutzstaffel, the secret police 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.[107]

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, and is a common insignia for military communications units throughout the world. A lightning bolt is also the NATO symbol for a signal asset.

Related phenomena

Ball lightning

Main article: 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.[108] 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.[109] 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.

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.[110] Given inconsistencies and the lack of reliable data and completely contradicting and unpredictable behavior, the true nature of ball lightning is still unknown[111] and was often regarded as a fantasy or a hoax.[112]

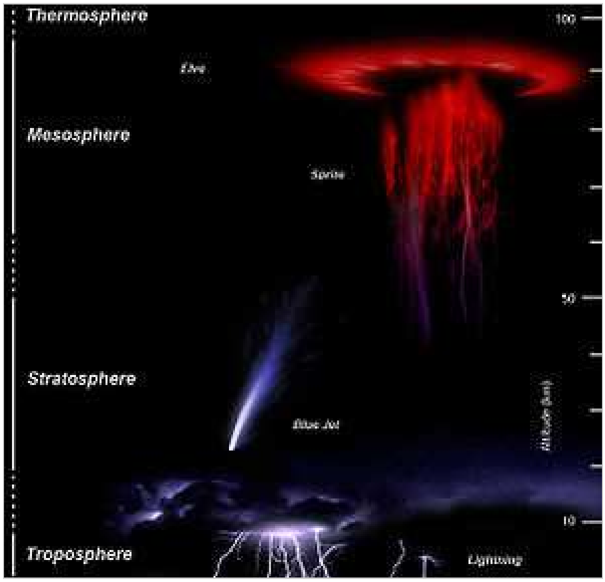
Reports of the phenomenon were dismissed for lack of physical evidence, and were often regarded the same way as UFO sightings.[111] Severely contradicting descriptions of ball lightning makes it impossible even to create a plausible hypothesis that will take into account described behavior.

Natural ball lightning appears infrequently and unpredictably, and is therefore rarely (if ever truly) photographed. However, several purported photos and videos exist. Perhaps the most famous story of ball lightning unfolded when 18th-century physicist Georg Wilhelm Richmann installed a lightning rod in his home and was struck in the head – and killed – by a "pale blue ball of fire."[113]

Upper-atmospheric discharges

Main article: Upper-atmospheric lightning

Sprites are large-scale electrical discharges that occur high above a thunderstorm cloud, giving rise to a range of visual shapes. They are triggered by the discharges of positive lightning between the thundercloud and the ground.[53] The phenomena were named after the mischievous sprite (air spirit) Puck in Shakespeare's *A Midsummer Night's Dream*. They often occur in clusters, lying 50 to 90 kilometres (31 to 56 mi) above the Earth's surface. Sprites have been mentioned as a possible cause in otherwise unexplained accidents involving high altitude vehicular operations above thunderstorms.[114]



Representation of upper-atmospheric lightning and electrical-discharge phenomena

Blue jets differ from sprites in that they project from the top of the cumulonimbus above a thunderstorm, typically in a narrow cone, to the lowest levels of the ionosphere 25 miles (40 km) to 50 miles (80 km) above the earth.[115] They are also brighter than sprites and, as implied by their name, are blue in colour.

ELVES often appear as dim, flattened, circular in the horizontal plane, expanding glows around 250 miles (400 km) in diameter that last for, typically, just one millisecond.[116] They occur in the ionosphere 60 miles (97 km) above the ground over thunderstorms. Their color was a puzzle for some time, but is now believed to be a red hue. Elves is an acronym for **E**missions of **L**ight and **V**ery Low Frequency Perturbations from **E**lectromagnetic Pulse **S**ources.[117] This refers to the process by which the light is generated; the excitation of nitrogen molecules due to electron collisions (the electrons possibly having been energized by the electromagnetic pulse caused by a discharge from the Ionosphere).[118]

See also

- Atmospheric convection
- Dry thunderstorm
- Keraunomedicine: the medical study of lightning casualties
- Lichtenberg figure
- Lightning safety
- National Weather Service: NWS
- National Oceanic and Atmospheric Administration: NOAA
- Paleolightning
- Radio atmospheric
- St. Elmo's fire
- USAF 45th Weather Squadron: lightning safety for rocket launches
- Vela satellites: satellites which could record lightning *superbolts*
- Whistler (radio)

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Sample (http://assets.cambridge.org/052158/3276/sample/0521583276WS.pdf) , in .pdf form, consisting of all of the book through page 20.

- The Mirror of Literature, Amusement, and Instruction, Vol. 12, Issue 323, July 19, 1828 (http://www.gutenberg.org/ebooks/12873) The Project Gutenberg eBook (early lightning research)

External links

- How Lightning Works (http://science.howstuffworks.com/nature/natural-disasters/lightning.htm) at HowStuffWorks
- How to survive in a lightning storm (http://www.edu4hazards.org/lightning.html) A guide for children and youth

- Lightning Safety Page – National Weather Service Pueblo Colorado (http://www.lightningsafety.noaa.gov/ams_lightning_rec.htm)
- Outdoor guide to lightning safety and first-aid (http://www.wildernessutah.com/learn/lightning.html)
- Map of lightning strikes in USA over last 60 minutes (http://www.strikestarus.com/)
- Live storm data and sferics for southern England (http://www.isleofwightweather.co.uk/live_storm_data.htm) Generated by data recorded by a weather station at Newport, Isle of Wight, UK
- Thunderstorms and Lightning (http://www.dmoz.org/Science/Earth_Sciences/Atmospheric_Sciences/Meteorology/Weather_Phenomena/Thunderstorms_and_Lightning/) at the Open Directory Project
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- European Cooperation for Lightning Detection (http://www.euclid.org/)
- NASA Finds Lightning Clears Safe Zone in Earth's Radiation Belt (http://www.nasa.gov/home/hqnews/2005/mar/HQ_05070_radiation_belt.html)
- National Geographic Lightning Simulator (http://environment.nationalgeographic.com/environment/natural-disasters/lightning-interactive.html)
- Lightning strikes governed by moving cloud layers (http://www.newscientist.com/article/dn13518-lightning-strikes-governed-by-moving-cloud-layers.html?feedId=online-news_rss20) – the first theory to fully explain lightning formation and dynamics, *New Scientist*, 23 March 2008
- Social & Economic Costs of Lightning (http://www.economics.noaa.gov/?goal=weather&file=events/lightning/) from "NOAA Socioeconomics" website initiative
- Signature of Antimatter Detected in Lightning (http://www.wired.com/wiredscience/2009/11/antimatter-lightning/)
- WWLLN (http://wwlln.net) World Wide Lightning Location Network
- Venezuela Lightning Network (VLN) (http://met.ivic.gob.ve/vln/)

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