Supporting Information for:

Characterization of the planar differential mobility analyzer (DMA P5): resolving power, transmission efficiency and its application to atmospheric cluster measurements

Zhengning Xu[1], Jian Gao[1], Zhuanghao Xu[1], Michel Attoui[3], Xiangyu Pei[1], Mario Amo-González[4], Kewei Zhang[1], Zhibin Wang[1,2,5*]

[1]College of Environmental and Resource Sciences, Zhejiang Provincial Key Laboratory of Organic Pollution Process and Control, Zhejiang University, Hangzhou 310058, China

[2]ZJU-Hangzhou Global Scientific and Technological Innovation Center, Zhejiang University, Hangzhou 311215, China

[3]University Paris-Est Creteil, University Paris-Diderot, LISA, UMR CNRS 7583, France

[4]MION S.L., Avda. Francisco Valles 8, Boecillo, Valladolid, 47151, Spain

[5]Key Laboratory of Environment Remediation and Ecological Health, Ministry of Education, Zhejiang University, Hangzhou, 310058, China

Correspondence to: Zhibin Wang (wangzhibin@zju.edu.cn)

Section 1: Theoretical derivation of the operation principle of planar DMA

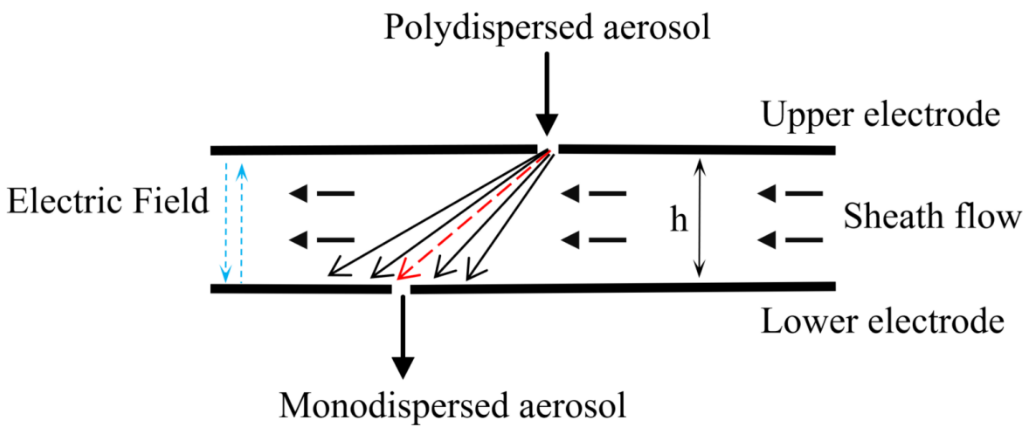

Figure S1 operation principle of planar DMA

V_{DMA}: Voltage between the two electrodes;

h: Distance between the two electrodes;

The electric field between the two electrodes: $E = \frac{V_{DMA}}{h}$.

During the scanning period of planar DMA, the electric field is applied on the z-direction, a laminar particle-free sheath flow is circulating thorough the capacitor along the x-direction at the flow rate of Q_{sh}, and the aerosol flow is fed into the capacitor thorough input slit located at the top electrode at the flow rate of Q_a. The direction of aerosol flow is parallel to the electric field and perpendicular to the sheath flow.

The particle velocity in x-direction is given as: $u_x(z) = \frac{d_x}{d_t}$

The equation can be transformed as $d_x = u_x(\mathrm{z}) \cdot d_t$ (1)

The particle velocity in z-direction is given as:

$$u_z = \frac{dz}{dt} = \frac{Q_a}{S_{slit}} + E \cdot Z_p = \frac{Q_a}{S_{slit}} + \frac{V_{DMA} \cdot Z_p}{h}$$

where Zp represent the electric mobility of the particle and S_{slit} represent the cross-section area of inlet slit.

Since $\frac{Q_a}{S_{slit}}$ is much smaller than $\frac{V_{DMA} \cdot Z_p}{h}$, this equation can be written as: $u_z = \frac{dz}{dt} = \frac{V_{DMA} \cdot Z_p}{h}$;

The equation can be transformed as $d_t = \frac{h}{V_{DMA} \cdot Z_p} \cdot d_z$ (2)

Combined equation (1) and (2), we can get the relation that

$$d_x = \frac{u_x(z) \cdot h}{V_{DMA} \cdot Z_p} \cdot d_z \qquad (3)$$

Integrating equation (3), we can get the equation that $\int_0^L d_x = \frac{h}{V_{DMA} \cdot Z_p} \int_0^h u_x(z) d_z$

where L represent the distance between the inlet slit and the monodispersed particle exit.

Assuming that $\bar{u}_x(z) = \frac{Q_{sh}}{w \cdot h}$, where w represents the width of the capacitor and w·h represent the cross-section area of the capacitor, the integral equation can be transformed as $\int_0^L d_x = L = \frac{Q_{sh}}{w \cdot h} \cdot \frac{h}{V_{DMA} \cdot Z_p} \int_0^h d_z = \frac{Q_{sh \cdot h}}{w \cdot V_{DMA} \cdot Z_p}$ (4)

Equation (4) can be written as $Z_p = \frac{Q_{sh \cdot h}}{w \cdot U \cdot L}$, and combined with the assumption that $Q_{sh} = \bar{u}_x(z) \cdot w$ ·h, we can get the expression of $Z_p = \frac{\bar{u}_x(z).h^2}{V_{DMA} \cdot L}$ (5)

In equation (5) $\bar{u}_x(z)$ represent the average speed of sheath flow along z-direction; L and h represent the horizontal distance of inlet the exit and between the two electrodes, respectively; V_{DMA} represent the voltage applied between the two electrodes.

Account for the planar DMA P5, the sheath flow speed is uniform along z-direction ($\bar{u}_x(z) = u_x$), the physical dimension of L and h are 40mm and 10mm, respectively. The relation of the electric mobility (Z_p) and the voltage applied by planar DMA P5 (V_{DMA}) can be expressed as:

$$Z_p = \frac{u_x.h^2}{V_{DMA} \cdot L} \qquad (6)$$

Section 2: Mobility diameter calculation

Calculation of diameter from mobility (Tammet, 1995; Wiedensohler et al., 2012)

$$Z = \frac{neC_c(D_p)}{3\pi\mu D_p}$$

$$C_c = 1 + \frac{2\lambda}{D_p}\left(1.165 + 0.483exp\left(-0.997\frac{D_p}{2\lambda}\right)\right)$$

$$\lambda = \lambda_0\left(\frac{T}{T_0}\right)^2\left(\frac{P_0}{P}\right)\left(\frac{T_0 + 110.4\ K}{T + 110.4\ K}\right)$$

$$\mu = \mu_0\left(\frac{T}{T_0}\right)^{3/2}\left(\frac{T_0 + 110.4\ K}{T + 110.4\ K}\right)$$

n is Number of elementary charges on the particle; e is Elementary charge = 1.60×10^{-19} C; C_c is Cunningham slip correction; D_p is Mobility diameter; μ is Dynamic gas viscosity; λ is Mean free path of gas; T is Temperature, and is set as 298.15 K; P is Pressure, assuming P equals to 1atm; T_0 is Reference temperature (296.15 K); P_0 is the Reference pressure = 1atm = 101325 Pa; λ_0 is Mean free path at 296.15K and 1atm = 67.3×10^{-9} m; μ_0 is the gas viscosity at 296.15K and 1atm, which is equals to 1.83245×10^{-5} kg m^{-1} s^{-1}

Section 3: Supplementary figures and tables

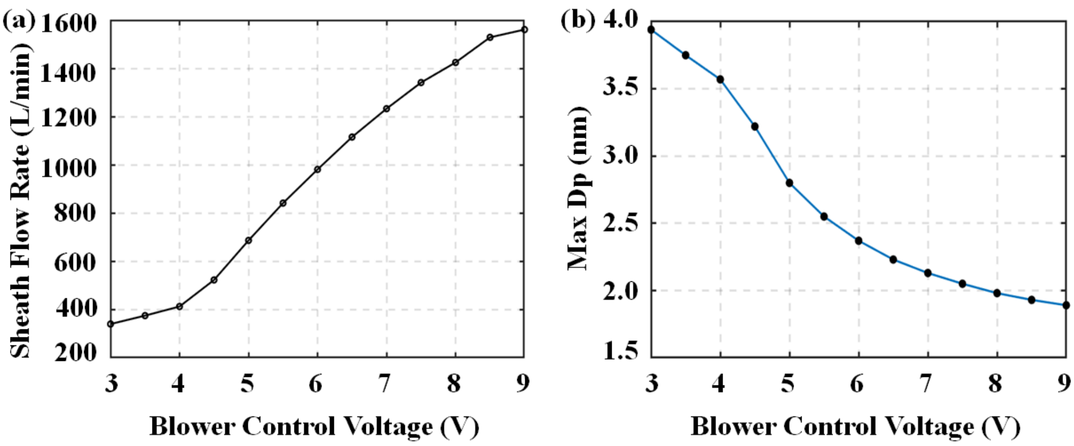

Figure S2 The relation of blower control voltage with sheath flow rate and corresponding DMA P5 sizing range

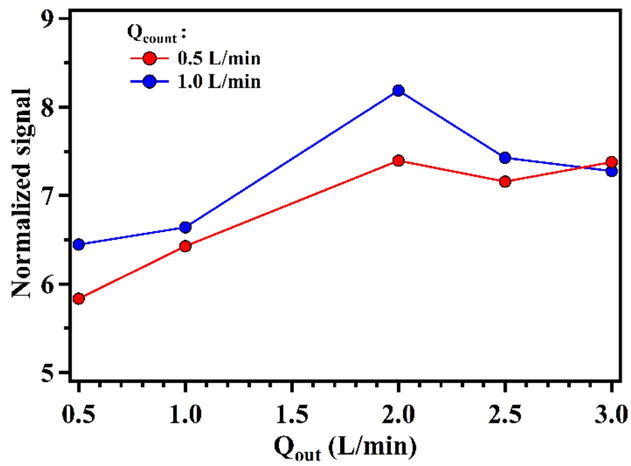

Figure S3 THA$^+$ Signal intensity normalized by monodispersed flow rate

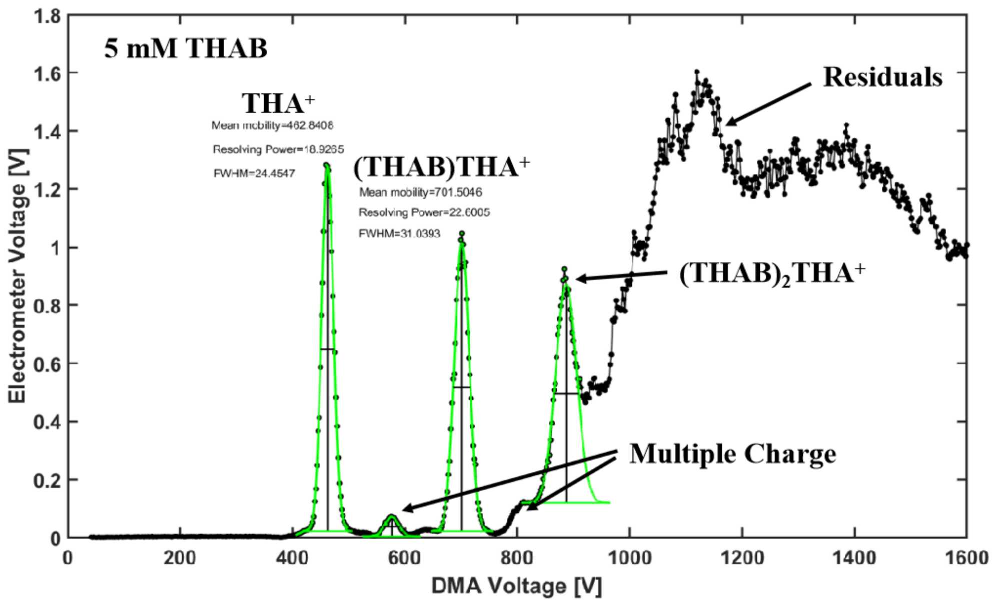

Figure S4 Positive ion mobility spectrum of electrospraied THAB solution obtained from HalfMini + Lynx E12

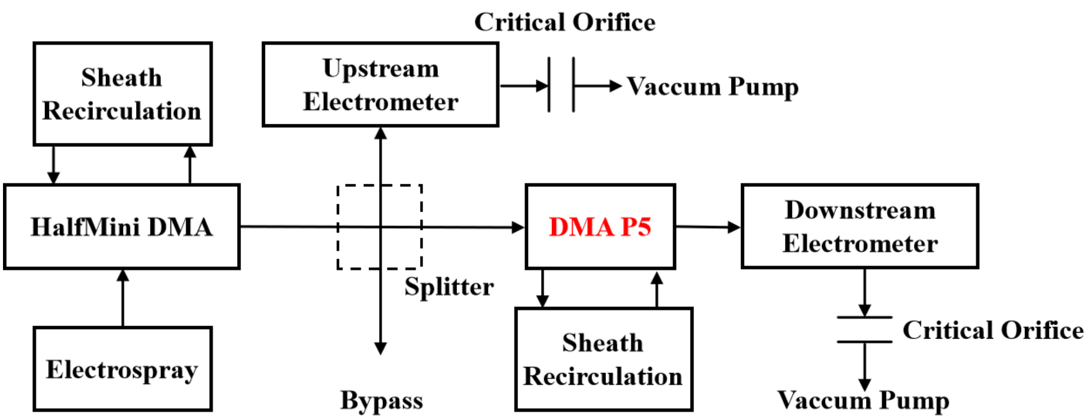

Figure S5 Schematic diagram of tandem DMA system

Table S1 Inverse mobilities 1/Z (V s/cm^2) for four tetra-alkyl ammonium positive ions

Peak$^+$	TMAI		TBAI		THAB		TDAB	
	this work	Ude et al. 2005	this work	Ude et al. 2005	this work	Ude et al. 2005	this work	Ude et al. 2005
A^+	0.458	0.459	0.723	0.718	1.03	1.03	1.269	1.285
$A^+(AB)$	0.667	0.677	1.164	1.153	1.533	1.529	1.811	1.846
$A^+(AB)_2$	-		1.475	1.450	1.898	1.893	-	

Table S2 Inverse mobilities 1/Z (V s/cm^2) for four tetra-alkyl ammonium negative ions

Peak$^-$	TMAI	TBAI	THAB	TDAB
B^-	0.423	0.422	0.436	0.436

References

Tammet, H.: SIZE AND MOBILITY OF NANOMETER PARTICLES, CLUSTERS AND IONS, J. Aerosol Sci., 6, (3), 459-475, https://doi.org/10.1016/0021-8502(94)00121-E, 1995.

Wiedensohler, A., Birmili, W., Nowak, A., Sonntag, A., Weinhold, K., Merkel, M., et al.: Mobility particle size spectrometers: harmonization of technical standards and data structure to facilitate high quality long-term observations of atmospheric particle number size distributions, Atmos. Meas. Tech., 5, (3), 657-685, 2012.