Investigating the Effect of Relative Humidity on Bipolar Charge Fractions using the Tandem AAC-DMA

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Motivation

- Bipolar charging is used ubiquitously in aerosol science in order to bring an aerosol to a known steady state charge distribution such as in a Scanning Mobility Particle Sizer (SMPS).
- SMPS are used in atmospheric and hygroscopicity studies wherein the Relative Humidity can vary significantly (0 – 90%).
- Literature shows that negative ions are prone to growth in humid environments, where as the positive ion mobility is less effected by changes in RH [1,2].
- However, there is minimal experimental evidence determining how RH influences the charge fractions acquired when subjecting an aerosol to a bipolar ion environment.
- A new methodology developed by Johnson et al. [3], using a tandem Aerodynamic Aerosol Classifier (AAC) and Differential Mobility Analyser (DMA), allows for accurate measurements of the charge fractions of spherical aerosols.

Experimental Methodology

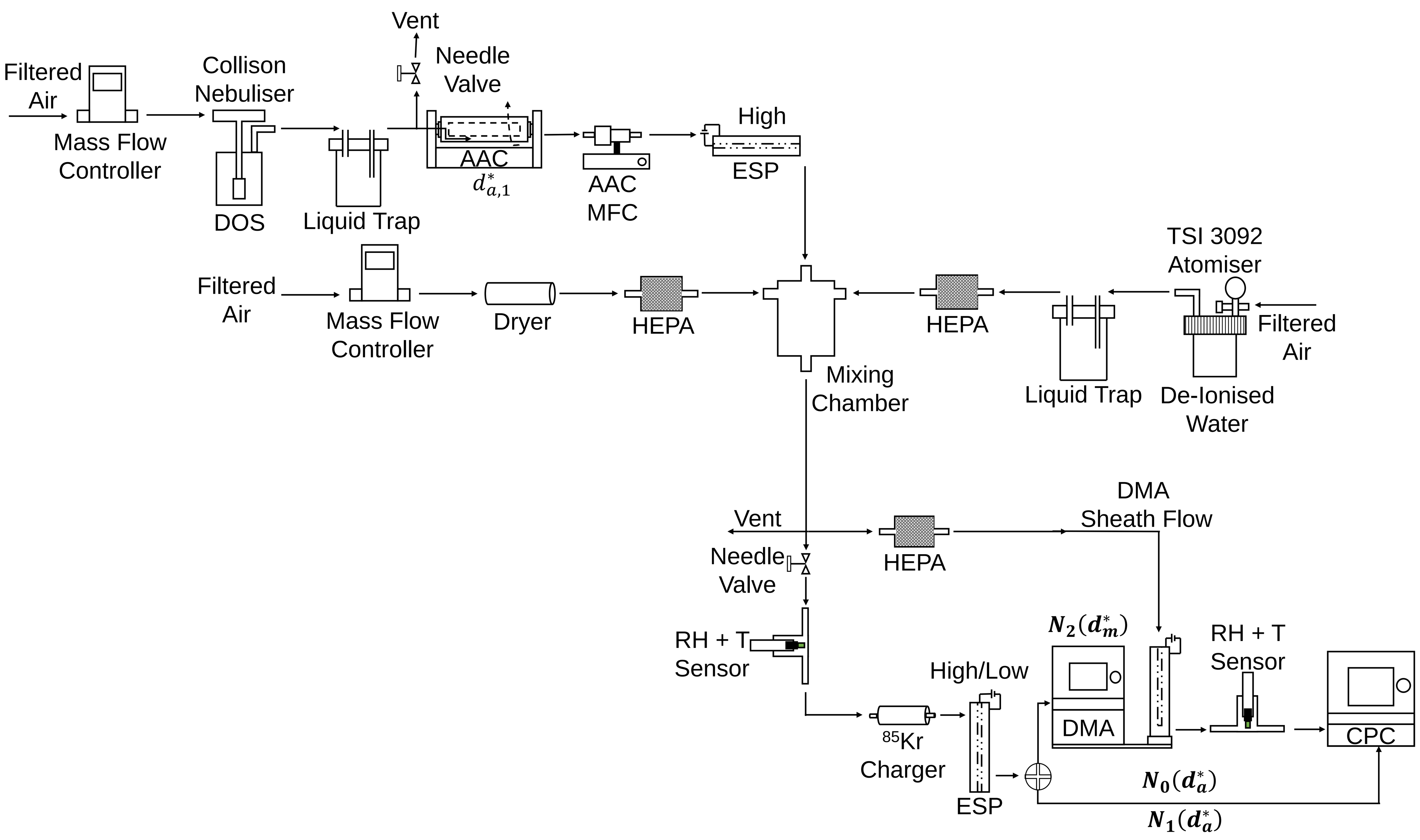

Figure 1: Experimental schematic depicting the method use to measure bipolar charge fractions as a function of Relative Humidity

Equation 1

$$\frac{N_2(d^*_m)}{N_1(d^*_a)} = \frac{\sum_{n_{min}}^{n_{max}} f_n \int \Omega_{\mathrm{DMA,B},n} \Omega_{\mathrm{AAC,B}} d d_m}{\int \Omega_{\mathrm{AAC,B}} d\tau}$$

- A monodisperse, neutral aerosol was produced by first size selecting nebulised DOS particles by aerodynamic diameter using the Aerodynamic Aerosol Classifier (AAC) and subsequently precipitating out any charged particles using an Electrostatic Precipitator (ESP).
- The aerosol stream was then humidified to the desired level by mixing dry air produced by controlled flow through a dryer containing molecular sieve 13x beads with humidified air generated by HEPA filtered atomised De-Ionised water.
- The charge distribution (at 0.3 lpm) produced by a ^{85}Kr charger was measured by stepping the DMA voltage and measuring the number concentration.
- The raw data was fit using a least squares minimisation to the transfer function de-convolution theory (Equation.1) developed by Johnson et al. [3].

Results

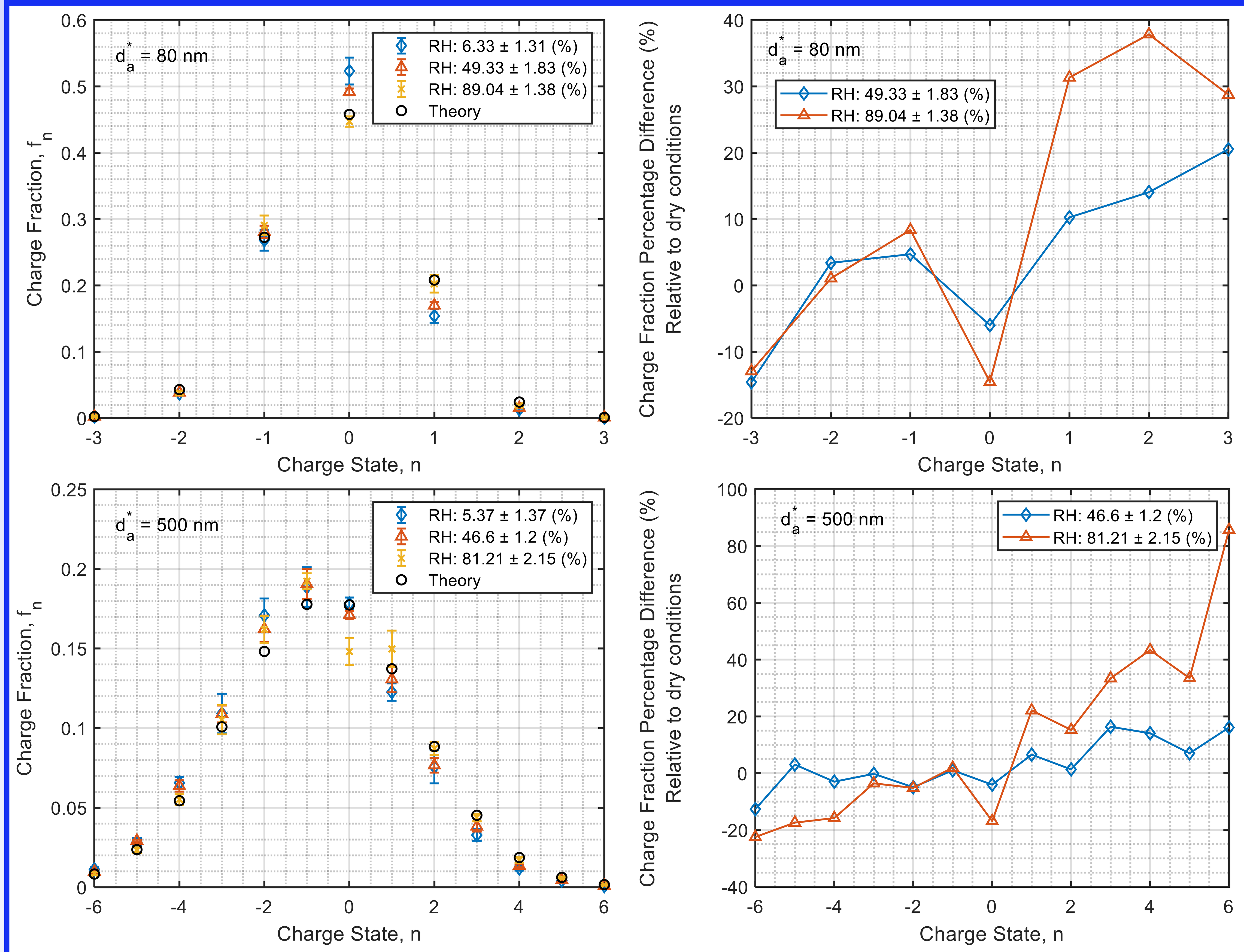

Figure 2: Results from Tandem AAC-DMA measurement. (a) Charge fractions of 80 nm particles, (b) Percentage difference of 80 nm charge fractions relative to dry conditions, (c) Charge fractions of 500 nm particles, (d) Percentage difference of 500 nm charge fractions relative to dry conditions

- Particle fractions of both 80 nm and 500 nm DOS particles are shown in Figures 2a and 2c along with the theory of Wiedensholer [4].
- Contradictory to theory, on average the measurements at high humidity (>80%) are closest to the theory of Wiedensholer which is based on dry conditions.
- Other fitting parameters used within the least squares minimisation including the transfer function width factor, DMA transmission efficiency and particle effective density were within 28% of theoretical values. The largest deviations occurs within the transfer function width factor.
- For both 80 nm and 500 nm aerodynamic DOS particles the positive charge fractions at high humidity deviate significantly (by up to 80% percentage difference, see Figures 2b and 2d) from those at dry conditions.
- The relative increase in the positive charge fractions at higher humidity is likely due to growth of the negative ion clusters. Literature measurements of the electrical mobilities of both positive and negative ions at high humidity conditions show growth of negative ions, with minimal changes in the mobility spectra of positive ions [1,2].
- Reduction of the electrical mobility of negative ions would result in a relative bias of the charging process towards the positive side of the charge distribution between dry and humid conditions.

Summary

- The bipolar charger fractions of a 85Kr charger at different RH points were measured at two different aerodynamic diameters for three RH set-points
- Deviation in the positive charge fractions is observed at humid conditions when compared to dry conditions

Future Work

- Extend analysis to other commonly used charging methods such as:
  - ➢ Photoelectric charging via Ultra-violet light
  - ➢ Soft x-ray bipolar diffusion charging
  - ➢ Corona Needle Unipolar diffusion charging

References

[1] Liu, Yiliang, et al. "Size-resolved chemical composition analysis of ions produced by a commercial soft X-ray aerosol neutralizer." Journal of Aerosol Science 147 (2020): 105586.

[2] Lee, Hye Moon, et al. "Effects of mobility changes and distribution of bipolar ions on aerosol nanoparticle diffusion charging." Journal of chemical engineering of Japan 38.7 (2005): 486-496.

[3] Johnson, T. J. et al. "Measuring the Bipolar Charge Distribution of Nanoparticles: Review of Methodologies and Development using the Aerodynamic Aerosol Classifier", Journal of Aerosol Science 143 .December2019 (2020), p. 105526.

[4] Wiedensohler, A. "An approximation of the bipolar charge distribution for particles in the submicron size range." Journal of aerosol science 19.3 (1988): 387-389.

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