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# Bipolar diffusion charging for aerosol nanoparticle measurement using a soft X-ray charger

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**Abstract**

The availability of a bipolar charger using soft X-ray of 9.5 keV to aerosol nanoparticle measurement was evaluated by investigating the characteristics of ion generation and by comparing the ion generation rate and the bipolar charging states of aerosol nanoparticles to those of $^{241}$Am α-ray bipolar chargers of 82 and 164 μCi radiation. Ion generation of the soft X-ray charger stabilized within 7 s after being turned on and off, and remained stable for hours at a sufficient generation rate. The electrical mobilities of bipolar ions in dry nitrogen were close to each other, in contrast to those observed in the α-ray chargers. Owing to these electrical mobilities, the electrical mobility distributions of positively and negatively charged particles could be brought to almost identical states, as could the particle size distributions derived individually from the two mobility distributions. This means that inaccuracies can be minimized in measurements using a differential mobility analyzer. The effect of water vapor in ionized gas was also examined to discuss the fundamental applicability of the charger to atmospheric aerosols. For both humid nitrogen and air, the electrical mobilities of bipolar ions were found to be in accordance with those reported in the existing studies, indicating that humidity affected the electrical mobility of, in particular, negative ions.


*Keywords:* Aerosol nanoparticles; Measurement; Bipolar charging; Soft X-ray

## 1. Introduction

Bipolar diffusion charging plays a significant role in the process of aerosol nanoparticle classification using a differential mobility analyzer (DMA) (Okuyama, Shimada, Okita, Otani, & Cho, 1998). In the

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measurement of particle size distribution, the concentration of the particles classified electrically by the DMA is usually measured by a Faraday cup electrometer (FCE) or a condensation nucleus counter (CNC). Since the classified aerosol particles are expressed in terms of the electrical mobility distribution, some data processing is required to convert the electrical mobility distribution into size distribution.

In order to perform the data processing, one must determine the stationary bipolar charging characteristics of the aerosol particles. Kousaka, Okuyama, and Adachi (1985) and Adachi, Okuyama, Kousaka, Moon, and Seinfeld (1990) obtained the Fuchs's average charge distribution by modifying both Boltzmann's law and Fuchs's charging theory and used it to settle the problem of the Boltzmann's law and determine the stationary bipolar charging characteristics of aerosol particles. For both the Boltzmann's law and Fuchs's average charge distribution, the positive and the negative charging ratios of particles are assumed to be identical. However, because the positive and the negative ions are generally different in electrical mobility and mass, the combination probability of negative ions with particles is higher than that of positive ions, and consequently, the negative charging ratio is substantially higher than the positive charging ratio (asymmetric charging) (Adachi, Kousaka, & Okuyama, 1985; Hoppel & Frick, 1990). This indicates that the size distributions converted individually from the electrical mobility distributions of positively and negatively charged particles are not identical and that both size distributions deviate from the actual distribution. Therefore, the development of a new bipolar charger is needed to solve the problem associated with the data processing by attaining identical bipolar charging ratios (symmetric charging).

Hoppel and Frick (1990) showed that the bipolar charging ratios could be brought close to each other when a bipolar charger with a plate $^{232}$Th source was used. This charger was specially designed so that the "downstream charging" was magnified artificially. "Downstream charging" denotes the charging occurring downstream of the ionization space, and leads to an enhanced charging by positive ions which are lost less frequently to walls than negative ions due to their smaller mobility. However, the $^{232}$Th charger was so complex that it was not easy to adjust it to an optimum condition for obtaining symmetric charging. Recently, Shimada, Han, Okuyama, and Otani (2002) and Han, Shimada, Okuyama, and Choi (2003) developed a bipolar charger using soft X-ray photoionization. Shimada et al. (2002) concluded that this charger was capable of charging particles as well as one with a radioactive source. They also reported that the electrical mobility of ions generated in the charger was different from those in a $^{241}$Am radioactive charger. While the mobility of positive ions from the soft X-ray charger was almost the same as that from the $^{241}$Am radioactive charger, the mobility of negative ions in dry nitrogen was smaller, and thus the difference between the mobilities of negative and positive ions was smaller than the radioactive charger. In addition to this, the mobility of negative ions in humid room air was different from that in dry nitrogen. However, the effects of such difference in ion mobility on particle charging were not addressed in those previous studies. The reason for the difference between dry nitrogen and room air was not investigated, either.

The aim of this study is to examine the performance of the soft X-ray bipolar charger for measurement of aerosol nanoparticles. The effects of the difference in bipolar ion mobilities on the charging of aerosol particles were studied both experimentally and theoretically, and it is proved that the soft X-ray charger is useful for the aerosol measurement by reducing the inaccuracy in data reduction processing using Fuchs's average charge distribution. First, we investigated the characteristics of bipolar ions generated by the soft X-ray charger. Then, the bipolar charging states of monodisperse and polydisperse nanoparticles charged by the soft X-ray charger and $\alpha$-ray bipolar chargers were compared to verify that the soft X-ray charger gives less asymmetric charging. In addition, the effect of water vapor included in nitrogen and air on the electrical mobility of generated ions was investigated as the