Positive and Negative Cloud-to Ground Lightning*

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Positive cloud-to ground lightning (+ CGL) occurs in a minor fraction of all thunderstorms [1]. We propose that the microscopic mechanism is the same as in the more common negative CGL, whereas the different polarity is due to the macroscopic cloud dynamics [2]. The origin of collisional charging involves three stages in the basic process [3]. In the first stage kinetic roughening of the surface is induced by rapid growth from the vapor, causing an increased density of grain boundaries, steps and dislocations. Ionization of water molecules is enhanced on the thus roughened surfaces. Because the OH- ions remain bound to the surface while positive ions migrate into the ice crystal, a charged double layer is formed. The grain boundary area is proportional to the deposition rate of new molecules, and because the OH- ions are localized at the grain boundaries, the surface charge density, and hence contact potential, is proportional to the growth rate. The second stage is an ice-ice collision, where a temporary liquefaction is caused by the inelastic energy loss. Melting liberates the negative surface ions into the melt liquid, but the major fraction of the positive ions remain in the crystal. The third stage is separation, when the two particles take roughly equal shares of the melt liquid. Thus, the particle that had the greater roughening, and hence growth rate, loses net negative charge. We have tested the theory on a detailed experiment [4], and obtain quantitative agreement using only one adjustable constant. A recent study [5] adopts the general outlines of our theory [3], but modifies it in certain details, and offers it as a new model. These modifications are detailed in a comment and criticism [6].

Ice growth in clouds can occur via two direct mechanisms: (a) deposition from vapor on ice particles, and (b) riming of graupel, as supercooled droplets impacting the graupel freeze and their vapor condenses on the surrounding areas of the same particle or other particles [7]. In storms typical of the – CGL, process (a) is dominant, in which small particles are growing while rising in updrafts, so that the positively charged small particles are carried to upper regions of the cloud, and the negatively charged graupel is the dominant charge carrier in the lower regions. However, as the growth rate of rising particles increases, the charge transfer saturates, and reverses [3,4]. Hence, we speculate that in storms producing + CGL, either (i) the process outlined above is weaker, so that the graupel becomes positively charged, or (ii) the saturation effect is dominant. The reversal of the polarity in case (i) is consistent with some observations that + CGL is more common in the late stages of violent storms, where updrafts are weaker [1].

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References

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