Why is alternating current better than direct current? -- MK, California

The genius of George Westinghouse and Nikola Tesla in the late 1800's was to realize that producing alternating current made it possible to transfer power easily from one electric circuit to another with the help of an electromagnetic device called a transformer. When an alternating electric current passes through the primary wire coil of a transformer, the changing magnetic and electric fields that this current produces transfer power from that primary current to the current passing through another coil of wire--the secondary coil of the transformer. While no electric charges move between these two wires, electric power does. With the help of a transformer, it's possible for a generating plant to move power from a large current of relatively low energy electric charges--low voltage charges--to a small current of relatively high-energy electric charges--high voltage charges. This small current of high voltage electric charges can move with relatively little power loss through miles and miles of high voltage transmission lines and can go from the generating plant to a distant city without wasting much power. Upon arrival at the city, this current can pass through the primary coil of another transformer and its power can be transferred to a large current of relatively low voltage charges flowing through the secondary coil of that transformer. The latter current can then deliver this electric power to your neighborhood. A transformer can't transfer power between two circuits if those circuits operate with direct current. Edison tried to use direct current in his power delivery systems and fought Westinghouse and Tesla tooth and nail for years. Edison even invented the electric chair to "prove" that alternating current was much more dangerous than direct current. Still, Westinghouse and Tesla won out in the end because they had the better idea.

Why is direct current so much better than alternating current?

It depends on the situation. You cannot use a transformer with direct current, so in that sense, alternating current is better. But many electronic devices need direct current because they require a steady flow of charges that always head in the same direction. So there are times when you need DC and times when you need AC.

A bird lands on an uninsulated 10,000 volt power line. Will it become extra crispy? — RKS, Texas

No. Birds do this all the time. What protects the bird is the fact that it doesn’t complete a circuit. It touches only one wire and nothing else. Although there is a substantial charge on the power line and some of that charge flows onto the bird when it lands, the charge movement is self-limiting. Once the bird has enough charge on it to have the same voltage as the power line, charge stops flowing. And even though the power line’s voltage rises and falls 60 times a second (or 50 times a second in some parts of the world), the overall charge movement at 10,000 volts just isn’t enough to bother the bird much. At 100,000 volts or more, the charge movement is uncomfortable enough to keep birds away, so you don’t see them landing on the extremely high-voltage transmission lines that travel across vast stretches of countryside.

The story wouldn’t be the same if the bird made the mistake of spanning the gap from one wire to another. In that case, current could flow through the bird from one wire to the other and the bird would run the serious risk of becoming a flashbulb. Squirrels occasionally do this trick when they accidentally bridge a pair of wires. Some of the unexpected power flickers that occur in places where the power lines run overhead are caused by squirrels and occasionally birds vaporizing when they let current flow between power lines.

What does a transformer do?

A transformer transfers power between two or more electrical circuits when each of those circuits is carrying an alternating electric current. Transfers of this sort are important because many electric power systems have incompatible circuits--one circuit may use large currents of low voltage electricity while another circuit may use small currents of high voltage electricity. A transformer can move power from one circuit of the electric power system to another without any direct connections between those circuits.

Now for the technical details: a transformer is able to make such transfers of power because (1) electric currents are magnetic, (2) the magnetic fields from an alternating electric current changes with time, (3) a time-varying magnetic field creates an electric field, and (4) an electric fields pushes on electric charges and electric currents. Overall, one of the alternating currents flowing through a transformer creates a time-varying magnetic field and thus an electric field in the transformer. This electric field does work on (transfers power to) another alternating current flowing through the transformer. At the same time, this electric field does negative work on (saps power from) the original alternating current. When all is said and done, the first current has lost some of its power and the second current has gained that missing power

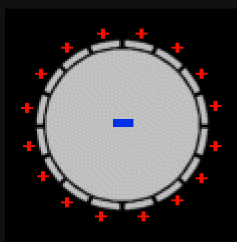
What is the difference between current and voltage?

Current is the measure of how many charges are flowing through a wire each second. A 1-ampere current involves the movement of 1 Coulomb of charge (6,250,000,000,000,000,000 elementary charges) per second. Voltage is the measure of how much energy each charge has. A 1-volt charge carries 1 Joule of energy per Coulomb of charge. To use water in a pipe as an analogy, current measures the amount of water flowing through the pipe and voltage measures the pressure (or energy per liter) of that water.

What is lightning?

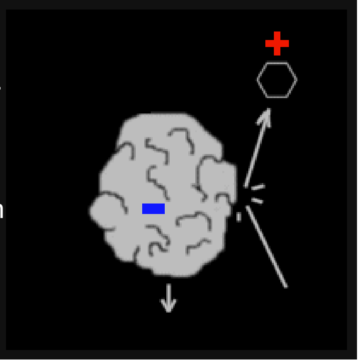
Lightning is an electrical discharge in the atmosphere, very similar to a spark. It is the electrical breakdown of insulating air to provide a transient, conductive path along which a current can run to neutralize the charge.

Where and why does lightning occur?

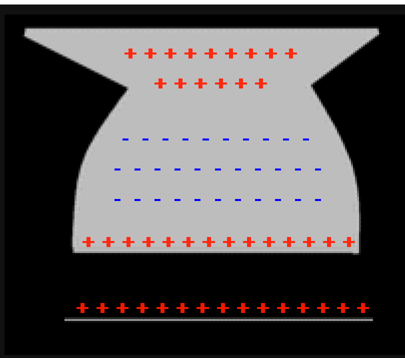


Lightning mostly occurs in thunderstorms. Other situations in which lightning occurs are dust storms, blizzards, volcanic eruptions and nuclear explosions. It seems to be a phenomenon occuring in large volumes of particle clouds when they are being transported in the atmosphere.

In thunderstorms, charge is being separated by what is thought of being several processes. Water droplets freeze from the outside, and when doing so, ice splinters may splinter off; they then carry a positive charge and are carried upward into the anvil of the storm.

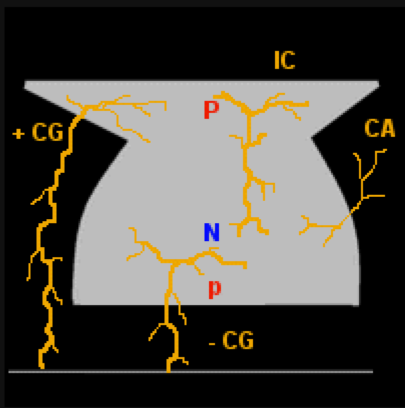


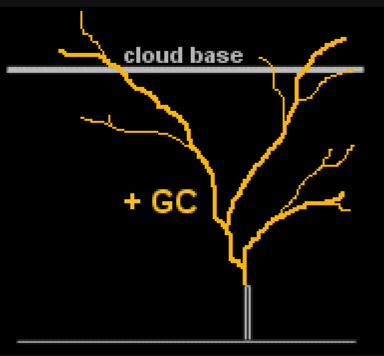
Other processes are graupel-ice crystal collisions, selective ion capturing, inductive-charge separation, and phase transitions of water. All these can produce charge separation, but not much is known about which effect plays the most important role in cloud electrification.



Simplified, a thunderstorm has a positively charged top, a negatively charged lower section, and a small layer of positive charge at the cloud base which is carried up a little bit into the updrafts. We call the top (+) charged region the P region, the lower (-) charged region the N region, and the (+) charge near the base, the p region.

Types of lightning discharges





In most cases, a thunderstorm discharges due to a lightning flash between the large N and P regions. This type of flash occurs within the cloud, and is not directly visible to our eyes. One usually just sees the cloud lighten up from the inside, and we call this sheet lightning. Such a flash is called an intracloud (IC) lightning discharge. Lightning may also occur from the lower N region via the p region to ground. This is a cloud-to ground flash, usually called CG for short.

Also, a lightning discharge may occur from ground to cloud (distinguishable by the way it is branched: upwards). These discharges happen from tall mountain tops, or tall structures like radio transmitter towers.

Occasionally, lightning flashes may come out of a cloud and into the clear air. These are air discharges and don't really help to neutralize the cloud charge; rather, they carry charge away from a highly charged region to regions of lower charge density. When thunderstorms are clustered into a line or Mesoscale Convective System (MCS), discharges may occur from one thunderstorm cell to another, the so-called cloud-to-cloud flashes, or CC for short.

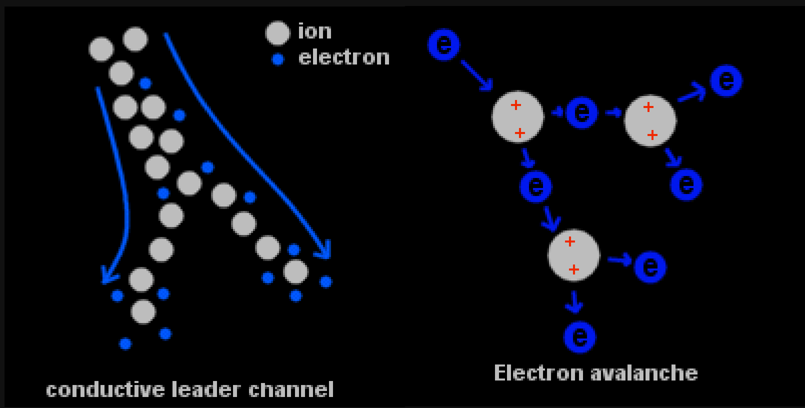
Coronal discharge is another type of discharge, which is by far not as dramatic as a lightning flash. Corona is also known as St. Elmo's fire, and is a faint blueish glow surrounding high points under a thunderstorm, like tree tops, antennas and the like. The electrical field near these high, relatively sharp tips, is enhanced, up to a point where air molecules are being ripped apart (electrons taken off), so that a more or less continuous flow of electrons through the air takes place.

A very different type of discharge, discovered only recently, takes the form of red sprites and blue jets far above thunderstorms into the mesosphere. These discharges were first reported by airplane pilots. They are very faint, hardly visible to the naked eye, and are some sort of plasma currents associated with powerful positive lightning flashes, mainly occuring at the end of a storm.

Finally, there is the phenomenon called ball lightning. There are a few theories to explain ball lightning, but none of them have proved very successful yet. Ball lightning takes the form of an aluminous ball, sizes differing between fractions of a centimeter to the size of a bus, but typically 20 cm in diameter. They can be orange-colored, yellow or blueish. One theory suggests that ball lightning is caused by spontaneous MASER action (microwave amplification by stimulated emission of radiation) of the air, in high electrical and radiation fields. Perhaps a ball lightning is nothing more than a shell of highly conductive plasma, acting as a container-waveguide for MASER-produced microwaves within the ball, heating the plasma shell from the inside and keeping it alive.

Other theories suggest that ball lightning is a ball of heated gas, or slowly-oxidating silicon mesh produced by lightning discharges to soil.

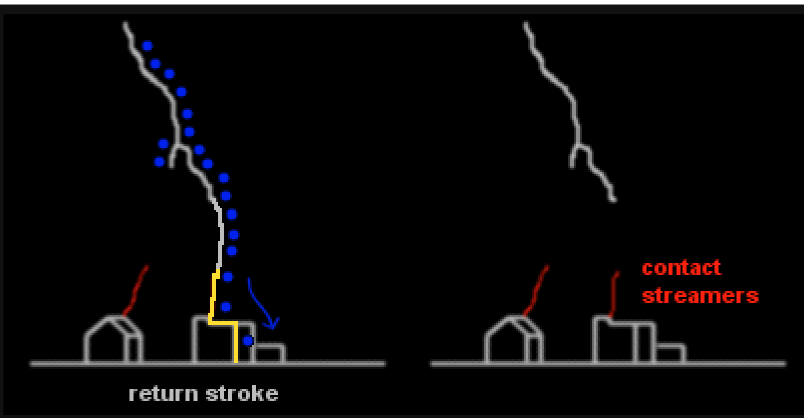
What happens during a lightning flash?



Consider a cloud-to-ground lightning flash, carrying negative charge down from the cloud to the ground. This lightning flash starts somewhere in the lower portions of the N region.

When the electric field there becomes higher than a certain threshold value, a free electron (freed by cosmic radiation, usually) is being accelerated up to a point that it has enough kinetic energy to knock other electrons out of molecules,when it eventually strikes these. These other electrons start accelerating as well, and a chain-reaction takes place, called an electron avalanche. It is a rush of electrons, making a conductive path due to the leftover positively charged ions. This is the start of the so called stepped leader, precursor to the actual lightning discharge.

This stepped leader advances in steps of a few meters at a time, in the general direction of the ground below. During each step, electron avalanches occur away from the highly (-) charged tip. Now, free electrons initiating avalanches are being produced by photoionization, as the tip of the leader emits light. At some points, several avalanches are produced, and the leader branches at such a point.



While the stepped leader zips downwards at a rate of about 10000 m/s, charge is being deposited along the channel. When the leader approaches ground, the electric field rises and (+) charged filaments of charge, called streamers, shoot upward from any object residing there (usually a tall structure like a tree, a building, etc.). When one of these streamers connects with the stepped leader, a short circuit occurs, and charge starts to flow downward through the new channel. First, the charge nearest to the shortage point starts moving, later charge higher up in the channel moves. This is called the return stroke and it consists of an ionizing wavefront, similar to a line of cars on the highway which dissolves. The current rises to several 10000 A, up to sometimes more than 100000 A. This immense current flow heats the channel, causing an explosion, a shock wave, and an intense light flash, which we see as lightning.

When the channel is discharged, subsequent leaders may zip down along the old channel, as it is still conductive for a few tens of a second. A new return stroke may occur, and the process may go on as long as new charge is made available to the top part of the channel, inside the cloud. Up to 20 or even 30 partial return strokes may occur in a single lightning flash, all in about 1 to 2 seconds total duration. The human eye sees this as a flickering of the lightning flash. The top part of a lightning flash can't connect to anything physical in the cloud, as the cloud itself is not conductive. In this respect, a lightning flash is totally different from a spark. The cloud is never directly connected to ground electrically (just like you can't connect a rope to a pond of water, for instance - there's nothing to connect it to). Rather, the lightning channel branches out inside the cloud as a tree-like structure, and draws free electrons to it, freed from cloud particles by the high electrical field.

After a lightning flash has occured, the storm cloud will recharge itself in a certain amount of time, depending on the activity of the storm. Some storms produce nearly continuous lightning (over 100 flashes per minute), some others produce just a single flash during their entire lifetime of about 1 hour or so.

Subtypes of lightning

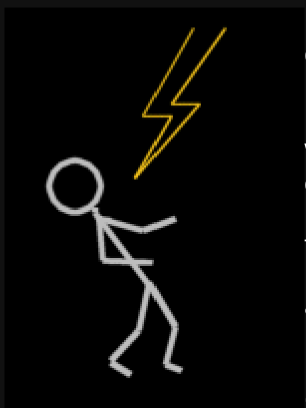
The most common lightning discharges, the CC and CG, have different subtypes. Spider lightning is an extensive discharge, usually along the cloud base. The discharge is so long that it seems to crawl along the cloud base (or anvil, high up). Another name for this type of lightning is crawler.

Then, there exists a phenomenon called bead lightning. This is a lightning discharge during which the conductive channel seems to break up into luminous spheres, or balls, of light. This happens in a few tens of a second.

Ribbon lightning is a name for two effects sometimes visible at a nearby lightning flash, in which the channel moves sideways either by wind or by "meandering" of the channel. Multistroked lightning will show every stroke displaced a small distance from the previous one, giving a ribbon-like impression.

A rare type of lightning is rocket lightning. This is a lightning discharge that very slowly makes its way up to the cloud or down from the cloud, giving the impression of a rocket with a flaming trail.

What damage does lightning do?



Lightning strikes can kill people, knock out radio communications, electrical power, destroy houses or trees. How exactly does this happen?

When a person is struck by lightning the chances are about 50% that it will be fatal. Usually, the lightning enters the head or one of the ears. Contrary to what one might think, lightning usually strikes out of the body skin again after a few centimeters, because it is a highly transient electrical current, and these flow mostly at the surface of conducting material (like flesh). However, a person usually suffers cardiac arrest, apart from burns, temporary blindness and deafness. A strike can have profound effects on someone's life, if the person survives. In many cases neurons are permanently damaged.

When a tree is struck by lightning the liquids inside the trunk and branches turn to gas instantly, leading to high pressure and literally an explosion of anything that is between the gas and the open air. Usually, the lightning current runs just underneath the bark, down to ground, and the tree is scarred by a strip of blown-away bark. It usually survives such a strike. Sometimes, the current may run down near the center of the trunk, and then there may be little left of the tree afterwards. This is one of the reasons why it isn't safe under a tree during lightning - the exploding bast and timber will blow away at high velocity and act like projectiles.

When a house is hit by lightning, the electrical current will find its way down by anything conductive, preferably around the perimeter of the house. This may include antennas, plumbing and gutters. Any person taking a bath, making phonecall, washing hands, or otherwise touching metal plumbing either directly or indirectly, may be shocked or killed. Electrical appliances are likely to be damaged or destroyed, either by large peak currents or by the electromagnetic shock wave.

Protection

Buildings and other structures can be protected from lightning strikes by lightning rods. A lightning rod is designed to provide lightning with an easy, harmless path to the ground. It is not used to repel lightning, but to safeguard more expensive equipment by letting itself be struck and drain the current away.

How can people protect themselves from being struck?

When a storm is close, situations which should be avoided are:

- near or under solitary trees;
- near or in water;
- on top of a tall building, hill, knoll etc;
- being in the open field;
- being near to long metal wires or fences.
- being in a building and close to a window;
- taking a bath, washing hands;
- making phone calls.

The safest place to be is in a building, away from the windows, or in a metallic, conductive cage like a car or an (aluminum) airplane. These act as Faraday-cages.