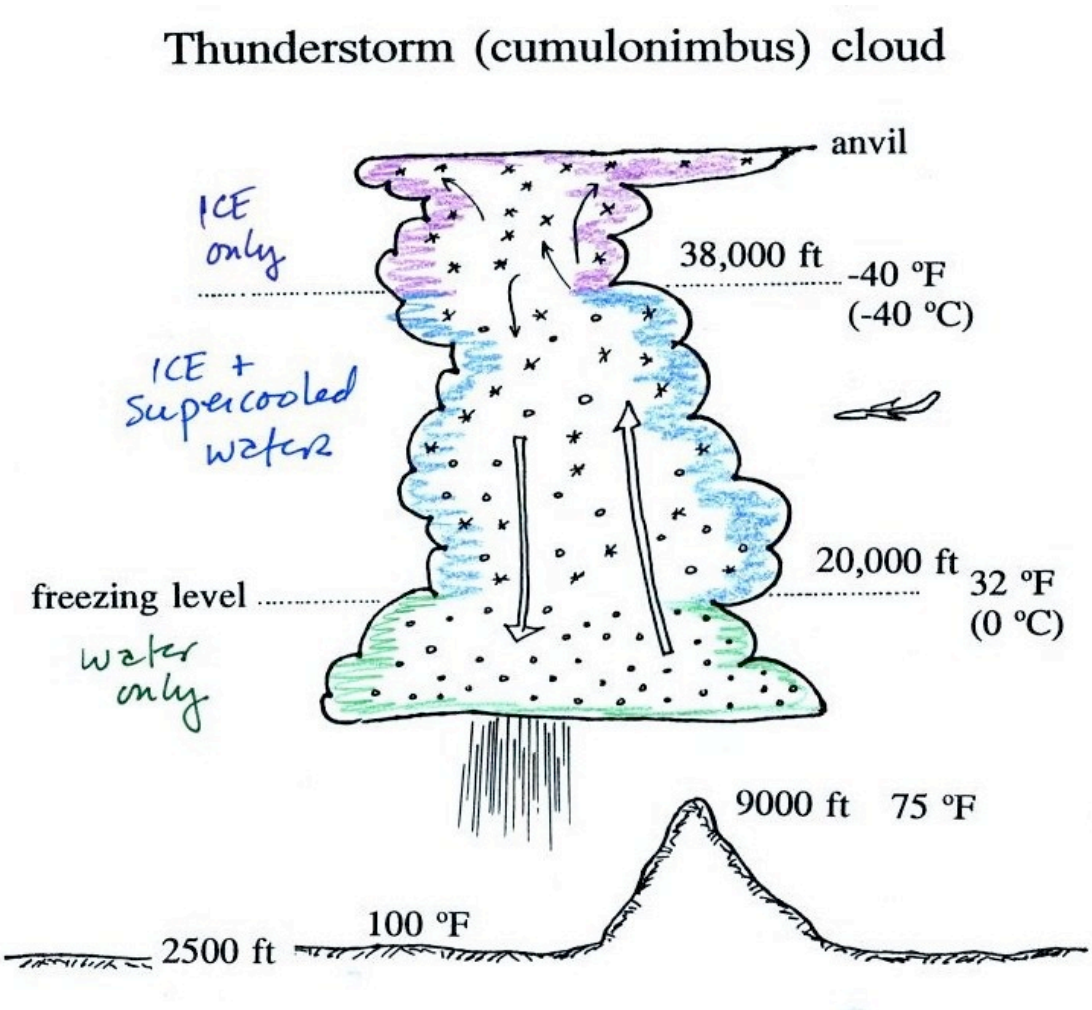
Module 11 - Lecture 33

Lightning kills slightly less than 100 people every year in the United States. This is greater than the fatalities from tornadoes or hurricanes, but less than fatalities from flooding, summer heat or winter cold. Lightning also causes about 30% of all power outages and causes billions of dollars of property damage every year. In the western United States, lightning starts about half of all forest fires.

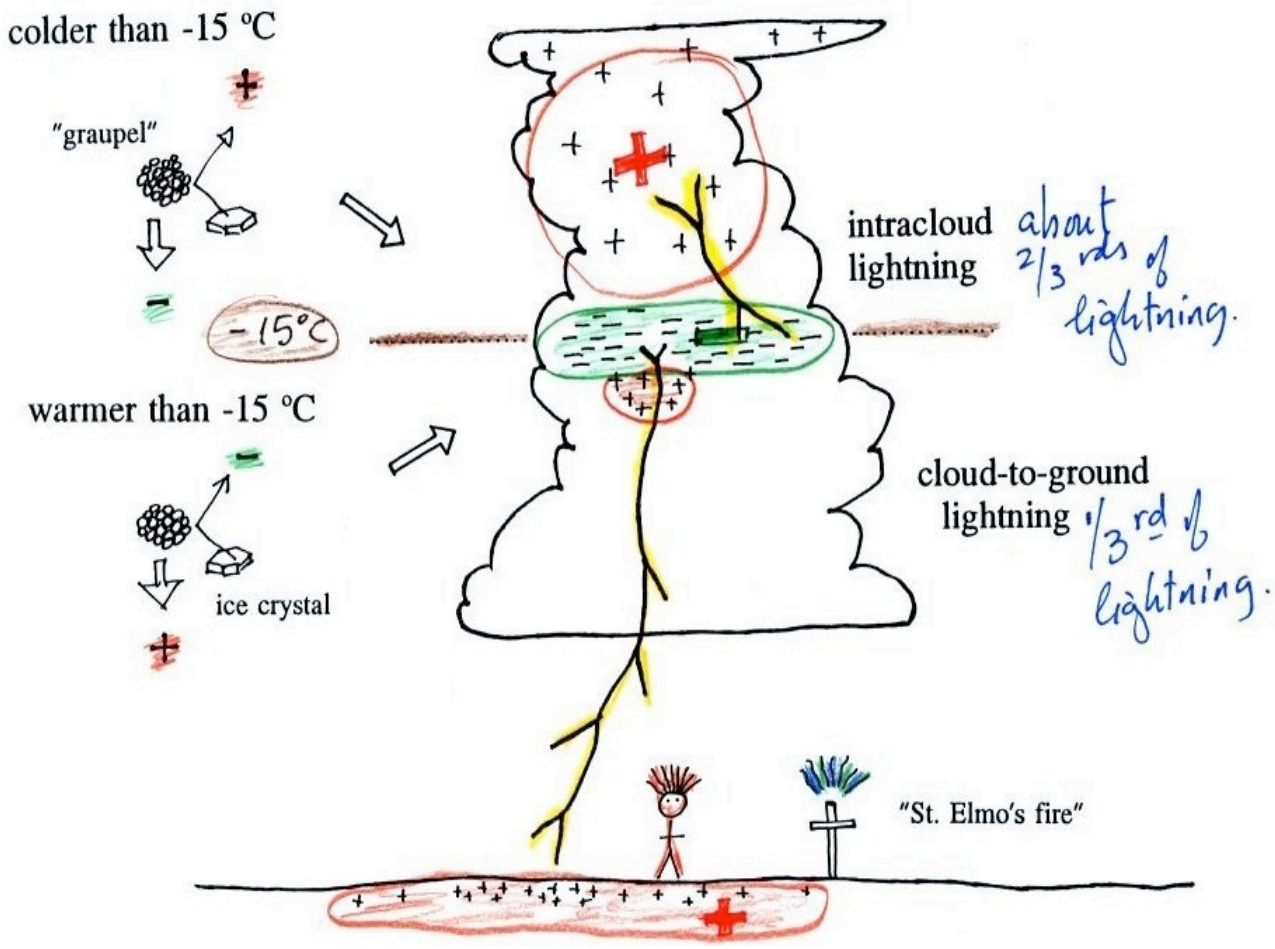
Lightning is most commonly produced by thunderstorms but has also been observed in dust storms and volcanic eruptions such as the eruption of Eyjafjallajokull in Iceland (http://www.boston.com/bigpicture/2010/04/more_from_eyjafjallajokull.html) in 2010. Lightning-caused fires are a particular problem at the beginning of the thunderstorm season in Arizona. At this time, the air underneath thunderstorms is still relatively dry and falling rain tends to evaporate before reaching the ground. Lightning strikes the dry ground, starts a fire, and there is no rain to put out or at least slow the spread of the fire. This is called "dry lightning."

A typical summer thunderstorm in Tucson is shown in the figure below. Even on the hottest Tucson summer day, the middle region of the cloud is below freezing and contains a mixture of super cooled water droplets and ice crystals. This is where precipitation forms and electrical charges are created.



Collisions between precipitation particles produce the electrical charge needed for lightning. When temperatures are colder than -15^{0}C, graupel becomes negatively charged after colliding with a snow crystal. The snow crystal is positively charged and is carried toward the top of the cloud by the updraft winds. At temperatures warmer than -15^{0}C (but still below freezing), the polarities are reversed. Large positive and negative charge centers begin to build up inside the cloud. When the electrical attractive forces between these charge centers becomes high enough, lightning is discharged.

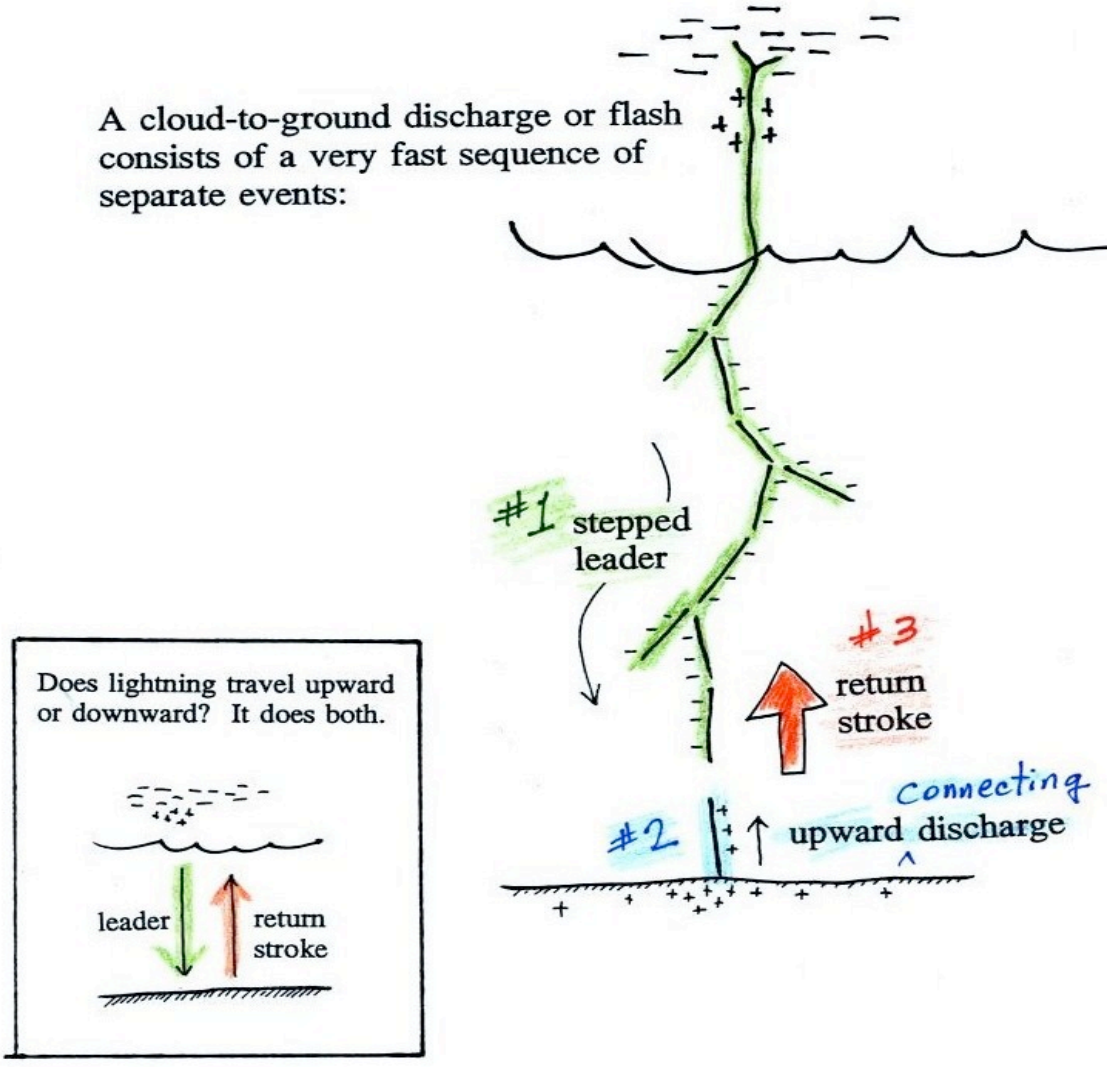
Most lightning stays within the cloud and travels between the main positive charge center near the top of the cloud and the large layer of negative charge in the middle of the cloud. This is intra-cloud lightning and accounts for about two thirds of all lightning. Cloud-to-ground lightning (actually negative cloud-to- ground lightning) accounts for the other third. We will spend most of this lecture learning about cloud-to-ground lightning.



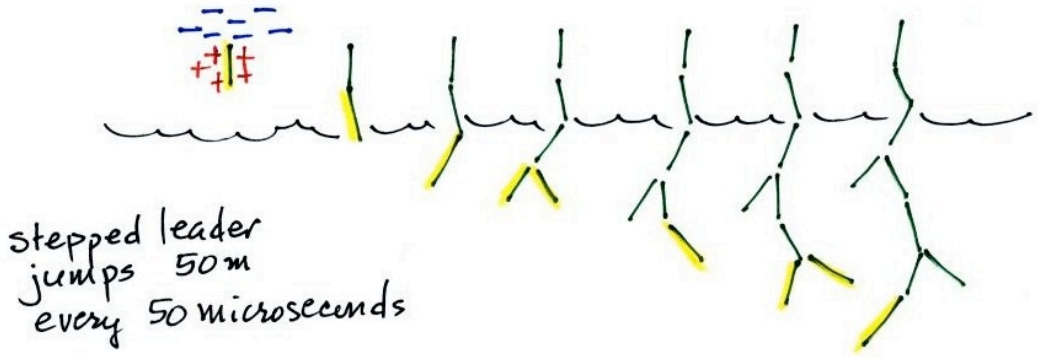
When the attraction between the positive charge in the ground and the layer of negative charge in the cloud becomes strong enough, a person's hair will literally stand on end (see photo below from the Pittsburgh National Weather Service Forecast Office http://www.erh.noaa.gov/pit/safe.htm). Incidentally this is a dangerous situation to be in because lightning may be about to strike.

St. Elmo's fire http://en.wikipedia.org/wiki/St._Elmo%27s_fire is a faint electrical discharge that sometimes develops at the tops of elevated objects during thunderstorms. It was first observed coming from the tall masts of sailing ships at sea (St. Elmo is the patron saint of sailors).

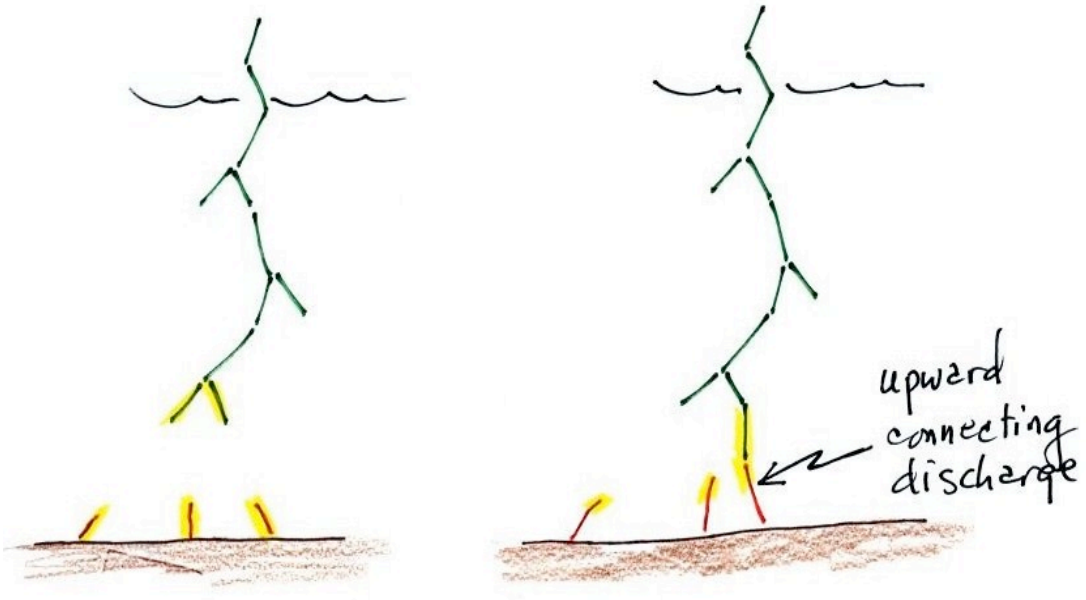
Here is an illustration of how cloud-to-ground lightning is generated.



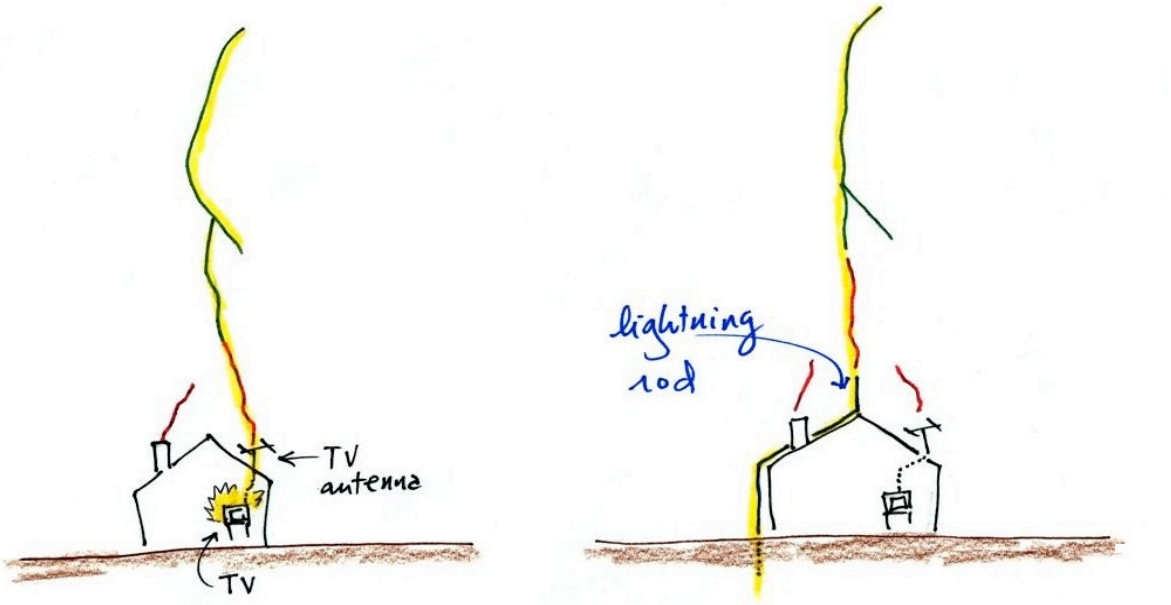
Most cloud-to-ground discharges begin with a negatively-charged, downward-moving stepped leader. A developing channel makes its way down the cloud in 50 meter jumps that occur about every 50 millionths of a second. Every jump produces a short flash of light (think of a strobe light dropped from an airplane that flashes periodically as it falls toward the ground). The sketch below shows what you would see if you were able to photograph the stepped leader on moving film. Every 50 microseconds or so, you would obtain a new picture of a slightly longer channel that is displaced slightly on the film. The bottom segment, highlighted in yellow, produces a bright flash of light while the remainder of the channel is often weakly illuminated.



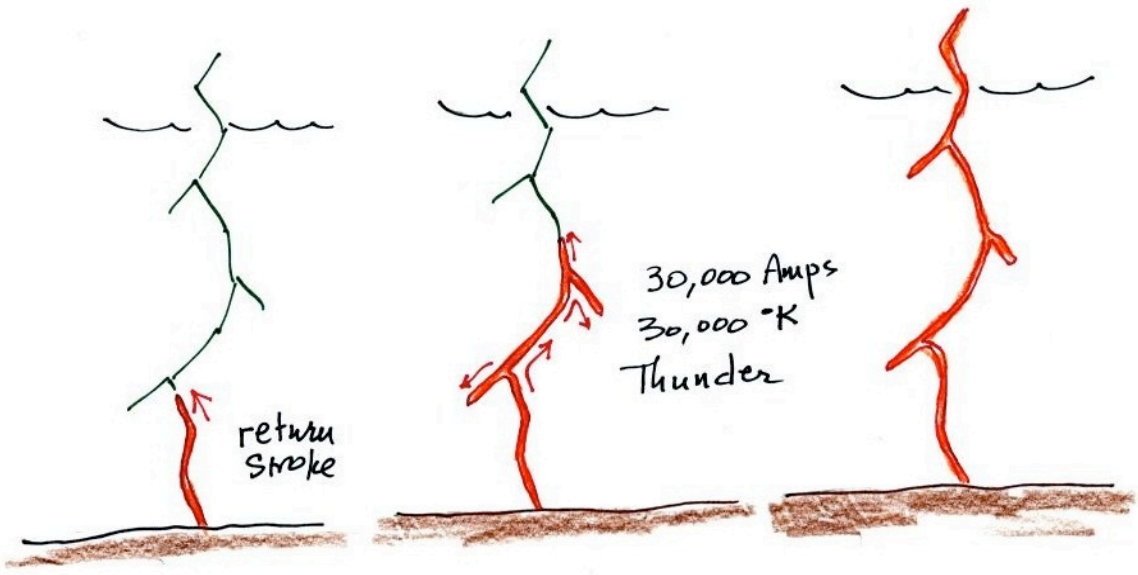
As the leader channel approaches the ground, a strong electrical attraction develops between the negative charge in the leader channel and positive charges on the surface of the ground. Several positively charged sparks develop and move upward toward the stepped leader. One of these will intercept the stepped leader and close the connection between the negative charge in the cloud and the positive charge on the ground.



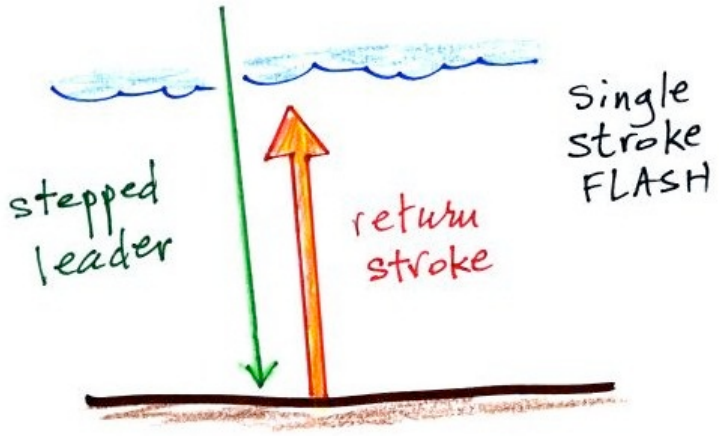
Lightning rods take advantage of this principle. Houses with and without lightning rods are shown below. When lightning strikes a house without a lightning rod, the powerful return stroke travels into the house destroying the television and possibly starting the house on fire. A lightning rod is supposed to intercept the stepped leader and safely carry the lightning current around the house and into the ground. A lightning rod does not really attract lightning. The lightning does not know where it is going to strike until it gets within about 100 meters of the ground.



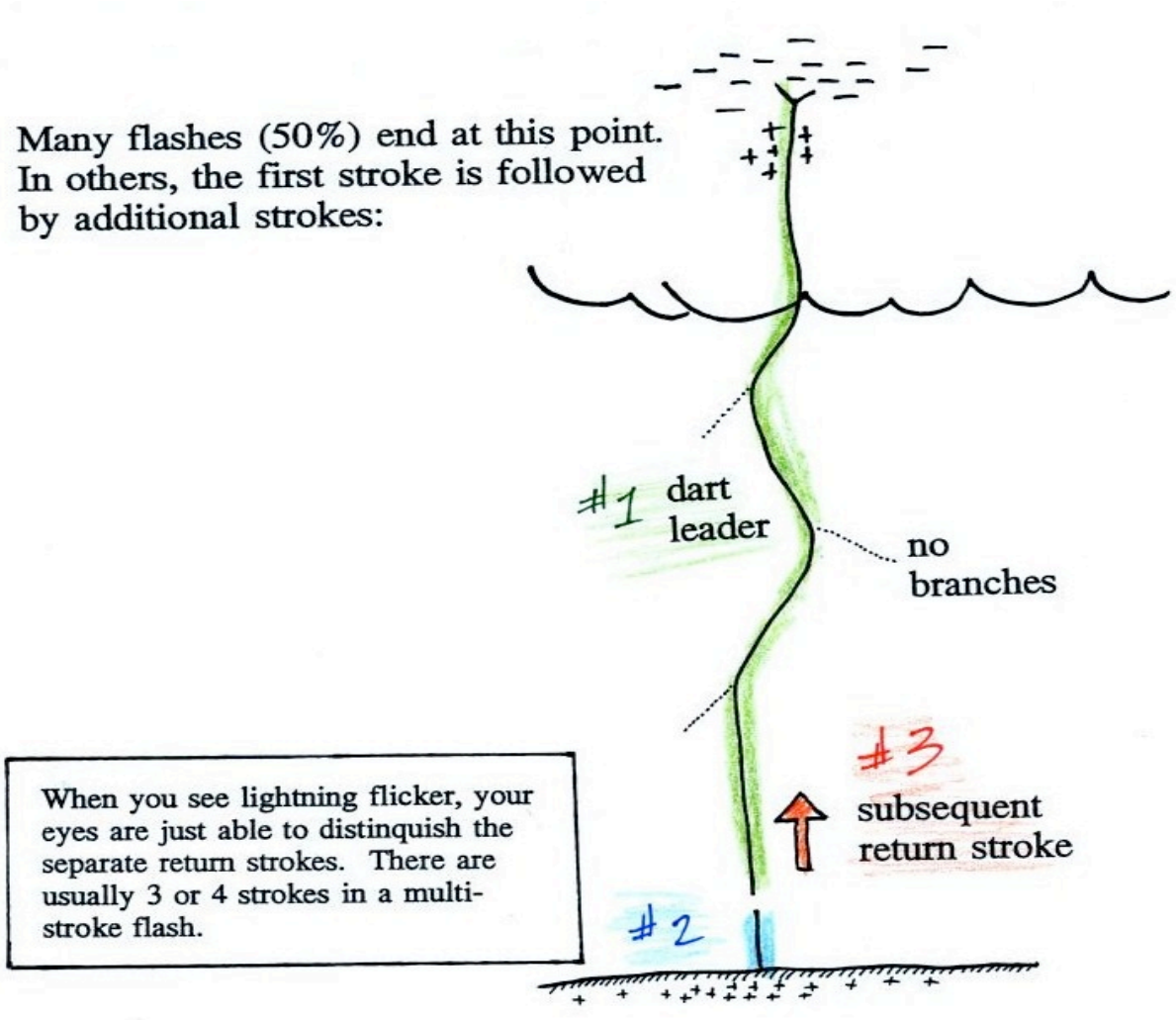
The connection between the stepped leader and the upward discharge creates a "short circuit" between the charge in the cloud and the charge in the ground. A powerful current travels back up the channel from the ground toward the cloud. This is the return stroke. Large currents (typically 30,000 amps in the first return stroke) heat the air to around $30{,}000^0$K (5 times hotter than the surface of the sun) which causes the air to explode. When you hear thunder, you are hearing the sound produced by this explosion.



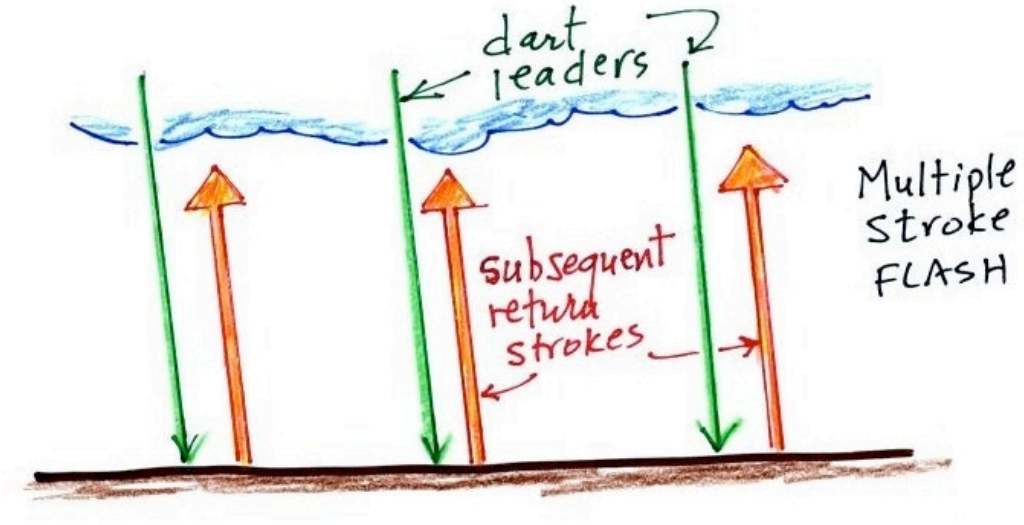
The figure below shows in simplified what we have learned so far.



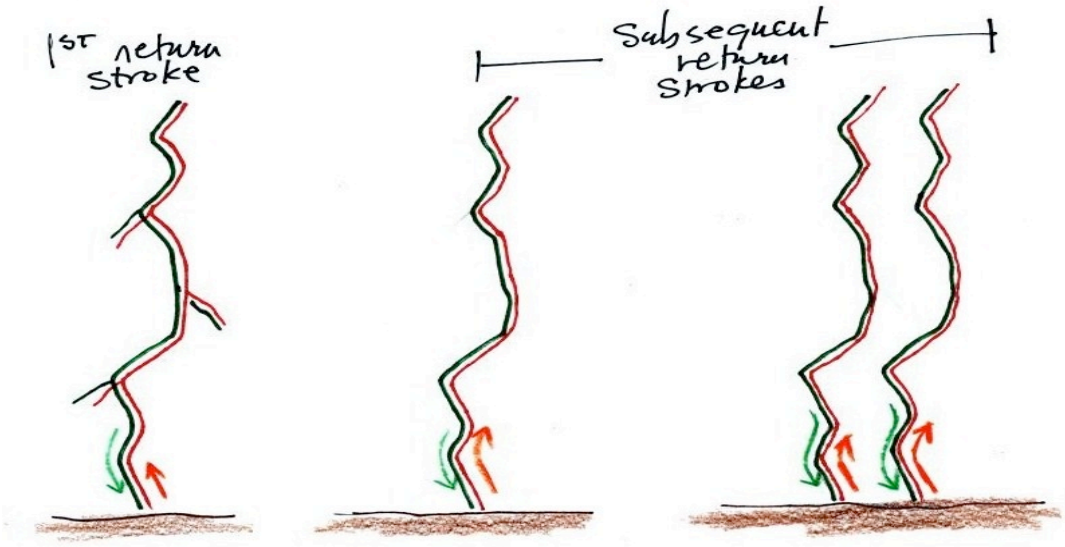
About 50% of cloud-to-ground discharges produce more than one upward return stroke.



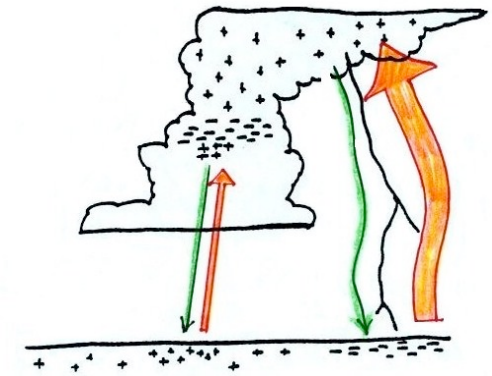
A downward dart leader travels from the cloud to the ground. The dart leader does not step but travels smoothly along the channel created by the stepped leader and avoids the branches. It is followed by a slightly less powerful subsequent return stroke that travels back up the channel to the cloud. This second stroke might be followed by a third, a fourth, and so on.



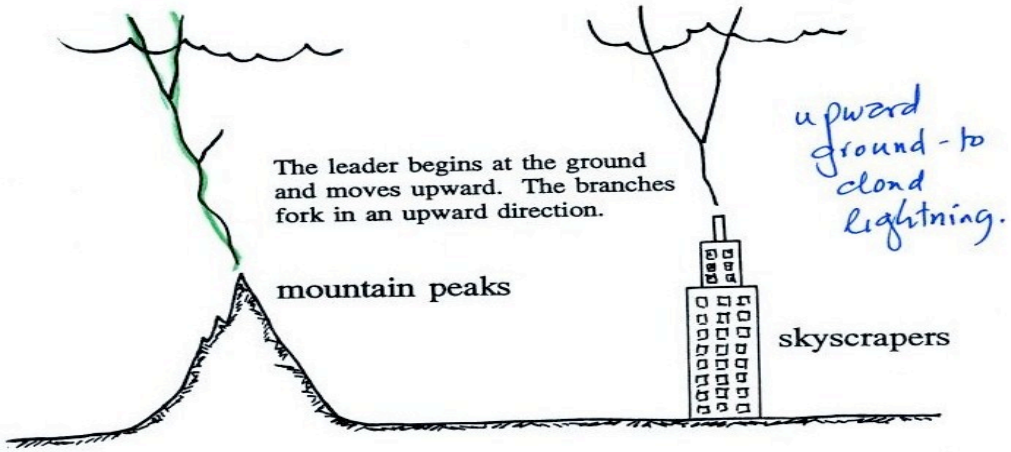
A normal still photograph would capture the separate return strokes superimposed on each other. If you bumped or moved the camera during the photograph the separate return strokes would be spread out on the image. The image below shows a multiple stroke flash consisting of four separate return strokes. Note that the first stroke on the left is the only stroke with branches. There is enough time between separate return strokes (about one tenth of a second) for your eye to distinguish the individual flashes of light. When lightning appears to flicker you are seeing the separate return strokes in a multiple stroke flash. The entire flash usually lasts 0.5 to 1 second. Here is an animation http://www.atmo.arizona.edu/courses/fall06/atmo325/media/cgmovie.gif of the stepped leader-upward connecting discharge and return stroke. Here also is a slow motion video of an actual stepped leader http://www.youtube.com/watch?v=2XwFF5idD_0.

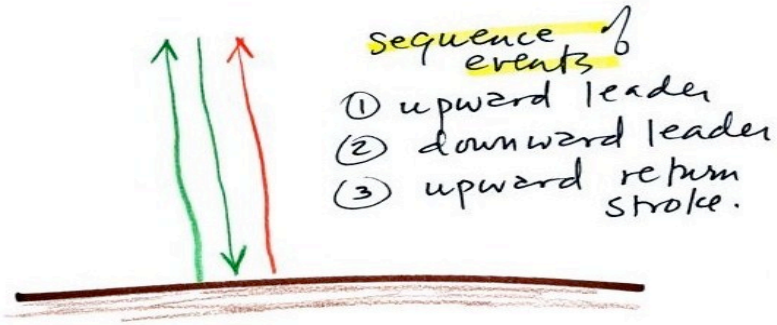


Approximately 5% of the time, a lightning stroke will travel from the positive charge region in the top of the thunderstorm cloud to the ground. Positive strikes are more common near the end of a storm and during winter storms. This is probably because the top part of the cloud gets pushed sideways away from the middle and bottom portions of the cloud. Positive strokes are very powerful and can sometimes produce an unusually loud and long lasting clap of thunder.

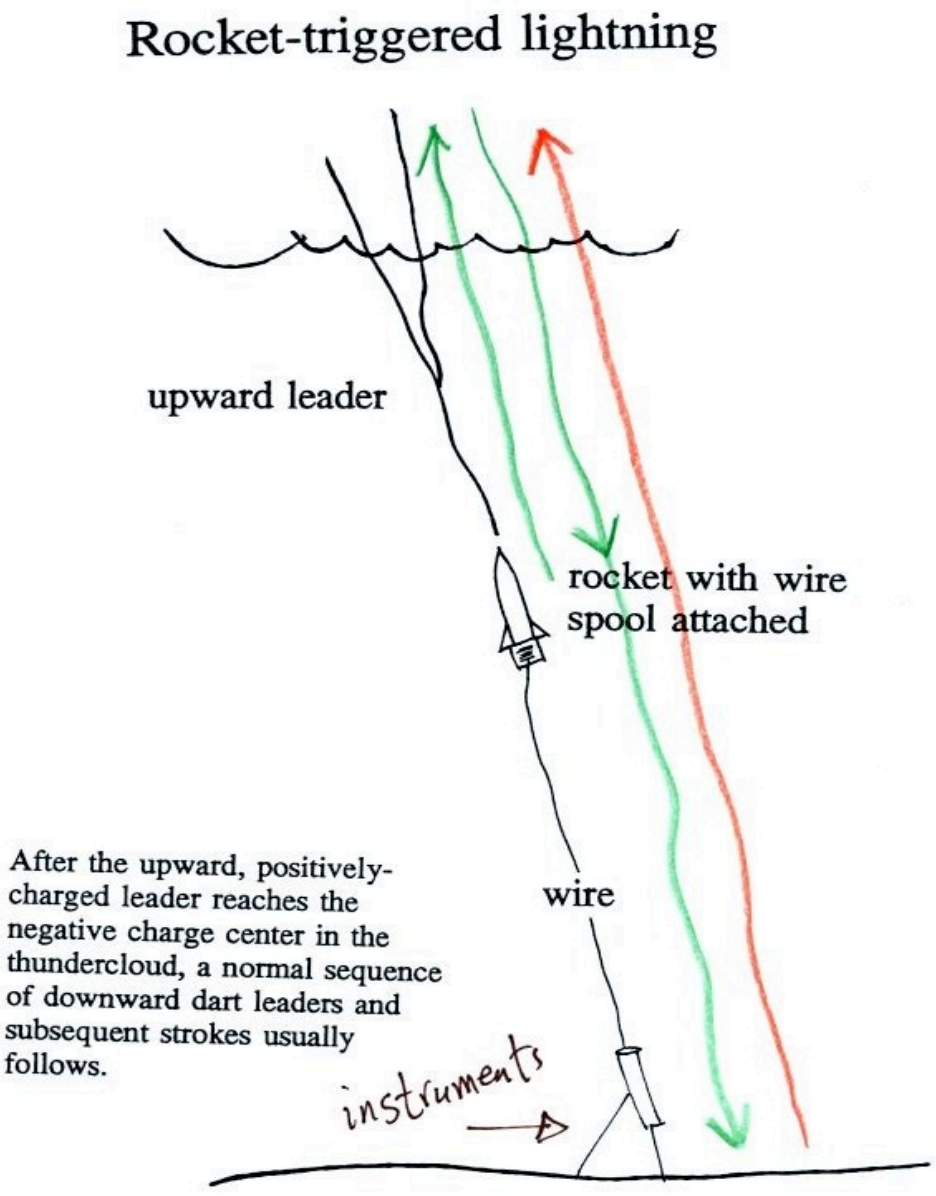


Lightning that originates from the ground and travels upward is an even more rare. Upward lightning is usually only initiated by mountains and tall objects such as a skyscraper or a tower. These discharges are initiated by an upward leader, followed by a more normal downward leader rather than a return stroke. Once the second leader reaches the ground, an upward return stroke travels back up the channel to the cloud. Here is a [slow motion video of upward lightning](http://www.youtube.com/watch?v=-bvmEYxEYiA&NR=1) http://www.youtube.com/watch?v=-bvmEYxEYiA&NR=1.

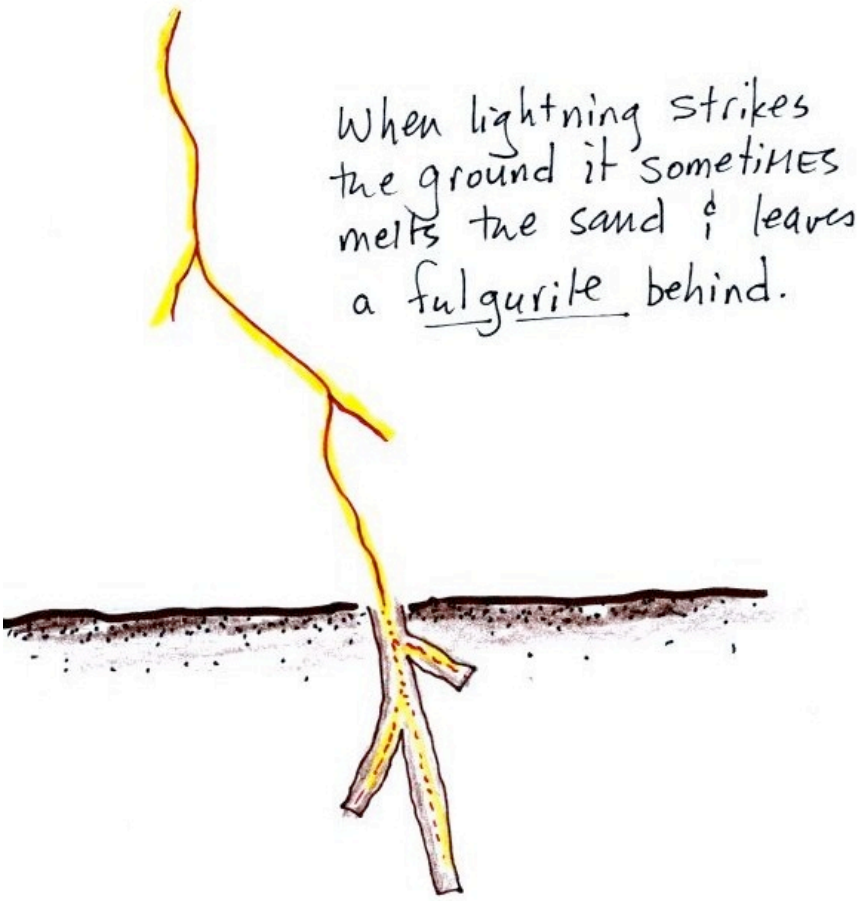




French scientists developed a technique to trigger lightning by firing a small rocket up towards a thunderstorm. The rocket is connected by a thin wire to the ground. When the rocket gets 50 to 100 meters above the ground, upward lightning will develop at the top of the wire. The technique of triggered lightning enables scientists to take close-up photographs and make measurements of lightning currents. Triggered lightning can also be used to test the operation of lightning protection devices. Here are a few short videos of rocket triggered lightning http://www.youtube.com/watch?v=buSaGIoNXu8 from experiments conducted by the University of Florida Lightning Research Group http://www.lightning.ece.ufl.edu/. A University of Arizona scientist participated in the triggered lightning studies and has made major contributions to lightning research.



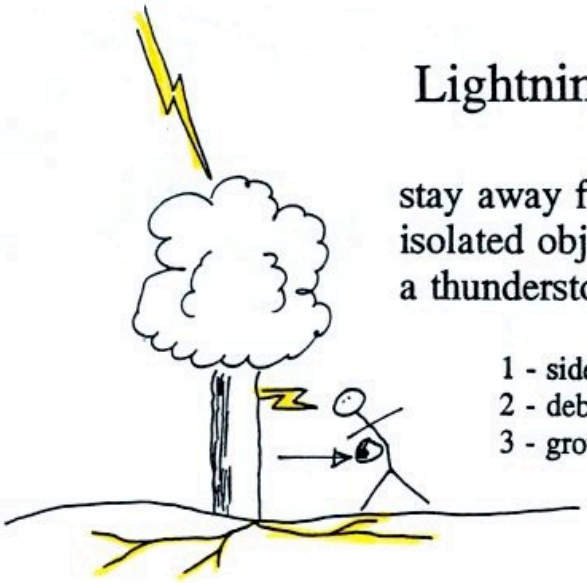
When lightning strikes the ground it will often melt the soil (especially sandy soil) and leave behind a root like structure called a fulgurite. A fulgurite is just a narrow 1/2 to 1 inch across segment of melted sand similar to glass.



Here is some lightning safety information. Lightning is a serious weather hazard that kills slightly less than 100 people every year in the United States. One of the most important precautions against lightning is to stay away from tall isolated objects during a lightning storm. Even if you are not directly struck by lightning, you can be hurt or killed just by being close to a lightning strike.

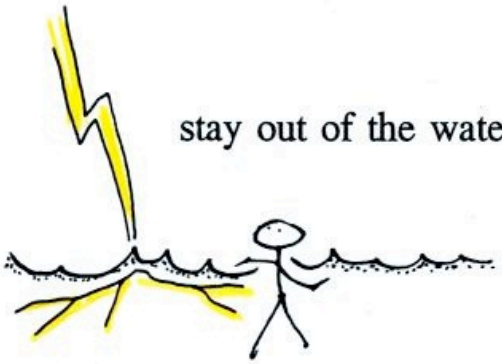
An automobile with a metal roof and body provides good protection from lightning because the lightning current will travel through the metal and around the passengers inside. The rubber tires really do not play any role at all. The scientists in Florida who were triggering lightning with rockets were perfectly safe inside a metal trailer. All of the connections to equipment outside the trailer were done using fiber optics and there were no metal wires entering or leaving the trailer.

Lightning hazards/safety

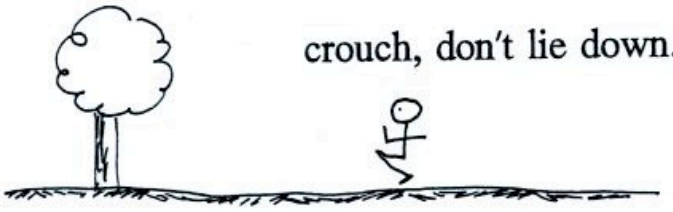


stay away from tall, isolated objects in a thunderstorm.

1 - side flash
2 - debris
3 - ground currents

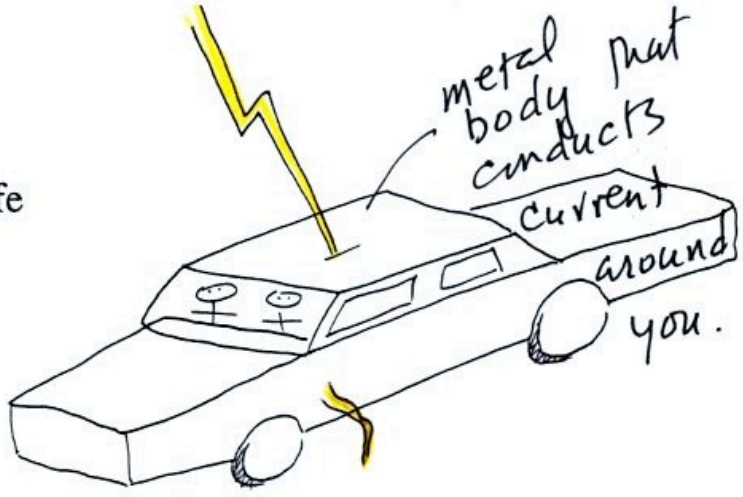


stay out of the water

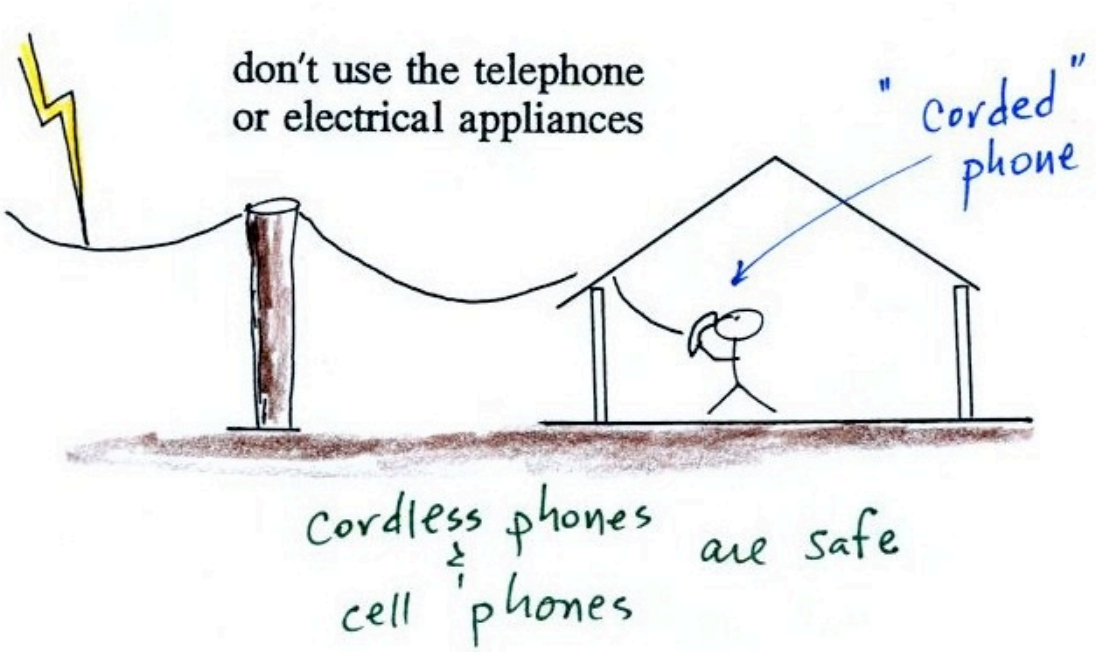


crouch, don't lie down.

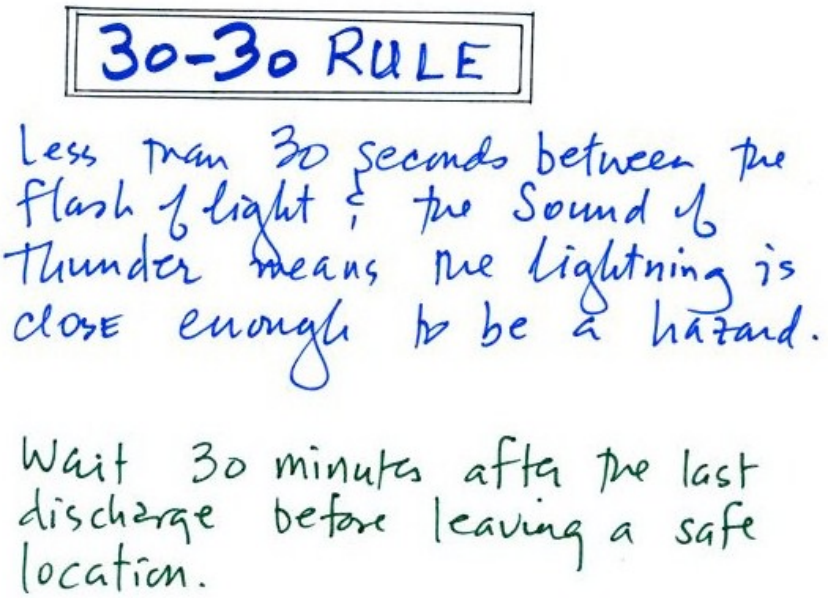
automobiles offer safe shelter; but it's not because of the tires



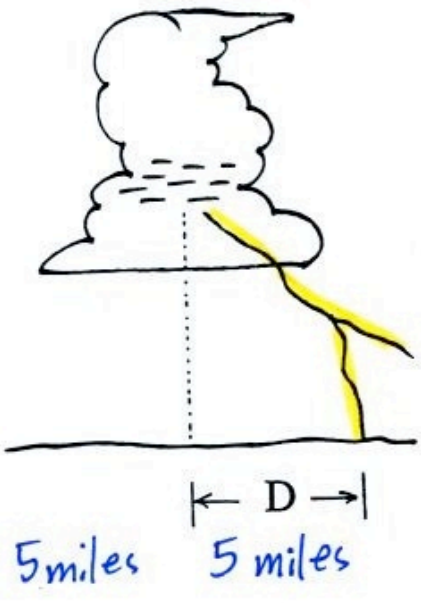
You should not use a corded phone or electrical appliances during a lightning storm because lightning currents can follow wires into your home. Cordless phones and cell phones are safe. It is also a good idea to stay away from plumbing as much as possible (do not take a shower during a lightning storm, for example). Vent pipes that are connected to the plumbing go up to the roof of the house which puts them in a perfect location to be struck.



The latest lightning safety recommendation is the 30/30 Rule. People should seek shelter if the delay between a lightning flash and its thunder is **30 seconds** or less. People should remain under cover until **30 minutes** after the final clap of thunder.



To estimate the distance to a lightning strike, count the number of seconds between the flash of light and when you first hear the thunder. Divide this by 5 to get the distance in miles. For example, a delay of 15 seconds between the flash of light and the sound of thunder would mean the discharge was 3 miles away. Research has shown that about 95% of cloud to ground discharges strike the ground within 5 miles of a point directly below the center of the storm. That is a circle with a diameter of 10 miles, which could cover a medium sized city.



95% within a
5 mile radius