Does a Stroke Between Cloud and Ground Travel Upwards or Downwards?

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DOES A STROKE BETWEEN CLOUD AND GROUND TRAVEL UPWARDS OR DOWNWARDS?

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The answer to the question "Does lightning between cloud and ground go upwards or downwards?" is that, in a sense, it does both. The usual lightning flash between cloud and ground (excluding the discharges initiated by tall structures discussed in Chapter 6) begins with a visually-undetected downward-moving traveling spark called the stepped leader (see Chapters 2 and 6). Since the lightning flash begins with a downward-moving discharge, lightning moves from the cloud to the ground. On the other hand, when the stepped leader reaches ground (or is contacted by an upward-moving discharge some tens of yards above the ground) the leader channel first becomes highly luminous at the ground and then at higher and higher altitudes. The bright, visible channel, or so-called return stroke, is formed from the ground up, and one could say, therefore, that visible lightning moves from the ground to the cloud.

It is thought by most lightning researchers that the usual cloud-to-ground discharge begins as a local discharge between the p-charge region in the cloud base and the N-charge region above it (Fig. 9.1, see also Fig. 8.3). This discharge frees electrons in the N-region previously immobilized by attachment to water or ice particles. (Electrons are fundamental particles which carry the smallest known unit of negative electrical charge.) Because of their small mass, free electrons are extremely mobile compared to air atoms or to charged ice or water particles. The free electrons overrun the p-region, neutralizing its small positive charge, and then continue their trip toward ground. The vehicle for moving the negative charge to earth is the stepped leader.

Exactly how the stepped leader works is not understood. What is known is that it moves from cloud to ground in rapid luminous steps about 50 yards long. In Figs. 9.1 and 9.2 the luminous steps appear as darkened tips on the less-luminous leader channel which extends upward into the cloud. Each leader step occurs in less than a millionth of a second. The time between steps is about 50 millionths of a second. Negative charge is continuously lowered from the N-region of the cloud into the leader channel. The average velocity of the stepped leader dur-

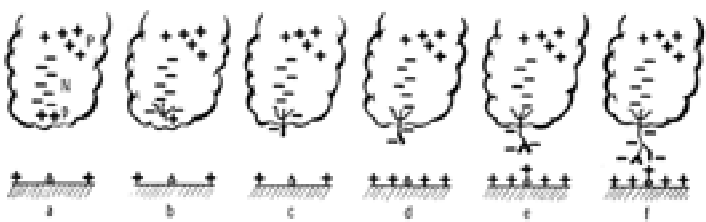

Figure 9.1: Stepped leader initiation and propagation. (a) Cloud charge distribution just prior to p-N discharge. (b) p-N discharge. (c)-(f) Stepped leader moving toward ground in 50-yard steps. Time between steps is about 50 millionths of a second. Scale of drawing is distorted for illustrative purposes.

ing its trip toward ground is about 75 miles per second with the result that the trip between cloud and ground takes about 20 thousandths of a second. A typical stepped leader has about 5 coulombs of negative charge distributed over its length when it is near ground. To establish this charge on the leader channel an average current of about 100 or 200 amperes must flow during the whole leader process. The pulsed currents which flow at the time of the leader steps probably have a peak current of about 1000 amperes. The luminous diameter of the stepped leader has been measured photographically to be between 1 and 10 yards. It is thought that most of the stepped-leader current flows down a narrow conducting core less than an inch in diameter at the center of the observed leader. The large photographed diameter is probably due to a luminous electrical corona surrounding the conducting core.

When the stepped leader is near ground, its relatively large negative charge induces large amounts of positive charge on the earth beneath it and especially on objects projecting above the earth's surface (Fig. 9.2). Since opposite charges attract each other, the large positive charge attempts to join the large negative charge, and in doing so initiates upward-going discharges (Figs. 2.1 and 9.2). One of these upward-going discharges contacts the downward-moving leader and thereby determines the lightning strike-point. When the leader is attached to ground, negative charges at the bottom of the channel move violently to ground, causing large currents to flow at ground and causing the channel near ground to become very luminous. Since elec-

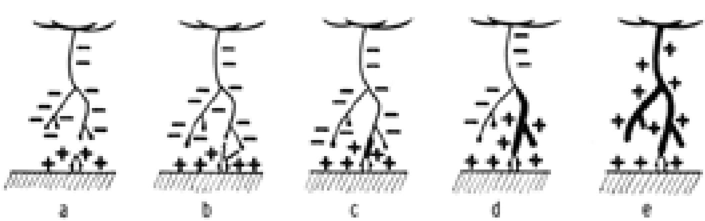

Figure 9.2: Return stroke initiation and propagation. (a) Final stages of stepped leader descent. (b) Initiation of upward-moving discharges to meet downward-moving leader. (c)-(e) Return stroke propagation from ground to cloud. Return stroke propagation time is about 100 millionths of a second; propagation is continuous. Scale of drawing is distorted .

trical signals (or any signals, for that matter) have a maximum speed of 186,000 miles per second—the speed of light—the leader channel above ground has no way of knowing for a short time that the leader bottom has touched ground and has become highly luminous. The channel luminosity, the return stroke, propagates continuously up the channel and out the channel branches at a velocity somewhere between 20,000 and 60,000 miles per second, as shown in Fig. 9.2. The trip between ground and cloud takes about 100 millionths of a second. As the return stroke luminosity moves upward so also does the region of high current. When the leader initially touches ground, copious numbers of electrons flow to ground from the

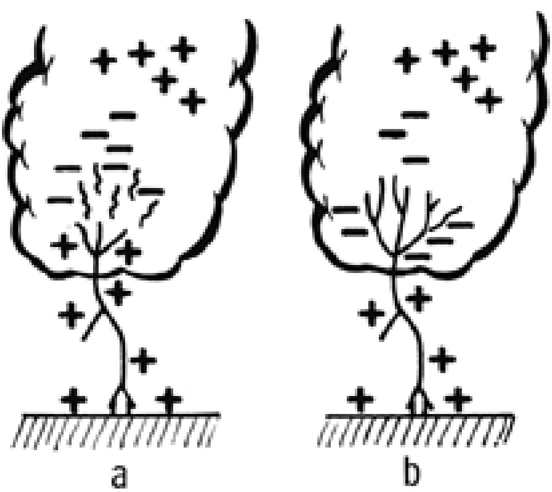

Figure 9.3: K-streamers and J-streamers making more negative charge available to the channel top during the 50 thousandths of a second or so following the cessation of current flow in the first return stroke. Scale of drawing is distorted.

channel base. As the return stroke moves upward, large numbers of electrons flow at greater and greater heights. Electrons at all points in the channel always move downward even though the region of high current and high luminosity moves upward. Eventually, in some thousandths of a second, the coulombs of charge which were on the leader channel have all flowed into the ground. The current at ground associated with this charge transfer is shown in Fig. 5.7. Since the return stroke channel is a good conductor and is tied to the ground, it will become positively charged like the ground in response to the negative charge in the lower part of the cloud.

It is the return stroke that produces the bright channel of high temperature (Chapter 11) that we see. The eye is not fast enough to resolve the propagation of the return stroke and it seems as if all points on the channel become bright simultaneously. The reason we do not visually detect the stepped leader preceding a first return stroke is because the eye cannot resolve the time between when the weakly luminous leader is formed and the bright return stroke illuminates the leader channel. The return stroke produces most of the thunder we hear (see Chapter 12).

After the stroke current has ceased to flow, the lightning flash may be ended, in which case the discharge is called a single-stroke flash. As noted in Chapter 5, most flashes contain three or four strokes, typically separated by gaps of 40 or 50 thousandths of a second. Strokes subsequent to the first are initiated only if additional charge is made available to the top of the previous stroke channel less than about 100 thousandths of a second after current has stopped flowing in the previous stroke. Additional charge can be made available to the channel top by the action of electrical discharges (so called K-streamers and J-streamers) which move upward from the top of the previous return stroke into higher areas of the N-charge region of the cloud (Fig. 9.3). When this additional charge is available, a continuous (as opposed to stepped) leader, known as a dart leader, moves down the defunct return stroke channel again depositing negative charge from the N-region along the channel length. The dart leader thus sets the stage for the second (or any subsequent) return stroke. The dart leader's earthward trip (Fig. 9.4) takes a few thousandths of a second. Because it occurs so close in time to the return stroke, it is not seen by the eye. To special cameras it appears as a luminous section of channel about 50 yards long which travels smoothly earthward at about 1000 miles per second. The dart leader generally deposits some what less charge along its path than does the stepped leader, with the result that subsequent return strokes generally lower less charge to ground and have smaller currents (Fig. 5.7) than first strokes.

The first stroke in a flash is usually strongly branched downward because the stepped leader is strongly branched (Figs. 9.1 and 9.2). Dart leaders generally follow only the main channel of the previous stroke and hence subsequent strokes show little branching (Fig. 9.4).

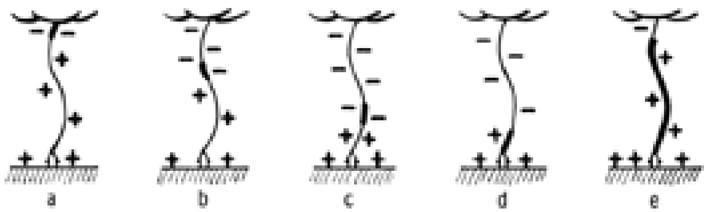

Fig. 9.4. Dart leader and subsequent return stroke. (a)-(c) Dart leader deposits negative charge on defunct first-stroke channel during its thousandth-of-a-second trip to ground. (d)-{e) Subsequent return stroke propagates from ground to cloud in about 100 millionths of a second. Scale of drawing is distorted.

The time between strokes which follow the same path can be tenths of a second if a continuing current (Chapter 5) flows in the channel between strokes. Apparently, the channel is ripe for a dart leader only after the continuing current has terminated.

A typical cloud-to-ground discharge lowers about 25 coulombs of negative charge from the N-region of the cloud to the earth. This charge is transferred in a few tenths of a second by the three or four component strokes and any continuing current which may flow. While the leader-return stroke process transfers charge to ground in two steps (charge is put on the leader channel and then is discharged to ground), the continuing current represents a relatively steady charge flow between the N-region and ground.

Thus far in this chapter we have discussed the usual stepped leader which lowers negative charge between the cloud and the earth. Occasionally downward-moving stepped leaders are observed that lower positive charge. Currents due to the resulting "positive" return strokes have been measured directly during discharges to instrumented towers. Positive strokes are characterized by rates-of-rise of current at the ground roughly five times slower than those for typical negative strokes, and by charge transfers roughly three times greater than those of typical negative strokes. The maximum measured charge transfer due to a positive stroke is 300 coulombs. Positive strokes are probably initiated between the P-charge region of the cloud and ground when strong winds blow the cloud such that the P-region is brought relatively close to a mountain side or to the earth's surface. Positive discharges rarely consist of more than one stroke.

REFERENCES

The material contained in Chapter 9 is considered in more detail in the following three references presented in order of decreasing technical content: *Lightning*, M. A. Uman, Dover Publications, Inc., New York, 1984. *Physics of Lightning*, D. J. Malan, The English Universities Press Ltd., London, 1963. *The Flight of Thunderbolts*, B. F. J. Schonland, 2nd Edition, Clarendon Press, Oxford, 1964.

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