Lightning

In an electrical storm, the storm clouds are charged like giant capacitors in the sky. The upper portion of the cloud is positive and the lower portion is negative. How the cloud acquires this charge is still not agreed upon within the scientific community, but the following description provides one plausible explanation.

In the process of the water cycle, moisture can accumulate in the atmosphere. This accumulation is what we see as a cloud. Interestingly, clouds can contain millions upon millions of water droplets and ice suspended in the air. As the process of evaporation and condensation continues, these droplets collide other moisture that is in the process of condensing as it rises. Also, the rising moisture may collide with ice or sleet that is in the process of falling to the earth or located in the lower portion of the cloud. The importance of these collisions is that electrons are knocked off of the rising moisture, thus creating a charge separation.

The newly knocked-off electrons gather at the lower portion of the cloud, giving it a negative charge. The rising moisture that has just lost an electron carries a positive charge to the top of the cloud. Beyond the collisions, freezing plays an important role. As the rising moisture encounters colder temperatures in the upper cloud regions and begins to freeze, the frozen portion becomes negatively charged and the unfrozen droplets become positively charged. At this point, rising air currents have the ability to remove the positively charged droplets from the ice and carry them to the top of the cloud. The remaining frozen portion would likely fall to the lower portion of the cloud or continue on to the ground. Combining the collisions with the freezing, we can begin to understand how a cloud may acquire the extreme charge separation that is required for a lightning strike.

When there is a charge separation in a cloud, there is also an electric field that is associated with the separation. Like the cloud, this field is negative in the lower region and positive in the upper region.

The strength or intensity of the electric field is directly related to the amount of charge buildup in the cloud. As the collisions and freezing continue to occur and the charges at the top and bottom of the cloud increase, the electric field becomes more and more intense -- so intense, in fact, that the electrons at the earth's surface are repelled deeper into the earth by the strong negative charge at the lower portion of the cloud. This repulsion of electrons causes the earth's surface to acquire a strong positive charge.

All that is needed now is a conductive path for the negative cloud bottom to contact the positive earth surface. The strong electric field, being somewhat self-sufficient, creates this path.

The strong electric field causes the air around the cloud to "break down," allowing current to flow in an attempt to neutralize the charge separation. Simply stated, the air breakdown creates a path that short-circuits the cloud/earth as if there were a long metal rod connecting the cloud to the earth. Here's how this breakdown works.

When the electric field becomes very strong (on the order of tens of thousands of volts per inch), conditions are ripe for the air to begin breaking down. The electric field causes the surrounding air to become separated into positive ions and electrons -- the air is ionized. Keep in mind that the ionization does not mean that there is more negative charge (electrons) or more positive charge (positive atomic nuclei / positive ions) than before. This ionization only means that the electrons and positive ions are farther apart than they were in their original molecular or atomic structure. Essentially, the electrons have been stripped from the molecular structure of the non-ionized air.

The importance of this separation/stripping is that the electrons are now free to move much more easily than they could before the separation. So this ionized air (also known as plasma) is much more conductive than the previous non-ionized air. Incidentally, the ability or freedom of the electrons to move is what makes any material a good conductor of electricity. Often times, metals are referred to as positive atomic nuclei surrounded by a fluid-like cloud of electrons. That makes many metals good conductors of electricity.

These electrons have excellent mobility, allowing for electrical current to flow. The ionization of air or gas creates plasma with conductive properties similar to that of metals. Plasma is the tool nature wields to neutralize charge separation in an electric field. Those readers who are familiar with the chemical reaction of fire will recall that oxidation plays an important role. Oxidation is the process by which an atom or molecule loses an electron when combined with oxygen. Simply put, the atom or molecule is changed from a lower positive potential to a higher positive potential. Interestingly enough, the process of ionization, which creates plasma, also occurs through the loss of electrons. By this comparison, we can view the ionization process as "burning a path" through the air for the lightning to follow, much like digging a tunnel through a mountain for a train to follow.

After the ionization process, the path between the cloud and the earth begins to form.

Once the ionization process begins and plasma forms, a path is not created instantaneously. In fact, there are usually many separate paths of ionized air stemming from the cloud. These paths are typically referred to as step leaders.

The step leaders propagate toward the earth in stages, which do not have to result in a straight line to the earth. The air may not ionize equally in all directions. Dust or impurities (any object) in the air may cause the air to break down more easily in one direction, giving a better chance that the step leader will reach the earth faster in that direction. Also, the shape of the electric field can greatly affect the ionization path. This shape depends on the location of the charged particles, which in this case are located at the bottom of the cloud and the earth's surface. If the cloud is parallel to the earth's surface, and the area is small enough that the curvature of the earth is negligible, the two charge locations will behave as two charged parallel plates. The lines of force (electric flux) generated by the charge separation will be perpendicular to the cloud and earth.

Flux lines always radiate perpendicularly from the charge surface before moving toward their destination (opposite charge location). Given this knowledge, we can say that if the lower surface of the cloud is not straight, the flux lines will not be uniform. Try this: Draw two points on opposite ends of a basketball. Next, draw a line on the basketball that connects the two points. The curvature of the line is analogous to the flux lines in a non-uniform electric field. The lack of uniform force can cause the step leaders to follow a path that is not a straight line to the earth.

Considering these possibilities, it becomes obvious that there are various factors that affect the direction of the step leader. We are taught that the shortest distance between two points is a straight line; but in the case of electric fields, the lines of force (flux lines) may not follow the shortest distance, as the shortest distance does not always represent the path of least resistance.

So now we have an electrically charged cloud with ever-growing step leaders stretching out toward the earth in stages. These leaders are faintly illuminated in a purplish glow and may sprout other leaders in areas where the original leaders bend or turn. Once begun, the leader will remain until the current flows, regardless of whether or not it is the leader that reaches the ground first. The leader basically has two possibilities: continue to grow in stages of growing plasma or wait patiently in its present plasma condition until another leader hits a target.

The leader that reaches the earth first reaps the rewards of the journey by providing a conductive path between the cloud and the earth. This leader is not the lightning strike; it only maps out the course that the strike will follow. The strike is the sudden, massive, flow of electrical current moving from the cloud to the ground.

As the step leaders approach the earth, objects on the surface begin responding to the strong electric field. The objects reach out to the cloud by "growing" positive streamers. These streamers also have a purplish color and appear to be more prominent on sharp edges. The human body can and does produce these positive streamers when subjected to a strong electric field such as that of a storm cloud. In actuality, anything on the surface of the earth has the potential to send a streamer. Once produced, the streamers do not continue to grow toward the clouds; bridging the gap is the job of the step leaders as they stage their way down. The streamers wait patiently, stretching upward as the step leaders approach.

Next to occur is the actual meeting of a step leader and a streamer. As discussed earlier, the streamer that the step leader reaches is not necessarily the closest streamer to the cloud. It's very common for lightning to strike the ground even though there is a tree or a light pole or any other tall object in the vicinity. The fact that the step leader does not take the path of a straight line allows for this to occur.

After the step leader and the streamer meet, the ionized air (plasma) has completed its journey to the earth, leaving a conductive path from the cloud to the earth. With this path complete, current flows between the earth and the cloud. This discharge of current is nature's way of trying to neutralize the charge separation. The flash we see when this discharge occurs is not the strike -- it is the local effects of the strike.

Any time there is an electrical current, there is also heat associated with the current. Since there is an enormous amount of current in a lightning strike, there is also an enormous amount of heat. In fact, a bolt of lightning is hotter than the surface of the sun. This heat is the actual cause of the brilliant white-blue flash that we see.

When a leader and a streamer meet and the current flows (the strike), the air around the strike becomes extremely hot. So hot that it actually explodes because the heat causes the air to expand so rapidly. The explosion is soon followed by what we all know as thunder.

Thunder is the shockwave radiating away from the strike path. When the air heats up, it expands rapidly, creating a compression wave that propagates through the surrounding air. This compression wave manifests itself in the form of a sound wave. That does not mean that thunder is harmless. On the contrary, if you are close enough, you can feel the shockwave as it shakes the surroundings. Keep in mind that when a nuclear explosion occurs, typically the most destruction is caused by the energy of the rapidly moving shockwave. In fact, the shockwave that produces the thunder from a lightning strike can most certainly damage structures and people. This danger is more prominent when you are close to the strike, because the shockwave is stronger there and will dampen (decrease) with distance. Physics teaches us that sound travels much slower than light, so we see the flash before we hear the thunder. In air, sound travels roughly 1 mile every 4.5 seconds. Light travels at a blazing 186,000 miles (299,000 kilometers) per second.

You are sitting in your car and you see a flash from a lightning strike. The first thing you notice is that there were many other branches that flashed at the same time as the main strike. Next you notice that the main strike flickers or dims a few more times. The branches that you saw were actually the step leaders that were connected to the leader that made it to its target.

When the first strike occurs, current flows in an attempt to neutralize the charge separation. This requires that the current associated with the energy in the other step leaders also flows to the ground. The electrons in the other step leaders, being free to move, flow through the leader to the strike path. So when the strike occurs, the other step leaders are providing current and exhibiting the same heat flash characteristics of the actual strike path. After the original stroke occurs, it is usually followed by a series of secondary strikes. These strikes follow only the path of the main strike; the other step leaders do not participate in this discharge.

In nature, what we see is often not what we get, and this is definitely the case with the secondary strikes. It is very possible that the main strike can be followed by 30 to 40 secondary strikes. Depending on the time delay between the strikes, we may see what looks like one long-duration main strike, or a main strike followed by other flashes along the path of the main strike. These conditions are easy to understand if we realize that the secondary strike can occur while the flash from the main stroke is still visible. Obviously, this would cause a viewer to think that the main-stroke flash lasted longer than it actually did. By the same token, the secondary strikes may occur after the flash from the main strike ends, making it appear that the main strike is flickering.

Now you know the mechanics of a lightning strike. It's amazing to realize that all of the activity, from the time the ionization begins to the time of the strike, occurs in a fraction of a second. High-speed cameras used to take pictures of lightning have actually caught the positive streamers on film.