Bipolar Neutralization using Radioactive, X-ray, and AC Corona Methods

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Outline

• Motivation
• Background – charge fraction
• Experimental charging conditions
  – Neutralizers
  – Carrier gas
• Results
  – Size distributions
  – Ion mobility
  – Charged fraction
• Summary and conclusions
Motivation – particle size distribution measurements

![Diagram of DMA and CPC measurement setup]

- Particle size distribution measurements
- DMA (Differential Mobility Analyzer) connected to CPC (Condensation Particle Counter)
- Graphs showing CPC counts over time and particle size distribution
- Neutralizer connected to DMA

**Graphs:**
- CPC counts vs. Time, s
- dN/dLogDp, part/cm³ vs. Dp, nm

**Series 1**
- CPC counts distribution
- Graphs show peak at around 10 nm
Motivation – particle size distribution measurements

- Prevailing conditions
- Delay time
- Residence time
- Transfer function ($\Omega$)
- Transport losses
- CPC counting efficiency
- Fraction of particles with +1 charge
Objectives and methodology

- Objective: determine sources of uncertainty in the charge-to-concentration inversion required for size distribution measurement.
- **Measure charging characteristics in diverse systems using different neutralization techniques**
  - Particle charging (+1 fraction) depends on ion mobility and mass.
  - Ion mobility and mass depends on carrier gas properties.
    - Quantify experimentally
      - Particle size distributions
      - Ion distributions
      - Particle charge
    - Calculate sensitivity (Fuchs’ theory)
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Fuchs’ limited sphere model to calculate charge distribution
- Temperature
- Ion mobility
- Ion mass

Wiedensohler approximation of Fuchs’ (Implemented in SMPS™ software)
- Ion mobility – measured (radioactive source)
- Ion mass – fitted result (Hussin et al. 1983)

Our calculations
- Ion mobility – measured
- Ion mass – calculated from Kilpatrick (1972) relationship
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Experimental apparatus

• Aerosol neutralizers
  — TSI 3077 (2 mCi $^{85}$Kr with est. current activity = 0.84 mCi)
  — TSI 3077A (10 mCi $^{85}$Kr with est. current activity = 8.3 mCi)
  — MSP M1090 Electrical Ionizer (AC corona discharge)
  — TSI 3087 Advanced Aerosol Neutralizer (soft X-ray)

• Neutralizing conditions
  — Dry nitrogen ($N_2$)
  — Humidified air (various $H_2O$)
  — Humidified air with 20 ppb sulfur dioxide ($SO_2$)
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• Summary and conclusions
Apparatus – particle size distributions

- Silver
- Olive oil
- Soot

Flowrate = 1.5 L/min

Size distribution inversion from Wiedensohler, 1988 (standard method)
Silver size distributions (high concentration)

Carrier gas: air with 28% RH

- 2 mCi 85Kr
- 10 mCi 85Kr
- X-ray
- AC corona
Silver size distributions (high concentration)

Carrier gas: air with 28% RH

- 2 mCi 85Kr
- 10 mCi 85Kr
- X-ray
- AC corona

Normalized total concentration

10 mCi 85Kr: 1.00
2 mCi 85Kr: 0.46
Soft X-ray: 0.93
AC Corona: 1.57
Silver size distributions (low concentration)

Carrier gas = air with 50% RH

- 2 mCi 85Kr
- 10 mCi 85Kr
- X-ray
- AC Corona
Silver size distributions (low concentration)

Carrier gas = air with 50% RH

- 2 mCi 85Kr
- 10 mCi 85Kr
- X-ray
- AC Corona

Normalized total concentration

1.00 0.96 0.82 1.37

10 mCi 85Kr2 mCi 85Kr Soft X-ray AC Corona
Oil droplet size distributions

Challenge gas = air with 50% RH

- 2 mCi 85Kr
- 10 mCi 85Kr
- X-ray
- AC Corona
Oil droplet size distributions

**Challenge gas = air with 50% RH**

![Graph of Oil droplet size distributions](image)

- **2 mCi 85Kr**
- **10 mCi 85Kr**
- **X-ray**
- **AC Corona**

Normalized total concentration:
- **10 mCi 85Kr**: 0.93
- **2 mCi 85Kr**: 0.93
- **Soft X-ray**: 1.01
- **AC Corona**: 1.20
Soot size distributions

\[ \frac{dN}{d\log Dp}, \text{part/cm}^3 \]

- 2 mCi 85Kr
- X-ray
- AC corona

Soot size distributions

Apparatus – ion mobility distributions

- Silver tube furnace
- NanDMA
- Electro meter
- Flowrate = 1.5 L/min
- "Test" neutralizer
- HEPA filter
- "Test" carrier gas
- Vent
Measured mobilities from radioactive source

Positive ions

Negative ions

Ion mobility depends on carrier gas properties
Measured ion mobilities for air, 50% RH

Mean mobility, cm²/V-s

Positive ions = solid; negative ions = hashed

Ion mobility depends on neutralizer

Effect of mobility on inverted size distribution

Calculated +1 charge fractions

Inverted arbitrary distribution

Arbitrary particles are “charged” according to the corresponding ion mobility but all distributions are inverted using the same Wiedensohler (1988) charge fraction approximation.

30% higher charge fraction = 30% concentration of particles
Apparatus – particle charged fractions

Nano-DMA with $^{85}\text{Kr}$

Silver tube furnace

“Test” carrier gas

Vent

“Test” neutralizer

Flowrate = 1.5 L/min

3025 CPC

HV supply

ESP
Measurements are compared with the Wiedensohler approximation and with calculations using Fuchs’ theory (as adapted by Wiedensohler) with measured ion mobilities but calculated masses as input parameters.
Summary and conclusions

- Measurements of size distributions of diverse aerosols revealed large differences, even for low particle concentrations
  - The incorrect +1 fraction is being used to invert data
- Why is this?
  - Measurements showed ion mobility (thus, charging) depends on:
    - Carrier gas composition
    - Relative humidity
    - Neutralizer type
  - These parameters are different for every measurement
• “If ultimate absolute concentration accuracy is of utmost importance to a project, it is recommended that a CPC…be used as a concentration reference in addition to a [sizing spectrometer].”

  – YES!

• Hypothesis: Fuchs’ theory alone not sufficient to predict differences in neutralizers, even if all else is known.
Thank you for your attention

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