

ELECTRIFICATION OF AEROSOLS

by

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The main object of this research was the design and construction of a device which would produce an aerosol with particles of uniform size, bearing electric charges of the same magnitude and of the same sign. A secondary objective was the derivation of theoretical equations that would explain the phenomena occurring in the charging device and permit intelligent design of such equipment. Finally, it was desired to devise a method of measuring the charges on the aerosol particles and of detecting any non-uniformity in size or charge.

A representative aerosol produced as a result of this work is shown in Figure 1 in terms of frequency distributions of charge and diameter, the measurements being made with a Millikan cell. The average diameter of the particles in this case was 1.43 microns with a geometric standard deviation in diameter of 1.28. The average electrical charge on the particles was 230 electron units, with a geometric standard deviation in charge of 1.25.

It can be seen that several problems are encountered in producing a uniform aerosol for test purposes. Firstly, one must produce a monodisperse or homogeneous aerosol. Secondly, one must place an electrical charge on the aerosol in as uniform a manner as possible, yet without causing excessive electrostatic precipitation of the particles. Thirdly, a satisfactory method of measuring the properties of the test aerosol must be available.

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Production of a Homogeneous Aerosol

Reasonably uniform aerosols of glycerol were produced in a generator similar to the one described by LaMer and Hochberg (4). The glycerol was heated by an air temperature bath to about 120°C. Air was bubbled through the liquid and superheated in a second chamber. Salt nuclei were generated in the air stream by vaporization of sodium chloride in contact with a red hot wire. The vapor-laden air was then conducted through an insulated chimney wherein condensation of the glycerol into small droplets occurred. The resulting aerosol was then transferred through a glass tube to the corona charging device. Aerosols of about one micron diameter were produced in concentrations of 10^6 to 10^8 particles per cc. Particle sizes were measured from the angle of the scattered light (the "Owl") and by means of a high velocity cascade impactor. The aerosol coming from the generator was essentially uncharged, at least insofar as Millikan cell and "charge-spectrometer" measurements could detect.

Theory of the Electrical Charging of Aerosols

An electrical charge may be placed on aerosol particles by friction, by radioactive radiation, by corona discharge, by thermionic emission, or even by contacting the particles with a highly charged surface. Charged aerosols are also known to be formed in the process of atomization and during certain chemical reactions such as the oxidation of magnesium and the combination of hydrochloric acid and ammonia. The simplest technique of placing a high yet uniform electric charge on the aerosol particles appears to be the exposure of the particles to the ionized field of a corona discharge.

In this work, an unique property of a corona discharge between two concentric cylindrical electrodes was utilized to insure that the charges on all the aerosol particles would be identical. First, it is known that the field intensity between two such electrodes during the discharge is practically constant at all radial positions except very close to the central electrode (1). Secondly, the maximum charge developed on an aerosol particle is proportional to the field intensity, and to the particle diameter squared (6). If the particles are of uniform size, and the field intensity acting on all of the particles is the same, then the maximum charges on all the particles in the aerosol are identical. Naturally if the retention time of the particles in the corona is insufficient for the maximum charge to be attained the particles will not all have identical charges. On the other hand, if the particles are permitted to remain in the corona field for too long a time, they will be precipitated on the walls of the corona device in a manner similar to the Cottrell precipitator.

It can be seen from the above discussion that a device for the electrical charging of aerosol particles with a corona has several diverse requirements. The corona charging device must charge the particles uniformly yet without causing an excessive amount of particle precipitation. In order to design a corona charging device properly, the differential equations of motion of an aerosol particle in the corona device were solved (3). After determining the trajectories of the aerosol particles as they travel axially between the two concentric corona electrodes, it is possible to calculate the average amount of charge on the particles leaving the corona device, the statistical variability or lack of uni-

formity of charges on the effluent particles, and the extent of particle precipitation within the corona charging device. The results of these calculations are shown in Figure 2 as lines of constant charge, constant per cent precipitation and constant geometric standard deviation of the charges on the particles. The isograms are plotted as functions of the two dimensionless parameters N_ϕ and N_β , which describe the operating conditions and size of the corona device.

From the graph it appears that the parameters should have values of about $N_\phi = 300$ and $N_\beta = 20$ for optimum operation.

The Electrical Charging of Aerosols

A corona charging device fulfilling the theoretical requirements is shown in Figure 3. The aerosol flows through a 1/2" diameter copper tube electrode and a coaxial wire electrode (not shown). Machine screws hold the electrodes in place and permit making electrical connection to the electrodes. A potential of 3500 volts is impressed across the electrodes, the central wire being negative. The field intensity in the corona device is calculated (1) (2) from the ion current by $E_r = \sqrt{2i/K}$. The aerosol stream passes through the corona with a velocity of approximately 50 cm./sec. in laminar flow.

As a test of the theory of charging, the glycerol aerosol was charged by the corona charging device, and the electrical charges on the particles were measured both with the Millikan cell and with the "charge-spectrometer" described in the next section. In addition, a theoretical estimate of the charge was made using the equations derived previously.

The theoretical average charge on the effluent aerosol particles is

$$q_p = \left\{ 3\pi\mu KD_p / 4CN\phi \right\} \exp \left\{ \frac{N_A - 32/105}{N_B} \right\}$$

In Figure 4, the theoretically predicted charges are compared with the charges that were actually measured on the effluent aerosol from the corona charging device. A fair agreement exists. The 25 per cent experimental bias is probably due to charging of particles occurring just outside the entrance and exit of the copper electrode. This additional charging effect was not considered in the theoretical treatment. The lack of uniformity of charges on the particles is shown in Figure 1. The primary cause for the non-uniform charging is a non-uniformity in the diameter of the particles.

Measurement of Electric Charge on the Aerosol

The device developed to measure the electrical charge on aerosol particles is shown in Figure 5 (5). Air is made to travel in laminar motion along a rectangular channel. The aerosol is injected at the centerline of the flowing air stream. By the application of a voltage across the two electrodes, the aerosol beam is deflected an amount dependant on the charge on the particles. The trajectory of the beam can either be photographed (Figure 6) or measured with an optical cathetometer using illumination by a Tyndall beam. On the basis of the equations of motion of a charged particle in an electric field and the velocity profile in a rectangular duct, the average charge on the aerosol particles may be calculated from the trajectory (3).

$$q_p = 6\pi\mu D_p v_o yS / CE_x$$

In addition, any non-uniformity in either the charge or the diameter is graphically illustrated by the aerosol beam spreading as it flows along the channel. It is possible to measure the width of the aerosol beam and thereby estimate the lack of uniformity in charge and diameter (3).

A comparison of data taken with the Millikan cell and with the "charge-spectrometer" is shown in Figure 4. The better reproducibility of the latter is apparent.

Conclusions

The results of this work indicate that uniform test aerosols of electrically charged particles can be produced and measured. It is now planned to use the test aerosols in the evaluation of electrostatic air cleaning equipment and for other studies on the properties of electrified particles.

Nomenclature

Any set of dimensionally consistent units may be used.

b - One half the electrode spacing in the "charge-spectrometer"

C - $\{1 + 1.6 \lambda / D_p\}$, Cunningham correction

D_p - Particle diameter

E_r - Radial component of the electric field intensity

ϵ - Dielectric constant of the aerosol particle

G - Parameter characterizing the rate of diffusion of ions, 0.20 cm^2/sec .

i - Corona current per unit length of electrode

K - Mobility of air ions, $1.75 \text{ cm}^2/(\text{sec.})(\text{volt})$

L - Length of the electrodes in the corona charging device

λ - Mean free path of air molecules, $9 \times 10^{-6} \text{ cm.}$

N_{β} - $\frac{KE_{rL}}{8Rv_0}$

N_{ϕ} - $3\pi\mu K/CE_rD_p \left(1 + 2 \frac{\epsilon - 1}{+ 2}\right)$

N_{\wedge} - $\frac{GL}{2\pi Rv_0D_p} \left(1 + 2 \frac{\epsilon - 1}{+ 2}\right)$

q_p - Electrical charge on the aerosol particle

R - Inner radius of outer corona electrode

S - $3.6 \left[1 - (y^2/3b^2) - 0.41(2b/\pi y)\sin(\pi y/2b) + \dots\right]$

μ - Viscosity of air

v_0 - Average air or aerosol stream velocity

x - Position downstream in "charge-spectrometer" measured from inlet of aerosol

y - Lateral distance of aerosol beam from centerline in the "charge-spectrometer"

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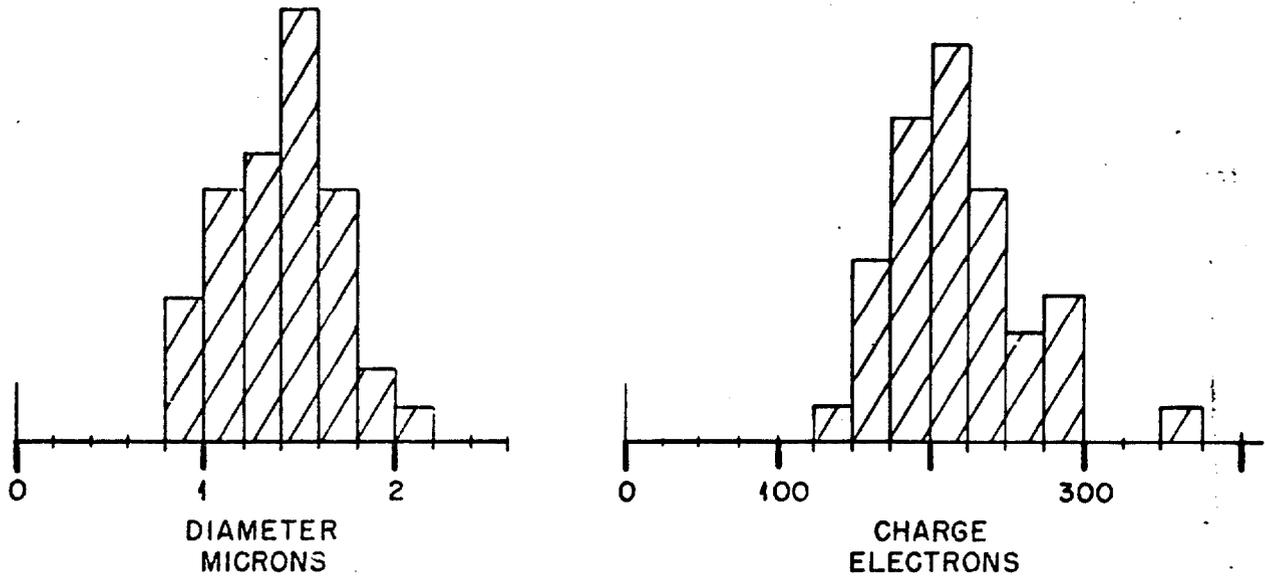


Fig. 1—Statistical distribution of sizes and particle charges in a typical aerosol.

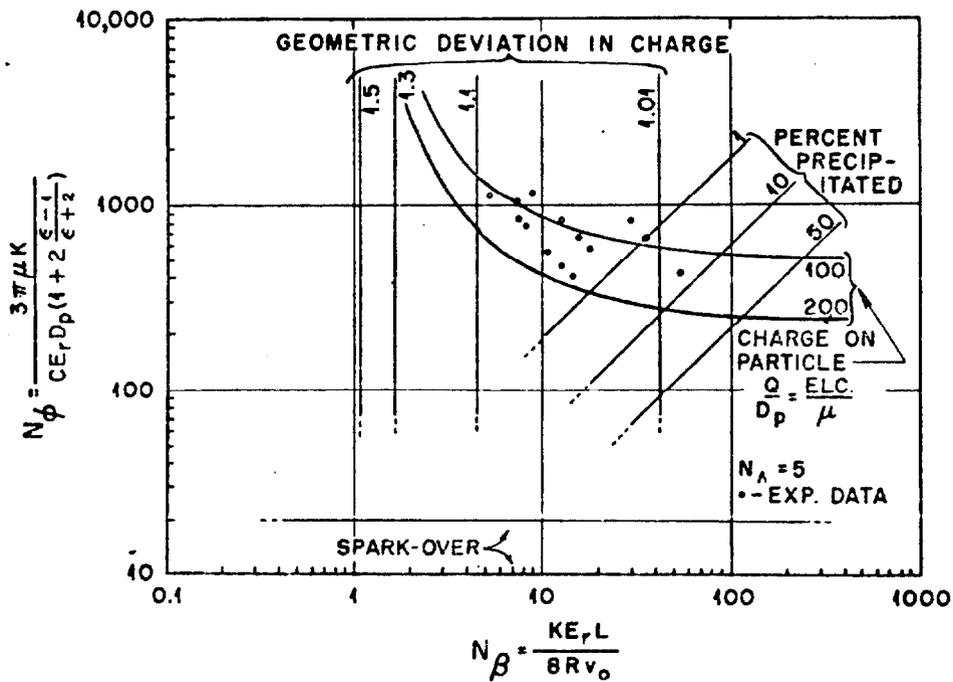


Fig. 2—Summary of theoretical equations of aerosol electrification.

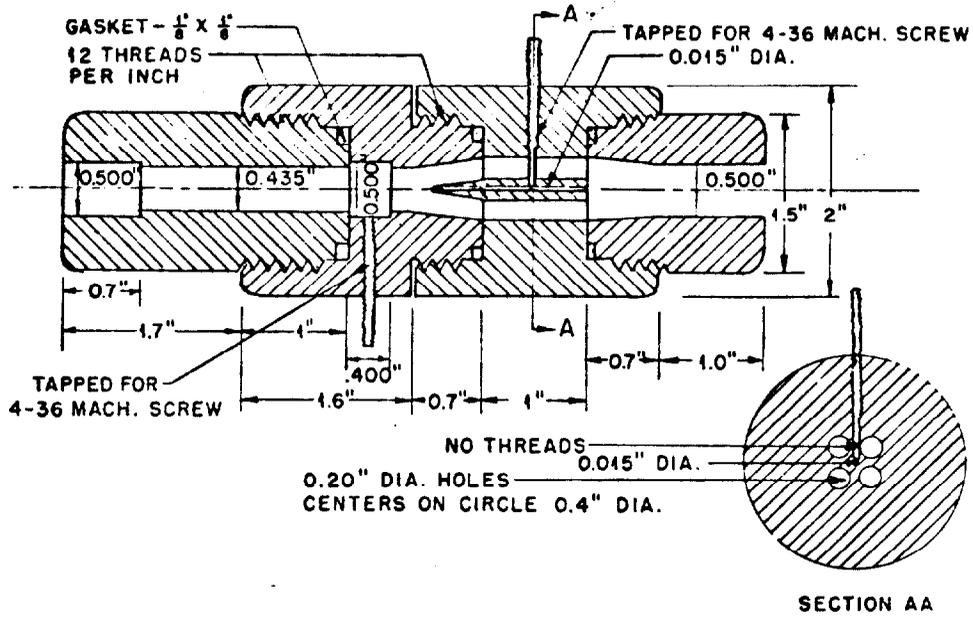


Fig. 3—The corona charging device for electrical charging of aerosols.

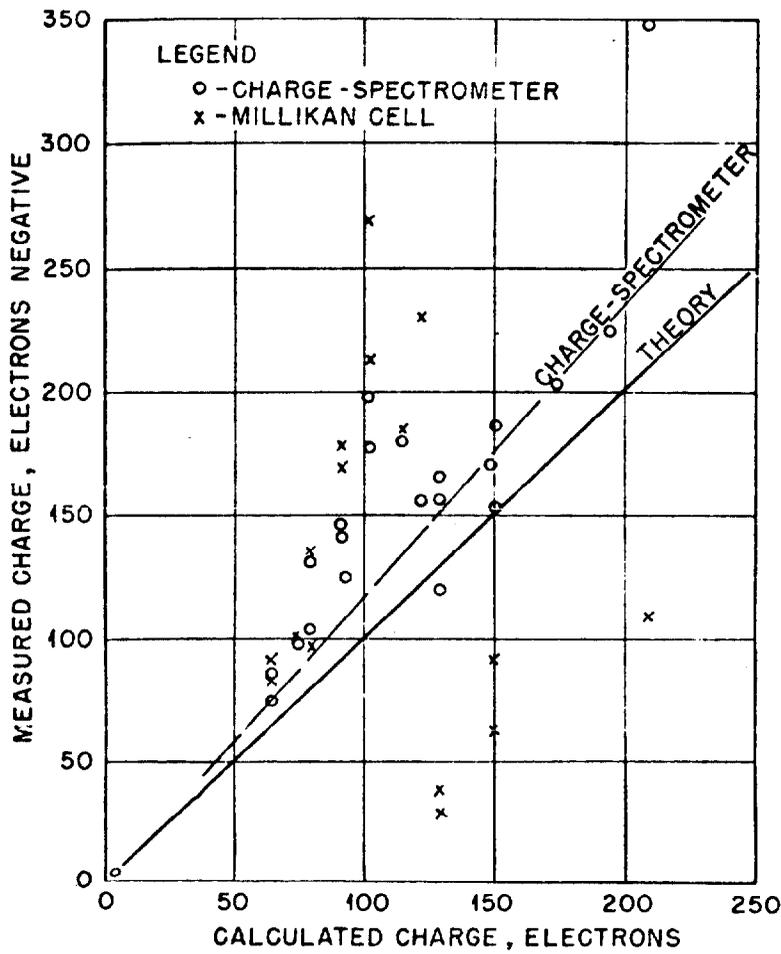


Fig. 4—The electrical charge on aerosol particles, a comparison of theoretical and measured values.

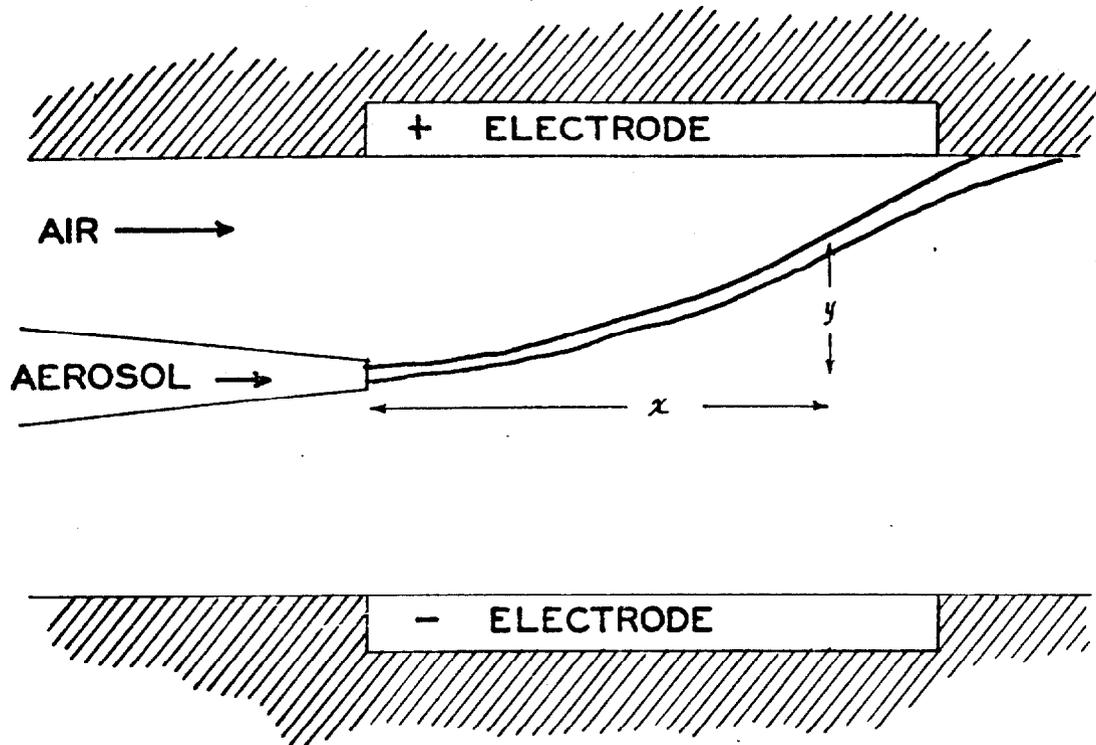


Fig. 5—The charge-spectrometer for the measurement of electrical charge on aerosols.

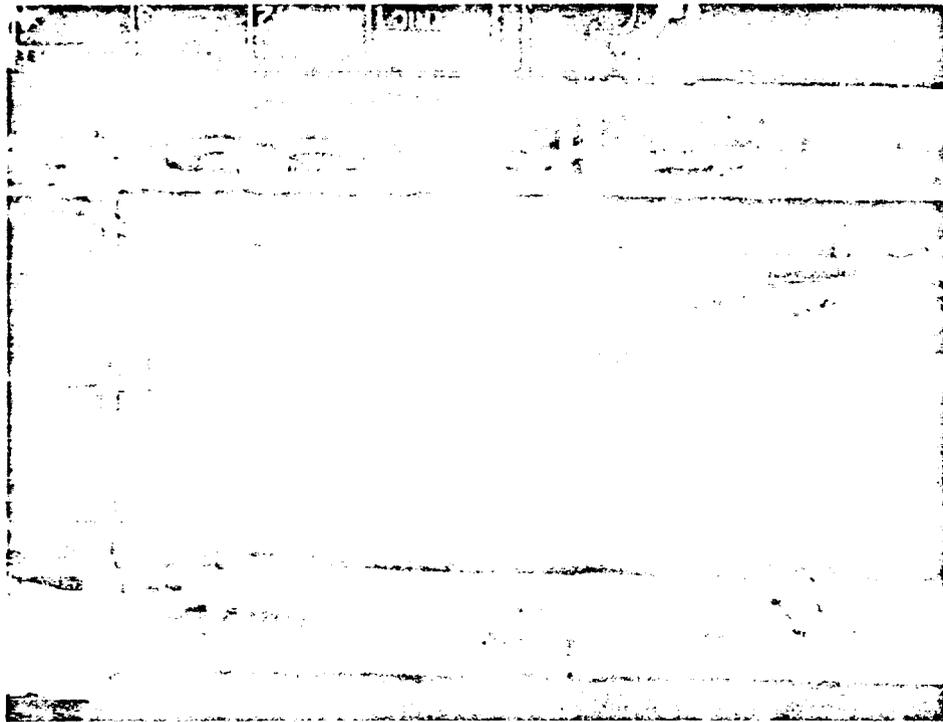


Fig. 6—Photograph of the aerosol in the charge-spectrometer.