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The Fundamentals and Physics of Lightning
presented by Albert Nibbe, M.D.

4-13-2007

Table 1. Varieties of Lightning

Heat (also known as silent, sheet or intracloud lightning)
Chain (or bead)
Triggered (or induced)
Cold
Hot
Ball
"Greased"
Intercloud
Cloud to Plane
Cloud to Space
Negative
Positive
Cloud to Ground
Ground to Cloud

Figures

All of the figures were taken from: Rakov, V.A. and Uman, M.A. (2003). Lightning: Physics and effects. New York: Cambridge University Press.

Figure 1.

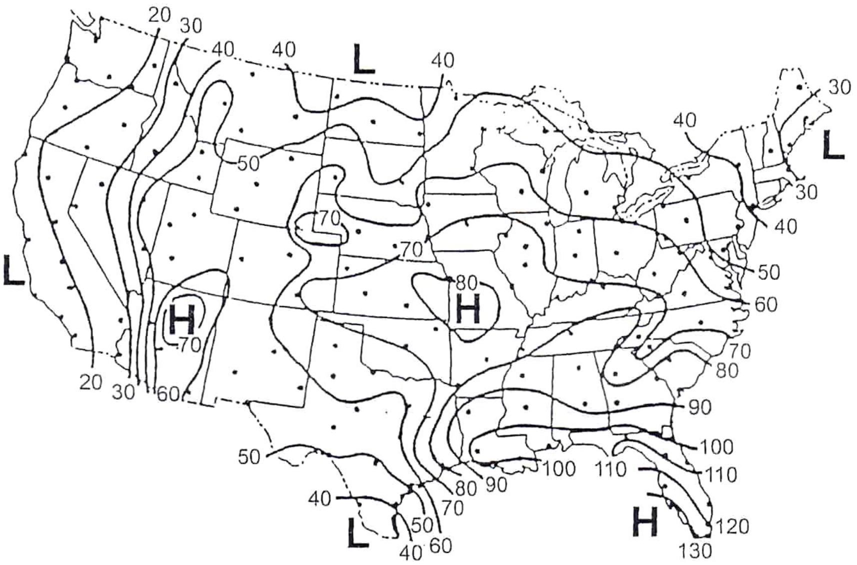

Fig. 2.15. Average annual numbers of thunder events in the contiguous United States. Adapted from Changnon (1988b).

Apparently, negative charge centers always occur at about the same cloud-temperature level, typically −10 to −34 °C, although these temperatures occur at different heights above the local terrain in different locations (Fig. 3.7).

Figure 2.

4.2. General picture

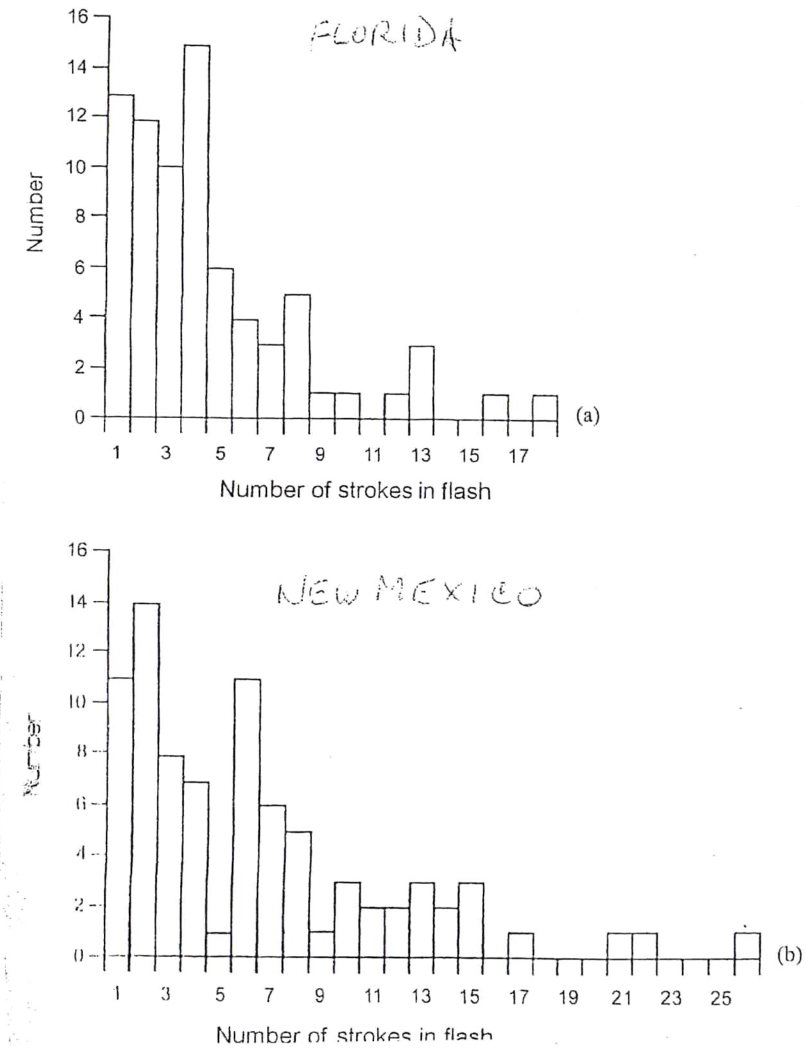

Figure 3.

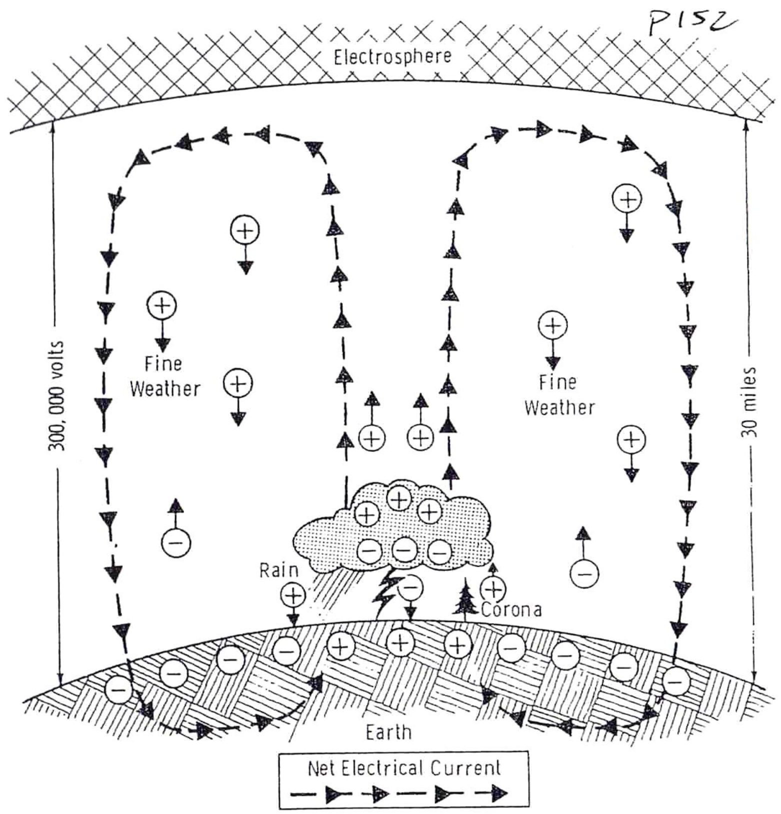

Fig. 18.1. Thunderstorms act as batteries to keep the earth charged negatively and the atmosphere charged positively. Atmospheric electrical currents flow downward in fine weather and upward in thunderstorms. Thunderstorms deliver charge to the earth by lightning, rain, and corona discharges.

Figure 4.

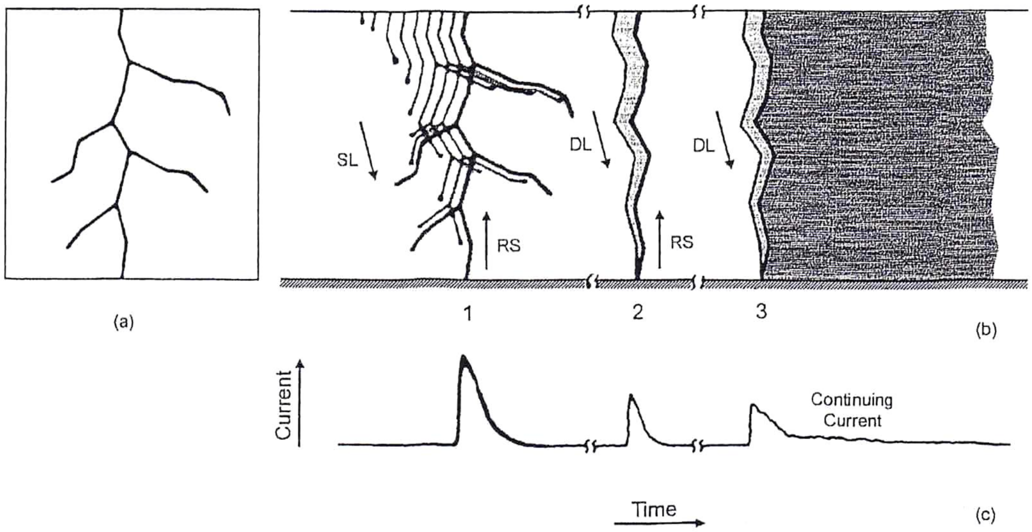

Fig. 4.2. Diagram showing the luminosity of a three-stroke ground flash and the corresponding current at the channel base: (a) still-camera image, (b) streak-camera image, and (c) channel-base current.

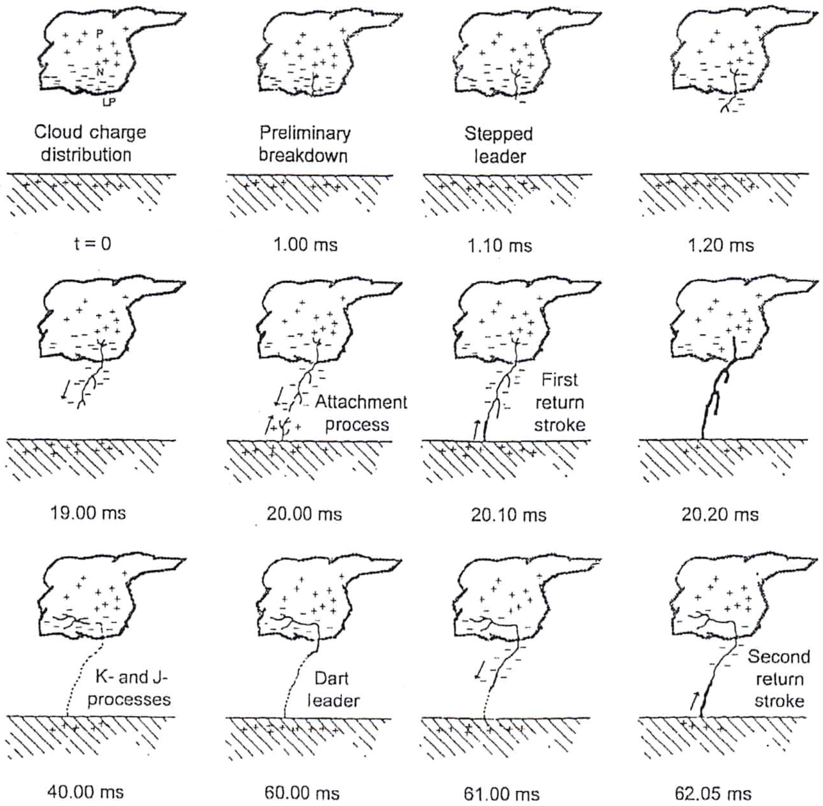

Fig. 4.3. Various processes comprising a negative cloud-to-ground lightning flash. Adapted from Uman (1987, 2001).

Figure 5.

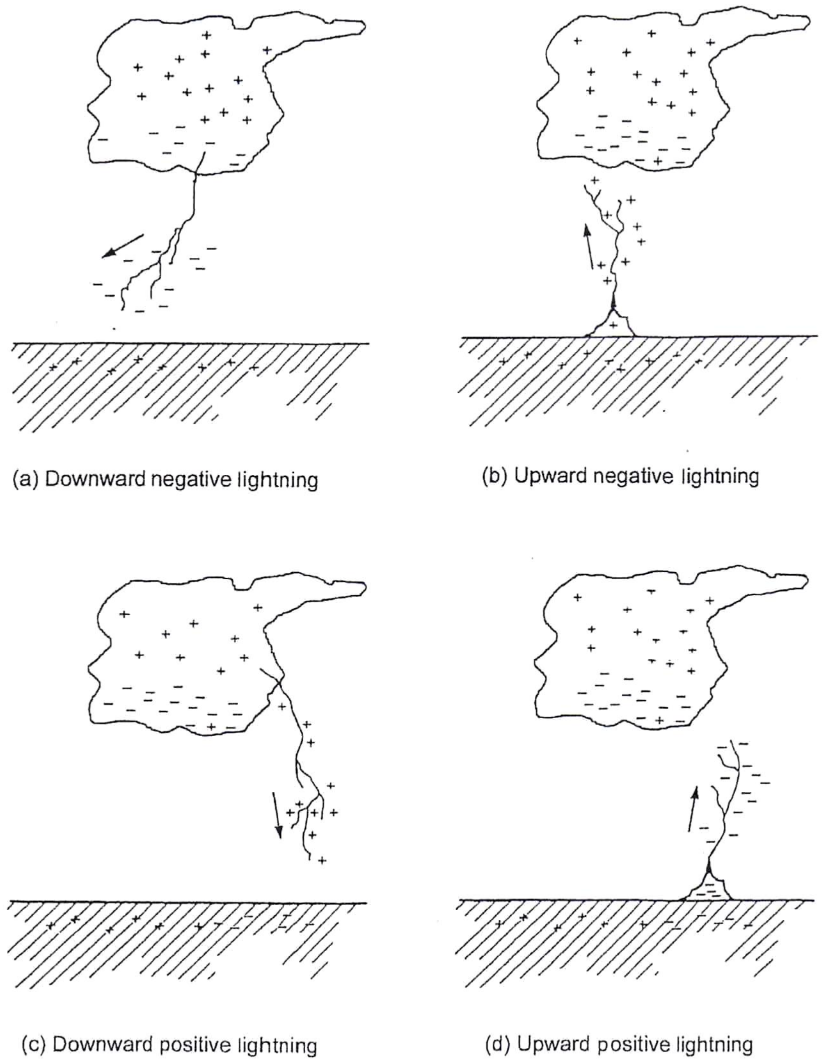

Fig. 1.1. Four types of lightning effectively lowering cloud charge to ground. Only the initial leader is shown for each type. In each lightning-type name given below the sketch, the direction of propagation of the initial leader and the polarity of the cloud charge effectively lowered to ground are indicated.

Figure 6.

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Table 4.9. *Estimated characteristics of the lightning channels associated with various processes of the lightning discharge. Adapted from Rakov (1998)*

Channel characteristics[a]	Pre-dart-leader channel (ahead of dart-leader front)	Pre-return-stroke channel (behind dart-leader front and ahead of return-stroke front)	Return-stroke channel (behind return-stroke front)
Temperature, K	~ 3000	$\geq 20\,000$	$\geq 30\,000$
Conductivity, $S\ m^{-1}$	~ 0.02	$\sim 10^4$	$\sim 10^4$
Radius, cm	~ 3	~ 0.3	~ 3
R, $\Omega\ m^{-1}$	$\sim 18\,000$	~ 3.5	~ 0.035

[a] For comparison, the electrical conductivity of carbon is 3×10^4 S m^{-1}, of seawater is 4 S m^{-1}, and of copper is 5.8×10^7 S m^{-1} (Sadiku 1994); the temperature of the solar interior is 10^7 K and of the solar surface is 6000 K, and the temperatures at which tungsten and lead melt are 3600 K and 600 K, respectively (Halliday and Resnick 1974).

Figure 7.

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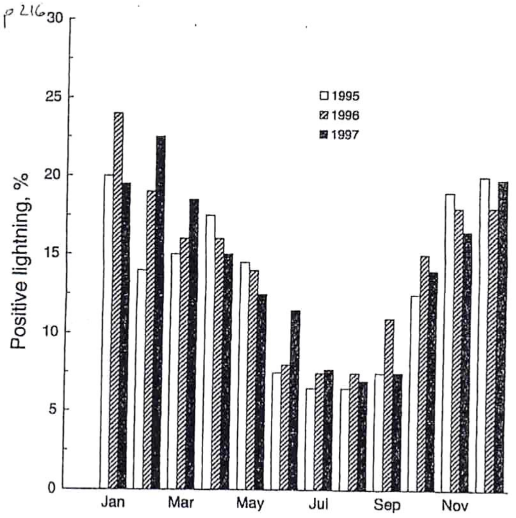

Fig. 5.2. The percentage of positive flashes over the contiguous United State: through 1997. The minimum occurs in late summer and the maximum is in J: Orville and Huffines (1999).

Figure 8.

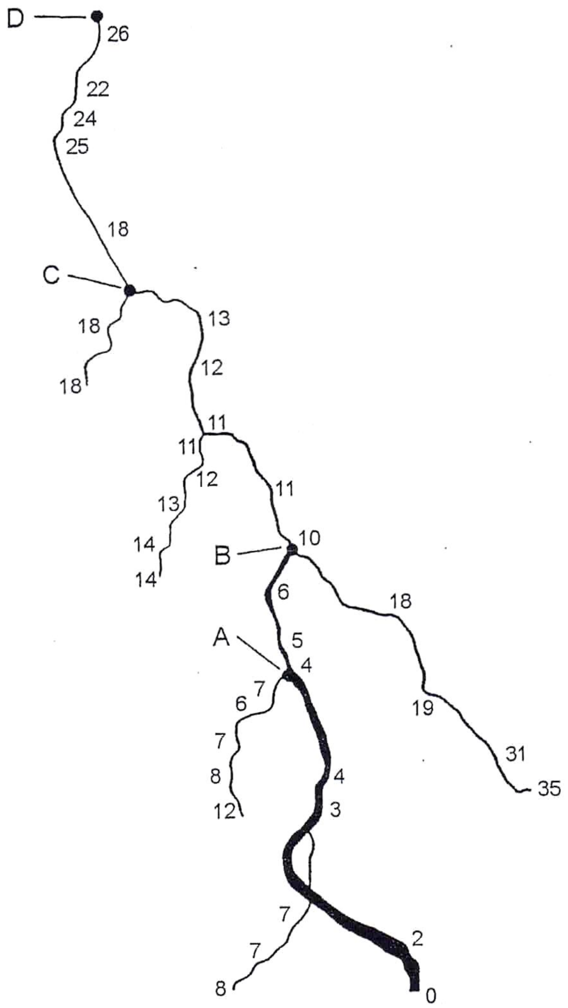

Fig. 4.36. The luminous development of a first return stroke. The numbers indicate the time of arrival in microseconds of the upward-propagating return-stroke front at various points on both the main channel and branches. Adapted from Schonland (1956).

Figure 9.

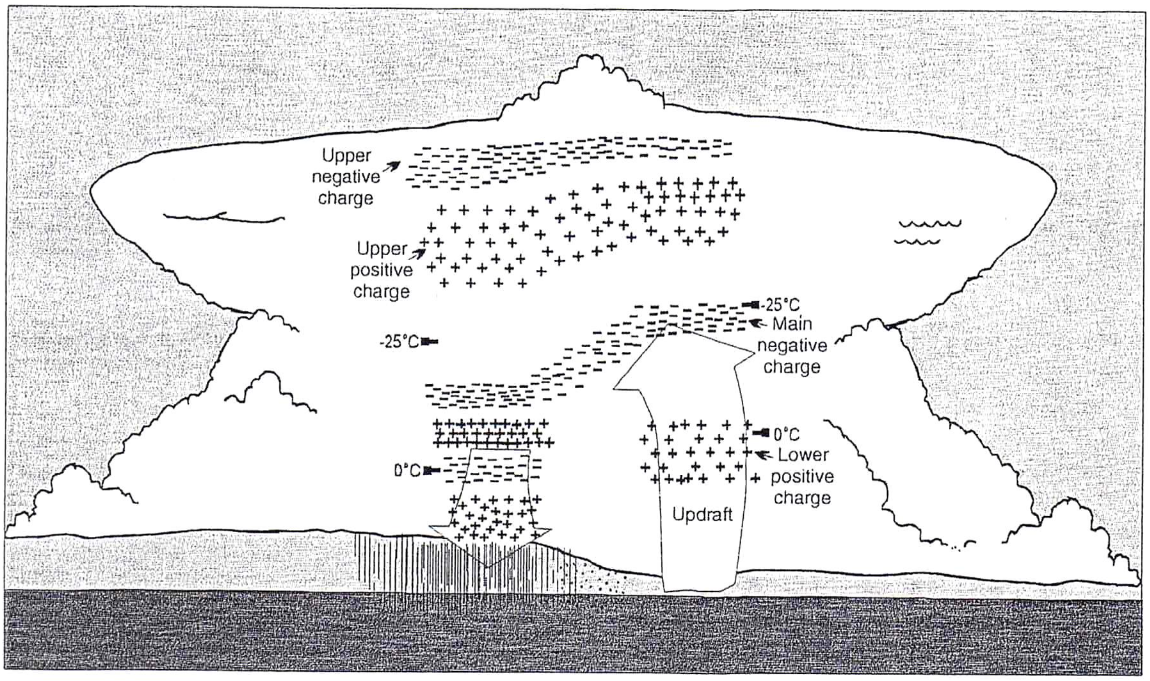

Fig. 3.11. Schematic of the basic charge structure in the convective region of a thunderstorm. Four charge layers are seen in the updraft region, and six charge layers are seen outside the updraft region (to the left of the updraft in the diagram). The charge structure shown applies to the convective elements of mesoscale convective systems (MCS), isolated supercell storms, and New Mexican air-mass storms. Note that there is a variability in this basic structure, especially outside the updraft. Adapted from Stolzenburg *et al.* (1998b).

Figure 10.

Table 3.2. *Maximum electric field magnitudes measured in thunderclouds*

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Reference	Sounding type	Maximum electric field, V m^{-1}
Gunn (1948)	Aircraft	3.4×10^5
Imyanitov *et al.* (1971)	Aircraft	2.8×10^5
Winn *et al.* (1974)	Rockets	4×10^5
Winn *et al.* (1981)	Balloons	1.4×10^5
Weber *et al.* (1982)	Balloons	1.1×10^5
Byrne *et al.* (1983)	Balloons	1.3×10^5
Fitzgerald (1984)	Aircraft	1.2×10^5
Marshall and Rust (1991)	Balloons	1.5×10^5
Kasemir (as reported by MacGorman and Rust 1998)	Aircraft	3×10^5

1-2 kV/cm

Note: The value of 1.2×10^6 V m^{-1} cited by Uman (1987, 2001) as measured by Fitzgerald (1976) is a misprint.

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Figure 11.

Fig. 15.1. Ball lightning in a 19th century woodcut. The original title, translated from French, reads "Ball lightning crossing a kitchen and a barn." Perhaps the ball lightning came down the chimney used to exhaust the cooking fires. How the young lady's blouse came to be in such a state of disarray is not known. (Courtesy, Burndy Library)

Figure 12.

5.3. Characterization of positive lightning

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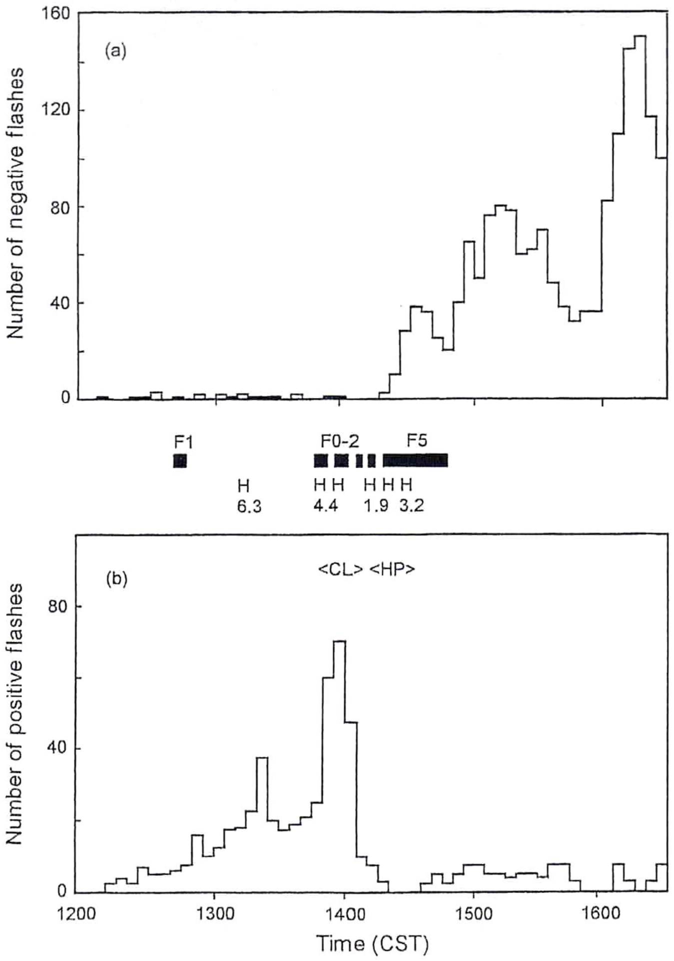
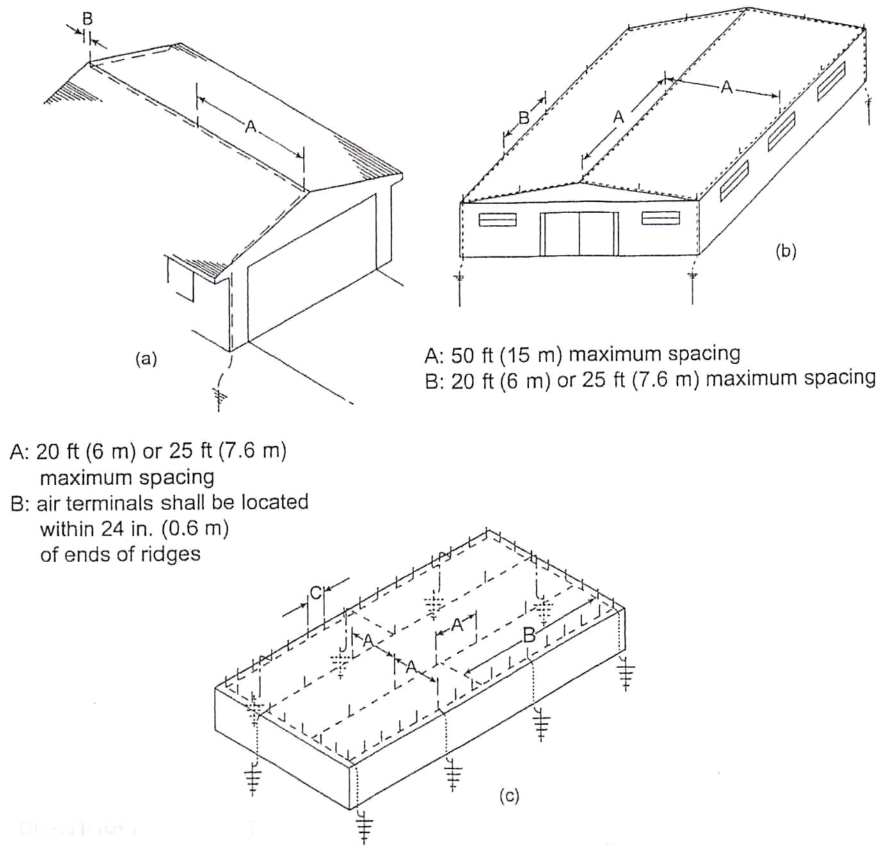


Fig. 5.3. Five-minute counts of (a) negative and (b) positive cloud-to-ground lightning flashes over a 4.5-hour period of the storm that produced the Plainfield, Illinois, F5 tornado on 28 August 1990. The bars between the two plots indicate the approximate time of the tornadoes, labeled with the F-scale rating of damage given by Storm Data. The F5 tornado began between 1415 and 1420 CST and traveled approximately 26 km over a period of 25–30 minutes. The left-hand edges of the H's mark the time of large hail reports; an H that overlaps a symbol indicating an earlier report is omitted. The hail reports are labeled with the hail diameter in centimeters. When the diameters of two or more reports overlap, the diameter of only the larger or largest report is given. The bracketed periods labeled CL and HP in (b) indicate the times at which the storm was classified as a classic supercell or a heavy-precipitation supercell, respectively. Note that positive discharges are clearly dominant at the beginning of the storm. Adapted from MacGorman and Burgess (1994)

Figure 13.



A: 50 ft (15 m) maximum spacing between air terminals
B: 150 ft (45 m) maximum length of cross run conductor permitted without a connection from the cross run conductor to the main perimeter or down conductor
C: 20 ft (6 m) maximum spacings between air terminals along edge

Fig. 18.1. Lightning protection of ordinary structures via diversion as recommended by NFPA-780.

Figure 14.

Schwaiger (1938) found from a literature survey that the proposed protective ratios from the time of Franklin to the date of his study varied between 0.125 and 9.0. Some of these proposed ratios and associated zones of protection are depicted in Fig. 18.3, as originally published

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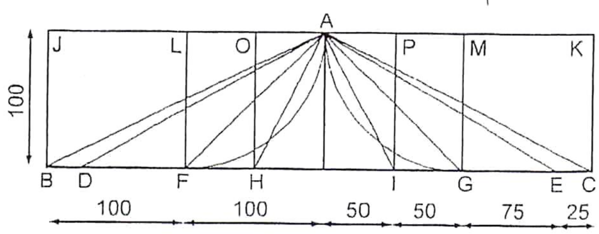

Fig. 18.3. Zones of protection of a vertical lightning rod. JBCK, cylinder, Gay Lussac (1823); BAC, cone, DeFonville (1874); DAE, cone, Paris Commission (1875); LFGM, cylinder, Chapman (1875); FAG, cone, Adams (1881); OHIP, cylinder, hypothesis, and FAG, special cone, Preece (1880); HAI, cone, Melsens. Adapted from Lodge (1892) and Golde (1977b).

Figure 15.

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Holle *et al.* (1996) extrapolated insurance claims for lightning losses in Colorado, Utah, and Wyoming from 1987 to 1993 to the whole United States and found that there was about \$330 million in annual insured losses due to lightning in the United States. Since 20 to 30 million cloud-to-ground flashes occur annually (subsection 2.5.2), the financial cost per ground flash is \$10 to \$15. In fact, according to Holle *et al.* (1996) there is one claim for every 57 ground flashes. The average claim is about \$1000 with significant damage to structures resulting in claims up to the \$100 000 range. Additional information on lightning damage in the US is found in Curran *et al.* (2000).

Figure 16.

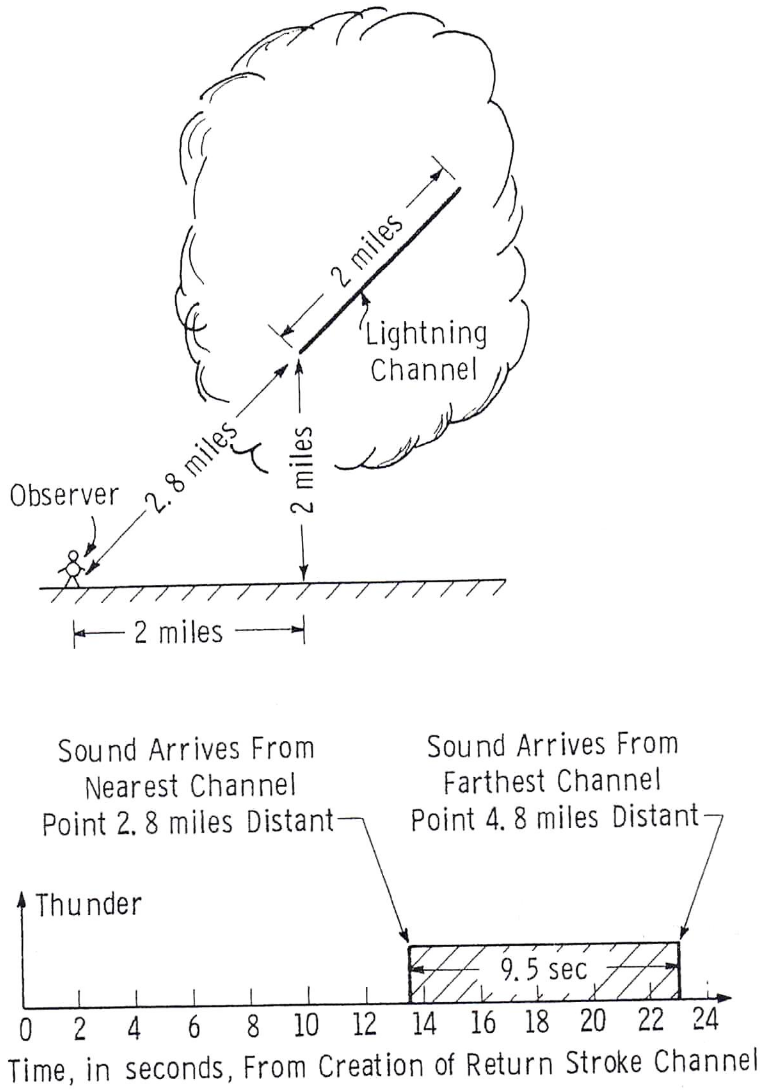

Fig. 12.1. Intracloud lightning flash and its thunder.

Figure 17.

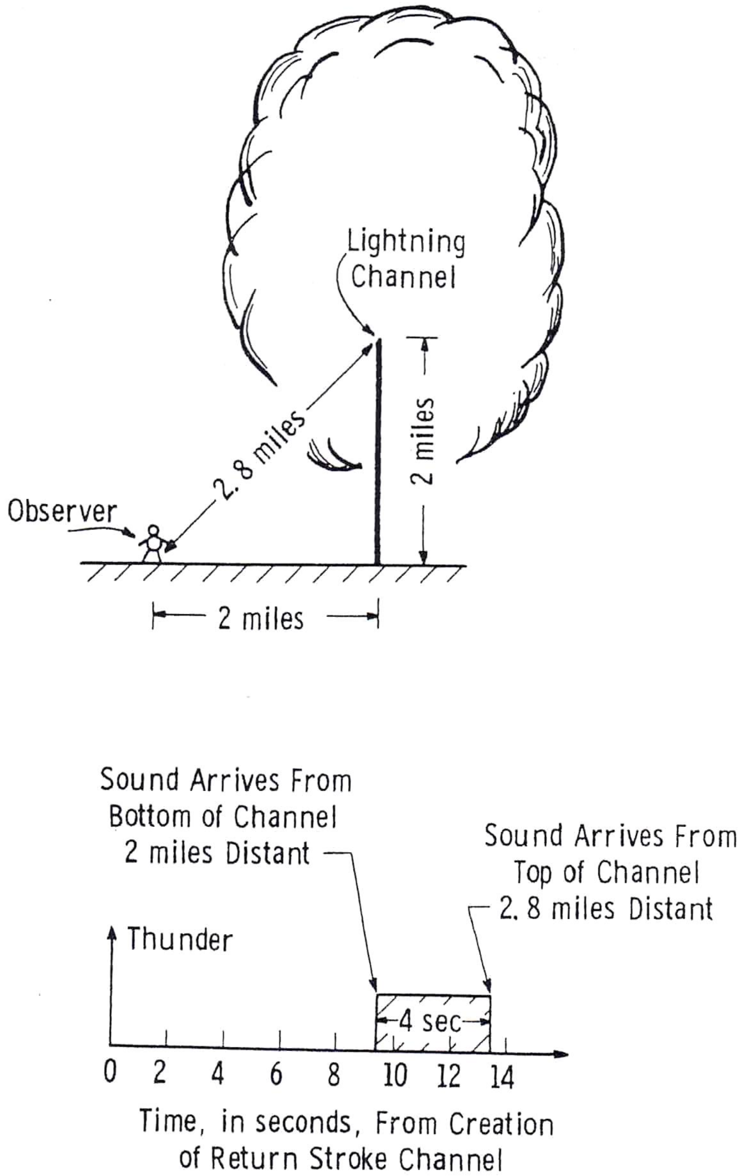

Fig. 12.2. Cloud-to-ground lightning flash and its thunder.