SHORTER CONTRIBUTION

WATER-VAPOR CONDENSATION AS A CLOUD-DROPLET CHARGING MECHANISM

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Introduction.—Since the early work of Gerdien (1905), several theories have been proposed to explain the mechanism of the charging of cloud droplets leading to thunderstorm electricity. Most of the later works were based on the classic theories of Simpson (1909) and of Wilson (1929), and involve the breakup or the coalescence of cloud droplets in ascending air currents. Reports are found in the literature showing that the condensation of water vapor produces negative charges and evaporation positive charges (Volta, 1820; Gunn, 1935; Gish, 1951; Findeisen, 1940; Frenkel, 1944). An experimental investigation of this phenomenon and of its applicability to the problems of atmospheric electricity was rendered possible by the development in the Cloud Physics Project laboratory of generators of suitable clouds of aqueous droplets.

Experimental.—The experimental study of this phenomenon was made on salt-solution droplets grown under controlled conditions by the condensation of water vapor on salt nuclei. Electrostatic precipitation and light scattering served as a means of measuring the electric charge on the cloud of droplets.

The first attempts involved the use of the LaMer-Sinclair generator (LaMer and Gendron, 1952) as modified in our laboratory for use with water as a source of droplets. However, subsequent investigations revealed that the sodium-chloride nuclei produced in this generator are themselves charged. The charge spectrum of the salt nuclei, as would be expected if caused by thermal emission, is temperature dependent, at high enough temperatures. Clearly some other source of uncharged nuclei was necessary.

A water-droplet generator, developed in our laboratory, made use of NH_4Cl smoke particles as nuclei and was found very satisfactory. It consisted merely of a glass column, 2-cm diameter and 100-cm length, in which droplets were allowed to grow from a carefully controlled mixture of water vapor, ammonia and hydrochloric-acid gases. The base of the column was fitted with a coarse fritted glass inlet for moist air. The inlets for the NH_3 and HCl gases were situated 3 in from the base of the column and diametrically opposed to each other. The moist air was laboratory air that had been dried, cleansed of dust with a millipore filter, and moistened by being passed over water. Ions were removed from the wet air with an ion trap under a field of 6000 volts/cm. The gases were introduced into the condensation region by passing tank nitrogen over concentrated HCl and concentrated NH_4OH solutions. In another version, nitrogen was slowly bubbled through the solutions, at the rate of one bubble per second (4 cc/min).

This generator produced NH_4Cl solution droplets of sufficiently uniform sizes to permit the accurate measurement of their sizes by standard light-scattering techniques (Sinclair, 1950). The spread of particle sizes was known to be less than ± 10 per cent from the average size. The average droplet size of the cloud could be varied between 0.3-μ and 0.8-μ radius, depending on the flow rate conditions.

The droplets were fed into an electrostatic precipitator, similar to that described by Gillespie and Langstroth (1952), which consisted of two silver-plated copper plates 1.2-cm apart and 30-cm long, mounted in lucite (fig. 1). The input arrangement was such that a ribbon of cloud could be formed and maintained throughout the entire length of the precipitator. The ribbon was fed in a plane halfway between the two plates and was clearly visible in a strong beam of light.

It was calculated, from the dimensions of the precipitator and the observed flow rate, that a field of 7 kv/cm would be adequate to remove droplets carrying unit electrical charge.

The output of the precipitator was fed into a forward-angle light-scattering cell where the intensity of the scattered light was measured with a Photovolt

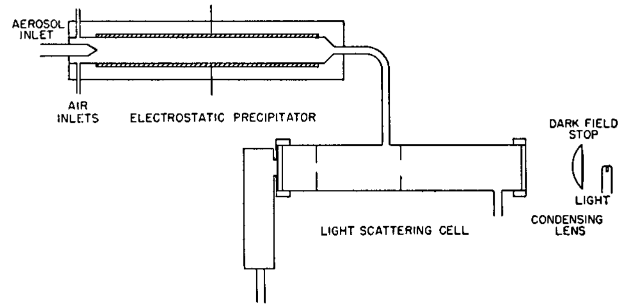

FIG. 1. Apparatus for measuring charge on aerosols.

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microphotometer, as a function of the electric field applied to the electrostatic precipitator. The intensity of the light scattered by the cloud of uniform droplets is a function of the droplet concentration, and consequently an inverse function of the number of charged droplets precipitated in the electric field. The measure of the droplet penetration through the precipitator as a function of the applied field is a measure of the charge distribution of the cloud droplets. Charged droplets could also be detected visually by observing the spreading of the thin ribbon of droplets in the precipitator under low electric field and its almost complete disappearance under high fields.

Results.—Early results showed that almost all droplets grown by condensation carried one or two unit charges. Further investigation revealed, however, that a bubbler, used for saturating the air to the generator, acted as an ion source which supplied a large quantity of ions captured by the growing droplets. Removal of the bubbler, and filtration of all ions from the air fed to the generator, provided an ion-free atmosphere for growth of the droplets. Under such conditions, no charged droplet could be detected in the samples studied. The intensity of the light scattered, in arbitrary units as a function of the field applied to the electrostatic precipitator, was 42.4 ± 0.1 at 0 kv, 42.5 ± 0.2 at 8 kv, and 42.2 ± 0.1 at 10 kv. Each of these intensities is an average of ten readings taken at 5-sec intervals. The average deviation from the mean is also given.

Complete penetration was observed under all fields, indicating the complete absence of charges on droplets grown by water-vapor condensation in an ion-free atmosphere. Readings were also taken with droplets grown in a simulated "fair weather" field. Strips of copper, 1-in wide, were placed on either side of the generator tube and a potential of 45 volts was applied. Similar results were obtained.

Conclusion.—There is no observable charging of ammonium-chloride solution droplets grown by condensation onto NH_4Cl particles from ion-free air containing water, ammonia and hydrochloric acid. The charge observed on droplets growing in an atmosphere of normal ion concentrations can be attributed to ion capture due to diffusion, electrostatic attraction or collisions, rather than to water-vapor condensation (Gott, 1933; Gunn, 1954).

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