Reply

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I am glad that Drs. Vonnegut, Illingworth and Krehbiel are interested in warm rain electrification mechanisms and have read our paper in depth. This gave us a chance to explain our laboratory work further (Takahashi and Endoh, 1983).

Observations of warm clouds showed that the negative charge accumulates during the cloud's development (Fitzgerald and Byers, 1958; Takahashi, 1982). When the cloud is shallow, cloud drops and drizzle are mostly electrified negatively (Sergieva, 1959; Krasnogorskaya, 1969; Takahashi, 1972b, Takahashi and Craig, 1973). When the cloud is taller than about 3 km, positive raindrops predominate at the ground (Takahashi, 1982) and they originate near the cloud top (Takahashi, 1975). Near the cloud top, both cloud drops and precipitation particles are electrified positively while small particles are electrified negatively: this may negate the explanation of collision-breakup charging. Negative small particles accumulate their space charge in the cloud while precipitation particles discharge their electricity to the ground (Takahashi, 1975).

Takahashi (1972a) noted a predominantly positive small particle charge in dry environments while predominantly negative small particles were observed in moist environments. He assumed the existence of a charging process between small ions and drops during drop condensation and evaporation and performed a laboratory experiment on this subject (Takahashi, 1973). The cloud model seemed to simulate many cloud observations by condensation and evaporation charging processes (Takahashi, 1974 and 1979).

Griffiths and Vonnegut (1975), however, raised the question of a possible influence of contact potential during electrification in my experiment. With Dr. T. Endoh, we reexamined the previous experiment by floating drops in a vertical wind tunnel so that contact potential problems could be avoided. This was a very difficult experiment and the results are still qualitative. In order to encourage further experiments, I will try to explain our past experiment in more detail along with replies to Drs. Vonnegut, Illingworth and Krehbiel's questions.

1) Probably due to the difference in mobility with the sign of small ions, or because of the preferential attachment of ions to the wall and metal mesh, a certain small voltage was needed to create some unbalanced ion concentrations with sign. There was no electrification while drops were floating without changing size. No spurious charge signal was recorded while the blower was running without the presence of floating drops.

2) Lucite pieces were used as insulators to hold the Faraday cage. The surfaces of the lucite pieces were coated with clean paraffin to hold good insulation even in a humid environment. Good insulation was verified by the observation of an initial electric charge on drops during the experiment in humid air without a supply of ions.

3) Process A was designed to make sure that the drop is not electrified in the ion-rich air when the drop is not evaporating. The ion concentrations are the same in both process A and process C. The only difference is that the drop is evaporating in (C) and not in (A).

4) Due to the extremely low concentration of ions in the natural air in Hawaii, the drop charge was maintained without modification even during drop evaporation. Process B was designed to assure that there were no spurious charges in the natural air.

5) A very strong drop charge permits us to disregard the effect of the sign of other small ions in the calculation of the charge neutralized (Whipple and Chalmers, 1944). There is no electric field in the chamber.

6) We observed signals of small amplitude only when the drop entered and left the Faraday cage and these phenomena were verified visually. However, further experiments need a simultaneous record of both charge signal and drop location in the wind tunnel as Drs. Vonnegut, Illingworth and Krehbiel have pointed out. The occurrence of spurious charges was rare except in times of rain shower and heavy traffic. This was checked in the experimental process B and the experiments were disconnected in those periods. When drops became small and were electrified

positively, the Coulomb force caused by the net positive charge of the drops seems to reject a positive ion flow to the drops. Therefore the data on electrification in the last stages just before the drops moved out of the wind tunnel were not considered.

7) As stated in the paper, aerosols seem to be involved in this drop evaporation charging process. Positive electrification was always observed during drop evaporation but the rate of electrification changed each day. The aerosol may play a role in modification of the change instead of being involved in the fundamental positive charging process during drop evaporation.

In conclusion, I believe that these laboratory experiments are sound. However, further experiments would be needed to confirm the conclusion. This application of the warm-rain electrification process will then be assured.

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