Miniaturized cylindrical nano-DMA of high resolving power

Juan Fernandez de la Mora, (Yale University) and Michel Attoui (U. Paris) for nucleation studies
Objectives:

1) Minimize flow rate (hundreds rather than thousands of lit/min) in high Re DMA
2) Yet keep high resolving power
3) Efficient diffuser to enable sonic operation
4) Clean materials and temperature control for ion induced nucleation studies
Design criteria

i) Resolution of 50 not compromised by eccentricity

ii) Expected eccentricity of 10 μm, hence $R_1 - R_2 = 2$ mm

iii) Minimize $R_1$ while maintaining rigidity of bullet support: $R_2 = 4$ mm

iv) $R_1 = 4$ mm, $R_2 = 6$ mm, $L = 4$ mm
HalfMini DMA. Critical dimensions: $R_i = 4 \text{ mm}; R_o = 6 \text{ mm}$ (inner and outer radii); Classification length $L = 4 \text{ mm}$.

$\frac{1}{4}''$ OD aerosol inlet tube somewhere here (not shown)

Sheath gas outlet 2

Sheath gas outlet 1

Voltage connection to inner electrode

Classified aerosol outlet. Same voltage as inner electrode

Sheath gas outlet

6 spacers fixing with of aerosol inlet slit. Currently 0.010'' thick. Should probably be widened if aerosol/sheath air ratio is increased above $\sim 3\%$.
DMA + vacuum cleaner pump (1.4 kW; ~$150)
Aerodynamic performance

Diffuser efficiency and Mach number

Diffuser efficiency limited by modest Reynolds number

Reaching Mach = 1 not easier with small than with large DMA in air
Sonic operation in CO$_2$
Larger Re and smaller sound speed

Critical: M = 1

Tetramethylammonium iodide
<table>
<thead>
<tr>
<th>$V_0$(kV)</th>
<th>FWHM</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.126444</td>
<td>0.014685</td>
<td>68.09677</td>
</tr>
<tr>
<td>2.033462</td>
<td>0.01237</td>
<td>80.84</td>
</tr>
<tr>
<td>1.679387</td>
<td>0.023494</td>
<td>42.5641</td>
</tr>
<tr>
<td>1.466438</td>
<td>0.018582</td>
<td>53.81481</td>
</tr>
<tr>
<td>1.335442</td>
<td>0.018896</td>
<td>52.92</td>
</tr>
<tr>
<td>1.021325</td>
<td>0.019925</td>
<td>50.18859</td>
</tr>
<tr>
<td>0.886449</td>
<td>0.021665</td>
<td>46.15789</td>
</tr>
<tr>
<td>0.530924</td>
<td>0.034483</td>
<td>29</td>
</tr>
</tbody>
</table>
VDMA (Volt) FWHM

<table>
<thead>
<tr>
<th>Voltage</th>
<th>FWHM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1655</td>
<td>0.022</td>
</tr>
<tr>
<td>1759</td>
<td>0.019</td>
</tr>
<tr>
<td>1948</td>
<td>0.019</td>
</tr>
<tr>
<td>2078</td>
<td>0.018</td>
</tr>
<tr>
<td>2170</td>
<td>0.014</td>
</tr>
<tr>
<td>2215</td>
<td>0.015</td>
</tr>
<tr>
<td>3292</td>
<td>0.016dimer</td>
</tr>
</tbody>
</table>
Achieving supersaturated conditions in a sonic DMA
for studies of ion-induced nucleation

In collaboration with Prof Michel Attoui (Paris)
\[ G(R) = 4\pi R^2 \gamma + \frac{q^2(1 - 1/\varepsilon)}{8\pi\varepsilon_0} \left( \frac{1}{R} - \frac{1}{R_i} \right) - \frac{4\pi}{3v_0} R^3 kT \ln S, \]

\[ R_R^3 = \frac{q^2(1 - 1/\varepsilon)}{64\pi^2 \varepsilon_0 \gamma}, \]

\[ R_K = \frac{2\gamma v_0}{kT \ln S}, \]

\[ \alpha = \frac{R_R}{R_K} = \left[ \left( \frac{q^2(1 - 1/\varepsilon)}{(64\pi^2 \varepsilon_0 \gamma)} \right)^{1/3} \frac{kT}{2\gamma v_0} \right] \ln S, \]

\[ x^\pm = \frac{R^\pm}{R_R} \quad \alpha_{\text{max}} = \alpha^* = \frac{3}{4^{4/3}} \approx 0.47247 \]

\[ 1 - x^{-3} = \alpha x \quad x = x^* = 4^{1/3} \approx 1.5874 \]
\[ x = x^* = 4^{1/3} \approx 1.5874 \]

\[ \alpha_{\text{max}} = \alpha^* = \frac{3}{4^{4/3}} \approx 0.47247 = \left[ \left( \frac{q^2(1 - 1/\epsilon)}{64\pi^2\epsilon_0\gamma} \right)^{1/3} \frac{kT}{2\gamma v_0} \right] \ln S \]
Work in progress
Conclusions

1) High resolution (>50) achievable

2) Sonic conditions in air defeated (with one pump) by reduced diffuser efficiency at reduced Re

3) Sonic conditions readily attained in CO₂

4) Sonic condition can be maintained in closed circuit via corrugated SS tubing in cold water

5) Temperature and supersaturation control achieved for precise control of supersaturation in working region. Low flow rate achieved by miniaturization is very helpful in this respect

6) Measurement of critical embryo size expected soon

7) Versatile tool to vary vapor and ion