ON THE ROLE OF CORONA DISCHARGE IN THE DEVELOPMENT OF THUNDERSTORMS

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Abstract

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GEOPHYSICS

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ON THE ROLE OF CORONA DISCHARGE IN THE DEVELOPMENT OF THUNDERSTORMS

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There are several hypotheses concerning the mechanism of the processes leading to the formation in clouds of a strong electric field that determines the development of thunderstorm phenomena. One of them relates the charging of small cloud droplets (and crystals) to their adsorption of atmospheric ions, and the formation of thunderstorm phenomena to the accumulation of charges on precipitation particles (rain, graupel, hail) falling through the cloud as a result of the coagulation of these particles with charged cloud droplets.

Ya. I. Frenkel' (4) showed that, when the influence of the double electric layer is taken into account, the charge of small droplets should be proportional to the radius $q = \varphi r$, where φ is the potential of the droplet and r is its radius. Experiments (3) confirmed the linear relation between the charge and radius of small droplets, but the magnitude of the measured charges proved to be an order of magnitude smaller than the values predicted by Ya. I. Frenkel' .

The author of the present article (5) attempted to estimate the possible growth of the charge of precipitation particles by coagulation with cloud droplets, under the assumption that all small droplets carry the charge measured in the experiments. It turned out that the charges calculated in this way are quite sufficient to explain the formation in clouds of large electric-field intensities. But when the system of equations for the change in the concentration of atmospheric ions in a cloud was solved (1), taking into account the processes of natural ion formation, ion recombination, and adsorption of ions by cloud droplets, it turned out that the computed specific charge of cloud droplets fully provides for the coagulation charging of precipitation particles in heavy showers (7), in agreement with measurements, but that the occurrence of thunderstorm phenomena cannot be explained in this way. Evidently, the charges of individual cloud droplets obtained in experiments do not correspond to the mean charge values.

Calculations showed that, for the values of the quantities entering the system of equations—the velocity of the ascending flow $u = 1 \div 10$ m/sec, the concentration

Fig. 1. Growth with time of the charge concentrated on cloud droplets at different ionization rates ν (ion pairs/cm^3 • sec)

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of cloud droplets in the lower part of the cloud $n = 100$ cm^{-3}, the initial conductivity at the level of the lower boundary of the cloud $\lambda_0 = 6 \cdot 10^{-4}$ sec^{-1}, and the ratio of polar conductivities $(\lambda_+/\lambda_-)_0 = 1.1$ (the ionization intensity was taken to be $v = 10$ ion pairs/cm^3 $\cdot$ sec)—the lower part of the cloud is charged negatively up to a height of 1.0-1.5 km, and its upper part positively. The charge concentrated on the droplets changes strongly in the lower layer 2-2.5 km thick, while higher up it remains almost unchanged, amounting to +(100—200) e/cm^3 (e is the absolute value of the elementary charge).

This causes an almost linear coagulation change with height in the charge of precipitation particles as they fall from the level of the upper boundary of their trajectories to a height of 1.5-2.0 km above the lower boundary (^{7}). The maximum charge of precipitation particles in this layer does not exceed 0.1 esu. In the lower part of the cloud, recharging of precipitation particles takes place. Under the indicated conditions, the electric-field intensity does not exceed 50 V/cm. In the region of linear change in the charge of precipitation particles it is easily calculated from the formula

$$E = 2\pi NQZ, \tag{1}$$

which is obtained by integrating equation (5)

$$dE/dZ = 4\pi NQ \tag{2}$$

for an unchanged concentration N of precipitation particles and under the assumption that the influence of the charge of cloud droplets and of the air may be neglected for the zone where strongly charged precipitation particles are present. In equations (1) and (2), $Q \sim kZ$ is the charge of precipitation particles, and k is the proportionality coefficient.

Subsequent calculations, with variation of the parameters u, n, λ_0, $(\lambda_+/\lambda_-)_0$ within reasonable limits, showed that this does not make it possible to explain the occurrence of fields exceeding 100 V/cm. The only quantity not varied in these calculations was the ion-formation rate. The value indicated above is due to the action of natural radioactivity, cosmic rays, and ultraviolet radiation.

Fig. 1. Growth with time of the charge concentrated on cloud droplets at different ionization rates ν (ion pairs/cm^3 • sec)

However, in the presence of strongly charged precipitation particles in a cloud, a new ion-formation mechanism arises, associated with the phenomenon of corona.

As J. Sartor (^{10}) points out, when charged spheres of equal size approach to within 0.1 radius, the field strength at their surface increases by a factor of 14; at a distance of 0.01 radius, by a factor of 92; at 0.001 radius, by a factor of 690; and at 0.0001 radius, by a factor of 5600.

A. Müller (^{8}), J. Sartor, and V. Atkinson (^{9}) experimentally discovered luminescence in the region of the corona discharge between approaching droplets having charges of opposite sign. In the experiments of the latter authors the droplets had a radius of 0.08 μ and charges of ± 0.021 esu. When many pairs of droplets fell one after another along converging trajectories, the corona discharge was observed not only at the immediately approaching droplets, but also at an adjacent pair of droplets separated from one another and from the preceding pair by distances of several diameters. The authors suggest that the corona discharge for the second pair of falling droplets is caused by the ultraviolet radiation of the discharge of the first pair or by the action of the electric field of this discharge.

Under these conditions, an increase by many times in the ionization rate of the air in the vicinity of large charged particles approaching one another during their fall is entirely possible.

We carried out calculations of the charging of small cloud droplets at increased ionization rates $\nu = 10^3, 10^4, 10^5$ ion pairs/cm^3 • sec. It turned out that a sudden increase in the ionization rate, compared with the usual one, leads to a rapid change in the charge concentrated on droplets in the upper part of the cloud, from +(100-200) e/cm^3 to −(10 000-20 000) e/cm^3 within several tens of seconds (see Fig. 1). The specific charge of cloud droplets, i.e., the charge per unit mass of cloud water, then reaches values of 2-4 esu/g.

Subsequently, if the ion-formation rate is maintained, the charge of the small droplets practically does not change.

If a column of cloud several kilometers thick is encompassed by corona discharges, then the charge of precipitation particles coagulating with strongly charged cloud droplets grows rapidly as they fall and reaches such large values that the strength of the resulting field may become of the order of $3\text{-}5 \cdot 10^3$ V/cm and higher. In such a field, the onset of streamer development inside the cloud is already possible. According to N. I. Kaptsov (^{2}), the minimum field strength for the propagation of streamers from a charged body

for small sizes is (at $P = 760$ mm Hg) 4400 V/cm. At reduced pressure in the central or upper part of the cloud, the critical value of the field strength naturally decreases.

Let us note that, after corona discharge begins in this zone of the cloud, negative charging of cloud droplets occurs, and consequently also of precipitation particles. Their convergence during falling with particles that have still retained a positive charge increases the probability of corona discharge.

Further, along with providing accelerated charging of cloud particles and precipitation particles, corona discharges create a carrier of the thunderstorm discharge

—a strongly ionized medium containing a large number of free electrons.

Thus, it may be concluded that the condition for a cloud to pass into a thunderstorm state is the formation within it of sufficiently large and strongly charged precipitation particles; when these approach one another in the course of falling, the phenomenon of intense corona discharge arises, initiating a distinctive process of electrical self-excitation of the cloud.

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