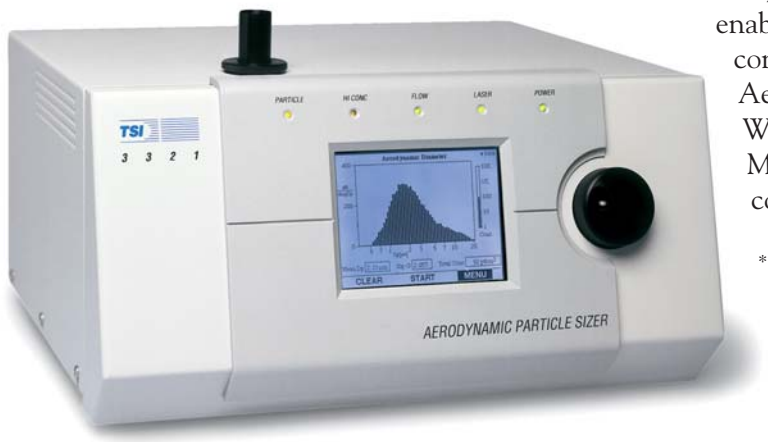
Model 3321 Aerodynamic Particle Sizer® Spectrometer

High-resolution aerodynamic sizing plus light-scattering intensity!

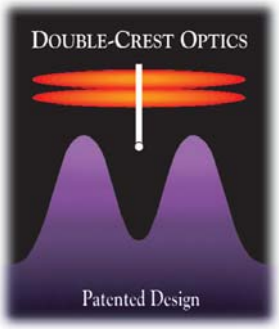
The Model 3321 Aerodynamic Particle Sizer® (APS) spectrometer is a high-performance, general-purpose aerosol instrument. Its unique design provides two measurements:

Aerodynamic diameter. The APS *sizes* particles in the range from 0.5 to 20 micrometers using a sophisticated time-of-flight technique that measures aerodynamic diameter in real time. Because time-of-flight aerodynamic sizing accounts for particle shape and is unaffected by index of refraction or Mie scattering, it is superior to sizing by light scattering. In addition, the monotonic response curve of the time-of-flight measurement ensures high-resolution sizing over the entire particle size range.

Relative light-scattering intensity. The APS *detects* particles from 0.37 to 20 micrometers using a light-scattering technique. While light-scattering intensity is not always a reliable indicator of particle size, it remains a parameter of interest. The APS keeps this second measurement separate and distinct from aerodynamic size.



The ability to provide two measurements of each particle using the same sensor allows you to gain exciting new insights into the makeup of an aerosol. The APS uses a patented*, double-crest optical system to detect the occurrence of particle coincidence (when more than one particle is in the detection area) and to identify poor signals near the instrument's lower detection threshold. This results in robust, high-quality measurements you can trust.



A well-designed and easy-to-use front panel includes a control knob and built-in display. The control knob allows users to scan through data on the display and monitor or control various functions. Other features, such as microprocessor-controlled volumetric flow control, barometric pressure correction, and separate pumps for sheath and total flows, enable the APS to operate under a wide range of conditions and still maintain calibration. The Aerosol Instrument Manager® software, a 32-bit Windows®-based program, is included with each Model 3321 for complete instrument and data control.

*United States Patent Number 5,561,515

TSI®

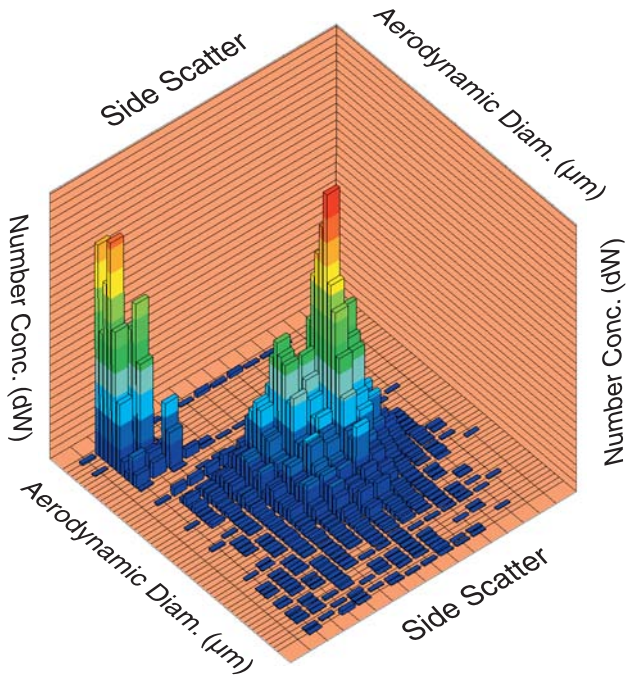
A Revolutionary Aerosol Instrument

Why is Aerodynamic Diameter Important?

Aerodynamic diameter is defined as the physical diameter of a unit density sphere that settles through the air with a velocity equal to that of the particle in question. It is the most significant aerosol size parameter because it determines the particle's behavior while airborne. Particles exhibiting the same airborne behavior have the same aerodynamic diameter, regardless of their physical size, shape, density, or composition.

Knowledge of a particle's aerodynamic diameter allows you to determine:

- If and where the particle will be deposited in the human respiratory tract
- How long the particle will remain airborne in the atmosphere or in an aerosol
- Whether the particle will penetrate a filter, cyclone, or other particle-removing device
- Whether the particle will enter a particle-sampling system
- Whether the particle will penetrate a pipe, tube, duct, or channel

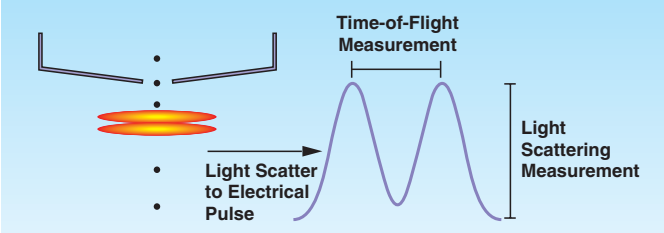


The Aerosol Instrument Manager software (included with the APS) enables you to correlate aerodynamic diameter and light-scattering intensity.

Why is the Model 3321 Superior?

Traditionally, TSI has designed its time-of-flight spectrometers to provide the truest high-resolution measurements of aerodynamic size. With the introduction of the Model 3320 in 1997, TSI produced the first aerosol spectrometer capable of detecting coincidence. The Model 3321 builds upon this accomplishment with a redesigned nozzle configuration and improved signal processing. These enhancements provide greater small-particle sizing efficiency, improved accuracy of mass-weighted distributions, and virtual elimination of false background counts.

Coincidence affects all single-particle-counting instruments. It occurs when more than one particle is present in an instrument's measuring volume. This can distort sizing information and lead to underreporting of particle concentration.



The Model 3321 uses a patented optical system to produce one double-crested signal for each particle, resulting in highly accurate measurements.

The Model 3321 APS uses a patented optical system with two partially overlapping laser beams to detect coincidence. As a particle passes through these overlapping beams, it generates one signal with two crests. The time between the crests provides aerodynamic particle-size information. If more than one particle is in the viewing volume, more than two crests appear, and the APS logs this separately as a coincidence event. While it does not eliminate the occurrence of coincidence, the instrument does effectively limit the effect of coincidence on particle-size distributions.

Why Include Light-Scattering Intensity?

Converting light-scattering intensity to geometric size often produces inaccuracies when sizing particles of different shapes and refraction indices. The APS measures relative light-scattering intensity, but rather than use it to determine particle size, the APS logs this measurement as a separate parameter. Light-scattering measurements can be made alone, in addition to aerodynamic diameter, or correlated to aerodynamic diameter on a particle-by-particle basis. Thus, researchers are able to gain additional insights into aerosol composition.

Applications

The Model 3321 is well-suited to a wide variety of particle-sizing applications. These include:

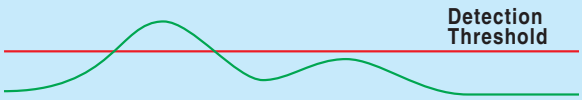
- Inhalation toxicology
- Drug delivery studies
- Biohazard detection
- Atmospheric studies
- Ambient air monitoring
- Indoor air-quality monitoring
- Filter and air-cleaner testing
- Characterization of test aerosols used in particle instrument calibration
- Spray technology
- Performance evaluations of aerodynamic devices
- Powder sizing
- Basic research

Time-of-Flight Measurement Results

Every particle signal is processed in real time as one of four distinct events. The Model 3321 logs the occurrence of all events, but only Events 1 and 2 are included in size distribution results. Light-scattering intensity is recorded for Event 2 only.

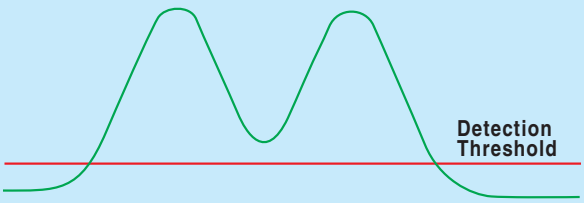
Event 1

This event occurs when the signal for a small particle cannot stay above the threshold and only one crest is detected. The measurement is aborted, and the time-of-flight of the particle is not recorded. However, the event is logged for concentration calculations and displayed in the <0.523-µm size channel in uncorrelated mode.



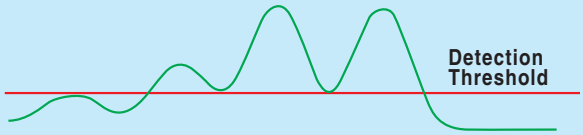
Event 2

This is a valid particle measurement. The signal stays above the threshold and two crests are detected. The time-of-flight between the two crests is recorded and the events are included in the concentration calculations.



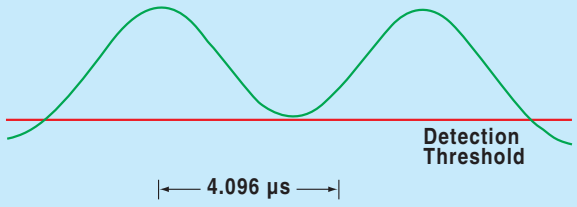
Event 3

This event is caused by coincidence. Although the signal stays above the threshold, three or more crests are detected. Events of this type are logged but not recorded for concentration or time-of-flight.



Event 4

This event is outside the maximum range of the timer. The signal remains above the threshold until it moves outside the timer range, and only one crest is detected. A type 4 event is normally caused by large or recirculating particles. Again, the event is logged, but no time-of-flight is recorded.



Advanced Technology That Is Easy to Use

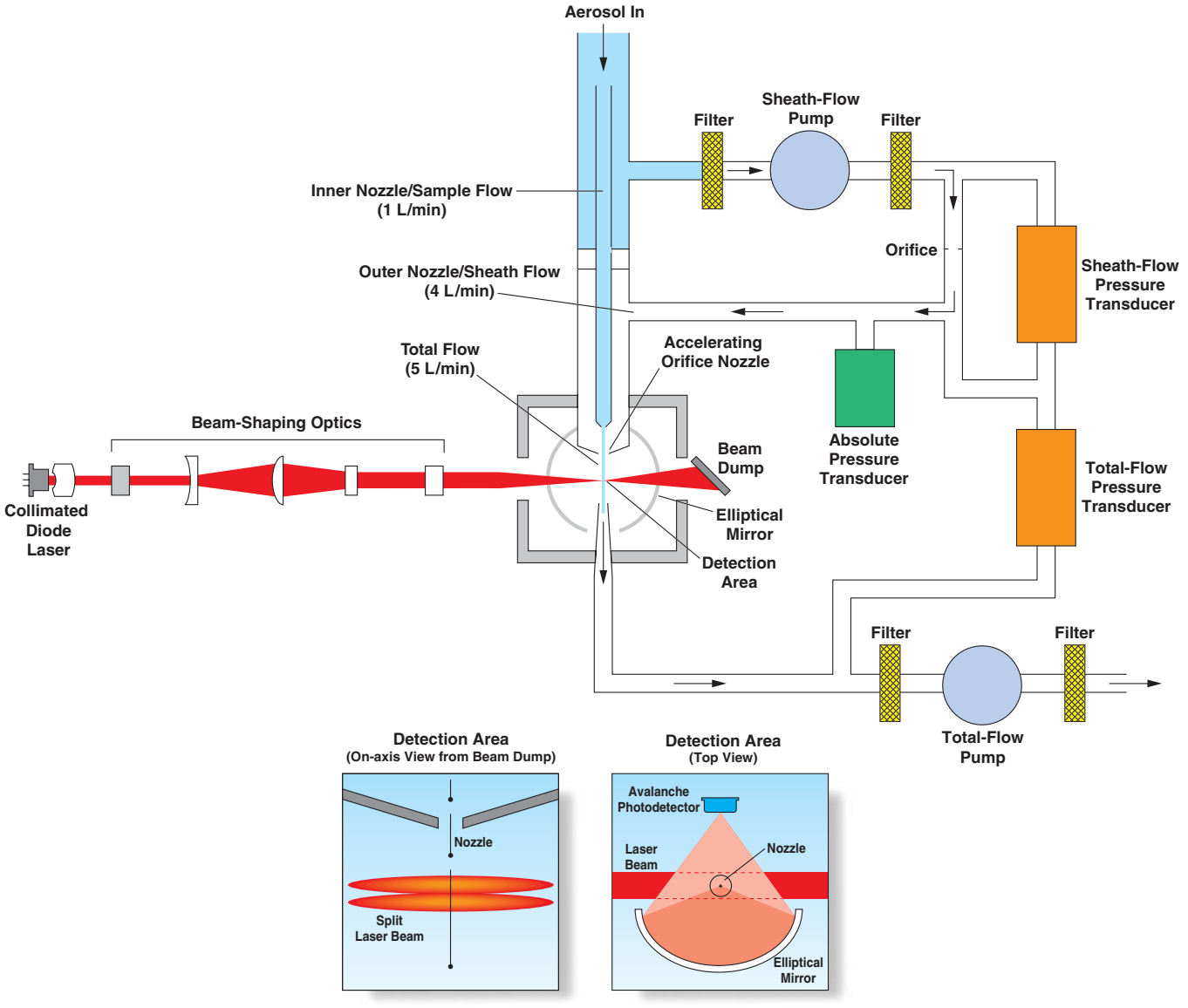
Operation

The APS accelerates the aerosol sample flow through an accelerating orifice. The aerodynamic size of a particle determines its rate of acceleration, with larger particles accelerating more slowly due to increased inertia. As particles exit the nozzle, they cross through two partially overlapping laser beams in the detection area.

Light is scattered as each particle crosses through the overlapping beams. An elliptical mirror, placed at 90 degrees to the laser beam axis, collects the light and focuses it onto an avalanche photodetector (APD). The APD then converts the light pulses into electrical pulses. The configuration of the detection area improves particle detection and minimizes Mie-scattering oscillations in the light-scattering-intensity measurements.

The use of two partially overlapping laser beams results in each particle generating a single two-crested signal. Peak-to-peak time-of-flight is measured with 4-nanosecond resolution for aerodynamic sizing. The amplitude of the signal is logged for light-scattering intensity.

The smallest particles may have only one detectable crest and are binned separately. In uncorrelated mode, these particles are displayed in the smallest size channel (less than 0.523 micrometer). Particles with more than two crests, indicative of coincidence, are also binned separately but are not used to build aerodynamic-size or light-scattering distributions.

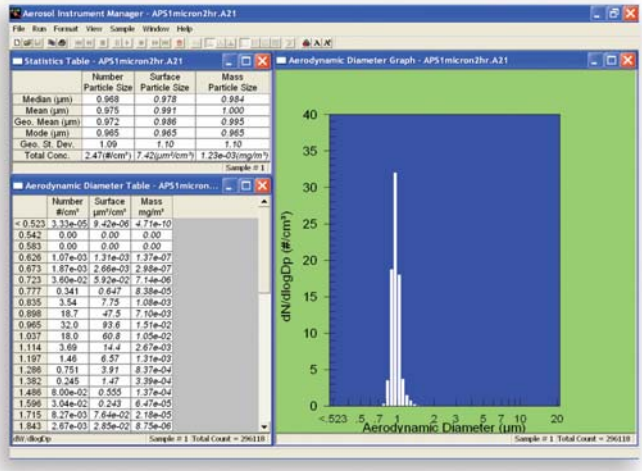


Software

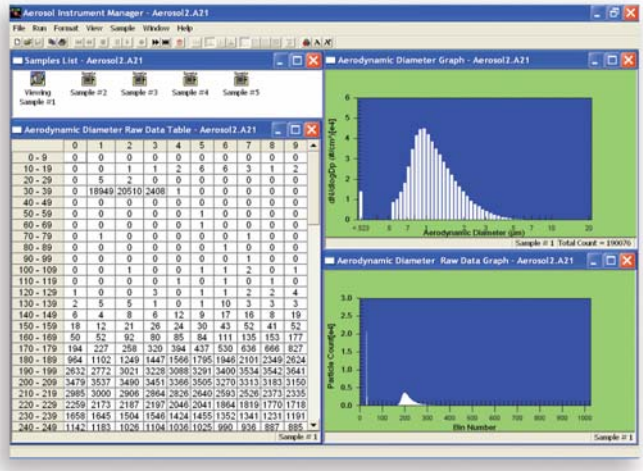
For setup and initial sampling, you can operate the Model 3321 APS without a computer using the front panel control knob and built-in display. However, to save, interpret, or print data, you must use a computer or some other data collection system.

The Model 3321 includes the Aerosol Instrument Manager software, a 32-bit program designed for use with Windows operating systems. The Aerosol Instrument Manager software controls instrument operation, plus it provides impressive file management capabilities and numerous choices for data display. Graphs and tables make it easy to view channel data as well as raw data, giving you the highest resolution possible. You can view all data types—time-of-flight, light-scattering, or correlated data—with the Aerosol Instrument Manager software. An export function allows easy transport of data files to spreadsheet or other applications for customized data handling. (See computer requirements on the next page.)

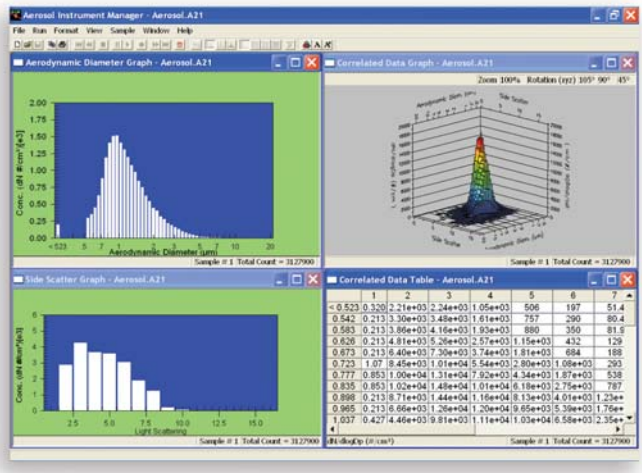
The APS communicates with Pentium®-based personal computers. (Computers are sold separately.)



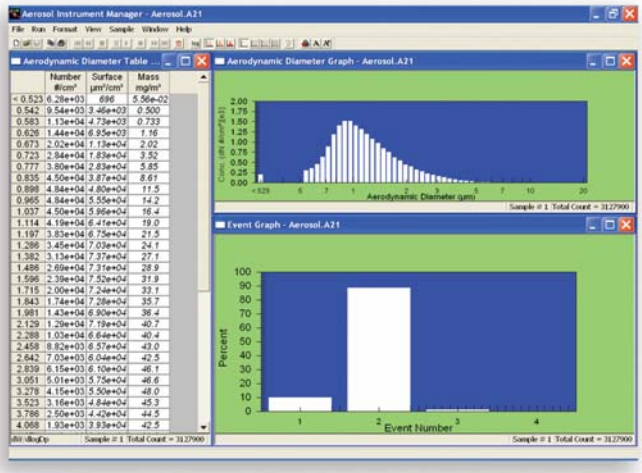
Aerodynamic diameter graph displayed with particle size and statistics tables



Aerodynamic diameter graph displayed with raw-data table and graph



Three graphs showing aerodynamic diameter, side scatter, and correlated data



Aerodynamic diameter and events displayed simultaneously

Specifications and More Details

Model 3321 Aerodynamic Particle Sizer Spectrometer

Measurement Technique Time-of-flight of individual particles measured in an accelerating flow field with a single, high-speed timing processor; coincidence detection achieved using a patented, double-crest optical system; particle size binning based on internally stored calibration curve

Particle Size Range 0.5 to 20 µm aerodynamic sizing, 0.37 to 20 µm optical detection (PSL equivalent)

Aerodynamic Size Resolution 0.02 µm at 1.0 µm, 0.03 µm at 10 µm

Display Resolution

- Particle Size: 32 channels per decade of particle size (logarithmic), 52 channels total; 1,024 bins of raw time-of-flight data (4 nsec per bin) in uncorrelated mode
- Light Scattering (log-compressed): 16 channels of light-scattering intensity (displayed); 64 channels of raw light-scattering data

Particle Type Airborne solids and nonvolatile liquids

Maximum Recommended Particle Concentration 1,000 particles/cm^3 at 0.5 µm with <5% coincidence; 1,000 particles/cm^3 at 10.0 µm with <10% coincidence; usable data up to 10,000 particles/cm^3

Minimum Particle Concentration 0.001 particle/cm^3

Concentration Range ±10% of reading plus variation from counting statistics

Maximum Processing Rate for Aerodynamic Sizing >200,000 particles/sec

Sampling Time Programmable and repeatable from 1 sec to 18 hr per sample; sampling schedules selected by user

Flow Rates*

Aerosol Sample	1.0 L/min ±0.1
Sheath Air	4.0 L/min ±0.1
Total	5.0 L/min ±0.2

Atmospheric Pressure Correction Automatic correction between 400 and 1,030 mbar (full correction between 700 and 1,030 mbar)

Laser Source 30-mW, 655-nm laser diode

Detector Avalanche photodetector (APD)

Front-panel Display 320 × 240 pixels

Operating Temperature 10 to 40°C (50 to 104°F)

Operating Humidity 10 to 90% R.H., noncondensing

Power 100 to 240 VAC, 50/60 Hz, 100 W, single phase or 24 VDC

Computer Requirements Pentium processor; Microsoft® Windows NT, 2000, or XP operating system; 10 Mb of free disk space (data files require additional disk space); CD-ROM drive; 256 Mb or more of RAM; pointing device

*Flow accuracy affects size and concentration measurements. Flow specifications are the minimum expected performance of a properly calibrated instrument at standard temperature and pressure.

APS configured with optional Aerosol Diluter for conditioning high-concentration aerosols.

APS with optional Impactor Inlet for MDI/DPI aerosol analysis.

Communications	RS-232 (9-pin) port
Outputs	
Digital I/O	15-pin port (3 inputs, 3 outputs) for external device control and two analog inputs (0 to 10 V)
Configurable Analog	BNC (0 to 10 V)
Analog Pulse	BNC
Digital Time-of-flight	BNC
Dimensions	
Aerosol Inlet	3/4 in. (O.D.)
Sensor (LWH)	38 cm × 30 cm × 18 cm (15 in. × 12 in. × 7 in.)
Weight	10 kg (22 lb.)

Specifications are subject to change without notice. TSI, the TSI logo, Aerodynamic Particle Sizer, and Aerosol Instrument Manager are trademarks of TSI Incorporated. Windows is a trademark of Microsoft Corporation. Pentium is a trademark of Intel Corporation.

To Order

Aerodynamic Particle Sizer® Spectrometer

Specify	*Description*
3321	APS sensor with Aerosol Instrument Manager® software

Optional Accessories

Specify	*Description*
3302A	Aerosol Diluter
3306	Impactor Inlet
3433	Small-Scale Powder Disperser

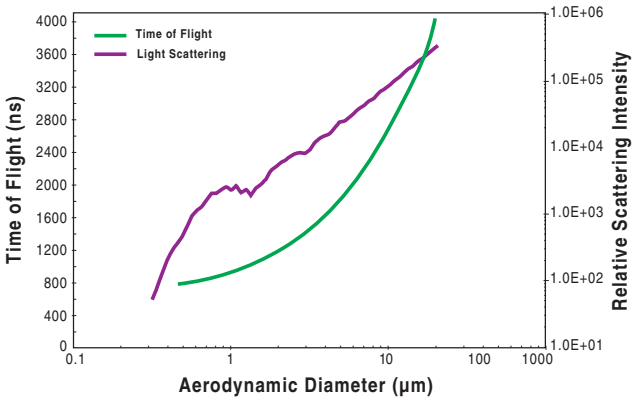
Please specify voltage requirements for Model 3433.

Upgrades

Model 3320 Aerodynamic Particle Sizer spectrometers may be upgraded to a Model 3321. Ask your TSI representative for additional information.

Optional Small-Scale Powder Disperser for classifying bulk powders with accuracy. (See manual for setup requirements.)

Typical Monotonic Time-of-Flight Response and Calculated Light-Scattering Response for APS 3321



The monotonic response curve of the time-of-flight measurement ensures high-resolution sizing over the entire particle size range.

Bibliography

Leith D and TM Peters, Concentration Measurement and Counting Efficiency of the Aerodynamic Particle Sizer 3321, *J. Aerosol Sci.* **34**(5):627-634 (2003).

Stein SW, PB Myrdal, BJ Gabrio, DR Oberreit, and TJ Beck, Evaluation of a New Aerodynamic Particle Sizer® Spectrometer for Size Distribution Measurements of Solution Metered Dose Inhalers, *J. Aerosol Medicine* **16**:107-119 (2003).

Oberreit DR, RL Holm, PP Hairston, FR Quant, and GJ Sem, Improvements in Particle Mass Distribution Measurement with the TSI 3320 APS, poster paper presented at American Association for Aerosol Research Conference (2001).

Secker DR, E Hirst, and PH Kaye, Measurements of Deformed Droplets and Droplets with Inclusions in an Aerodynamic Particle Sizer, *J. Aerosol Sci.* **31**(S1):S971-S972 (2000).

Leinert S and A Wiedensohler, APS Counting Efficiency Calibration for Submicrometer Particles, *J. Aerosol Sci.* **31**(S1):S404-S405 (2000).

Holm RL, R Caldow, PP Hairston, FR Quant, and GJ Sem, An Enhanced Time-of-Flight Spectrometer that Measures Aerodynamic Size Plus Light-Scattering Intensity, *J. Aerosol Sci.* **28**(S1):S11-S12 (1997).

Baron PA, Aerodynamic Particle Sizer Calibration and Use, Aerosols: Science, Technology, and Industrial Applications of Airborne Particles, Proceedings of the First International Aerosol Conference, pub. Elsevier, New York, NY, USA and Amsterdam, The Netherlands, 215-216 (1984).

Agarwal JK and LM Fingerson, Real-Time Aerodynamic Particle Size Measurement with a Laser Velocimeter, *TSI Quarterly* **V**(1) (1979).

TSI Incorporated
500 Cardigan Road , Shoreview, MN 55126 U.S.A.
Tel: 651 490 2811 **Toll Free:** 1 800 874 2811 **Fax:** 651 490 3824 **E-mail:** particle@tsi.com

TSI Germany
Neuköllner Str. 4, 52068 Aachen, Germany
Tel: +49 241 523030 **Fax:** +49 241 5230349 **E-mail:** particle-europe@tsi.com

TSI United Kingdom
1 Beach Road West, Portishead, Bristol BS20 7HR, United Kingdom
Tel: +44 1275 847837 **Fax:** +44 1275 842437 **E-mail:** tsiuk@tsi.com

For current information
www.tsi.com

P/N 1930087 Rev. C

Printed in U.S.A.