electrostatic must be fed into the fluid. This is because, relative to its volume, the surface area of the droplets after breakup is larger than the surface of the original drop. Breakup into smaller droplets are often associated with surface instabilities.

How the droplet size and charges are distributed after breakup remains an unsolved problem although pioneering theories exist. One of such theories assumes that the breakup takes place in such a way as to minimize the sum of the surface and electrostatic energies of the system after the breakup.[2] According to this minimum energy theory, which assumes production of identical droplets after breakup, charges on a drop is exactly one-half of the Rayleigh limit given by (1).

Kelly developed a maximum entropy theory using a statistical mechanical approach in which the entropy of the system is maximized under the constraint of charging limit given by (1) and (2).[3] This theory predicts, among other features, that multiply charged states are possible for a given droplet size. An interesting result of this model is the prediction that for droplets whose radii are much larger than 1 μm, droplet charge number is directly proportional to droplet diameter. Data show that the proportionality constant is $1/a_0$ where a_0 is the first Bohr radius.[4]

In order to investigate behavior of charged drops whose radii are near 1 μm in detail, a quadrupole mass spectrometer/charge detector electrostatic spray described in the next section is used to accumulate data for the charge and size distributions of droplets in this regime. It is shown that the observed charge level of a droplet is smaller than the Rayleigh limit given by (1) and is also smaller than given by the minimum energy theory.[2] It is interesting to note that multiply charged states on a given droplet are observed in some of the experiments.

In order to spray liquids or powder, it is clear that net charges must be deposited to the droplets to be sprayed. Charging can be achieved by a number of means such as direct contact, induction and conduction. It is also possible to directly inject charges into fluids or powder particles by means of an electron gun. The SPRAYTRON gun developed at Charged Injection Corporation, is an electron gun which can inject an electron beam into the surrounding media. The energy of the beam is 25 keV or less and the current as much as 0.1 mA can be injected through an electron transparent window. It has been demonstrated that fine paint powders can be charged by the SPRAYTRON gun coating a metal surface smoothly including sharp edges. A fire-fighting water nozzle is being developed which uses the SPRAYTRON gun to charge and atomize water vapor and mist. If successful, this new nozzle can replace the conventional water sprinkler because of its much higher efficiency (much less water consumption) helped by an intrinsic property of charged drops which are preferentially attracted to the grounded conducting surfaces such as flames. Water damage can be drastically reduced and a fire breaking out from hidden corners of a room can be reached by the charged mist much more effectively than uncharged conventional water sprays.

While the idea is very interesting and the effort will be rewarded if such a spray nozzle can be developed, there are, however, a number of technical issues to be resolved before an engineering design can be started. For example, it is not clear how the beam electrons can be coupled to water. One approach is to inject charges into water vapor as would exist in vortex core of a pressure swirl atomizer and have the charges, in the form of ions, then enter the water. The coupling efficiency and beam penetration into water vapor are some of the basic questions for which we must find answers for the successful development of the nozzle. For this purpose, a numerical simulation model has been developed to understand coupling of the beam electrons with water vapor. The model along with some preliminary results will be presented later.

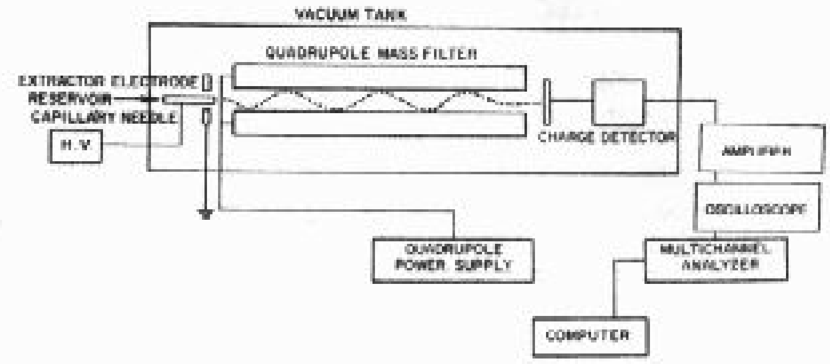

FIG. 1. Sketch of the Quadrupole Mass Spectrometer/Charge Detector Electrostatic Spray Appuratus installed at the Electrostatic Atomization Laboratory of Princeton Plasma Physics Laboratory.

II. EXPERIMENTAL STUDY OF CHARGED DROPLETS BY MEANS OF A QUADRUPOLE MASS FILTER/ CHARGE DETECTOR ELECTROSTATIC SPRAYER

A high mass quadrupole mass spectrometer/electrometer sprayer apparatus has been installed at the Electrostatic Atomization Laboratory located in the Plasma Physics Laboratory (PPPL) and the first experimental operations began in April 1995. The experiment has been running routinely to date with a large amount of data taken for the droplet size and charge distribution using Octoil, a diffusion pump oil. The purpose of the experiment is to investigate the basic properties of the electrostatic sprays in the industrially important droplet size range above one micron. Measurements of an octoil will expand the limited data base and permit the investigation of theoretically predicted phase transition in the 0.3 to 10 μm droplet size range.[3] This phase transition is of particular importance to develop micron size droplet sprays using far less charge and input energy than has heretofore been considered possible. Our data confirmed a presence of multiply charged states at droplet size at around one micron radius. Detailed comparisons of experimental data with available theories are in progress.

III. EXPERIMENTAL APPARATUS

There are three main components to the present experimental apparatus: the fluid reservoir/capillary sprayer, the quadrupole mass filter and the charge detector, plus computer equipments for data analysis as sketched in Fig. 1. All these components are enclosed in a 1.8 m by 0.4 m cylindrical vacuum tank. The tank pressure is maintained by a diffusion pump at about 5×10^{-6} Torr.