NOTES

Electrical Atomization of Water Dripping from Melting Ice Pieces and its Possible Role in Thunderstorms

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ABSTRACT

When a small isolated ice piece of conical shape is suspended with its apex facing down between two horizontal parallel electrodes and an electric field of 1 to 1.6 kV cm^{-1} is applied between them with the lower electrode at negative potential, a mist of fine monodisperse particles is observed for a fraction of a second from the apex of the ice piece. Charges on different ice pieces have been measured to be in the range of 10^{-9}–10^{-8} C after the occurrence of smoke. The phenomenon has been simulated for some conditions that exist in melting layers of thunderstorms and it is proposed that ice graupel or hailstones falling in melting layers of electrified thunderstorms may produce the type of mist observed in our experiments. It is further suggested that the positively charged mist particles generated in this phenomenon may influence the cloud microphysics and might be responsible for the lower positive charge pockets sometimes reported in the bases of well-developed thunderstorms.

1. Introduction

Recently, Kamra and Ahire (1984) reported some laboratory experiments in which a living plant was insulated from the ground and raised to high positive dc voltages of 8–10 kV. At such potentials, if water is dropped on a plant's leaf, then the water, instead of dripping from the leaf-tip as drops, comes off the tip as a mist of very fine monodisperse particles. Such a mist of monodisperse particles resulting from the electrical atomization of water, has been observed by Vonnegut and Neubauer (1952), Drozin (1955) and Ahire and Kamra (1983) coming out of a capillary-tip when a high positive dc voltage is applied to low-conductivity liquids placed in the capillary.

While making these observations in our experiments, we noticed that if low-conductivity water is flowing at slow rates at the pointed edge of a body and the body is raised to high positive potential or placed in a strong electric field then these are essential and perhaps sufficient conditions for the generation of smoke particles by electrical atomization of water. We envisage that such conditions exist at the surfaces of melting ice particles falling in the melting layer below the freezing level in an electrified thunderstorm. We have simulated some of these conditions in our laboratory experiments and the results are reported here.

2. Experimental arrangement

Small pieces of ice frozen from distilled water are shaped roughly in a conical form with base diameters ranging from 0.2 to 0.8 cm and heights from 0.8 to 2.2 cm; radii of curvature of the tips of the ice cones were generally of the order of 0.1 ± .05 mm. One ice piece with its apex facing down was suspended from a teflon ring between two horizontal electrodes 20 × 20 cm in size and kept 8.5 cm apart as shown in Fig. 1. The lower electrode was connected to the negative terminal of a high voltage dc power supply and the upper electrode grounded. It had a 2 cm diameter hole at its center for inserting the insulated ice piece into the electric field.

3. Observations and results

An insulated ice piece was suspended between two electrodes and discharged by momentarily grounding it. Water melting from the ice cone dripped down from its apex as drops with diameters of a few millimeters. However, when a high negative voltage of 9–14 kV (corresponding to an electric field of ~1–1.6 kV cm^{-1} between the electrodes) was applied to the lower electrode, a mist of very fine water droplets in the form of a cone diverging from the apex of the ice cone was observed for a fraction of a second. Smoke was not observed if the negative voltage was <9 kV or >14 kV. At voltages < 9 kV, water melting from the ice piece dripped down from its tip as positively charged drops of a few millimeters diameter. At voltages > 14 kV the smoke disappeared and fast waterjets were observed from the ice tips.

When the smoke was illuminated with a beam of parallel light then it sometimes was colored red, green and orange depending on the angle of observation, indicating that the particles were uniform and of the diameter ~ 1 μm.

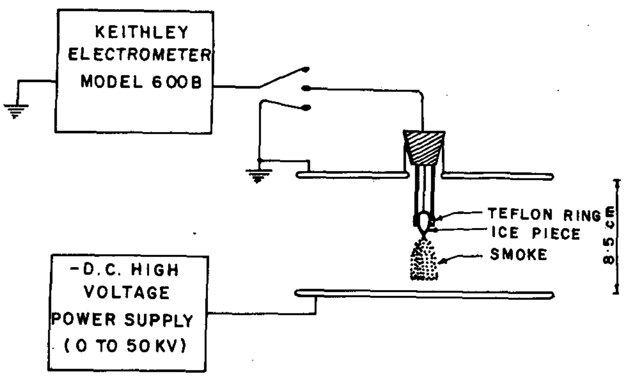

FIG. 1. Schematic diagram of the apparatus.

In an effort to simulate the temperatures existing in melting layers in clouds, we suspended an insulated ice piece in a cold box where ambient temperatures were a few degrees higher than 0°C. Melting rates of ice are, obviously much lower here. Arrangement of electrodes and their polarities are similar to Fig. 1. Smoke from ice tips was observed at almost the same values of negative voltage applied to the lower electrode as those in experiments carried out in open atmosphere.

In yet another effort to simulate falling ice particles, we suspended an insulated ice piece just above the test section of a vertical wind tunnel, and created updraught speeds in the range of 10 m s^{-1}. Melting water, in this case, separates from the upper rim of the ice. Therefore the ice cone is placed a little inclined with respect to the vertical so that the melting water should separate from its apex. The mist observed in this case was similar to that in earlier cases, except that the values of negative voltage applied to the lower electrode required to produce mist were 1–2 kV higher.

In our experimental arrangement, when an ice piece, soon after the occurrence of mist, was connected to a Keithley electrometer for the charge measurement, it was connected to the ground through an electrometer and fast waterjets appeared from ice tips. Therefore, to measure the charge on ice pieces after the occurrence of mist, the following procedure was adopted: The high voltage lower electrode was raised to about −10 kV. The uncharged and insulated ice piece along with the upper grounded electrode was quickly brought over to the negative high voltage electrode and placed 8.5 cm above it. Negative voltage on the lower electrode was finely adjusted to produce mist. Soon after the occurrence of mist, the upper grounded electrode along with the isolated ice piece was moved away from the high voltage lower electrode. The ice piece was connected to a Keithley electrometer and the charge on it measured. All these steps were carried out quickly so that no water other than the mist was separated from the ice piece during the observational period. The experiment was repeated several times for ice pieces of different sizes. Within the range of particle sizes mentioned herein, the charge on ice particles ranged from 10^{-9}–10^{-8} C.

4. Possible role of the phenomenon in thunderstorms

The phenomenon reported here may significantly influence the electrical and microphysical properties of thunderclouds. Hail and graupel particles falling in melting layers will have a layer of liquid water at their surfaces and will also be under a large electrical stress due to the cloud's negative charge directly overhead. It is likely therefore, that these ice particles, at some stage of their fall in the melting layers of thunderstorms, may produce the kind of mist observed in our experiments. As a result of this, small positively charged particles will be released into the atmosphere, leaving the corresponding negative charge on ice particles.

Our observations indicate that the occurrence of mist can provide 10^{-9}–10^{-8} C of negative charge to a particle of graupel or hailstone. In thunderstorms, graupel and hailstones have a large range of sizes and although the sizes of ice pieces in our laboratory experiments may be somewhat different, on the average the same order of magnitude of electric charge can be assumed to be imparted to the graupel or hailstones. However, even a much lower charge will not invalidate the hypothesis to be presented here. If a concentration density of 1 graupel/m^3 is assumed in the melting layer of thunderclouds, the mist phenomenon may provide negative charge of 10^{-9}–10^{-8} C m^{-3} on graupel or hailstones. Thus a negative charge of 1 to 10 C may be present on graupel or hailstones in a 1 km^3 volume in the base of the cloud. It is proposed that as the hail falls from the cloud base, the positive charge released in this region in the form of small mist particles will create a positive space charge and might be a source of the lower positive charge pockets observed in the bases of matured stages of some thunderstorms (e.g., see Simpson and Scrase, 1937; Simpson and Robinson, 1941; Kuettner, 1950). The fact that these positive charge pockets are generally observed below or around freezing level and that they exist in well-developed and already electrically active thunderstorms supports our view. Another observation supporting our hypothesis is that of MacCready and Proudfit (1965a) who observed from their aircraft measurements in cumulonimbus clouds that the polarity of charge on all graupel was positive unless the particles were melting. From their data, MacCready and Proudfit reported that "at the melting level positive hydrometeors switched abruptly to negative," and thus concluded that "a strong hydrometeor charging mechanism is associated with the melting of ice hydrometeors." On melting graupel, MacCready and Proudfit observed negative charges of up to about 10^{-9} C which agrees with our hypothesis. Results of these field experiments do not agree with the results of laboratory experiments conducted by MacCready and Proudfit (1965b) and others in which the melting of ice is duplicated. Again, Kuettner (1956) discussing his own measurements at Zugspitze states, "in nature a new charging effect takes over in the melting zone, adding negative charge to the precipitation particles at a faster rate than the pure ionic discharge currents would do."

Recently, Jacobson and Krider (1976), Holden *et al.* (1980) and Marshall and Winn (1982) have reported the presence of lower positive charge pockets from their observations in thunderclouds. Later, two of these reports attributed the formation of the lower positive charge pockets to lightning. Further experimental observations, however, are required either to confirm or discard the contributions of any of these or other mechanisms.

Another implication of the observed phenomenon is the possible increase in electrical conductivity of the region (Kamra, 1979) by the positively charged mist particles. It is interesting to compare the mist-producing characteristics of ice particles with their corona producing characteristics. There are some essential differences. Firstly, the mist is produced at much lower values of the electric field as compared to those required to produce a corona. Secondly, while corona occurs at both polarized ends of the ice particles and introduces both polarities of small ions into the surrounding atmosphere, the mist is observed to occur only at one end of the ice particle facing the negative charge of the cloud and introduces only positively charged droplets into the atmosphere. Thirdly, while the corona continues to occur as long as the electric field is strong enough to sustain it, mist will occur only over a small range of voltage and for a very short time. Since corona from hydrometeors and especially from ice particles is sometimes considered (Griffiths and Latham, 1974) to initiate the lightning discharge, it is quite probable that the increase in conductivity of the region because of mist particles may as well influence the initiation and propagation of lightning discharge in thunderclouds. In this reference it is interesting to note the observation of Kuettner (1950) that the lower positive charge pocket and the negative charge appear to be connected to the same vertical air column which has heavy precipitation, strong downdraughts, and initiation of lightning.

Another important aspect worth investigating is the effect of positively charged mist particles on the cloud microphysics of the region. In our experiments with plants (Kamra and Ahire, 1983) we estimated a production rate of about 10^9 particles per second for the mist. Even if the number of particles generated by graupel or hail is smaller by a few orders of magnitude, it is apparent that a large number of small particles of micrometer size may be introduced in this region by this process. Therefore, the size distribution of particles in the region may be significantly modified not only by the introduction of these particles but also by their collision and coalescence with other particles.

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