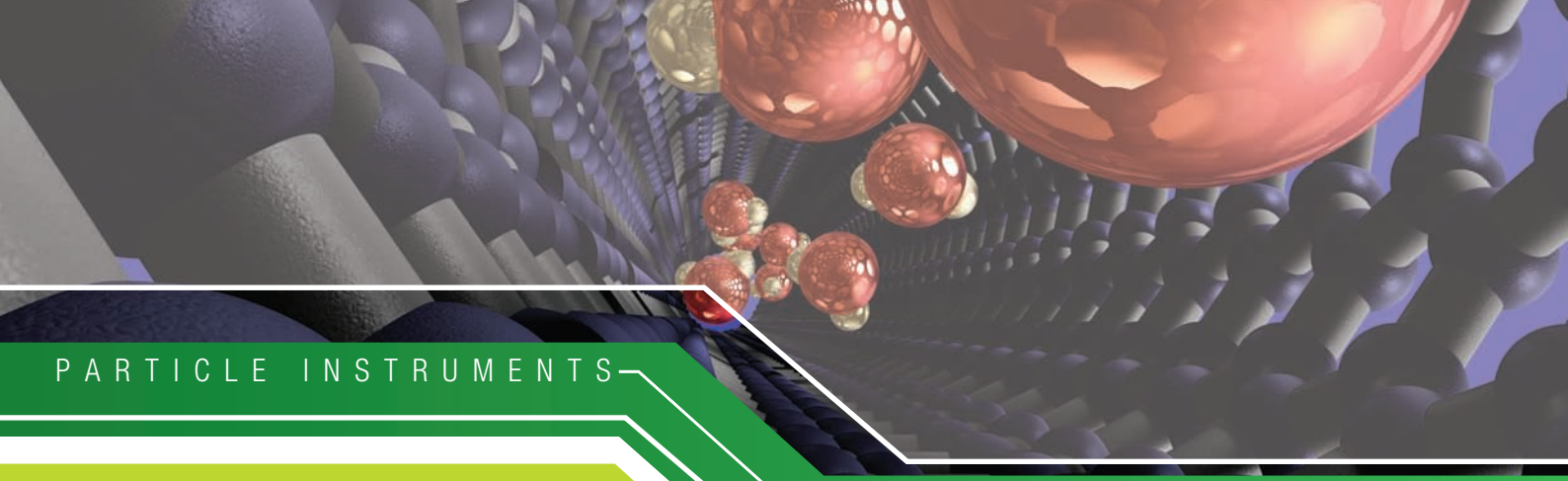

PARTICLE INSTRUMENTS

Scanning Mobility Particle Sizer™

3936N88

Scanning Mobility Particle Sizer™ Spectrometer (SMPS)
Model 3936

TSI's SMPS™ spectrometer is widely used as the standard for measuring airborne particle size distributions. This system is also routinely used to make accurate nanoparticle size measurements of particles suspended in liquids. The National Institute of Standards and Technology (NIST) uses a TSI DMA to size 60 nm and 100 nm standard size reference materials. SMPS™ spectrometer sizing is a discreet technique in which number concentrations are measured directly without assuming the shape of the particle size distribution. The method is independent of the refractive index of the particle or fluid, and has a high degree of absolute sizing accuracy and measurement repeatability. Trusted by researchers, TSI's Model 3936 has provided high quality data for over 30 years.

Highly accurate, real-time nanoparticle sizing systems you can rely on for years

Features and Benefits

- High resolution data: up to 167 channels
- Broad size range: from 2.5 nm to 1,000 nm
- ISO 15900:2009 compliant
- Fast measurements
- Wide concentration range up 10^7 particles/cm^3
- Component design for maximum flexibility
- Computer automated flow control
- Easy to set-up and operate
- Discreet particle measurement: works well for multi-mode samples
- Independent of optical properties of the particles and fluid
- Wide range of system options: choice of water or butanol CPC; choice of traditional or non-radioactive neutralizer

Applications

The Model 3936 is used for a wide variety of applications, a few of which are listed below.

- Nanotechnology research and materials synthesis
- Atmospheric studies and environmental monitoring
- Combustion and engine exhaust studies
- Indoor air quality measurements
- Nucleation/condensation studies
- Inhalation toxicology studies

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Differential Mobility Analysis

TSI's Scanning Mobility Particle Sizer™ Spectrometer (SMPS) measures the size distribution and concentration of particles in the size range of 2 nm to 1 µm using differential mobility analysis. This method is based on the physical principle that the ability of a particle to traverse an electric field (electrical mobility) is fundamentally related to particle size—no size calibration is necessary (first principle measurement). In a Differential Mobility Analyzer (DMA), an electric field is created, and the airborne particles drift in the DMA according to their electrical mobility. Particle size is then calculated from the mobility distribution. This method is independent of the particle zeta potential.

Highly Resolved Particle Sizing

This technique has been widely used by investigators for decades as the reference for particle size distribution measurements. Many researchers favor this real-time high resolution method for nanoparticle sizing over image analysis techniques (SEM, TEM, AFM, etc.) which are designed to image particles—not to provide statistically significant size distributions.

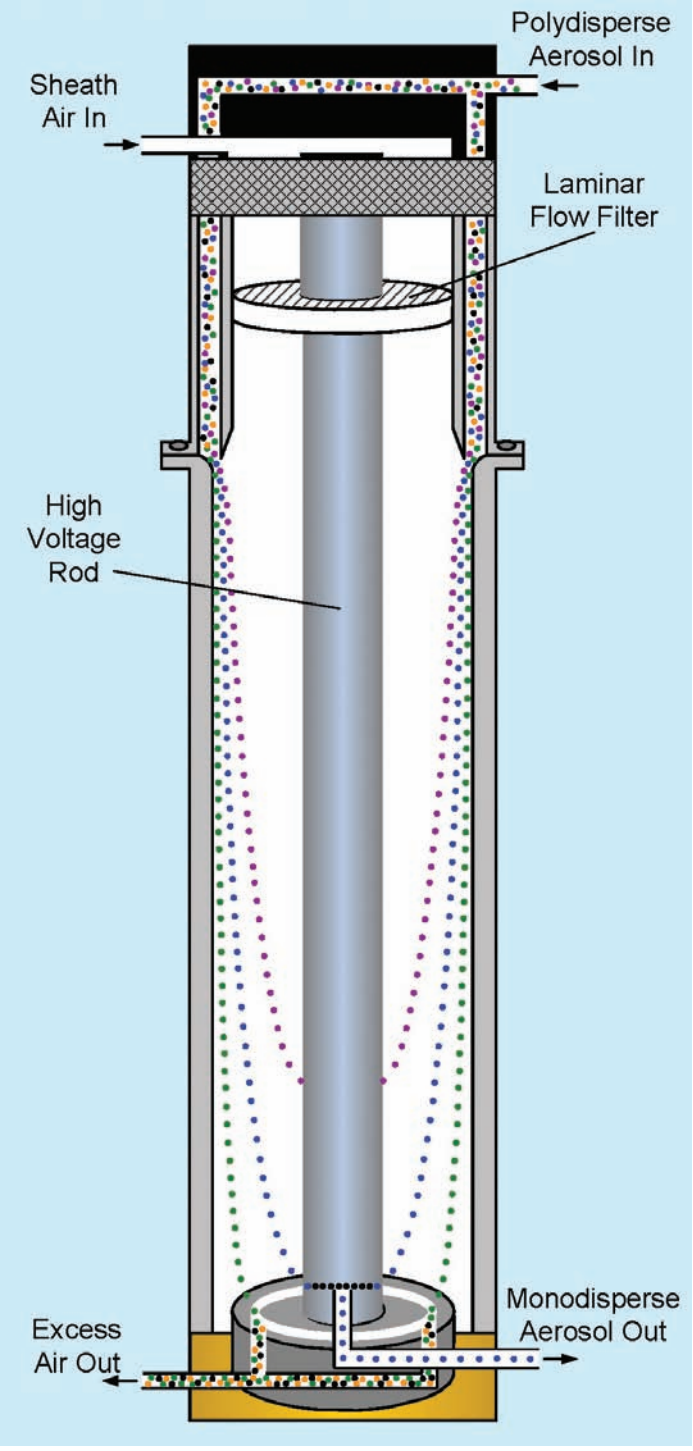
Sizing limitations of surface techniques include low sample sizes (non representative), image edge definition problems, 3D to 2D image distortion, and operator bias. Rigorous peer reviewed uncertainty analyses have been performed indicating TSI's DMA has a sizing uncertainty of approximately 3 – 3.5%[2].

Fast Scanning

In 1990 Wang & Flagan[3] noted that by scanning the DMA voltage exponentially each particle follows the same trajectory and retains DMA design resolution. The SMPS™ spectrometer incorporates this scanning technique enabling full size distribution scans in as little as 16 seconds. Longer scans are optimal for low concentration aerosols.

Versatility

TSI Component Systems feature the Model 3080 Electrostatic Classifier with your choice of Differential Mobility Analyzer (DMA), Condensation Particle Counter (CPC) and Aerosol Neutralizer. The versatility afforded by individual components enables you to select a system that best fits your sizing requirements.



Long Differential Mobility Analyzer (DMA) Model 3081

This classic DMA has been relied upon by aerosol researchers for over 40 years. Referred to in hundreds of peer-reviewed publications, the TSI Long DMA (LDMA) Model 3081 is based on one of the original DMAs used for sizing, which Knutson and Whitby designed in 1974[6]. Data from the DMA Model 3081 is well known to be precise, repeatable, and comparable to results measured by the luminaries in the field of aerosol science.

Custom Crafted

Because small irregularities in the dimensions and surface finish of the DMA can have large effects on sizing accuracy, repeatability and reliability, the DMA is custom machined at the TSI facility. As Whitby noted, "the operation of the mobility analyzer hinges on the particle paths within the analyzer"[4]. The laminar flow element used to provide the integral laminar sheath flow is also custom crafted at TSI and has been proven to be reliable and effective.

Aerosol Flow Path

The aerosol sample first passes through a single stage, inertial impactor which removes large particles outside the measurement range that may contribute to data inversion errors caused by multiple charging. Next, the aerosol passes through a bipolar ion neutralizer. This creates a high level of positive and negative ions and brings the aerosol charge level to a steady-state charge distribution. The aerosol particles then enter a Differential Mobility Analyzer (DMA) in which particles are separated according to their electrical mobility. After exiting the DMA, the classified particles are counted by a Condensation Particle Counter (CPC), using single particle counting technology. The flow rates in the DMA are carefully controlled in the system, and can be set and monitored via the instrument's software.

Nano Differential Mobility Analyzer (NDMA) Model 3085

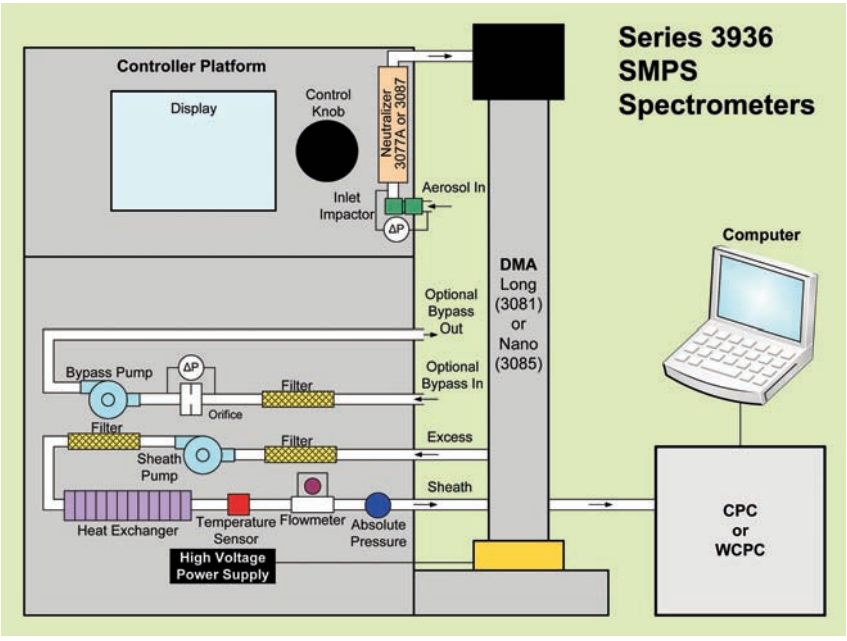
The nano DMA was designed in collaboration with university researchers to improve size resolution specifically over the particle size range of 3 – 150 nm[5]. The patented* NDMA also features increased nanoparticle transmission efficiency through the DMA.

Designed for Particles <150nm

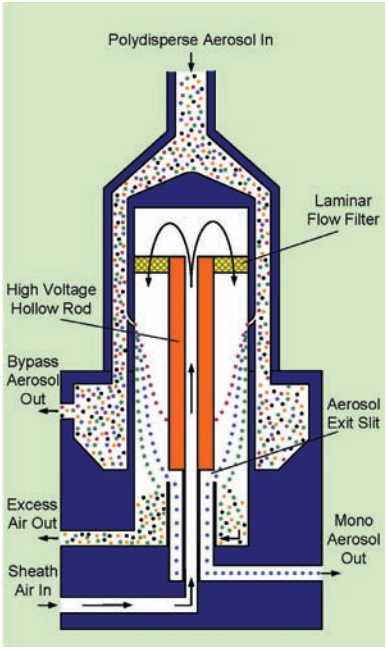
Particles less than 150 nm are extremely subject to the 'random walk' of Brownian diffusion. This diffusion leads to nanoparticle losses, and also decreased resolution (widening of DMA transfer function—also call diffusion broadening). In the Nano- DMA, the length of the particle transport path from the inlet to the classifying slit has been greatly reduced. That in conjunction with a higher flowrate significantly reduces residence time and accordingly reduces diffusion losses and diffusion broadening. Additionally, the entrance slit has been aerodynamically designed to ensure good matching between the aerosol and sheath flows even at high sheath/aerosol flow ratios. This enables high resolution measurement of nanometer particles. The monodiserpse aerosol outlet path has also been carefully designed in the NDMA to allow nanoparticles to exit the flow passage without significant electrostatic losses.

NDMA Performance Verification

The particle trajectories of the NDMA were rigorously modeled to ensure optimal performance. Experimental results have repeatedly shown that the resolution and transmission efficiency of the NDMA agree very well with the theoretical models for the entire size range. Due to careful engineering and manufacturing—there is no additional diffusion broadening (reduced resolution) or particle losses due to imperfect flow profiles, imperfect electric fields or machining tolerances. As predicted, the resolution of the NDMA improves with increased sheath/aerosol flow ratios.



The technology used in the SMPS Spectrometer is protected by US Patents 4,790,650 and 5,118,959



*US Patents 6, 230,572

Customized Software

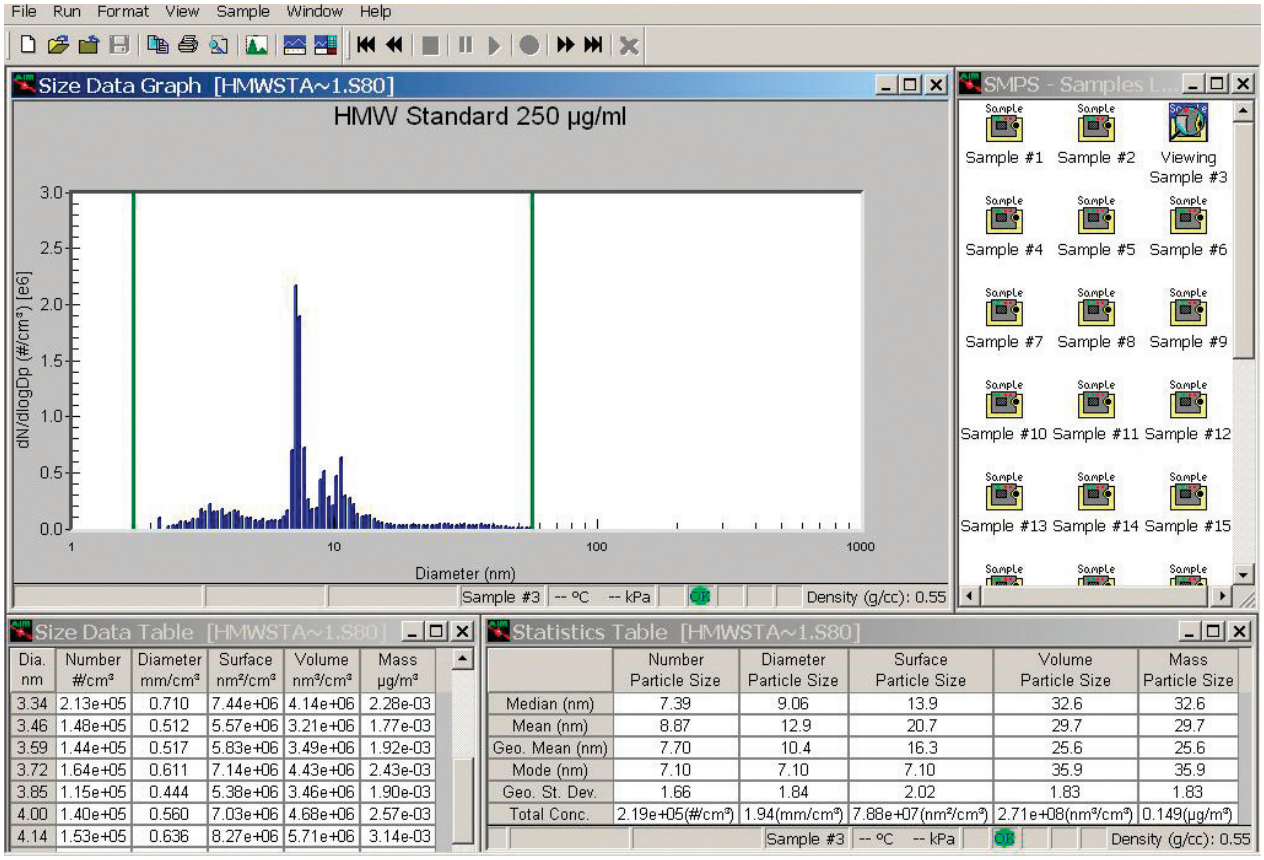
TSI's SMPS spectrometer includes the Aerosol Instrument Manager® software, a program designed for use with Microsoft® Windows® operating systems*. It features pull-down menus and dialogue boxes to simplify set up, operation, data collection, and analysis.

Data Collection and Data Management: Aerosol Instrument Manager® collects high-resolution data, and provides convenient file management capabilities. Data can be weighted by any moment of number concentration, including diameter, surface area, volume, or mass. Comprehensive statistical analysis is computed automatically for the entire distribution or specific size ranges defined. An export function allows easy transport of files to spreadsheet or other applications for customized data handling. Additional tools include, a buffer for comparing data sets, programmable start/stop times, and automatic file storage, and convenient auto export options.

Trusted, Tested Data Inversion: The software uses the complete set of values recommended in ISO 15900:2009[6] to calculate mean free path and viscosity of air, the Cunningham Slip Correction, and the bipolar charge distribution. TSI's data inversion has been investigated and verified by numerous researchers and scientists. The inversion is used to transform electrical mobility into particle diameter and automatically accounts for the flow rates of the CPC and DMA, measurement scan time, transfer function of the DMA, response time of the CPC, efficiency curve of the CPC, parameters of the working gas, and bipolar charge distribution.

Instrument Control: The software controls instrument operation. The flow rates on the Electrostatic Classifier and CPC can be set via the software. The sheath flow temperature and absolute pressure are also monitored before every sample, and these values are used to calculated real-time mean free path and gas viscosity– useful for atypical ambient pressures.

**Microsoft® Windows® 7 32/64 bit compatible*



Dia. nm	Number #/cm³	Diameter mm/cm³	Surface nm²/cm³	Volume nm³/cm³	Mass µg/m³
3.34	2.13e+05	0.710	7.44e+06	4.14e+06	2.28e-03
3.46	1.48e+05	0.512	5.57e+06	3.21e+06	1.77e-03
3.59	1.44e+05	0.517	5.83e+06	3.49e+06	1.92e-03
3.72	1.64e+05	0.611	7.14e+06	4.43e+06	2.43e-03
3.85	1.15e+05	0.444	5.38e+06	3.46e+06	1.90e-03
4.00	1.40e+05	0.560	7.03e+06	4.68e+06	2.57e-03
4.14	1.53e+05	0.636	8.27e+06	5.71e+06	3.14e-03

	Number Particle Size	Diameter Particle Size	Surface Particle Size	Volume Particle Size	Mass Particle Size
Median (nm)	7.39	9.06	13.9	32.6	32.6
Mean (nm)	8.87	12.9	20.7	29.7	29.7
Geo. Mean (nm)	7.70	10.4	16.3	25.6	25.6
Mode (nm)	7.10	7.10	7.10	35.9	35.9
Geo. St. Dev.	1.66	1.84	2.02	1.83	1.83
Total Conc.	2.19e+05(#/cm³)	1.94(mm/cm³)	7.88e+07(nm²/cm³)	2.71e+08(nm³/cm³)	0.149(µg/m³)

Sample #3 -- °C -- kPa Density (g/cc): 0.55

Aerosol Instrument Manager Software for the SMPS Spectrometer

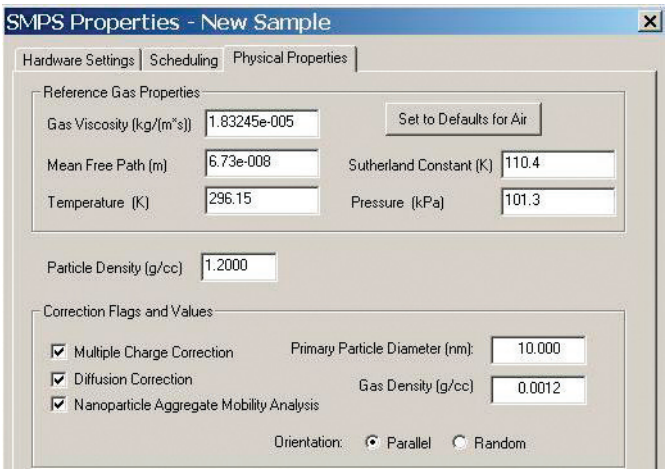
Sophisticated, User-Selectable Data Correction Algorithms

Multiple Charge Correction: Multiple charges on a particle increase its mobility, and allow the particle to be incorrectly binned into a smaller size channel. For particles less than 100 nm, very few particles have multiple charges. However, for larger particles, which will have multiple charges, the Multiple Charge Correction algorithm is an option which can be applied during a measurement or used post data collection to correct the measurement and account for up to 10 charges per particle.

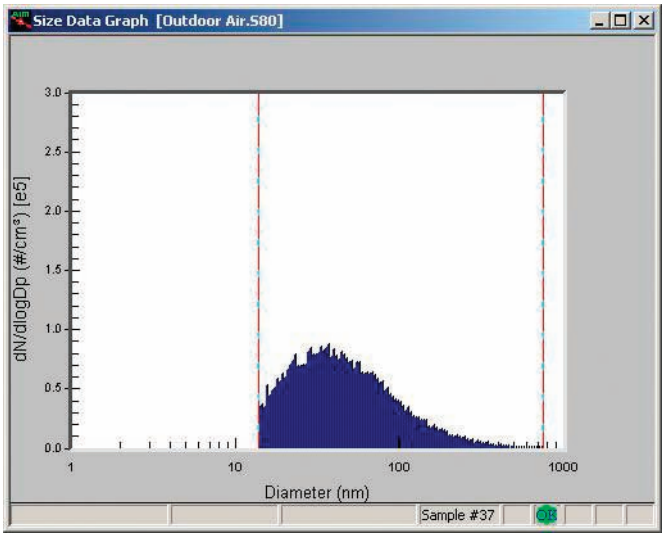
Diffusion Correction: Particle transport losses become significant below 100 nm. At 5 nm, only about 62% of the particles will make it through 2 feet of ¼" tubing at 0.3 L/min flow. These losses are size dependent (i.e. 97% of the 50 nm particles make it). A diffusion correction algorithm in the software takes into account particle penetration efficiencies through the SMPS spectrometer system (impactor, neutralizer, DMA, CPC and connection tubing). It can be applied post data collection, and is especially useful for examination of particle concentrations below 100 nm.

Nanoparticle Aggregate Mobility Analysis: Electrical mobility particle sizing is based on a spherical particle assumption. If the aerosol being investigated is an aggregate, applying the aggregate mobility correction will account for differences in the charge distribution and the electrical mobility of aggregates. Differences in the number size distribution between spheres and aggregates measured using differential mobility analysis are relatively slight, however differences in the surface area and particularly the volume/mass distribution are more significant. Use of the aggregate mobility correction will result in more accurate measurements of the size distribution of nanoparticle aggregates (Lall and Friedlander in 2006)[7].

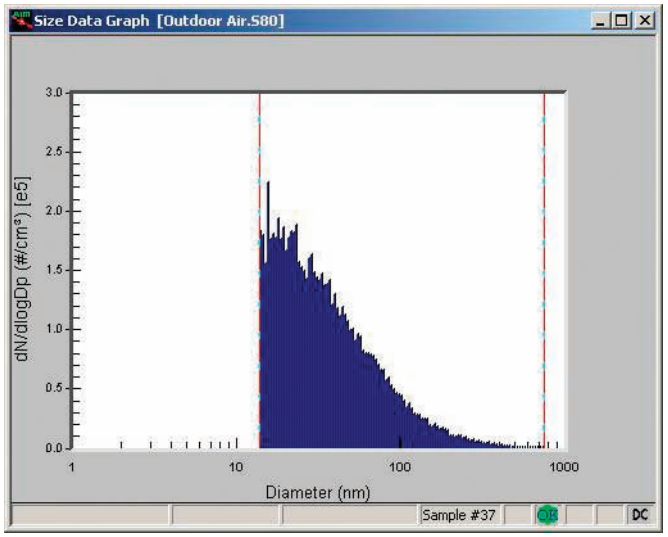
For more information on the Diffusion Correction or Nanoparticle Aggregate Mobility Analysis, visit www.tsi.com and review application notes SMPS-001 or SMPS-002.



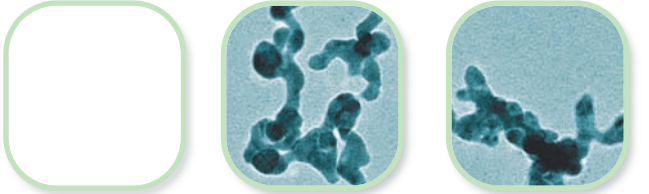
SMPS Spectrometer properties box.



Outdoor air measured with SMPS™ spectrometer *without* the diffusion loss correction.



Outdoor air measured with SMPS™ spectrometer *with* diffusion loss correction.



Condensation Particle Counters


Model 3776

TSI has extensive experience in the design and engineering of reliable, research quality Condensation Particle Counters (CPCs). The SMPS compatible instruments feature extended single particle counting range and on-board live-time coincidence correction for superior data accuracy. TSI CPCs are engineered with precision temperature and flow controls for precision particle concentration values and are able to measure particle sizes down to 2.5 nm.

Butanol CPCs

Ultrafine Condensation Particle Counter Model 3776
Detects particles down to 2.5 nm with single particle counting up to 300,000 particles/cm^3

Condensation Particle Counter Model 3775
Measures concentrations up to 10^7 particles/cm^3, using a photometric mode and detects sizes down to 4 nm.

Condensation Particle Counter Model 3772
A low-cost CPC for measuring particles down to 10 nm at concentrations up to 10,000 particles/cm^3

Water-based CPCs


Model 3788

TSI also offers a line of precision water-based CPCs as a VOC free alternative to alcohol based instruments. Using a patented* laminar flow water condensation technique these instruments combine sophisticated measurement technology with ease of use. They feature a touch screen user interface, use distilled water as the working fluid and have a wide variety of data acquisition options. The N-WCPC is also the world's fastest CPC commercially available opening up the possibility of faster SMPS measurements. **US Patent 6,712,881*

Nanoparticle Water-based Condensation Particle Counter (N-WCPC) Model 3788: Ultrafast nanoparticle counting down to 2.5 nm at concentrations up to 400,000 particles/cm^3 using single particle counting.

General Purpose Water-based Condensation Particle Counter (GP-WCPC) Model 3787 A low-cost SMPS compatible WCPC for measuring particles down to 5 nm at concentrations up to 250,000 particles/cm^3.

For more information on CPC selection, visit www.tsi.com and review the application note, "CPC-002."

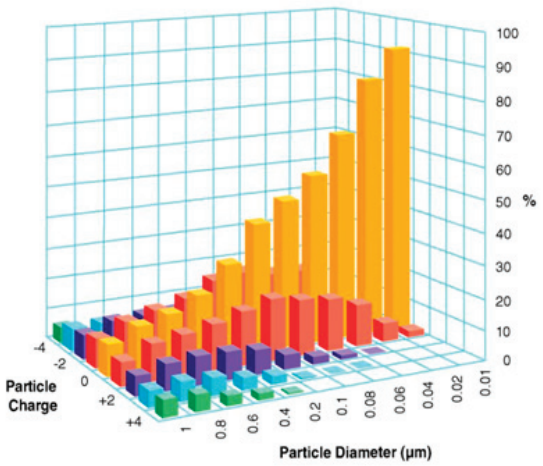
Choices for Aerosol Neutralization

TSI also offers a choice in aerosol neutralization. All of the options feature bipolar diffusion charging to bring the aerosol to a steady-state charge distribution. The traditional Kr^{85} neutralizers have been used in the industry for decades. The Advanced Aerosol Neutralizer provides a nonradioactive option, and features virtually identical sizing to radioactive sources when used in a sizing system.

Aerosol Neutralizer (370MBq/10mCi) Model 3077A: Kr^{85} radioactive source useful for a wide variety of aerosol charge states.

Aerosol Neutralizer (74MBq/2mCi) Model 3077: Kr^{85} radioactive source for aerosols that have a low level of charge.

Advanced Aerosol Neutralizer Model 3087: Neutralizes aerosol effectively without a radioactive source utilizing bipolar diffusion charging via soft x-rays. Useful for a wide variety of aerosol charge states.



Steady-state charge distibution graph.

Optional Accessories

Electrospray Aerosol Generator (EAG)
Model 3480

An EAG may be used on the front end of a component SMPS™ spectrometer system to aerosolize particles suspended in a liquid and enable accurate sizing of nanoparticles in liquids. The NCL/NIST protocol for gold nanoparticle size analysis details the use of an electrospray with a DMA[8] (i.e. ES-SMPS). This technique is used by a wide array of researchers as an alternative to Dynamic Light Scattering (DLS).

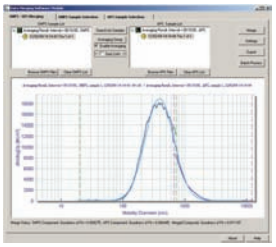
Nanometer Aerosol Sampler (NAS)
Model 3089

The NAS allows the collection of nanoparticle samples for surface analysis techniques. This electrostatic precipitator was designed to couple directly downstream of the 3080 Electrostatic Classifier and provides uniform substrate deposition and high collection efficiency. Samples from 2 to 100 nanometer can be collected on TEM grids, AFM substrates or glass slides.

Aerodynamic Particle Sizer™ Spectrometer (APS)
Model 3321

The Model 3321 measures larger particles, from 0.37-20 µm, with high resolution, making it an attractive companion instrument for the SMPS spectrometer. The APS™ spectrometer's measurements are independent of the refractive index of the sampled particles; thus, for real world and test aerosols alike, the resolution of the Model 3321 is profoundly superior to light-scatter based instruments, particularly in the 1 µm size range.

Data Merge Software
Model 390069



Data Merge Software* enables the merging of SMPS and APS™ data files to create a wide particle size range from 0.0025 to 20 µm. The advantage of combining these two related measurement techniques is that unlike optical methods, they require no knowledge of refractive index. Multimodal distribution functions can be fitted to the data, covering all three modes of particles found in the atmosphere, namely nuclei, accumulation, and coarse-mode aerosols.

**Developed under agreement with Chimera Technologies, Inc.*

To Order

When selecting a Scanning Mobility Particle Sizer™ (SMPS) spectrometer, the main considerations should be particle size range, particle concentration range, and CPC flow rate and working fluid. Contact your TSI representative for guidance in model selection.

Series 3936 SMPS Spectrometer Components

Specify	*Description*
3936XYY	Component SMPS system. Includes choice of DMA, CPC, interconnecting hardware, Aerosol Instrument Manager software for SMPS and a 3077A aerosol neutralizer X = DMA Choice; N = 3085 NDMA, L = 3081 LDMA YY= CPC Choice: Last 2 digits of CPC Model

To purchase an SMPS system with either a Aerosol Neutralizer Model 3077 or an Advanced Aerosol Neutralizer Model 3087, order the SMPS component system of choice and include a –N (i.e. 3936N88-N). Then order the chosen neutralizer as a separate line item (i.e. 3087 or 3077).

Select References

1. Mulholland, et. al., 2006, "Measurement of 100nm and 60nm Particle Standards by Differential Mobility Analysis," JRNIST, 111:4(256-312).

2. Kinney, et. al., 1991, "Use of Electrostatic Classification Method to Size 0.1um SRM Particles—A Feasibility Study," JRNIST, 96:2(147-176).

3. Wang, Flagan, 1990, "Scanning Electrical Mobility Spectrometer," AS&T, 13:230-240.

4. Knutson, Whitby, 1975, "Aerosol Classification by Electric Mobility: Apparatus, Theory and Applications," JAS, 6(443-451).

5. Chen, et. al., 1998, "Design and Evaluation of a Nanometer Aerosol Differential Mobility Analyzer (Nano-DMA)," JAS, 29:5/6(497-509).

6. ISO 15900:2009, Determination of particle size distribution—Differential electrical mobility analysis for aerosol particles.

7. Lall, Friedlander, 2006, "On-line Measurement of Ultrafine Aggregate Surface Area and Volume Distributions by Electrical Mobility Analysis: I. Theoretical Analysis," JAS, 37:3(260-271).

8. Pease III, Tsai, Zangmeister, Zachariah, Tarlov, 2010, "Analysis of Gold Nanoparticles by Electrospray Differential Mobility Analysis (ES-DMA)", NIST-NCL Joint Assay Protocol, PCC-10.

Scanning Mobility Particle Sizer™

Specifications

Scanning Mobility Particle Sizer Model 3936

Refer to separate product sheets for descriptions and specifications of individual components

SMPS Settings and Requirements

Data Averaging (Scans per Sample)	1 to 999, user-selectable
Aerosol Flow Rate	0.2 to 2 L/min, user-adjustable
Sheath Flow Rate	2 to 20 L/min, user-adjustable
Working Fluid	n-butyl alcohol (butanol) or distilled water (depends on cpc)
Operating Temperature	10 to 35°C
Storage Temperature	0 to 40°C
Aerosol-Inlet Temperature	10 to 35°C 5 to 35°C
Humidity	0 to 90%, noncondensing
Pressure	75 to 105 kPa

Data Logging

Via attached PC running Microsoft® Windows® (Windows® 7 32/64 bit compatible)

File Size per Sample

Varies by sample time 5.7 kilobyte (120 sec upscan, 15 sec downscan time)

Aerosol Neutralizer

3077	74 MBq (2 mCi), Kr^{85} ½ life 10.8-year
3077A	370 MBq (10 mCi), Kr^{85} ½ life 10.8-year
3087	Soft X-ray <9.5 keV ~8,760 operating hours

Display

320 × 240 pixel monochrome LCD for Electrostatic Classifier

Communications

RS-232 and USB for data; RS-232, USB, and Ethernet for status

Inlet accessory

Single-stage, inertial impactors (choice of three impactors, each with a different cut size)

Power Requirements

3772 CPC	210 W
3775/6 CPC	335 W
3787/8 WCPC	200 W
3080L/N	200 W

Dimensions (HWD/Weight)

3080L	64 × 41 × 46 cm/ 23.2 kg
3080N	41 × 41 × 46 cm/ 20.1 kg
3772	26 × 18 × 25 cm/ 5.5 kg
3775/6	25 × 32 × 37 cm/ 9.9 kg
3787/8	31 × 16 × 28 cm/5.5 kg

Model	DMA	CPC	Working Fluid	Particle Size Range (µm)	Particle Concentration (#/cm³)	Measurement time (sec)	Particle Resolution	Total Size Channels
3936L72	3081	3772	Butanol	0.01* to 1.0	1 to 10^{7}**	16 to 600 (selectable)	64 Channels per decade	Varies by configuration; spans 167 channels from 2.5 to 1,000 nm collectively
3936L75		3775						
3936L87		3787	Water					
3936L76		3776	Butanol					
3936L88		3788	Water					
3936N76	3085	3776	Butanol	0.0025 to 0.15				
3936N88		3788	Water					
3936NL75	3081 and 3085	3775	Butanol	0.004 to 1				
3936NL87		3787	Water	0.005 to 1				
3936NL76		3776	Butanol	0.0025 to 1				
3936NL88		3788	Water					

**Low end of particle size range determined by DMA Model 3081 specifications.*

***Upper end of concentration specification determined by Aersol Neutralizers Models 3077, 3077A, 3087, specifications*

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