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PARTICLE INSTRUMENTS

Particle Sizers

Model 3321
Aerodynamic Particle Sizer® Spectrometer

Operation and Service Manual

P/N 1930092, Revision G
February 2012



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Model 3321

Aerodynamic Particle Sizer® Spectrometer

Operation and Service Manual

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Manual History

The following is a manual history of the Model 3321 Aerodynamic Particle Sizer® Spectrometer (Part Number 1930092).

Revision	Date
Preliminary	March 1997
Preliminary 2	September 1997
Final	November 1997
	October 1998
A	July 2000
B	December 2001
C	January 2002
D	August 2002
E	January 2004
F	July 2009
G	February 2012

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Warranty

Part Number 1930092 / Revision G / February 2012

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(effective June 2011)

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b. Pumps are warranted for hours of operation as set forth in product or operator's manuals;

c. Parts repaired or replaced as a result of repair services are warranted to be free from defects in workmanship and material, under normal use, for 90 days from the date of shipment;

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Safety

This section gives instructions to promote safe and proper handling of the Model 3321 Aerodynamic Particle Sizer® Spectrometer.

There are no user serviceable parts inside the instrument. Refer all repair and maintenance to a qualified technician. All maintenance and repair information in this manual is included for use by a qualified technician.

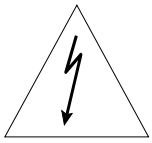
The Model 3321 Aerodynamic Particle Sizer® spectrometer is a Class I laser-based instrument. During normal operation, you will **not** be exposed to laser radiation. However, you must take certain precautions or you may expose yourself to hazardous radiation in the form of intense, focused, visible light. Exposure to this light may cause blindness.

Take these precautions:

- Do **not** remove any parts from the APS™ spectrometer unless you are specifically told to do so in this manual.
- Do **not** remove the APS™ housing or covers while power is supplied to the instrument.



W A R N I N G
The use of controls, adjustments, or procedures other than those specified in this manual may result in exposure to hazardous optical radiation.



W A R N I N G
High voltage is accessible in several locations within this instrument. Make sure you unplug the power source before removing the cover or performing maintenance procedures.

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Labels

The Model 3321 has eight labels as shown in Figure 1.

1. Laser Safety Information Label (back panel)
2. Serial Number Label (back panel)
3. Customer Service Label (back panel)
4. Danger High Voltage Label (Power Entry Module)
5. Danger High Voltage Label (Display Inverter)
6. Danger Laser Radiation (Optics Assembly)
7. Ground Label (inside bottom)
8. Danger High Voltage Label (Analog PC-Board)

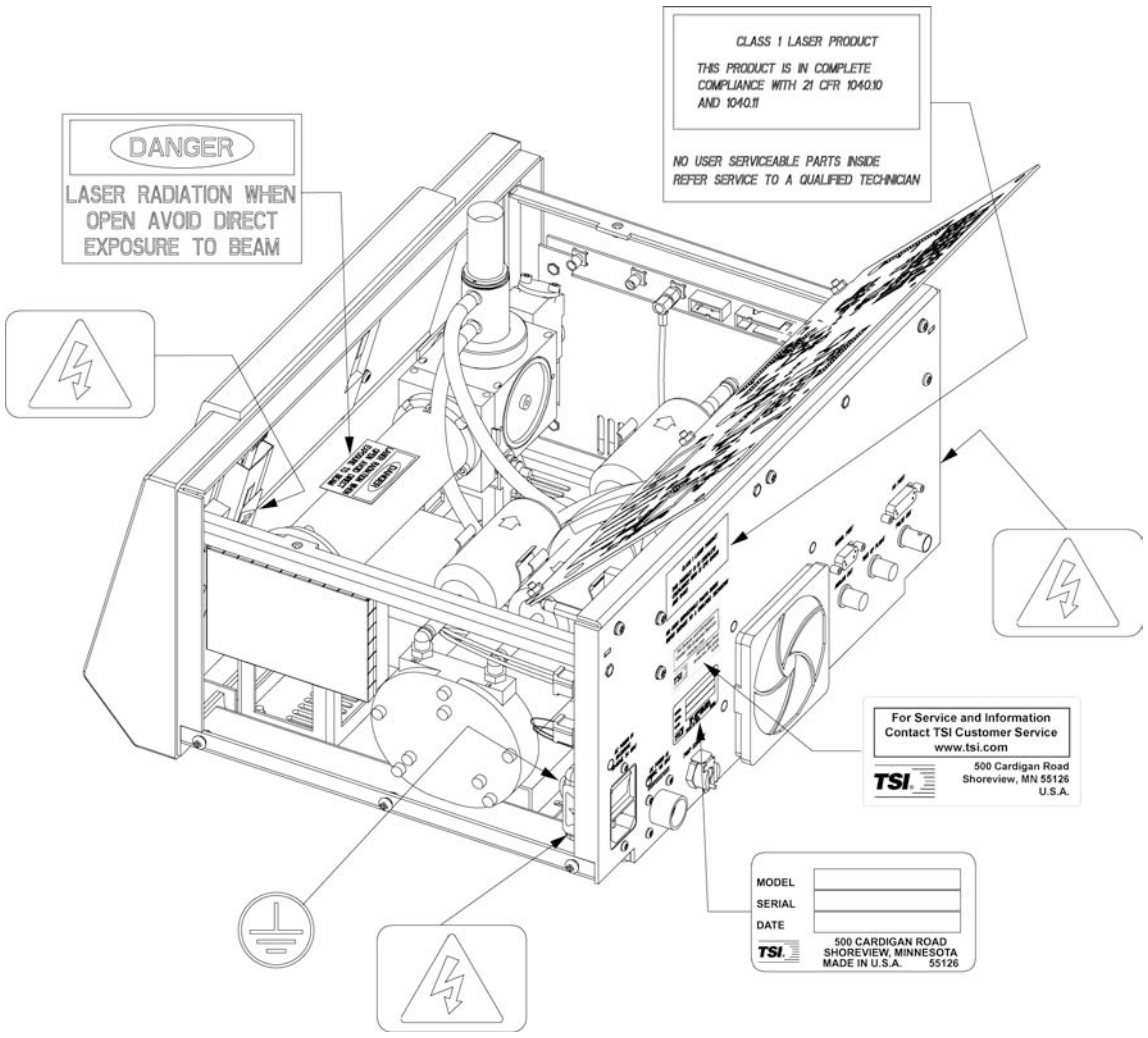


Figure 1
Location of Warning and Information Labels

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Description of Caution/Warning Symbols

The following symbols and an appropriate caution/warning statement are used throughout the manual and on the Model 3321 to draw attention to any steps that require you to take cautionary measures when working with the Model 3321:

Caution



Caution
Caution means ***be careful***. It means if you do not follow the procedures prescribed in this manual you may do something that might result in equipment damage, or you might have to take something apart and start over again. It also indicates that important information about the operation and maintenance of this instrument is included.

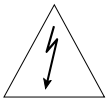
Warning



WARNING
Warning means that unsafe use of the instrument could result in serious injury to you or cause irrevocable damage to the instrument. Follow the procedures prescribed in this manual to use the instrument safely.

Caution or Warning Symbols

The following symbols may accompany cautions and warnings to indicate the nature and consequences of hazards:

	Warns you that uninsulated voltage within the instrument may have sufficient magnitude to cause electric shock. Therefore, it is dangerous to make any contact with any part inside the instrument.
	Warns you that the instrument contains a laser and that important information about its safe operation and maintenance is included. Therefore, you should read the manual carefully to avoid any exposure to hazardous laser radiation.
	Warns you that the instrument is susceptible to electro-static discharge (ESD) and ESD protection procedures should be followed to avoid damage.
	Indicates the connector is connected to earth ground and cabinet ground.

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About This Manual

Purpose

This is an operation and service manual for the Model 3321 Aerodynamic Particle Sizer® (APS™) Spectrometer.

Related Product Literature

- ***Aerosol Instrument Manager® Software for APS™ Sensors Manual*** (part number 1930064 TSI Incorporated)
- ***Model 3302A Diluter Manual*** (part number 1933786 TSI Incorporated)
- ***Model 3433 Small Scale Powder Disperser Manual*** (part number 1933769 TSI Incorporated)
- ***Model 3306 Impactor Inlet Manual*** (part number 1933787 TSI Incorporated)

Getting Help

To obtain assistance with this product or to submit suggestions, please contact:

TSI Incorporated
500 Cardigan Road
Shoreview, MN 55126 USA
Fax: (651) 490-3824
Telephone: 1-800-874-2811 (USA) or (651) 490-2811
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Submitting Comments

TSI values your comments and suggestions on this manual. Please use the comment sheet, on the last page of this manual, to send us your opinion on the manual's usability, to suggest specific improvements, or to report any technical errors.

If the comment sheet has already been used, send your comments to:

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CHAPTER 1

Product Overview

This chapter contains a product description of the Model 3321 Aerodynamic Particle Sizer® (APS™) spectrometer and a brief description of how the instrument operates.

Product Description

The Model 3321 APS™ spectrometer, shown in Figure 1-1, is a high-performance, general-purpose particle spectrometer that measures both aerodynamic diameter and light-scattering intensity. The Model 3321 provides accurate count size distributions for particles with aerodynamic diameters from 0.5 to 20 micrometers (μm). It detects light-scattering intensity for particles from 0.3 to 20 μm.

For setup and initial sampling, the Model 3321 can be operated without a computer. To save, interpret, or print data, however, it must be connected to a computer or some other data collection system. The Aerosol Instrument Manager® software with Model 3321 Module is included with the sensor to provide computer controlled operation and data interpretation.

The Model 3321 includes an LCD display and control knob. The control knob is a rotary, push-button encoder that gives you an easy way to scan through data on the LCD Display as well as to display and change settings.

Using the control knob you can select functions and read operating parameters from a menu displayed on the screen. Functions include start, stop, and length of measurement; parameters include inlet pressure, flow rate, and temperature. During the sampling process, the size distribution is shown on-screen in real time. You can also use the control knob to focus on a specific channel of the sensor and obtain detailed information about the concentration, particle size, and total particle count

Five LEDs on the front panel provide a visual indication of the status of important sensor functions.

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Figure 1-1
Model 3321 Aerodynamic Particle Sizer® Spectrometer

Applications

The Model 3321 APS™ spectrometer has application in the following areas:

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

How the 3321 Operates

Aerodynamic diameter is the most important size parameter because it determines a particle's airborne behavior. The Model 3321 is specifically engineered to perform aerodynamic size measurements in real time using low particle accelerations.

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Time-of-flight particle sizing technology involves measuring the acceleration of aerosol particles in response to the accelerated flow of the sample aerosol through a nozzle. 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, the time of flight between the Model 3321s two laser beams is recorded and converted to aerodynamic diameter using a calibration curve.

Previous time-of-flight spectrometers used two tightly focused laser beams, resulting in two distinct signals for each particle.

As shown in Figure 1-2, the Model 3321 overlaps the two laser beams, producing one double-crested beam profile. Each particle creates a single, continuous signal that has two crests. Particles with only one crest (phantom particles) or more than two crests (coincidence error) are not used in building size distribution calculations (they are logged for user-defined post analysis concentration correction). The result is an extremely accurate count distribution with almost no background noise to distort mass distribution calculations.

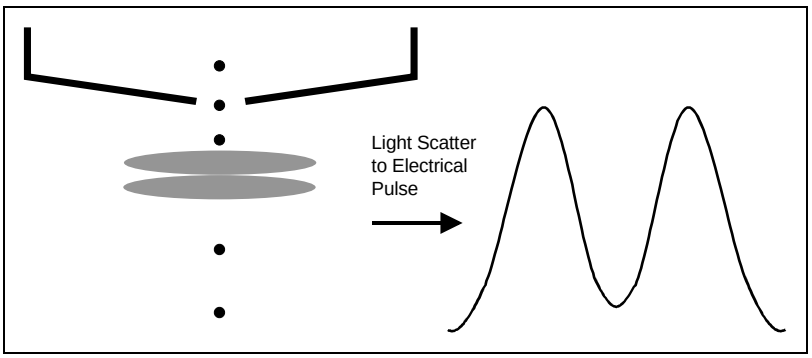


Figure 1-2
Double-Crested Signal From Particles Passing Through Overlapping Beams

The Model 3321 also provides a light-scattering measurement by examining each particle's side-scatter signal intensity. This measurement produces a second distribution that can be plotted against aerodynamic size to gain additional information about the aerosol sample.

Refer to Chapter 5, "Theory of Operation," for a detailed description.

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System History

The first APS™ spectrometer manufactured by TSI was designated the Model 3300. It consisted of a sensor with a parallel interface to an Apple II+ computer. This sensor was the first self-contained real-time instrument to give aerodynamic particle size in the 0.5 to 15 µm range. The sensor was based on work done by Agarwal and Fingerson (1979), and was in production from 1982 to 1987.

In 1987 the Model 3310 APS™ spectrometer was released. It used a serial interface to an IBM PC. This sensor had timer improvements allowing it to detect particles from 0.5 to 30 µm.

In 1993, the Model 3310 APS™ spectrometer received a face-lift and some minor engineering changes. This brought the instrument up-to-date in terms of electrical compliance and replaced obsolete parts. A new color scheme brought the APS™ spectrometer into line with the family of TSI scientific particle instruments.

The Model 3320 APS™ spectrometer is a complete redesign of earlier APS™ spectrometer models and began shipping in early 1997. This smaller, ruggedized sensor includes improvements such as: a front panel display, solid-state laser and avalanche photodetector, automatic flow control, barometric pressure compensation, and error reducing signal processing. Collecting and analyzing data from the Model 3320 is possible with the Windows® XP or Vista® (32-bit only), or Windows 7 (32 or 64-bit), Aerosol Instrument Manager® software.

The Model 3321 has several slight design and significant performance improvements over the 3320 for qualitative mass weighted distributions. The sample eduction nozzle has been redesigned to more effectively transport particles out of the detection region to the exhaust. This effectively eliminates recirculating particles under most operating conditions giving much better mass calculated distributions. The Model 3321 also has improved signal and data processing allowing more aerodynamic size resolution in correlated mode with only slightly less pulse height resolution than the Model 3320.

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CHAPTER 2

Unpacking and System Setup

This chapter provides information concerning the accessories shipped with the sensor and describes basic setup procedures.

Packing List

Table 2-1 provides a packing list of all items that should have been shipped to you as the APS™ spectrometer and accessory kit. Please compare the list to the items you received. If any items are missing, notify TSI immediately.

Table 2-1
Accessories Packing List

Qty	Description	Part No.
1	Model 3321 Sensor	332100
1	Model 3321 Aerodynamic Particle Sizer® Spectrometer Manual	1930092
1	Aerosol Instrument Manager® Software	390059
1	Aerosol Instrument Manager® Software for APS™ Sensors Manual	1930064
1	Line Cord	1303053 *or* 1303075
1	Serial Cable (9 pin, M–F, 4 meter)	962002
1	USB-to-Serial Converter	1102138
24 in.	Tubing 5/16 × 3/16	3001248
1	Fitting, Pump Exhaust Adapter	1601836

Mounting the Sensor

The Model 3321 APS™ spectrometer requires no special mounting requirements other than the ventilation requirements (see below). The cabinet has four non-marking rubber feet that give the instrument a good grip on clean, level surfaces. The rubber feet (Figure 2-1) are installed in the cabinet using integrated 8-32 UNC threaded fasteners and can be removed (by unscrewing) to allow other mounting fasteners to be used.

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***Note**: If the cabinet is mounted to a plate, drill holes in the plate to match the ventilation holes in the bottom of the cabinet or use standoffs to raise the bottom of the cabinet at least ½ inch (1.2 cm) above the mounting plate.*

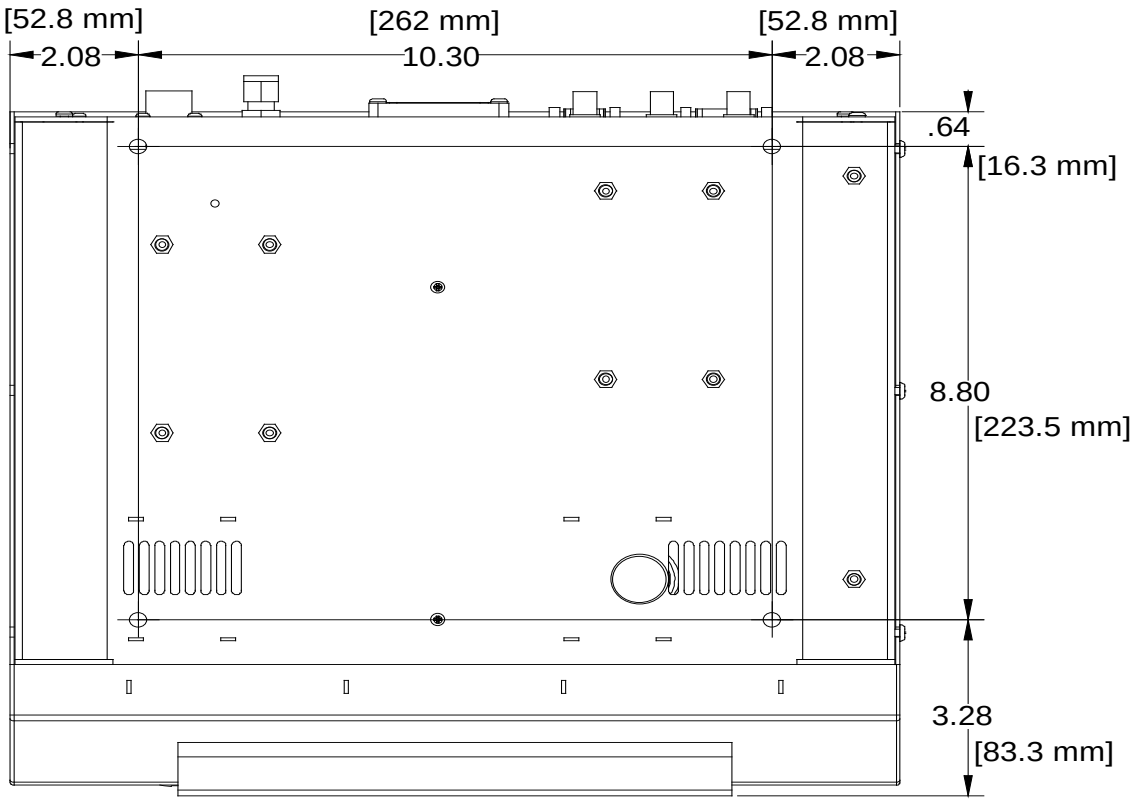


Figure 2-1
Remove the Rubber Feet on the Base Plate to Mount the Model 3321 on Another Surface

Ventilation Requirements

The APS™ Sensor cabinet is designed to be cooled by room air drawn in from the sides and bottom of the cabinet and exhausted through the back of the cabinet.

As shown in Figure 2-2, the cabinet should be installed with at least 2-inch (50 mm) clearance between the back panel and any other surface. The sides should have at least 2-inch (50 mm) clearance between the cabinet and any other surface. Most important, the cabinet should be set on a clean, hard surface so that the exhaust air can move freely from the cabinet.

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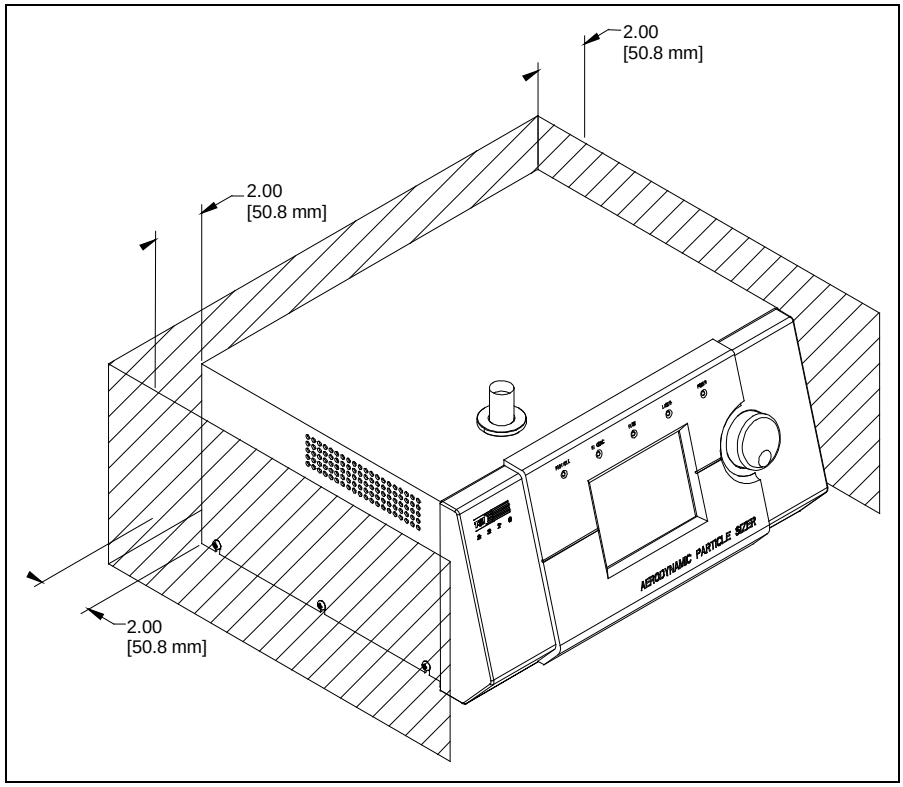


Figure 2-2
Install the Sensor on a Clean, Hard Surface and Provide Adequate Clearance for Ventilation

Power Connection

Connect the AC power cord (supplied) to the AC POWER IN connection on the back of the Model 3321 and then into an available power outlet. It is not necessary to select the correct voltage, the sensor accepts line voltage of 85 to 260 VAC, 50 to 60 Hz, 100 W max., single phase. The connection is self regulating.

Toggle the on/off switch at the POWER connection to the on position to verify the sensor has power.

Alternately, connect 24 VDC to the DC POWER IN connection. Contact TSI to order the necessary connector.

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Connecting the Computer

Connect the serial port of an IBM-compatible computer to the SERIAL PORT connector on the back of the Model 3321 (Figure 2-3). Use the 4-meter cable provided. If you need a longer cable, use a standard IBM 9-pin, serial extension cable.

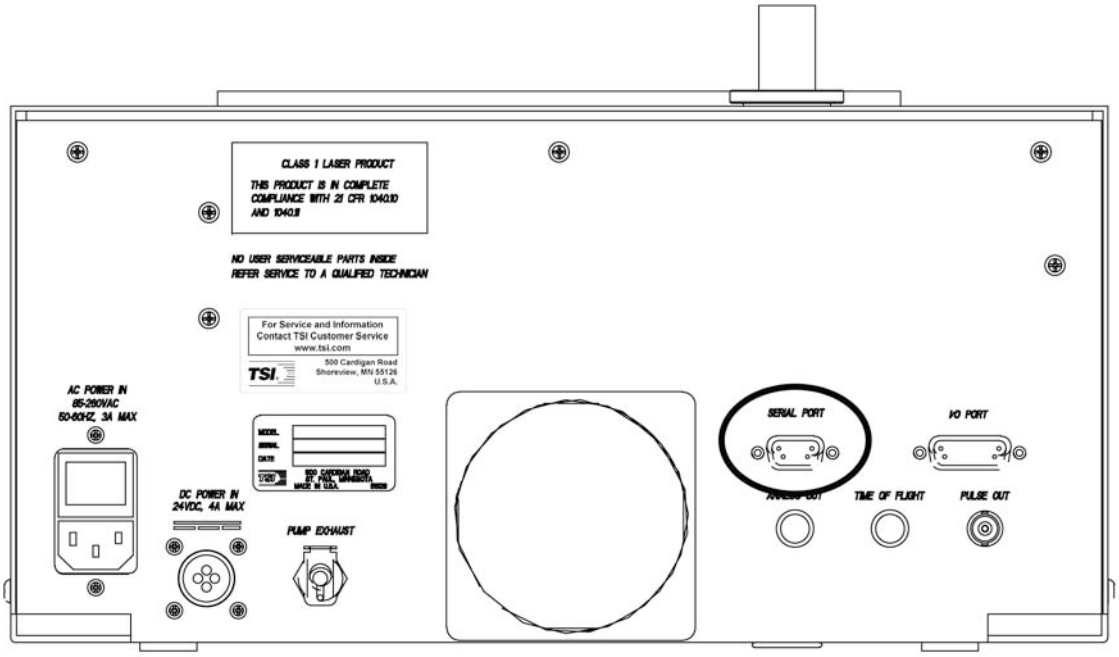


Figure 2-3
Serial Port Connector on the Back of the Model 3321 APS™ Spectrometer

I/O Port

The APS™ spectrometer has a 15-pin, D-subminiature connector port (Figure 2-4) labeled **I/O PORT**. This port provides three digital input and three digital output pins that can be used to control associated equipment or set device using commands described in Appendix C. This port also has two analog input pins to allow data logging of analog voltages from external devices such as temperature or relative humidity sensors.

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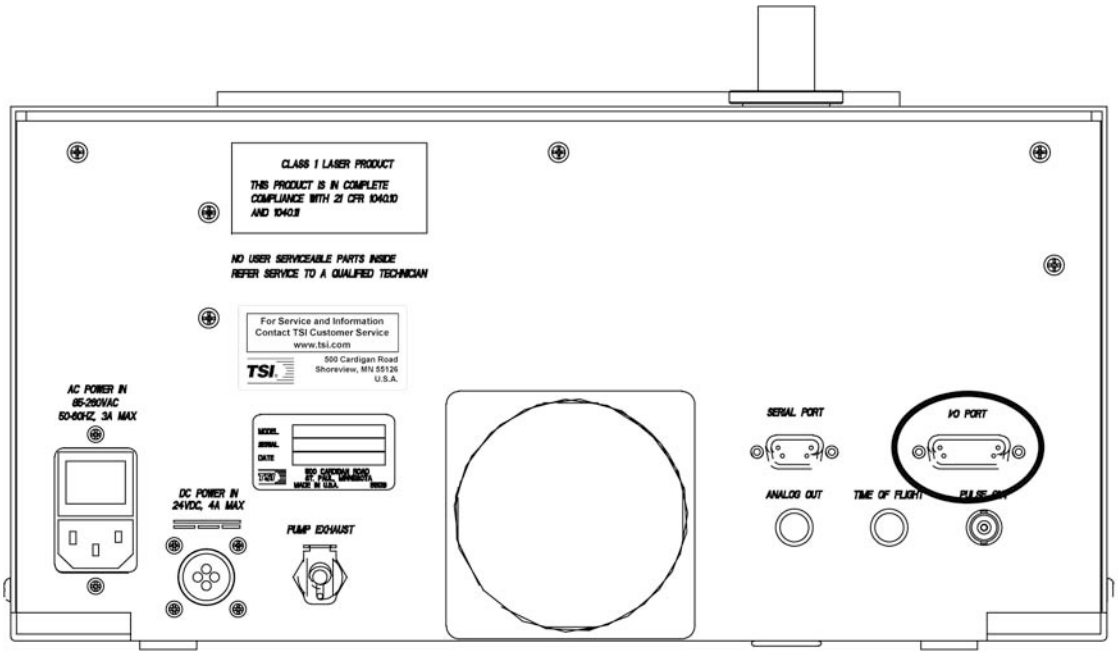


Figure 2-4
I/O Port of the Model 3321 APS™ Spectrometer

BNC Connectors

There are three BNC connectors on the Model 3321 for output of the following signals. Refer to Chapter 3 for a detailed description of each of the BNC connectors.

- Analog Out
- Time-of-Flight
- Pulse Out

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CHAPTER 3

Description of the APS™ Spectrometer

This chapter describes the front panel, back panel and internal components of the Model 3321 Aerodynamic Particle Sizer® (APS™) Spectrometer.

The front panel features LEDs to provide basic on/off status for five instrument functions and an LCD display and control knob that work together to provide continuous real-time sampling information and access to a menu of system functions. Through this menu you can perform initial sample setup and view detailed instrument status.

The back panel provides power and communications connections as well as sample exhaust outlet.

Internal components consist of the flow system, the optics system, and the signal processing electronics.

Front Panel

The main components of the front panel are the LCD display, the control knob, and the five status LEDs as shown in Figure 3-1.

The LCD display is used as a local interface to the APS™ sensor. Although most users will want to use a computer connected to the APS™ spectrometer to display, collect and save data, the LCD display allows the user to change settings and display data in various formats at the sensor itself.

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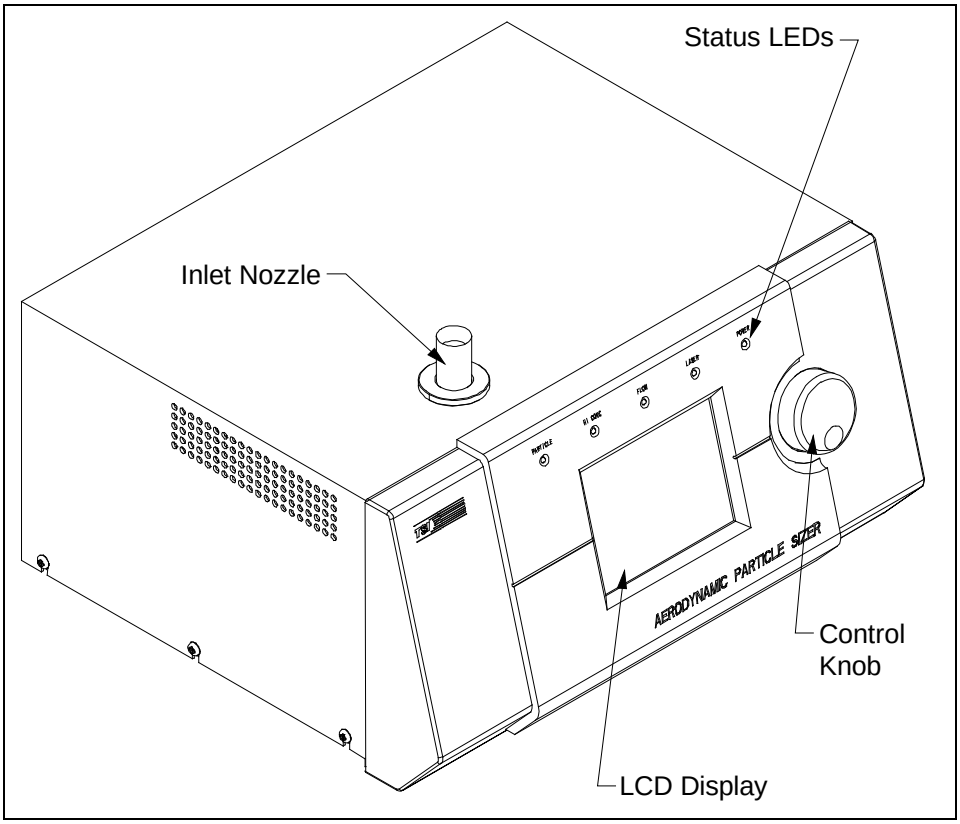


Figure 3-1
Front Panel of the Model 3321 APS™ Spectrometer

The 320 × 240 pixel LCD display provides continuous real-time display of sample data.

Sample data includes:

- Size distribution.
- Concentration.
- Mean aerodynamic particle size.
- Total particle count.

There are several operations you can perform using the control knob with the display.

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To turn the display on	Press or rotate the control knob.
To view information about a specific channel displayed on the graph	Turn the control knob so that the cursor is positioned on the bar of the appropriate channel. The channel size and concentration are displayed at the bottom of the screen. The scale automatically changes to accommodate the sample range and mode.
To clear the accumulator	Turn the control knob all the way to the right of the display. This will cause three buttons to appear at the bottom of the screen. Continue turning until the Clear button is highlighted, then press the control knob.
To start or restart a sample	Turn the control knob all the way to the right of the display. This will cause three buttons to appear at the bottom of the screen. Continue turning until the Start button is highlighted, then press the control knob.
To change from the graphic display to the system Menu	Turn the control knob all the way to the right of the display. This will cause three buttons to appear at the bottom of the screen. Continue turning until the Menu button is highlighted, then press the control knob. The Menu is shown in Figure 3-2, and allows you to select various sampling parameters and view many system parameters. Refer to Chapter 4 for a description of how to make selections and change values on the Menu.

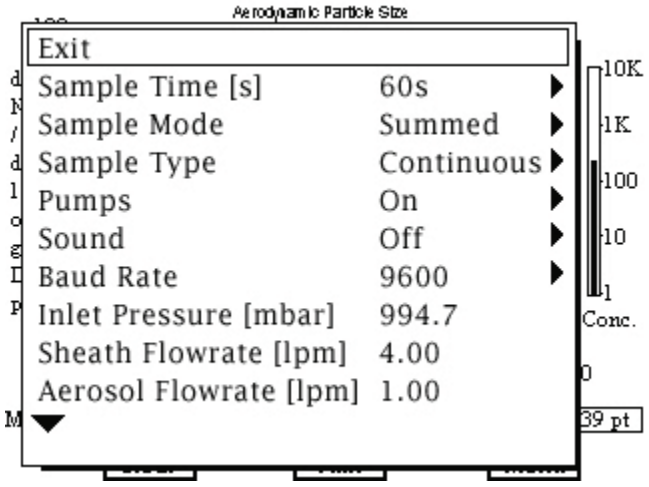


Figure 3-2
Model 3321 Menu Layout

Fine adjustment of the control knob (i.e., moving from one channel to the next) is best accomplished using the outer edge of the knob. Faster movement (i.e., scrolling across the screen to reach the menu) is best accomplished using your index finger and the dimple in the knob.

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Inlet Nozzle

The inlet nozzle on the top of the Model 3321 is designed so that aerosol can be sampled from a chamber or open air with good efficiency. Tubing can be attached to the inlet to sample when necessary. The inlet is .746 inches (18.9 mm) in diameter for use with ¾-inch Swagelok®-type connectors or with slightly smaller inner diameter flexible tubing.

***Note**: Conductive tubing is recommended for use with the APS™ spectrometer to minimize particle loss due to electrostatic charge. Suitable tubing is available from TSI.*

Indicators

There are five status LEDs on the APS™ spectrometer: PARTICLE, HI CONC, FLOW, LASER, and POWER.

- The amber PARTICLE LED blinks once each time a particle passes through the sensor. In normal room air, the LED will appear to be lit constantly. When sampling aerosols in low concentrations, the LED will appear to flicker.
- The amber HI CONC LED indicates that the concentration of particles being sampled is above the recommended level to prevent coincidence (see Chapter 5, "Theory of Operation"). When this LED is lit, many of the particles are ignored in the counting process since they cannot be accurately sized. The default setting is 1000 particles/cm^3.
- The green FLOW LED indicates that both the sample and sheath airflows are within their specified range.
- The green LASER LED indicates that the laser is on and functioning properly. A flashing LED may mean that the laser is not able to operate at the set power. See SL command.
- The green POWER LED indicates that power is supplied to the instrument.

Back Panel

As shown in Figure 3-3, the back panel of the APS™ spectrometer Model 3321 allows for power and data connections. The back panel also has a pump exhaust port and a fan. The cooling fan has a finger guard to prevent fingers, pens, etc., from being poked into the fan.

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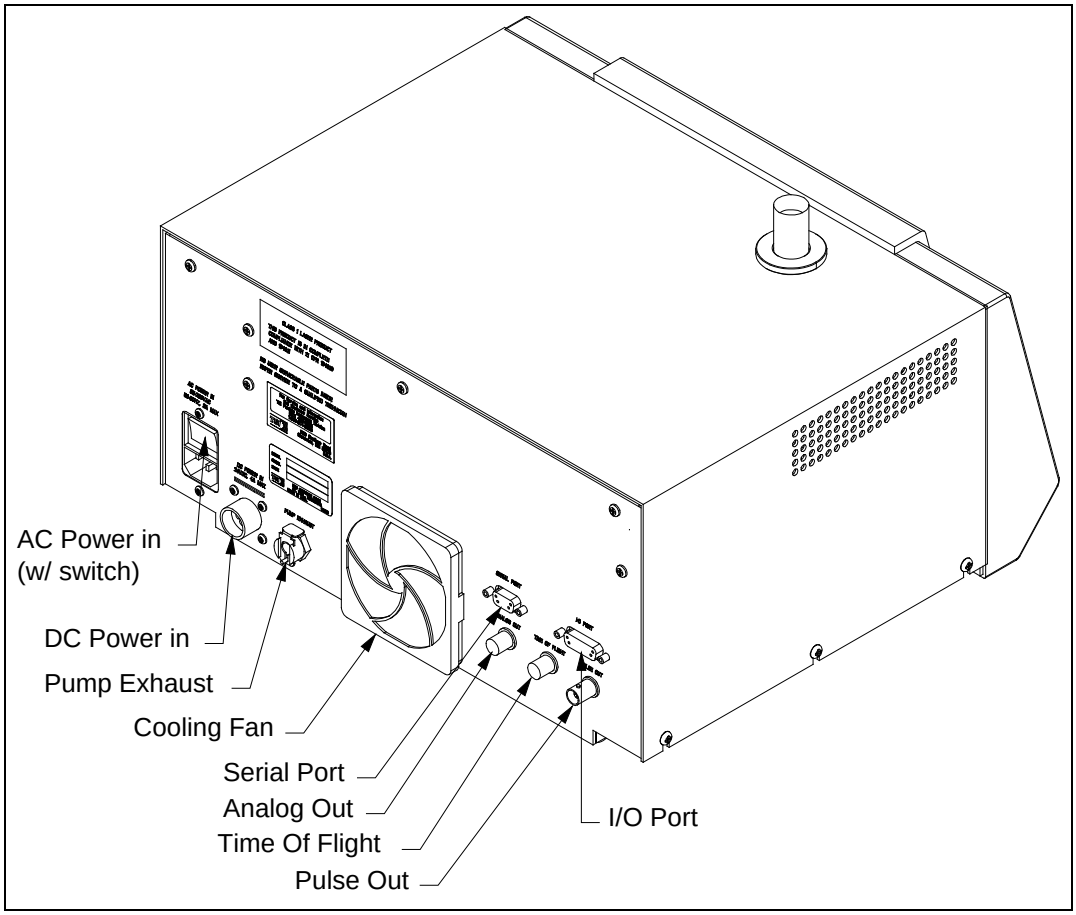


Figure 3-3
Back Panel of the Model 3321 APS™ Spectrometer

AC Power Connector

The AC Power Connector accepts the line cord (supplied) to provide AC power to the sensor. The connector has a built-in on/off switch. Power consumption and line voltage specifications can be found in Appendix D.

Note: *Make certain the line cord is plugged into a grounded power outlet. Position the Model 3321 so the power cord connector is easily accessible.*

DC Power Input

The DC power connector is a quarter-turn quick-connect entry point that allows you to power the APS™ spectrometer with a 22 to 26 VDC (24 VDC nominal) 4A max. power source. This power could be supplied by aircraft power or two 12 VDC automotive batteries in series. Contact TSI for the adapter cable (TSI P/N 1035551), and instructions on using this power method.

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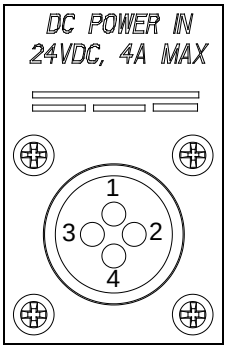


Figure 3-4
24V DC Power Input Pin Designations

Table 3-1
Power Connections for 24V DC Power Input

Pin Number	Signal	
1	GND Chassis	GRN/YEL
2	+24V	Blue
3	GND	Brown Shield
4	Chassis	Shield

Pump Exhaust

Sample aerosol is exhausted through the Exhaust Port.

The pump exhaust connector is a ¼-inch Swagelok-style connector that allows control of the exhaust flow. The exhaust can be vented to a hood or connected in line to equalize pressure when sampling from a chamber or in an aircraft. The exhaust flow is 5 to 6 L/min. Make certain the exhaust tube allows the exhausted sample to flow freely (check for crimps and constrictions).

If the aerosol sample is exhausted without tubing, make certain you do **not** block the Pump Exhaust.

Serial Port

The Serial Port is a standard RS-232 serial connection that allows communications between the system computer and the Model 3321 APS™ spectrometer. Serial commands are sent to and from the computer to provide instrument status and collect data information.

If you are developing specialized software for the APS™ spectrometer or performing troubleshooting, refer to Appendix C, "Using Serial Data Commands,". This appendix provides a complete description of the Serial Data Commands, as well as signal connections.

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I/O Port

This 15-pin, D-subminiature connector port provides three digital input and three digital output pins. It allows various signals to be sent to a data logger or control switches. Refer to Appendix C, "Using Serial Data Commands," for serial commands to control the I/O Port. This port also has two analog input pins to allow data logging of analog voltages for external devices such as temperature sensors or relative humidity sensor.

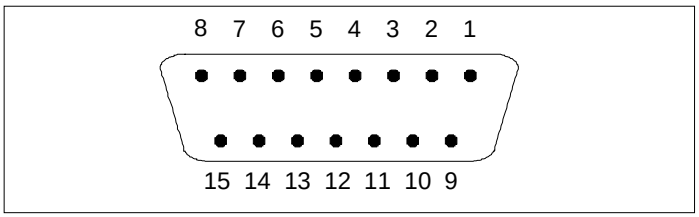


Figure 3-5
I/O Port Pin Designations

Table 3-2
Signal Levels for I/O Port Configurations

Pin Number	I/O Signal	Levels
1	Digital Input 1	0, 5V
2	Digital Input 2	0, 5V
3	Digital Input 3	0, 5V
4, 5	Digital GND	Ground
6	+5V Digital Supply Out	5V
7	Analog Input 1	0 to 10V
8	Analog Input 2	0 to 10V
9, 10	Digital GND	Ground
11	Digital Output 1	0, 5V
12	Digital Output 2	0, 5V
13	Digital Output 3	0, 5V
14	Digital GND	Ground
15	Analog GND	Ground

BNC Connectors

Three BNC connectors provide the following signals.

Analog Out

The Analog Out BNC connector provides a programmable analog signal that can be sent to a strip chart recorder or other analog device. Refer to Appendix C, "Using Serial Data Commands," for serial commands that control the signal output.

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Time of Flight

The Time of Flight BNC connector provides a digital signal corresponding to the gated level of the raw analog time of flight signal for each particle.

Pulse Out

The Pulse Out BNC connector provides amplified raw signals from the photodetector. This signal can be used with an oscilloscope, for example, to examine secondary characteristics of the pulses.

Internal Components

The location of the functional systems and electronics of the Model 3321 APS™ spectrometer are shown in Figure 3-6 and include:

- ❑ Digital PC board
- ❑ Analog PC board
- ❑ Sheath flow pump
- ❑ Total flow pump
- ❑ Filters
- ❑ Power Supply
- ❑ Optics
- ❑ Detector PC board
- ❑ Laser PC board
- ❑ Power PC board

The only serviceable components of the Model 3321 APS™ spectrometer are the filters, which require routine maintenance (refer to Appendix A). For a general description of these components, refer to Chapter 3, "Description of the APS™ Spectrometer." For a more detailed description, refer to Chapter 5, "Theory of Operation."

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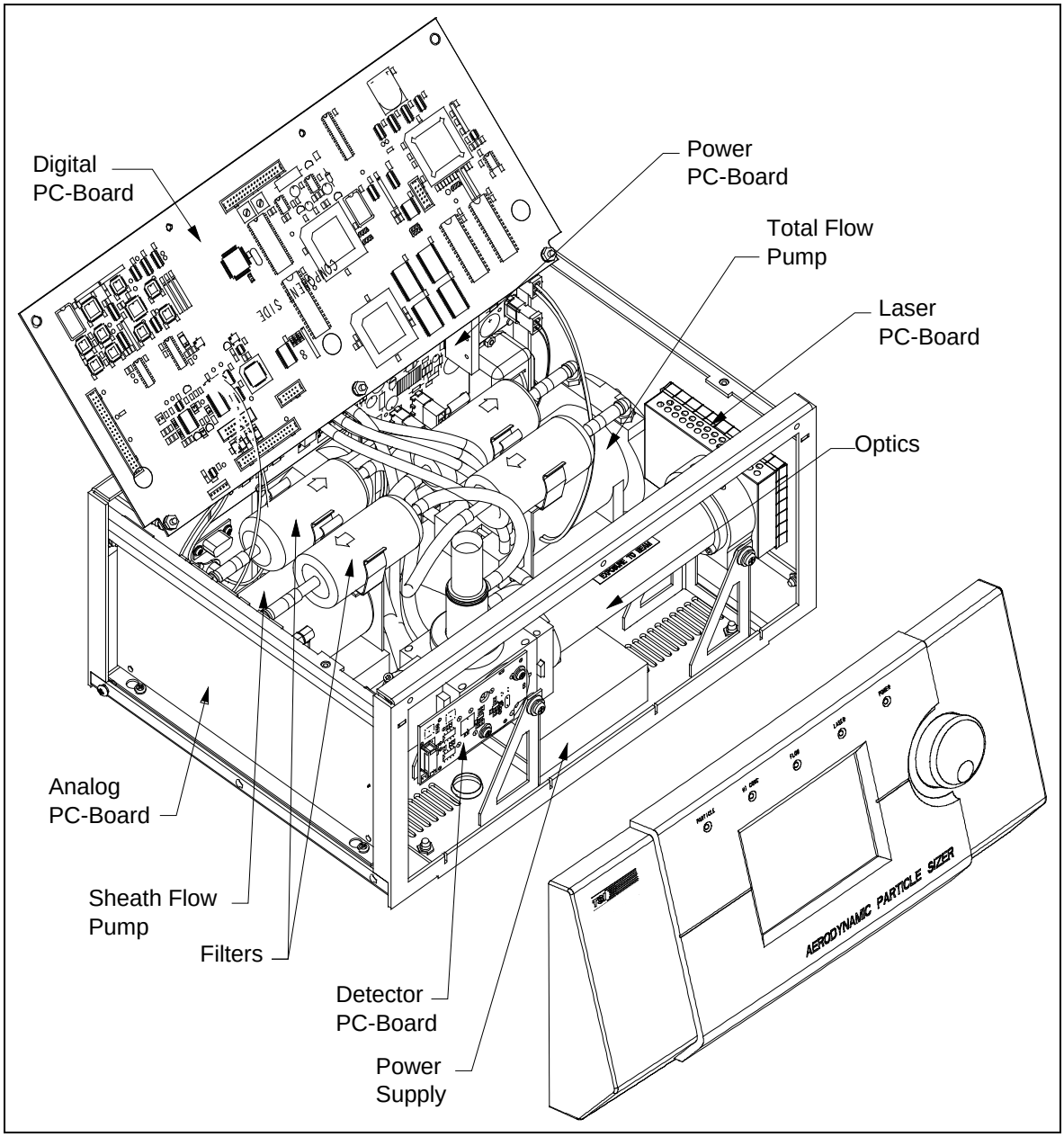


Figure 3-6
Internal Diagram of the Model 3321 APS™ Spectrometer

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CHAPTER 4

APS™ Spectrometer Operation

This chapter describes how to set up and operate the Model 3321 at the sensor using the control knob and LCD display. You can perform the same operations from your computer using the Aerosol Instrument Manager® software with Model 3321 module.

In most cases you will want to set up initial sampling parameters at the sensor and then, once you have verified that sampling conditions are as desired, use the computer to collect, store, interpret, and print the sample data. (Refer to the *Aerosol Instrument Manager® Software for APS™ Sensors Manual* (P/N 1930064) for more information on operating the software.)

Although you can set up parameters and begin sampling at the APS™ sensor, the data shown on the LCD display is not stored, nor can it be sent to a printer. To save or print data, you must collect it using the computer interface and the Aerosol Instrument Manager® software.

The data displayed on the front panel may not exactly match data recorded with the Aerosol Instrument Manager® software due to rounding differences. Also, concentration displayed for <0.523 µm on the front panel includes event 1 data and may not match the concentration reported by the Aerosol Instrument Manager® software. When performing any critical or detailed data analysis, Aerosol Instrument Manager® software should be used. The front panel LCD display should only be used as a remote indicator of instrument and measurement status.

Sample Setup

These instructions assume that the APS™ spectrometer is connected to an appropriate power source and the power on/off switch on the back panel is switched to the on position.

1. Turn the control knob clockwise until the cursor runs off the right side of the display and the CLEAR, START, and MENU buttons appear. Continue turning the control knob until Menu

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button is highlighted; then press the control knob. The menu shown in Figure 4-1 appears.

2. Turn the control knob clockwise until the cursor falls on the Sample Time[s] command. Press the control knob once. Turn the control knob clockwise or counterclockwise until the sample time is set as desired. Then press the control knob to lock in that time.

3. Turn the control knob to select other commands or verify other settings. All of the items on the menu are described in Table 4-1. When you are finished using the menu, turn the control knob until the cursor stops on the Exit command at the top or bottom of the menu and press the control knob to return to the graphical display.

4. After you exit the Menu, turn the control knob to highlight the START button and press the control knob. The APS™ spectrometer will immediately begin sampling according to the parameters set on the menu.

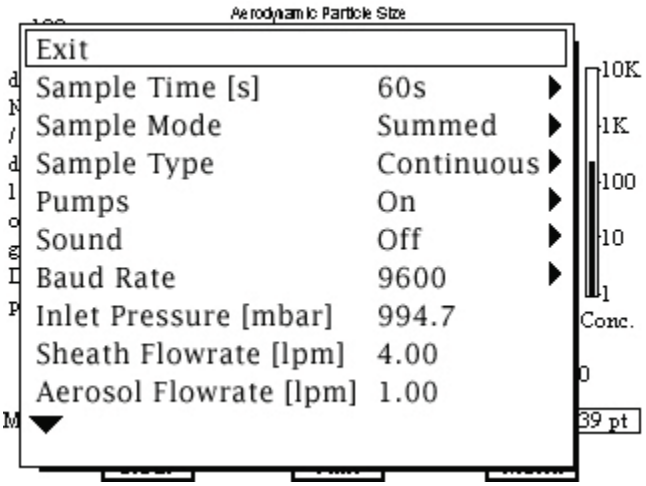


Figure 4-1
APS™ Spectrometer Menu

5. Monitor the display to verify that sampling is progressing as you intended. You can monitor the display until the sample period ends or go to the computer to begin a sample from there.

   To inspect the sample data that has been collected for a specific channel, turn the control knob until the cursor falls on the channel you want to inspect. The channel's particle diameter and concentration in particles per centimeter^3 are displayed below the graph. Inspect other channels in the same manner.

6. Return to the Menu to modify the sample time or set other parameters as necessary until you are satisfied that sampling is set up as desired.

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Table 4-1
Description of Menu Items

Command	**Function** (*see also Appendix C for serial commands related to Menu Items*).
Exit	Exit the Menu and display graphical information.
Sample Time [s]	Set the total sample time. Can be set from 1 to 64,800 seconds (18 hours) in summed mode and from 1 to 300 seconds in average mode. Default is 20 seconds.
Sample Mode	Select **Summed|Averaged|Sum.Corr.** Summed displays the total number of particles sampled for each channel. Averaged displays a calculated average number of particles sampled for each channel. Sum. Corr will not show useable data at the sensor's LCD display. Use the APS™ spectrometer software to interpret. The default is Summed.
Sample Type	**Continuous|Single**. Continuous sampling begins a new sample immediately following the end of the previous sample. Single sample takes one sample for the set sample time and then stops.
Pumps	Turn pumps on and off. Default is on.
Sound	Turn on and off the beeping sound that is activated when the Hi-Conc. limit is exceeded. The default is on. If necessary, set (reset) the limit from the computer software setup program as described in Chapter 5 or using a serial data command as described in Appendix C.
Baud Rate	Select the baud rate at which the sensor will communicate with your computer. Use the control knob to select: 38400, 19200, or 9600. The default is 9600. ***Note:*** *38,400 must be used in correlated mode.*
Inlet Pressure [mbar]	Displays the current inlet pressure of the sample. This value should correspond to your atmospheric pressure. No default value.
Sheath Flowrate [lpm]	Displays the flow rate of the outer nozzle (sheath) aerosol. This reading will approximate 4.0 liters (±0.1) per minute. No default value.
Aerosol Flowrate [lpm]	Displays the flow rate of the inner nozzle (sample) aerosol. This reading will approximate 1.0 (±0.1) liter per minute. No default value.
Total Flowrate [lpm]	Displays the total flow rate of the sample aerosol. This reading will approximate 5 (±0.2) liters per minute (unless sheath or sample flow has been modified). Used to verify proper sensor operation. No default value.
Optics Temperature [°C]	Displays the temperature of the optics components. Used to verify proper sensor operation. No default value. ***Note:*** *This is also the APD detector temperature.*
Cabinet Temperature [°C]	Displays the temperature inside the APS™ spectrometer. No default value.
Laser Current [mA]	Displays the laser current in milliamps. Range should be between 0 and 100 mA**.** This value rises as the laser ages. Used for diagnostic purposes.

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Command	**Function** (*see also Appendix C for serial commands related to Menu Items*).
Laser Power [%]	Displays the percent of laser power used from 0 to 100%. Default is 75%. This value is field selectable but should not be changed except for diagnostic purposes. Changing this setting will alter the calibration. Refer to Chapter 5 or Appendix C.
Laser	Turn the laser on and off. Default is on. Generally, the laser is on whenever the instrument is running. You might want to turn it off for diagnostic purposes.
APD Voltage [V]	Displays the voltage of the Avalanche Photodetector (APD). Changing the APD voltage with this setting disables APD autocalibration (see below).
APD Max Vop [V]	When the APS™ spectrometer is powered up, the APD voltage is set to APD Max Vop based on the temperature of the APD. This temperature compensated setting should give the APS™ spectrometer the maximum sensitivity to small particles.
APD Autocalibration	Enables the APD temperature compensation algorithm when set to On. When set to Off, the APD voltage will not change with APD temperature. This setting will always be enabled when the instrument is first powered on.
Alarm Level [pt/cm^3]	Level of total particle concentration at which the APS™ spectrometer will issue a high concentration alarm. The HI CONC led on the front panel will be turned on and the high concentration flag (see RF command) will be set; and if the sound is turned on, the APS™ spectrometer will beep. Default is 1000.
End of Sample Pause	When enabled, this setting freezes the display for 4 seconds at the end of a sample when in continuous sample mode. This gives you a chance to view the sample or to select Pause from the main menu. Default is off.
Display Image	Set the image Positive/Negative for the LCD display. Positive is black letters on light background. Negative is white letters on dark background.
Firmware Version	Displays the version number of the firmware installed in the APS™ spectrometer.
Exit	Exit the Menu and display graphical information.

Collecting Data

After the Model 3321 APS™ spectrometer is set up and operating as desired, use the computer and Aerosol Instrument Manager software to collect, save, interpret, and print sample data. Refer to the *Aerosol Instrument Manager® Software for APS™ Sensors Manual* (P/N 1930064) for more information on operating the software.

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CHAPTER 5

Theory of Operation

The Model 3321 is a time-of-flight spectrometer that measures the velocity of particles in an accelerating airflow through a nozzle.

In the instrument, particles are confined to the centerline of an accelerating flow by sheath air. They then pass through two broadly focused laser beams, scattering light as they do so. Side-scattered light is collected by an elliptical mirror that focuses the collected light onto a solid-state photodetector, which converts the light pulses to electrical pulses. By electronically timing between the peaks of the pulses, the velocity can be calculated for each individual particle.

Velocity information is stored in 1024 time-of-flight bins. Using a polystyrene latex (PSL) sphere calibration, which is stored in non-volatile memory, the Model 3321 APS™ spectrometer converts each time-of-flight measurement to an aerodynamic particle diameter. For convenience, this particle size is binned into 52 channels (on a logarithmic scale).

The particle range spanned by the APS™ spectrometer is from 0.5 to 20 µm in both aerodynamic size and light-scattering signal. Particles are also detected in the 0.3 to 0.5 µm range using light-scattering alone, and are binned together in one channel.

The APS™ spectrometer is also capable of storing correlated light-scattering-signal data and time-of-flight data.

Sample Flow Path

The sample flow path in the Model 3321 APS™ spectrometer is illustrated in Figure 5-1. Aerosol is drawn into the inlet and is immediately split into a sample flow, through the inner nozzle, and a sheath flow, through the outer nozzle.

The sheath flow is filtered and controlled by the sheath flow pump. The sheath flow is controlled by measuring the pressure drop through a sharp-edged sapphire orifice. This pressure drop is

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converted by the firmware to a volumetric flow with compensation for absolute atmospheric pressure.

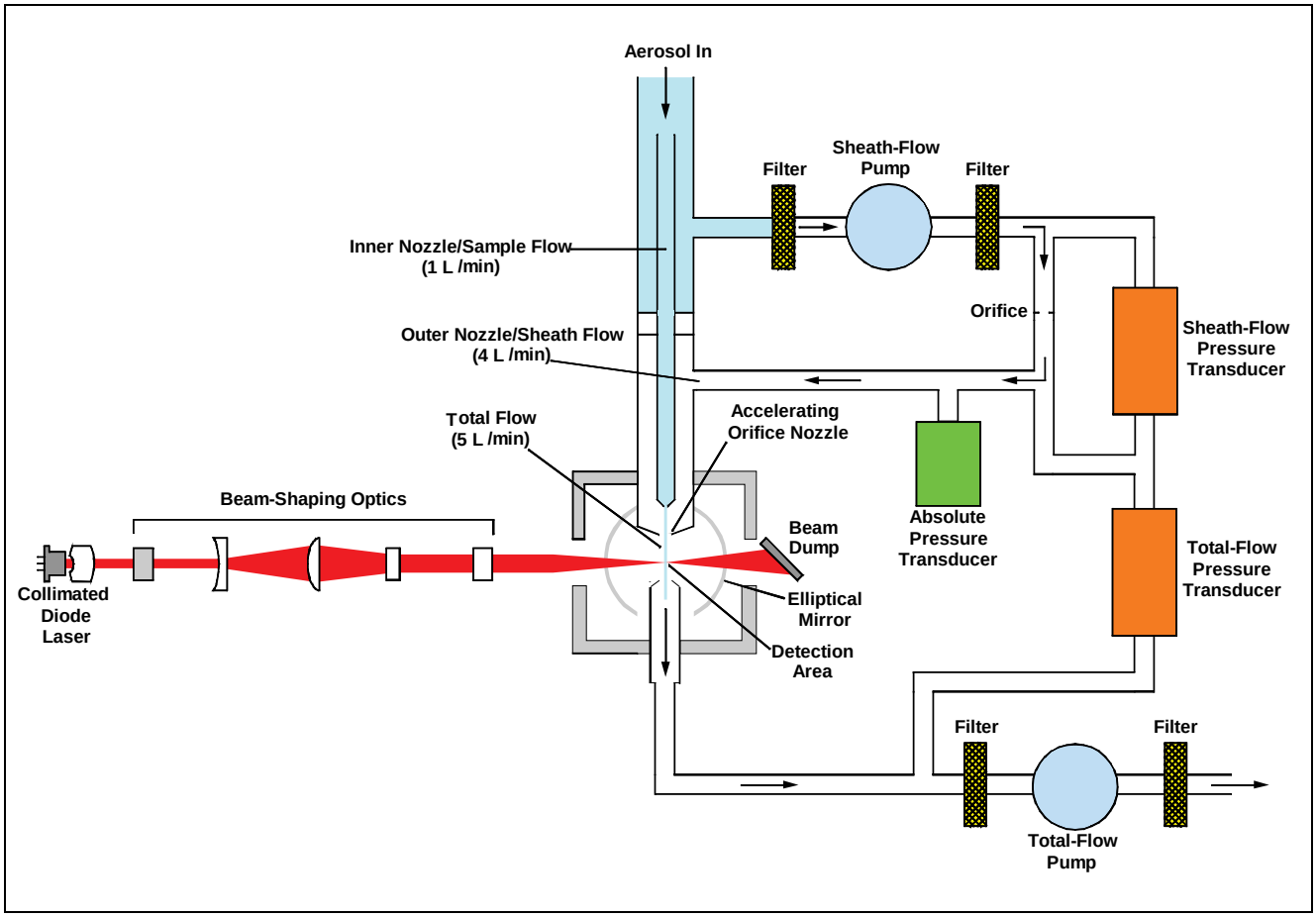


Figure 5-1
Aerosol Flow Through the Model 3321 APS™ Spectrometer

After passing through the orifice, the sheath flow is reunited with the sample flow at the accelerating orifice nozzle. This flow confines the sample particles to the center stream and accelerates the airflow around the particles. In this way, small particles (which can accelerate with the flow) reach a higher velocity than larger particles (which, due to inertia, lag behind the flow of the air stream).

Particle velocity is then measured in the optics chamber (refer to "Optics Path and Signal Processing Path," below).

After measurement, the particle stream exits the optics chamber, drawn by the total flow pump. The combined flow is controlled by the total flow pump and the pressure drop across the accelerating orifice nozzle.

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Sample flow is filtered before and after each of the two pumps. The filter upstream of the pump protects the pump from contamination. The filter downstream of the pump prevents contamination of the flow as the pump vanes wear.

Optics Path

The first component in the optics path, see Figure 5-2, is the laser diode. Light coming from the laser is polarized vertically. Using a polarization rotator (polymer half-wave plate) the polarization of the laser is rotated by 45 degrees. After rotation, the beam passes through negative and positive spherical lenses to focus the beam under the particle stream. A polarization beam splitter is then used to split the vertical and horizontal components of the beam into two separate beams spaced by 90 to 100 µm. The top beam (closest to the nozzle) is polarized horizontal and the bottom beam is polarized vertical. Spacing is controlled by the thickness of the splitter.

The beam pair next passes through a negative cylindrical lens. This lens controls the width of the beams independent of the focus under the particle stream. Two vertical knife edges clip the noisy edges of the beams to give a clean beam under the particle stream. A window is used solely as a sealing surface to keep the optics chamber separate from the optical elements, and a final aperture is used to stop stray light from the far edges of the beams before the beams reach their focal point under the particle stream.

The beams are then passed through a large aperture into a dual polarization beam stop. The first beam stop uses neutral density filter glass placed at the Brewster angle for vertical polarization. This captures all of the vertical polarization and most of the horizontal polarization. The remaining portion of the horizontal polarization is reflected into a second Brewster angle where it is captured. The large aperture in front of the beam stops prevents light from the beam stops escaping and helps to keep the beam stop glass clean.

The inset of Figure 5-2 shows that light scattered by the particle stream is collected by an elliptical mirror and focused onto a solid-state avalanche photodiode (APD) detector. The detector then converts the light pulses into electrical pulses.

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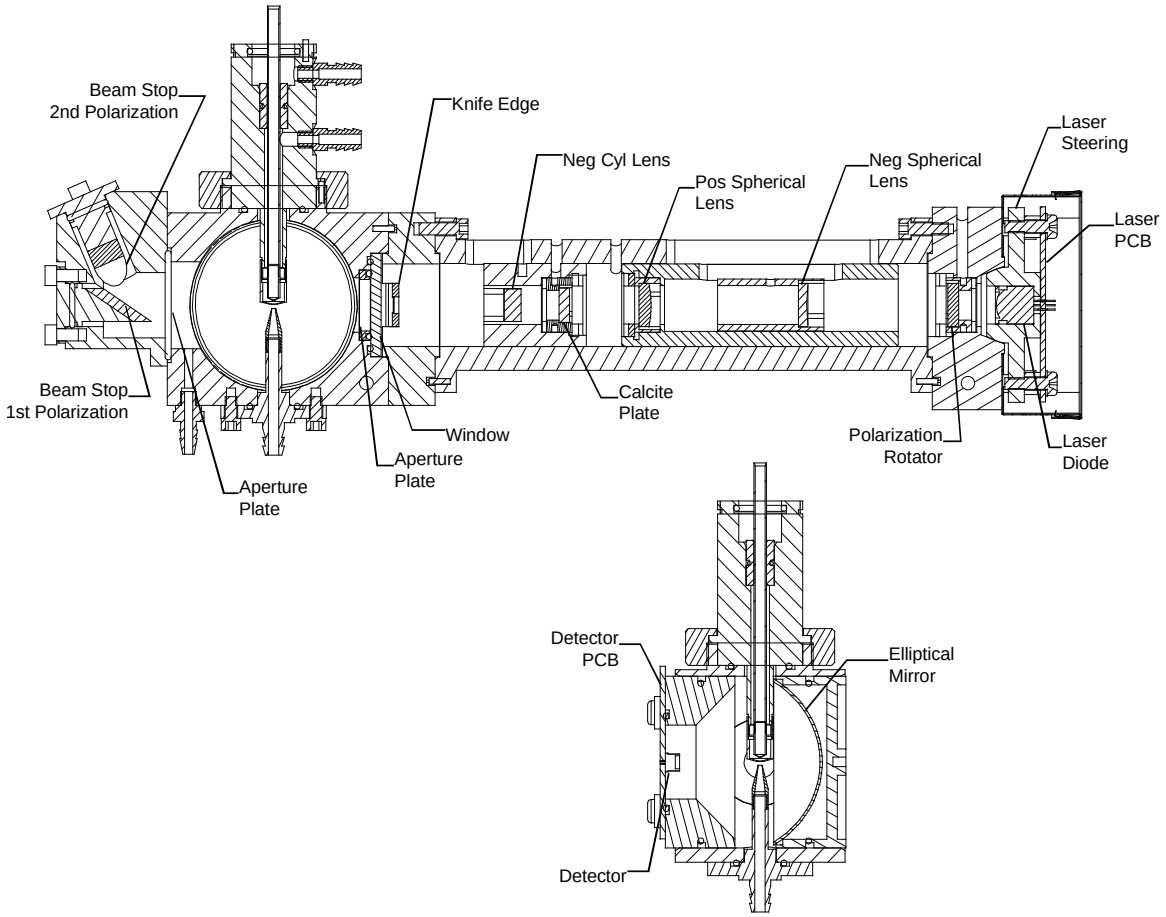


Figure 5-2
APS™ Spectrometer Optics Cross Section

Signal Processing Path

Signal processing is performed in the APD, Analog, and Digital modules.

APD Module

Signal processing begins at the APD module, where scattered light from the particle is detected and converted into an analog voltage signal. This signal, referred to as a double crested signal, consists of a pair of peaks.

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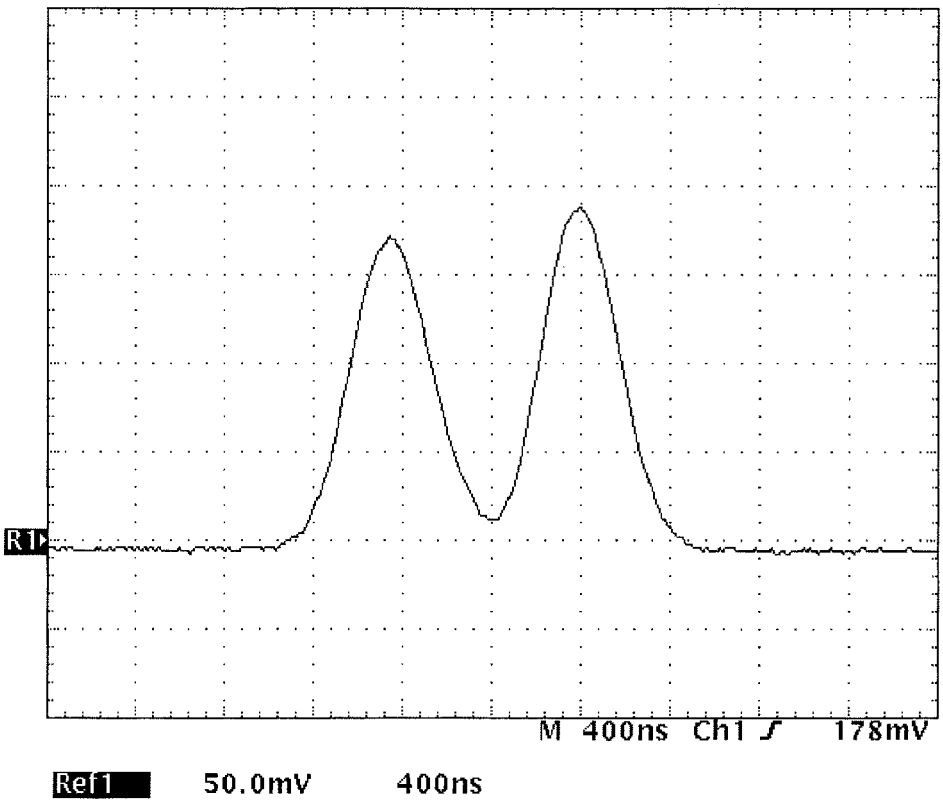


Figure 5-3
Typical Example of a Double Crested Signal

Each peak represents the presence of the particle in the center of the individual laser beams and can range in amplitude 0–10 volts. The signal is gained and buffered into two channels. One channel is for very small particles and has a high gain. The other channel is for large particles and has a low gain. Once the signals are gained up they are passed to the analog module.

Analog Module

Signals arriving at the analog module are sent to three different circuits for processing: the gate and differential circuits, and the side-scatter-intensity circuit. The output of these three circuits are then passed on to the digital module.

Gate Circuit

The gate circuit produces a digital gate (GATE) signal, or gate window, which represents the presence of the particle in the measurement volume. Producing this signal is accomplished by first adding the high gain and 10 times the low gain signal together. This addresses the dynamic range of pulse heights, roughly three orders of magnitude, for the size range of particles (0.3 to 20 μm).

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This summed signal is then sent through a delay line. Two different taps from this delay line, roughly 300 ns apart, are added together, filtered, gained, and clamped. This creates a signal that has very little valley in it and prevents it from going below the gate threshold. This signal is compared to the gate threshold, typically about 100 mV and can be set by the user through a serial command (see Appendix C). If it is above the threshold, the digital gate (GATE) signal goes active. When the signal drops back below the threshold, the GATE signal goes inactive. The time during which the GATE signal is active is called the gate window.

Differential Circuit

The differential circuit produces a digital difference (DIFF) signal that indicates the zero crossings of the differentiated double crested analog signal, which occur when the slope of the signal is equal to zero. Zero crossings, DIFF signal transitions, are positive going for a valley and negative going for a peak. The time between the negative going zero crossings of the differential signal (the peaks of the double crested analog signal) is called the transit time, or time-of-flight (TOF), of the particle. This time ranges from about 800 ns to 4.1 µs. It is this time, along with the calibration of the instrument, that determines the aerodynamic size of the particle.

The differential circuit produces the differential signal by taking two different taps from the delay line used in the gate circuit, roughly 300 ns apart and delayed from the first tap of the gate circuit by 20 ns. These two signals are then subtracted from each other, filtered, gained, clamped, and then filtered again. This produces a analog difference signal, both positive and negative, that is analogous to a differential signal. This difference signal is compared against a difference threshold, typically 0 V and is set via a potentiometer adjustment at the factory, producing a digital difference (DIFF) signal. If the difference signal is at or below the threshold, the DIFF signal is inactive. When the difference signal goes above the threshold the DIFF signal will go active giving a rising edge. When the summed signal goes through a peak the difference signal falls below the threshold and the DIFF signal will go inactive giving a falling edge. The DIFF signal will give a rising edge when going through the valley, and then give a falling edge when going through the second peak. It will stay inactive when the signal falls back to or below the difference threshold.

Side-Scatter Circuit

The third circuit is the side-scatter-intensity circuit. Both double crested analog signals from the low gain and the high gain outputs of the APD module are filtered, gained, clamped, and input to separate peak hold circuits, which hold the pulse height of the highest peak of each signal. An A/D converter is then used to give the digital value of each of the side-scatter-intensity pulse heights.

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The high gain value is checked for an over range in the A/D digital value, which indicates a large particle. If it is over range, the digital value from the low gain A/D is output to the digital module. If it is not over range, the digital value from the high gain A/D is output.

After the particle is processed, the peak hold circuits are cleared and readied for the next particle.

The GATE signal, DIFF signal and the side-scatter circuit output are then presented to the digital module to be processed and recorded.

Digital Module

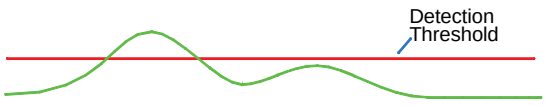
The GATE and DIFF digital signals from the analog module are used to trigger a high speed timer which has 4.0 ns resolution and a maximum range of 4.096 μs. After the gate signal goes active, the differential signal (which indicates the first peak of the double crested analog signal) starts the timer. The second peak then stops the timer, if the gate signal remained active for the duration between peaks.

Two PAL ICs (Programmable Array Logic Integrated Circuits) are also on the digital module. The first PAL is the Address PAL, which is used to record the time-of-flight data and side-scatter intensity.

The GATE and DIFF signals are also used to create two more signals, a gate window signal and a zero cross signal, which are provided to the Address PAL. The Address PAL uses these two signals to classify the particle into 4 separate events, in all cases a gate window signal must be present and at least one zero cross must occur.

Event 1

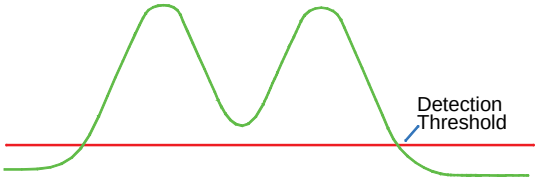
Occurs when only one zero cross occurs during a gate window. This happens when the particle is bright enough to exceed the threshold on the differential circuit when it intercepts one of the beams but not bright enough to exceed the threshold when it intercepts the other.



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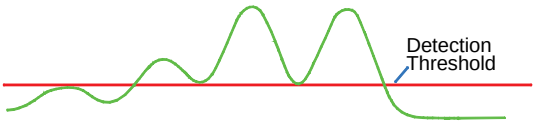
Event 2

Is a valid particle event and occurs only when two zero crosses happen during a gate window. Both the time of flight and light-scatter intensity are recorded for this event.



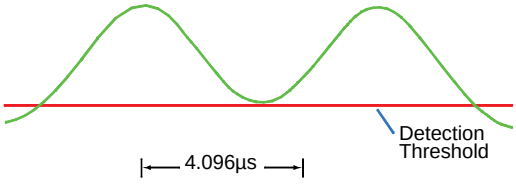
Event 3

Is a coincident event, and occurs when three zero crosses happen during a gate window. This is caused by a second particle entering the measurement area before the previous one has left.



Event 4

Is an over range event and occurs when a second zero cross does not occur and the window does not go away until after the timer over-ranges, exceeds 4.096 µs. This happens when a very large particle or a recirculating particle travels very slowly through the measurement area.



The second PAL is the Counting PAL, and is used by the address PAL to record all events. Events 1, 3, and 4 each have their own location in memory and are reported in the headers of the A, B, C, D, and S records. The events are recorded in bins of the accumulator as reported in the A record as follows: Event 1 in bin 32, Event 3 in bin 33, Event 4 in bin 34. Event 2 can be totaled by adding bins 100 through 1023 of the accumulator. Event 2 is recorded in memory according to the time of flight reported. The side scatter intensity is also recorded for each Event 2.

The APS™ spectrometer can be configured to record data in two different modes: uncorrelated and correlated.

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Uncorrelated Mode

The Address PAL creates two separate addresses. One address is 10 bits and represents the type of event (1, 3, 4), or the time-of-flight (TOF) in the case of an event 2. And the second address is 6 bits and represents the light-scatter intensity for an event 2. There is no second address in the case of an event 1, 3, or 4.

Correlated Mode

The Address PAL creates one single 16-bit address. The upper 10 bits of the address are the time-of-flight (TOF) for an event 2 or the type of event (1, 3, 4). The lower 6 bits are the side-scatter (SS) intensity in the case of an event 2. For events 1, 3, 4, the lower bits are zero.

Once the address(es) are created, the address PAL loads the number of particles from that address in memory into the counting PAL. The counting PAL then increments the number by one and stores it back to the same address. Once the PALs are finished recording the data, the timer is reset for the next particle.

Particle Coincidence

Particle coincidence is typically defined as more than one particle in the viewing volume of the particle counter creating a signal that causes the counter to incorrectly classify the particles as a single, mis-sized particle. Coincidence typically increases proportionally with particle concentration. In the case of the Model 3321 APS™ spectrometer; however, although coincidence is still a problem at high concentrations, the particles are not mis-classified. The double-crested signal processing technique allows the processor to determine when a signal is caused by a single low scattering particle (event 1—see above) and when it is caused by coincidence (event 3—see above). This means that the particle size distribution during coincidence can be accurately measured. Coincident particles can be detected as event 3s, but cannot be sized. Therefore they are not included in the size distribution, but are recorded for possible concentration corrections.

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APPENDIX A

Maintenance

Most components of the APS™ spectrometer are solid state and require no maintenance. This section provides information about the maintenance procedures that are required and includes a suggested maintenance schedule.

Maintenance Schedule

The following table contains a schedule of approximate recommended intervals for maintenance. The conditions under which the instrument is used will greatly affect this schedule. If the instrument is used to sample unusually dirty environments, the times between maintenance should be shortened. Likewise, if the instrument is used in clean environments, the times between maintenance can be safely extended. Use the schedule as a guideline only.

Table A-1
Maintenance Schedule

Maintenance Operation	Hours of Continuous Operation	User/Factory
Cleaning Inner Nozzle	750	user
Cleaning Outer Nozzle	2500	user
Replace Air Filters	5000	user
Check/Update Calibration	5000	user/factory

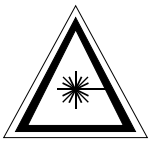
Cleaning the Inner Nozzle

Clean the nozzles according to the maintenance schedule and also under the following circumstances:

- The flows in the instrument are too low or erratic
- The APS™ spectrometer has been exposed to extremely high aerosol concentrations or fibers
- There is a constant level of particle noise even when the APS™ spectrometer samples filtered air

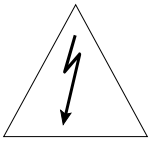
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To clean the nozzles, proceed as follows:



W A R N I N G

Make sure power is switched off and power cord is disconnected to avoid any exposure to hazardous laser radiation.



W A R N I N G

High voltage is accessible in several locations within this instrument. Make sure you unplug the power source before removing the cover or performing maintenance procedures.



C a u t i o n

The electronic circuits within this instrument are susceptible to electro-static discharge (ESD) damage. Use ESD precautions to avoid damage.

- ❑ Use only a table top with a grounded conducting surface
- ❑ Wear a grounded, static-discharging wrist strap

1. Switch the power off using the switch on the back of the cabinet and unplug the power cord from the APS™ spectrometer.
2. Remove the knurled retaining ring from the outer inlet nozzle.
3. Loosen the six screws on both sides of the cabinet (two turns is sufficient) and remove the cover straight upward.
4. Remove the outer inlet nozzle by gripping it and lifting straight up.
5. Grip the inner nozzle and lift straight up.
6. Clean the nozzle blowing backward through the nozzle with clean, compressed air [maximum pressure 35 psi (240 kPa)].
7. Check the nozzle by holding the tube up to a light and checking for a clear view of the nozzle orifice.
8. If the nozzle is still blocked, try rinsing the inner nozzle in soapy water and then cleaning with clean water. Dry thoroughly with clean compressed air.
9. If the nozzle is still blocked, try using isopropyl alcohol.
10. When the nozzle has been cleaned satisfactorily, make sure that the o-ring still has a thin layer of grease. If not, apply a thin coating of grease.
11. Reinsert the nozzle and make sure that it is seated firmly in the nozzle mount.
12. Replace the outer inlet in the nozzle mount. Note that there is an alignment pin that matches a slot in the side of the outer

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inlet. Rotate the outer inlet until the inlet seats on the alignment pin.

13. Replace the cover on the instrument.
14. Tighten the six screws holding the cover in place.
15. Replace the outer inlet retaining ring and tighten firmly.
16. Insert the power cord into the power entry connector on the back of the instrument.
17. Apply power to the instrument with the switch on the back panel.
18. Check that the flows are correct.

Cleaning the Outer Nozzle

Clean the nozzles according to the maintenance schedule and also under the following circumstances:

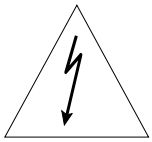
- ❑ The pumps are running at maximum flow and the nozzle flow is still too low
- ❑ The APS™ spectrometer has been exposed to extremely high aerosol concentrations or to fibers
- ❑ There is a constant level of particle noise even when the APS™ spectrometer samples filtered air

To clean the nozzles, proceed as follows:



W A R N I N G

Make sure power is switched off and power cord is disconnected to avoid any exposure to hazardous laser radiation.



W A R N I N G

High voltage is accessible in several locations within this instrument. Make sure you unplug the power source before removing the cover or performing maintenance procedures.



C a u t i o n

The electronic circuits within this instrument are susceptible to electro-static discharge (ESD) damage. Use ESD precautions to avoid damage.

- ❑ Use only a table top with a grounded conducting surface
- ❑ Wear a grounded, static-discharging wrist strap

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C a u t i o n

Any time that you remove a portion of the optics assembly for cleaning, there is a chance that you can adversely affect the alignment of the system and therefore the calibration. It is a good idea to check the calibration of the instrument after any procedure involving the optics. Do this by generating a know size of aerosol, ie. 1 µm polystyrene latex (PSL) and making sure that the aerosol is sized correctly by the instrument and software.

1. Switch the power off using the switch on the back of the cabinet and unplug the power cord from the APS™ spectrometer.
2. Remove the knurled retaining ring from the outer inlet nozzle.
3. Loosen the six screws on both sides of the cabinet (two turns is sufficient) and remove the cover straight upward.
4. Remove the outer inlet nozzle by gripping it and lifting straight up.
5. Grip the inner nozzle and lift straight up.
6. Remove the two screws securing the digital printed circuit board.
7. Tilt the printed circuit board upward and remove the large ribbon cable connector from the center front of the board.
8. Tilt the printed circuit board all the way back so that the pumps are visible and the board rests against the top edge of the back of the instrument.
9. Label the two tubes coming from the nozzle mount and going to the pumps (a fine-tip permanent marker works well). Label the top tube “top” and the bottom tube “bottom”.
10. Grip each tube and remove it from the nipple fitting attached to the nozzle mount.
11. Loosen the knurled retaining ring at the base of the nozzle mount.
12. Lift the nozzle mount away from the optics block taking care not to scratch or damage the delicate outer nozzle. Make sure that the O-ring under the nozzle mount stays with the optics block.

***Note**: The outer nozzle is very delicate. Take great care in cleaning or blowing compressed air through the nozzle.*

13. Blow clean, compressed air backwards through the outer nozzle to remove any debris.

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14. The finish on the outside of the nozzle should be flat black. Remove any coating on the outer nozzle with a clean, lint-free, soft cloth and clean water.

15. Check that the nozzle is clear by holding it up to a light and checking for a clear view through the nozzle orifice.

16. It is not recommended that you clean the inside of the outer nozzle with other than clean compressed air. Using a swab to clean may result in leaving difficult-to-remove fibers inside the nozzle or damaging the inner nozzle centering ring.

17. Reinsert the nozzle block into the optics block. The nozzle block has a slot that aligns with a pin in the optics block. Tighten the retaining ring so that the nozzle block can still rotate freely. Rotate the nozzle until the pin catches the slot in the nozzle. Tighten the retaining ring until the nozzle block is firmly seated.

18. Reinsert the inner nozzle and make sure that it is seated firmly in the nozzle housing.

19. Reattach the tubing to the nozzle mount, noting the labels on each tube.

20. Tilt the digital printed circuit board back down until the ribbon cable connector can be plugged back into the board. Plug in the ribbon cable connector.

21. Tilt the digital printed circuit board down fully and fasten with the screws provided.

22. Replace the outer inlet in the nozzle mount. Note that there is an alignment pin that matches a slot in the side of the outer inlet. Rotate the outer inlet until the inlet seats on the alignment pin.

23. Replace the cover on the instrument.

24. Tighten the six screws holding the cover in place.

25. Replace the outer inlet retaining ring and tighten firmly.

26. Insert the power cord into the power entry connector on the back of the instrument.

27. Apply power to the instrument with the switch on the back panel.

28. Check that the flows are correct.

29. Generate a known size of monodisperse aerosol (such as Polystyrene latex–PSL) and make sure that the calibration has not been altered by the cleaning procedure.

30. If the instrument does not size correctly, check the parts you have cleaned and make sure that they are assembled

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correctly: alignment pins in slots and retaining rings holding parts seated firmly.

31. If the instrument still does not size correctly, it may have to be recalibrated.

Replacing the Filters

Replace the four filters (TSI P/N 1602230) according to the maintenance schedule and under the following circumstances:

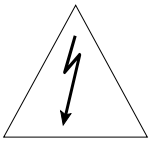
- If the pumps are at maximum power and still cannot achieve the correct flows for the instrument
- If the flow path has become wetted by any kind of liquid

To replace the filters, proceed as follows:



W A R N I N G

Make sure power is switched off and power cord is disconnected to avoid any exposure to hazardous laser radiation.



W A R N I N G

High voltage is accessible in several locations within this instrument. Make sure you unplug the power source before removing the cover or performing maintenance procedures.



C a u t i o n

The electronic circuits within this instrument are susceptible to electro-static discharge (ESD) damage. Use ESD precautions to avoid damage.

- Use only a table top with a grounded conducting surface
- Wear a grounded, static-discharging wrist strap

1. Switch the power off using the switch on the back of the cabinet and unplug the power cord from the APS™ spectrometer.
2. Remove the knurled retaining ring from the outer inlet nozzle.
3. Loosen the six screws on both sides of the cabinet (two turns is sufficient) and remove the cover straight upward.
4. Remove the two screws securing the digital printed circuit board.
5. Tilt the printed circuit board upward and remove the large ribbon cable connector from the center front of the board.

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6. Tilt the printed circuit board all the way back so that the pumps are visible and the board rests against the top edge of the back of the instrument.
7. The APS™ spectrometer contains a lot of tubing. To easily keep track of the connections, disconnect the tubing from one filter at a time and replace it, rather than disconnecting all tubing at once. Also, make note of the direction of the flow arrow on the filter before disconnecting it.
8. Lift up on a filter so that it comes out of its supporting clip.
9. Remove the tubing from each end by pushing the tubing from its end off of the filter rather than pulling the tubing off.
10. If any of the tubing becomes damaged, replace it with an equivalent length of the same tubing.
11. Snap the filter back into its holding clip.
12. Replace each filter in turn until all four have been replaced.
13. Tilt the digital printed circuit board back down until the ribbon cable connector can be plugged back into the board. Plug in the ribbon cable connector.
14. Tilt the digital printed circuit board down fully and fasten with the screws provided.
15. Replace the cover on the instrument.
16. Tighten the six screws holding the cover in place.
17. Replace the outer inlet retaining ring and tighten firmly.
18. Insert the power cord into the power entry connector on the back of the instrument.
19. Apply power to the instrument with the switch on the rear panel.
20. Check that the flows are correct.

Replacing the EPROM

Normally the EPROM will not be replaced, however, early shipments of the Model 3321 APS™ spectrometer may not have all functions/features in place and therefore EPROM replacement will be necessary in the field.

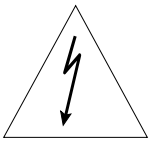
To replace the EPROM, proceed as follows:

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W A R N I N G

Make sure power is switched off and power cord is disconnected to avoid any exposure to hazardous laser radiation.



W A R N I N G

High voltage is accessible in several locations within this instrument. Make sure you unplug the power source before removing the cover or performing maintenance procedures.



C a u t i o n

The electronic circuits within this instrument are susceptible to electro-static discharge (ESD) damage. Use ESD precautions to avoid damage.

- ❑ Use only a table top with a grounded conducting surface
- ❑ Wear a grounded, static-discharging wrist strap

1. Switch the power off using the switch on the back of the cabinet and unplug the power cord from the APS™ spectrometer.
2. Remove the knurled retaining ring from the outer inlet nozzle.
3. Loosen the six screws on both sides of the cabinet (two turns is sufficient) and remove the cover straight upward.
4. Remove the two screws securing the digital printed circuit board.
5. Tilt the printed circuit board all the way back so that the pumps are visible and the board rests against the top edge of the back of the instrument.
6. The APS™ spectrometer uses two EPROM chips. They should be labeled with seven digit part numbers. It is important that they go in the correct sockets.
7. Locate the EPROM sockets from Figure A-1.

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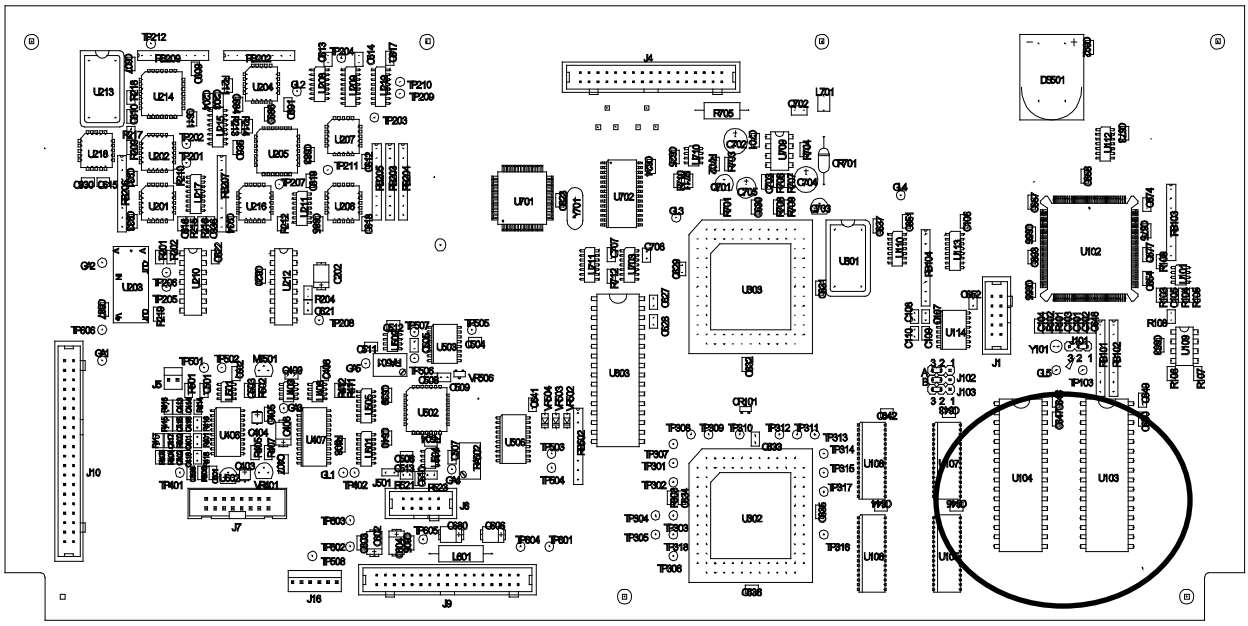


Figure A-1
Location of EPROM Chips on APS™ Spectrometer Digital PC-Board

8. Use the EPROM removal tool provided with the new EPROM chips to remove one of the old chips.
9. Remove the new EPROM with the same seven-digit part number from its static protection bag
10. Install the new chip into the vacant socket by aligning the notch on the top center of the chip with the notch shown on the silkscreen.
11. Then, while supporting the printed circuit board with one hand behind it, slightly insert one row of pins and then the other.
12. Once both rows of pins are slightly inserted, press the EPROM firmly the rest of the way into the socket.
13. Inspect the socket to make sure that all pins are inserted into the socket.
14. Repeat steps 8 to 13 to replace the remaining EPROM.
15. Tilt the digital printed circuit board back down until the ribbon cable connector can be plugged back into the board. Plug in the ribbon cable connector.
16. Tilt the digital printed circuit board down fully and fasten with the screws provided.
17. Replace the cover on the instrument.
18. Tighten the six screws holding the cover in place.
19. Replace the outer inlet retaining ring and tighten firmly.

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20. Insert the power cord into the power entry connector on the back of the instrument.

21. Apply power to the instrument with the switch on the back panel.

22. Check that the version shown on the screen on startup matches the new version of the EPROM.

Calibrating the APS™ Spectrometer

Calibrating the APS™ spectrometer is a fairly complex procedure. The calibration process requires special equipment and tools. Therefore, it is recommended you return the instrument to the factory for calibration.

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APPENDIX B

Troubleshooting

This appendix lists potential problems and their solutions.

***Note**: If none of the solutions provided corrects the problem, call your TSI representative for advice.*

Table B-1
Troubleshooting Symptoms and Recommendations

Symptoms	Recommendations
The pumps do not come on when the instrument is powered up	Check to see that the pumps are turned on from the front panel menu. Rotate the control knob all the way clockwise until the menu button is shown. Press the control knob in so that the menu appears. Rotate the knob to scroll the cursor down the menu until the pumps item is highlighted. Press the control knob to toggle the pumps on and off. Exit the menu. If the pumps are off when you exit the menu, the APS™ spectrometer will not start them on power-up. If they are on when you exit the menu, they will turn on when the APS™ spectrometer is powered up.
The pumps do not control the flows to the proper flow rates or the flows are erratic	Check for blockage in the flow path: The outlet in the back panel may be blocked or covered. Check and clear any obstruction. The inner or outer nozzle may be dirty or clogged. See Appendix A, "Maintenance." The filters may be clogged. See Appendix A, "Maintenance."
The HI CONC (High concentration) warning light is illuminated	The HI CONC LED is an indicator that the concentration of aerosol that the instrument is sampling is too high for the APS™ spectrometer to accurately measure. The LED is lit when the concentration exceeds 1000 particles/cm^3. Although the APS™ spectrometer can measure aerosols at concentrations greater than this value, concentration errors due to coincidence will increase and some of the particles will not be counted. To correct this problem, reduce the concentration of the sampled aerosol (by mixing filtered air with the sample, for instance) or use one or two diluters (TSI Model 3302A) with the APS™ spectrometer.

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Symptoms	Recommendations
The LASER LED does not come on when the instrument is powered up	Check to see that the laser is turned on from the front panel menu. Rotate the control knob all the way clockwise until the menu button is shown. Press the control knob in so that the menu appears. Rotate the knob to scroll the cursor down the menu until the laser power item is highlighted. Make sure that the setting is 50% or higher (factory setting is 75%). *Note: changing the power setting from the instrument calibration setting will change the calibration.* Rotate the knob to scroll the cursor down the menu until the laser item is highlighted. Press the control knob to toggle the laser on if necessary. Exit the menu. If the laser is off when you exit the menu, the APS™ spectrometer will not turn it on at power-up. If it is on when you exit the menu, it will turn on when the APS™ spectrometer is powered up.
No power	Check for good contact between the power cord and the wall outlet. Check for power at the outlet.
Serial Communications not working	See Table C-4, "Troubleshooting Serial Commands."

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APPENDIX C

Using Serial Data Commands

This chapter contains information you need if you are writing your own software for a computer or data acquisition system. Information includes:

- Pin connectors
- Baud rate
- Parity
- Command definitions and syntax.
- Examples, as well as input and troubleshooting directions are also provided.

Pin Connectors

The Model 3321 has a single 9-pin, D-subminiature connector port on the back panel labeled SERIAL PORT (See Figure 3-3 and Figure C-1). This communication port is configured at the factory to work with RS-232 type devices. Table C-1 provides the signal connections.

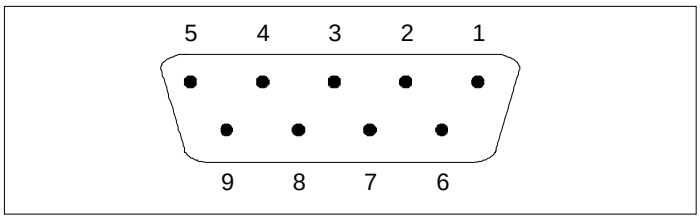


Figure C-1
SERIAL PORT Pin Designations

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Table C-1
Signal Connections for RS-232 Configurations

Pin Number	RS-232 Signal
1	—
2	Transmit Output
3	Receive Input
4	—
5	GND
6	—
7	—
8	—
9	—

Baud Rate

The baud-rate setting is the rate of communication in terms of bits per second (baud). The Model 3321 uses a baud rate setting of 9600, 19,200 or 38,400. For proper communications, make sure that all software used with the instrument is set at the appropriate rate. The baud-rate must be set to 38,400 for correlated mode. See SMT and SB commands.

Parity (7-Bits Even)

Parity is the additional bit that accompanies the seven data bits to confirm that they are transmitted correctly. It is set so that the number of "1" data bits (high) in a transmitted character is always an even number. The Model 3321 APS™ spectrometer uses even parity as the only setting.

Stop Bits and Flow Control

The APS™ spectrometer uses a Stop bits setting of 1 and a Flow Control Setting of None.

Commands

The Model 3321 APS™ spectrometer uses an ASCII-based communications protocol that uses the RS-232 port of a computer to transmit commands in the form of strings.

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The four types of commands are:

- Set commands, which set all the operating parameters for the APS™ spectrometer
- Action commands, which control mechanical components of the APS™ spectrometer
- Read (polled) commands, in which the APS™ spectrometer sends data in response to a specific request from the computer
- Unpolled commands, in which the APS™ spectrometer automatically outputs data records at specific intervals.

No line-feed characters are transmitted. Either the requested data or an "OK" is returned if the command is understood. The word “ERROR” is returned if the command is not understood or if the command has an invalid parameter.

***Note**: All characters must be UPPERCASE.*

The following tables (Figure C-2) provide a quick reference to all the serial commands. Command definitions, syntax, and examples begin after the tables. Directions for issuing commands and troubleshooting commands are provided at the end of this section.

(continued on next page)

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Set Commands

SB	Set Baud rate **SB***x*
SCA	Set Calibration for Aerodynamic diameters **SCA***c,sc,tc*
SCL	Set Calibration Label string
SCE	Set Calibration Environment **SCE***p,t*
SCR	Set Calibration Resolution **SCR***x*
SD	Set Digital output **SD***x*
SF	Set Front panel enable **SF***x*
SH	Set Hi Conc threshold **SH***x*
SL	Set Laser power **SL***x*
SMA	Set Mode for Analog output **SMA***x*
SMC	Set Mode for automatic Calibration of APD **SMC***x*
SMT	Set Mode and sample Time **SMT***a,t*
SP	Set Pumps **SP***x*
STU	Set Time for Unpolled report **STU***x*
SV	Set analog output Voltage **SV***x*

Action Commands

A	Autocal the APD
B	Beep **B***x*
C	Clear buffers and sample time
D	Dump command
F	Fill command **F***x*
G	Go (sample) **G***x*
H	Halt command
L	Laser on/off
Q	Quick concentration report
S	Sampling **S***x*

Read (Polled) Commands

R	Read accumulator **R***b,e*
RF	Read status Flags
RI	Read Input from pins 1, 2, 3 and 7, 8 of the I/O connector
RL	Read Laser power
RO	Read accumulated On time of instrument
	Read inlet pressure
RPI	Read sheath delta P
RPS	Read total delta P
RPT	Read aerosol flow
RQA	Read sheath flow
RQS	Read total flow
RQT	Read Unpolled Record
RR	Read Temperature in Box
RTB	Read Temperature of APD Detector
RTD	Read Temperature of Inlet
RTI	Read Version of firmware
RV	

Unpolled Commands

U	Unpolled operation begins
U+	Enable all records
U-	Disable all records
UA	Accumulator record **UA***0/1*
UB	SS accumulator record **UB***0/1*
UC	Correlated (paired) records **UC***0/1*
UD	Aerodynamic data record **UD***0/1*
US	SS data record **US***0/1*
UY	Auxiliary data record **UY***0/1*

Figure C-2
Serial Command Tables

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Set Commands

Set commands allow you to set up operating parameters for the Model 3321. If a set command is sent with no parameter, the current parameter is echoed.

***Note**: Some of the commands directly affect or are affected by other commands. Refer to other commands where indicated.*

SB—Set Baud Rate

SB lets you set and change the baud rate for the serial communications.

***Note:** Since this is changed with serial communication, once sent, the baud rate of the application sending commands must be changed to match baud rates or communications will fail.*

The baud rate can also be changed from the APS™ spectrometer front panel menu, see Table 4-1.

```
SBx
```

where:

x = 0 for 9,600
1 for 19,200
2 for 38,400

Examples:

To se the baud rate to 38,400:

```
SB2
```

***Note:** "OK" is sent in response to this command, but it is sent at the new baud rate and is not readable at the previous baud rate. You must now change your application baud rate to 38,400 in order to communicate with the APS™ spectrometer.*

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SCA—Set Calibration for Aerodynamic Diameters

SCA lets you enter calibration data for time of flight data (aerodynamic calibration).

```
SCAc,sc,tc
```

where:

c = channel boundary number (0 to number of channels +1).
sc = particle size in nm.
tc = time of flight for the boundary of the particle size channel.

The number of channels must be at least 1 (3 calibration records: lower size, upper size, and terminator) and no more than 52 (54 calibration records). The time values correspond to accumulator time. They must be between 0.00 and 1024.00. The value 0,0 terminates the calibration array. There can be up to 52 channels of particle size requiring 54 calibration points SCA0 to SCA53. The last entry of any calibration table must be 0,0. The calibration data is held in EEPROM and loaded into RAM on power up. The SCA0,0 terminator also causes the calibration data to be tested for monotonicity and if the data in the calibration table is not monotonic returns an error message “NOTVALID.”

Examples:

To set the lower boundary of the first channel to 403 nm bin 187.63:

```
SCA0,403,187.63
```

To terminate the calibration array of 52 channels:

```
SCA53,0,0
```

To echo the current calibration:

```
SCA
```

SCL—Set Calibration Label String

SCL lets you label a calibration with a text string (up to 80 characters).

Example:

To label the calibration done on December 25th of the APS™ spectrometer with serial number 104:

```
SCLS/N 104 Calibrated December 25, 1997
```


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SCE—Set Calibration Environment

SCE lets you set the temperature and pressure.

SCE*p,t*

where:
p = absolute pressure at calibration (in millibars).
t = absolute temperature at calibration (in degrees K).

SCE with no parameters echoes the current values of p and t, which are saved in EEPROM and loaded into RAM when the instrument is powered up.

Example:

To set the absolute pressure and temperature to 970.4 millibar and 393.3 K:

```
SCE970.4,393.3
```

SCR—Set Calibration Resolution

SCR lets you set the number of side scatter channels that will report.

SCR*x*

where:
x = 1, 2, 4, 8, 16, 32, or 64.

Note: 64 is the default on power up.

Example:

To set the number of side scatter channels that will report to 16:

```
SCR16
```


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SD—Set Digital Output

SD sets the logic level of the three digital I/O connector output pins 11, 12, and 13. (See Figure 3-3, Figure 3-5, and Table 3-2 for the location and pinout of I/O Port on back panel. (Referenced to pins 4, 5 Digital GND.)

SD*h*

where:

h = 0 to 7 and is a hex value representing three binary bits. If a bit is 0, the corresponding output is set to 0 volts. If a bit is a 1, the output is set to 5 volts.

Table C-2 shows the equivalent voltage level (in volts) of pins 11, 12, and 13 for all possible settings.

Table C-2
Digital Output Pin Settings

Hex Setting *(h)*	Binary Equivalent	Pin 13	Pin 12	Pin 11
0	000	0	0	0
1	001	0	0	5
2	010	0	5	0
3	011	0	5	5
4	100	5	0	0
5	101	5	0	5
6	110	5	5	0
7	111	5	5	5

Example:

To set the outputs for I/O connector pins 11, 12, and 13 to 0 volts:
SD0
To set the outputs for I/O connector pins 11, 12, and 13 to 5 volts:
SD7

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SF—Set Front Panel Enable

SF lets you disable the front panel of the Model 3321 to prevent clearing sample averages that are being read by an external computer.

SF*x*

where:
x = 0 or 1:
0 = front panel disabled
1 = front panel enabled

When the front panel is disabled, it has "view only" control. You can read front panel settings, but no modification is allowed. The default is 1 when the instrument is powered on. The parameter is not stored in EEPROM so the panel is always enabled on startup.

Example:

To disable the front panel of the 3321:

```
SF0
```

SH—Set Hi Conc Threshold

SH lets you set the conditions that will cause the HI CONC LED to light, the high concentration flag to be set (see RF command), and the APS™ spectrometer to beep if the sound is enabled (see B command).

SH*x*

where:
x = 0 to 65535 and is the total concentration of particles, in particles/cm^3.

Note *When x =0, the LED, flag, and beep are always on. When x = 65535, the LED, flag, and beep are always off.*

The value of x at power up is 1000 particles/cm^3. The status of the LED is updated every second.

Examples:

To light the HI CONC LED when the concentration ≥1500 particles/cm^3:

```
SH1500
```


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To prevent the HI CONC LED from lighting at any concentration:

```
SH65535
```

SL—Set Laser Power

SL sets the laser power as a percent of full-power.

```
SLx
```

where:
x = 0 to 100%

The default when the instrument is powered up is 75%.

Example:

To set the laser power to 50 percent of full power:

```
SL50
```

Notes:

- ❑ *Lx command must be Enabled (x = 1) for laser to output power (see Lx command).*
- ❑ *An SL setting <10 may cause Laser LED on front panel to flash (see Chapter 3, "Indicators").*
- ❑ *Front panel LED may flash if laser is not able to operate at set power. This indicates that the laser has degraded and may need to be replaced.*

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SMA—Set Mode for Analog Output

SMA sets the mode and range for the analog output BNC on the back panel

```
SMAx
```

where:
x = 0 to 6

0 = total concentration 1/cc 10 volts.
1 = total concentration 10/cc 10 volts.
2 = total concentration 100/cc 10 volts.
3 = total concentration 1,000/cc 10 volts.
4 = total concentration 10,000/cc 10 volts.
5 = total concentration Log 10,000/cc 5 volts.
1,000/cc 4 volts
100/cc 3 volts
10/cc 2 volts
1/cc 1 volts
.1/cc 0 volts
6 = host.

Table C-3
Analog Voltage Output Settings

SMA Setting	BNC Analog Output Voltage (V)						
X	0	1	2	3	4	5	10
0	0	.1/cc	.2/cc	.3/cc	.4/cc	.5/cc	1/cc
1	0	1/cc	2/cc	3/cc	4/cc	5/cc	10/cc
2	0	10/cc	20/cc	30/cc	40/cc	50/cc	100/cc
3	0	100/cc	200/cc	300/cc	400/cc	500/cc	1000/cc
4	0	1000/cc	2000/cc	3000/cc	4000/cc	5000/cc	10,000/cc
5	.1/cc	1/cc	10/cc	100/cc	1000/cc	10,000/cc	NA
6	0	1v	2v	3v	4v	5v	10v

Examples:

To set the analog output BNC voltage range 0–10 volts, to represent the total concentration range 0–10,000 particles/cc.

```
SMA4
```

To set the analog output BNC to host mode. (See the SV command for the actual voltage output)

```
SMA6
```


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SMC—Set Mode for Automatic Calibration of APD

SMC lets you set the mode for automatically calibrating the Avalanche photodetector (APD) for temperature based reading of RTD command.

SMC*x*

where:
x = 0 or 1

0 means that autocal is disabled.
1 means that autocal is enabled.

Example:

To enable automatic calibration of the APD:

SMC1

Default at power up = autocal is enabled

SMT—Set Mode and Sample Time

SMT lets you set the sample mode and sample time for continuous sampling operation. See S command for more details on starting/stopping sampling according to SMT command.

SMT*a,t*

where:
a = sample mode

0 means averaging mode
1 means summing mode
2 means correlated data (paired) mode

t = sample time in seconds

1 to 300 seconds if averaging mode is set
1 to 65535 seconds if summing mode or correlated data (paired) mode is set

***Note**: The value of t is saved in EEPROM and loaded when the instrument is powered up.*

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Examples:

To set the sample mode to averaging and the sample time to 240 seconds:

```
SMT0,240
```

To set the sample mode to summing and the sample time to 12 hours:

```
SMT1,43200
```

To set the sample mode to correlated data (paired) and the sample time to 60 minutes:

```
SMT2,3600
```

Note: *Baud rate must be set to 38,400 for correlated mode. See SB command. Baud rate can also be set from the front panel menu (see Table 4-1).*

SP—Set Pumps

SP lets you turn the pumps on and off.

```
Spx,y
```

where:
x = total pump status (0 = off, 1 = on)
y = sheath pump status (0 = off, 1 = on)

Note*: Turn both pumps on with SP1. Turn both pumps off with SP0.*

Examples:

To set the total pump off and the sheath pump on:

```
SP0,1
```

To set the total pump on and the sheath pump off:

```
SP1,0
```


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STU—Set Time for Unpolled Report

STU lets you set the time for unpolled reports. End of sample reports are sent regardless of the STU setting.

```
STUx
```

where:
x = 0 to 65535 seconds

Example:

To set the time for unpolled reports to 3600 seconds:

```
STU3600
```

SV—Set Analog Output Voltage

SV sets the analog output BNC voltage when configured for host mode. See SMA command.

```
SVx
```

where:
x = 0 to 10,000 mV

Example:

To set the analog output voltage to 2400 millivolts or 2.4 volts:

```
SV2400
```

Action Commands

Action commands control mechanical components of the Model 3321. If you enter an action command without a parameter, the mechanical state is echoed back.

A—Perform APD Autocal

Performs an automatic calibration of the Avalanche Photodetector if autocal is enable by the SMC command, see SMC.

Example:

To perform automatic calibration of the APD:

```
A
```


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B—Beep

B*x, y*

where:

x = no value, 0, 1, >1.
no value for x returns 1 if beep is active, 0 if not. A 0 turns beep off; a 1 turns beep on. >1 is number of beeps.
y = duration of beep in approximately 62.5 ms steps (for a 1-second beep, *y* = 16). If no *y* is given and x is >1, the beep will have a 1 second duration.

***Note**: Beep must be active, B1, to hear beeps. State of beep is stored. Single beeps require a value for y.*

C—Clear Buffer and Sample Time

Clears the buffer, accumulator, and sample time setting. Appends a line feed (LF) character after the terminating carriage return (CR). Used only in 3310 APS™ spectrometer mode. Refer to the G command.

D—Dump

Performs a dump or all 78 channels (3310 APS™ spectrometer type). Data beyond SCA calibration (max. of 52 channels), is reported as 0. Appends a LF character after the terminating CR.

F—Fill Accumulators

Fills accumulators with x. If no x is provided it returns 1 or 0 to indicate active or inactive. When active, an S1 command begins a sample of SMT time and fill data is not cleared after each one second summation. If x=0, then fill is disabled and data can be cleared. The pumps should be off or a filter in place to prevent particles from being added to the fill data.

F*x*

where:

x is 1–65535, but typically 10.

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G—Go

Enables a 3310 mode sample.

G*x*

where:
x is 1 to 65565 seconds of sample time.

In 3310 mode, the APS™ spectrometer runs without side-scatter and acquires accumulator data. The command appends a LF after the terminating CR.

H—Halt

Halts the 3310 mode. The command appends a LF after the terminating CR.

L—Laser Enable/Disable

Enables or disables the laser.

L*x*

where:
x is 0 or 1. L0 Disables the laser. Output power is 0. L1 Enables the laser. Output power is determined by the SL setting (see SL command).

Q—Quick Concentration Report

Produces a concentration report. This is a 3310 command. A LF is appended after the terminating CR.

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S—Sampling

Enables and disables sampling. (The mode of sampling is set by the SMT command.)

S*x*

where:
x is 0, 1 or 2 through 65565.
0 = Disable sampling.
1 = Enable continuous sampling. (Previous sample data automatically cleared when new sample begins.)
2 - 65565 = Enable a single sample for x seconds. (If SMT is set to average mode, a summed sample will be done. Previous data is not automatically cleared and must be cleared with the C command.)

If no parameter is specified, the command echoes current condition (0, 1 or sample time remaining if single sample is running). The default when the instrument is powered up is 0.

Read Commands (Polled)

Read commands are polled, which means the Model 3321 sends data in response to a specific request from the computer

R—Read Accumulator

This is a 3310 mode command. It dumps accumulator data taken using a G command.

R*b*, *e*

where:
b = the beginning accumulator bin (0-1023).
e = the ending accumulator bin (0-1023). *e* must be greater than or equal to *b*.

If *b* and *e* are not specified, the default values are *b* = 0 and *e* = 1023. Line feeds are appended after all carriage returns.

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Example	Response
R0,100	Reads bins 0 to 100
R,100	Reads bins 0 to 100
R400	Reads bins 400 to 1023
R	Reads bins 0 to 1023

RF—Read Flags

RF returns a four-character hexadecimal value representing the state of the Model 3321.

The values for the 10 flags are as follows:

0000 0000 0000 0001	Laser fault
0000 0000 0000 0010	Total Flow out of range
0000 0000 0000 0100	Sheath Flow out of range
0000 0000 0000 1000	Excessive sample concentration (alarm)
0000 0000 0001 0000	Accumulator clipped (i.e. > 65535)
0000 0000 0010 0000	Autocal failed
0000 0000 0100 0000	Internal temperature < 10°C
0000 0000 1000 0000	Internal temperature > 40°C
0000 0001 0000 0000	Detector voltage more than ±10% Vb
0000 0010 0000 0000	Reserved (unused)

Example	Response
RF	00AC

00AC can be converted to binary: 0000 0000 1010 1100
This indicates that:

Internal temperature is greater than 40°C
Autocal failed
Excessive sample concentration
Sheath flow out of range

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RI—Read Input From Pins 1, 2, 3 and 7, 8 of the I/O Connector

Pins 1, 2, and 3 are digital inputs and are reported as a binary number 000 to 111, where a 1 indicates 5 VDC level on the pin. (Digital ground pins for the inputs are 9 and 10.) Pins 7 and 8 are analog inputs referenced to pin 15 analog ground. The analog values are reported as a decimal number from 0.0 to 5.000 VDC. All readings are instantaneous.

Example	Response
RI	100,2.43,1.93

Pin 1 has logic level high (5 VDC). Pins 2 and 3 are logic level low (0 VDC). Pin 7 is 2.43 VDC. Pin 8 is 1.93 VDC.

RL—Read Laser Power

Reads the current laser power output in percentage (%) of maximum milliwatts and current in milliamps (ma)

Example	Response
RL	75.0, 65.3

Indicates the laser power output is 75 percent of maximum output and current is 65.3 ma.

RO—Read Accumulated On Time

Reads the accumulated on-time of the instrument (in hours). The time is updated once an hour and stored in EEROM.

Example	Response
RO	72

Indicates the Model 3321 has been on for approximately 72 hours.

RPI—Read Inlet Pressure

Reads the current absolute inlet pressure in millibars.

Example	Response
RPB	1013.3

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RPS—Read Sheath Delta P

Reads the change in pressure across the sheath flow orifice in Pascals.

Example	Response
RPS	117.29

RPT—Read Total Delta P

Reads the change in pressure across the nozzle flow orifice in Pascals.

Example	Response
RPT	130.72

RQA—Read Aerosol Sample Flow

Reads the aerosol sample flow rate in liters per minute (L/min). This is total flow rate minus sheath flow rate.

Example	Response
RQA	1.04

RQS—Read Sheath Flow

Reads the sheath flow rate in liters per minute (L/min).

Example	Response
RQS	3.96

RQT—Read Total Flow

Reads the total flow rate in liters per minute (L/min).

Example	Response
RQT	5.02

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RR—Read Record

Reads records A, B, C, D, S or Y. See description of records in following subsection.

RR*x*

where:
x = A, B, C, D, S, or Y records

Note: *To read C record, you must be in correlated mode (see SMT command).*

Example	Response
RRA	Record A is returned.

RTB—Read Temperature in Box

Reads the internal temperature of the Model 3321.

Example	Response
RTB	298.2

Indicates the internal temperature is 298.2 K or 25.0°C.

RTD—Read Temperature of Detector (APD)

Reads the APD and optics temperature of the Model 3321.

Example	Response
RTD	306.6

Indicates the APD and optics temperature is 306.6 K or 33.4°C.

RTI—Read Temperature of Inlet

Reads the inlet temperature constant of the Model 3321. This constant is used for flow control only and is fixed.

Example	Response
RTI	294.7

Indicates the inlet temperature is 294.7 K or 21.5°C.

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RV—Read Firmware Version

Reads the current version level of the Model 3321 firmware.

Example	Response
RV	Model 3321 APS Firmware Version 1.12 13-Dec-2001

Unpolled Commands

Using unpolled commands instructs the Model 3321 to automatically output data records at specific intervals. In unpolled mode, 0 disables a record and 1 enables the record. During unpolled operation, records that have been enabled are sent at the end of each averaging time. All U parameters are retained in EEPROM. Not all records available in all modes (e.g. UAx command is not available in correlated mode and may return ERROR).

U—Begin Unpolled Operation

Enables and disables unpolled operation.

```
Ux
```

where:
x is 0 or 1.

U1 enables unpolled operation and clears continuous running average buffers. U0 disables unpolled operation.

U+ —Enable All Records

Enables all unpolled records. See Data Records in the "Unpolled Record Formats" section of this chapter.

U- —Disable All Records

Disables all unpolled records.

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UA—Generate Accumulator Report Record (Report Record A)

Enables and disables reporting of Record A in unpolled operation.

```
UAx
```

where:
x = 1 Enables A Record
x = 0 Disables A Record

UA will echo current setting 0 or 1.

See Record A in the "Unpolled Record Formats" section of this chapter.

UB—Generate Side Scatter Accumulator Report Record (Report Record B)

Enables and disables reporting of Record B in unpolled operation.

```
UBx
```

where:
x = 1 Enables B Record
x = 0 Disables B Record

UB will echo current setting 0 or 1.

See Record B in the "Unpolled Record Formats" section of this chapter.

UC—Generate Correlated (Paired) Report Record (Report Record C)

Enables and disables reporting of Record C in unpolled operation.

```
UCx
```

where:
x = 1 Enables C Record
x = 0 Disables C Record

UC will echo current setting 0 or 1.

See Record C in the "Unpolled Record Formats" section of this chapter.

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UD—Generate Aerodynamic Data Report Record (Report Record D)

Enables and disables reporting of Record D in unpolled operation.

```
UDx
```

where:
x = 1 Enables D Record
x = 0 Disables D Record

UD will echo current setting 0 or 1.

See Record D in the "Unpolled Record Formats" section of this chapter.

US—Generate Side Scatter Data Report Record (Report Record S)

Enables and disables reporting of Record S in unpolled operation.

```
USx
```

where:
x = 1 Enables S Record
x = 0 Disables S Record

US will echo current setting 0 or 1.

See Record S in the "Unpolled Record Formats" section of this chapter.

UY—Generate Auxiliary Report Record (Report Record Y)

Enables and disables reporting of Record Y in unpolled operation.

```
UYx
```

where:
x = 1 Enables Y Record
x = 0 Disables Y Record

UY will echo current setting 0 or 1.

See Record Y in the "Unpolled Record Formats" section of this chapter.

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Unpolled Record Formats

The following are examples of unpolled record formats. These records are comma delimited.

Accumulator (TOF) Data Record (A)

CS,A,SNX,tindex,ffff,stime,dtime,evt1,evt3,evt4,total,a1,a2,a3,... an
(the record is not available in Averaging or Correlated modes)

CS	= Checksum
A	= Accumulator (TOF) Data Record
S	= S for Summed Mode C Correlated mode
N	= N for normal operation A if in autocal mode D if in autocal and autocal was “done” at the beginning of this sample
X	= X for spare position
tindex	= time index 0 to sample time value - 1 (note if enabled for unpolled operation the record is always reported when tindex = 0)
ffff	= 4 digit hex value for status flags (see RF command)
stime	= sample time not corrected for dead time
dtime	= dead time (ms for 3321, µs for 3320)
evt1	= number of single hump events
evt3	= number of 3+ hump events
evt4	= number of timer overflow events
total	= total (2-hump) particles measured (sum of reported channels, evt 2)
a1... an	= particle counts in each accumulator TOF bin (no zeros and n=1023)

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SS Accumulator Data Record (B)

CS,B,SNX,tindex,ffff,stime,dtime,ev1,evt3,evt4,total,b1,b2,b3,... bn
(the record is not available in Averaging or Correlated modes)

CS	= Checksum
B	= Side Scatter Accumulator Data Record
S	= S for Summed Mode C Correlated mode
N	= N for normal operation A if in autocal mode D if in autocal and autocal was “done” at the beginning of this sample
X	= X for spare position
tindex	= time index 0 to sample time value - 1 (note if enabled for unpolled operation the record is always reported when tindex = 0)
ffff	= 4 digit hex value for status flags (see RF command)
stime	= sample time not corrected for dead time
dtime	= dead time
evt1	= number of single hump events
evt3	= number of 3+ hump events
evt4	= number of timer overflow events
total	= total (2-hump) particles measured (sum of reported channels, evt 2)
b1... bn	= particle counts in each pulse height accumulator bin (n=64)

Correlated (Paired) Data Record (C)

The C record is a multi-record report with a header (C0) followed by n more records (C1...Cn)
CS,C,0,PNX,tindex,ffff,stime,dtime,evt1,evt3,evt4,total,n,m (the C records only available in Correlated mode)

CS	= Checksum
C	= Correlated (Paired) Data Record
0	= 0 indicates header record for C data report
P	= C for Correlated Mode
N	= N for normal operation A if in autocal mode D if in autocal and autocal was “done” at the beginning of this sample
X	= X for spare position
tindex	= time index 0 to sample time value - 1 (note if enabled for unpolled operation the record is always reported when tindex = 0)
ffff	= 4 digit hex value for status flags (see RF command)
stime	= sample time not corrected for dead time
dtime	= dead time (ms for 3321, µs for 3320)
evt1	= number of single hump events

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evt3 = number of 3+ hump events
evt4 = number of timer overflow events
total = total (2-hump) particles measured (sum of reported channels, evt 2)
n = number of C (TOF) records to follow this record
m = number of SS fields per record (set by SCR command)

CS,C,n,c1,c2,c3,... cm
CS = Checksum
C = correlated (paired) data record
n = C1 to Cn records of correlated data where n is the number of the aerodynamic dia. chan.
(each record contains data for one aerodynamic particle size channel)
c1... cm = particle counts in each pulse height accumulator bin (no zeros)

Aerodynamic (TOF) Data Record (D)

CS,D,ANX,tindex,ffff,stime,dtime,evt1,evt3,evt4,total,d1,d2,d3,... dn
CS = Checksum
D = Aerodynamic Data Record
A = A for Averaging Mode
S for Summed Mode
C for Correlated Mode
N = N for normal operation
A if in autocal mode
D if in autocal and autocal was “done” at the beginning of this sample
X = X for spare position
tindex = time index 0 to sample time value - 1
(note if enabled for unpolled operation the record is always reported when tindex = 0)
ffff = 4 digit hex value for status flags (see RF command)
stime = sample time not corrected for dead time
dtime = dead time (ms for 3321, µs for 3320)
evt1 = number of single hump events
evt3 = number of 3+ hump events
evt4 = number of timer overflow events
total = total (2-hump) particles measured (sum of reported channels, evt 2)
d1... dn = particle counts in calibrated diameter channels (n determined by SCA data usually 52)

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SS Data Record (S)

CS,S,ANX,tindex,ffff,stime,dtime,evt1,evt3,evt4,total,h1,h2,h3,... hn

CS	= Checksum
S	= Side Scatter Data Record
A	= A for Averaging Mode S for Summed Mode C for Correlated Mode
N	= N for normal operation A if in autocal mode D if in autocal and autocal was “done” at the beginning of this sample
X	= X for spare position
tindex	= time index 0 to sample time value - 1 (note if enabled for unpolled operation the record is always reported when tindex = 0)
ffff	= 4 digit hex value for status flags (see RF command)
stime	= sample time not corrected for dead time
dtime	= dead time (ms for 3321, µs for 3320)
evt1	= number of single hump events
evt3	= number of 3+ hump events
evt4	= number of timer overflow events
total	= total (2-hump) particles measured (sum of reported channels, evt 2)
h1... hn	= particle counts in SS channels (n set by SCR command)

Auxiliary Data Record (Y)

CS,Y,bpress,tflow,sflow,a0,a1,d0,d1,d2,lpower,lcur,spumpv,tpumpv,itemp,btemp,dtemp,Vop

CS	= Checksum
Y	= Auxiliary Data Record
bpress	= barometric inlet pressure (average over sample time)
tflow	= total flow (average over sample time)
sflow	= sheath flow (average over sample time)
a0	= Analog input voltage 0(I/O connector pin 7 ref to pin 15 (average over sample time)
a1	= Analog input voltage 1(I/O connector pin 8 ref to pin 15 (average over sample time)
d0	= Digital input level of I/O connector pin 1 ref to GND (pins 9, 10)
d1	= Digital input level of I/O connector pin 2 ref to GND (pins 9, 10)
d2	= Digital input level of I/O connector pin 3 ref to GND (pins 9, 10)
lpower	= laser power (% of maximum power)
lcur	= laser current (ma)
spumpv	= sheath pump voltage

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tpumpv	= total pump voltage
itemp	= inlet temperature in degrees C (ex. 25.5)
btemp	= internal box temperature in degrees C (ex. 31.5)
dtemp	= detector temperature for APD and optics in degrees C (ex: 25.5)
Vop	= APD operating voltage in volts

How to Input Commands and Troubleshoot the Results

Use the following information as a guide to inputting software commands and for troubleshooting possible problems.

Input Guidelines

- Input all alpha characters as capital letters (SMZ, *not* smz).
- Separate parameters with commas, not spaces.
- If you are in a command string, use the <Backspace> key to back up and make changes. Do *not* use <arrow> keys.
- At the end of a command string, press <**Enter**> to complete the string.

Troubleshooting Input

Use Table C-4 as a troubleshooting guide.

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Table C-4
Troubleshooting Serial Commands

Symptom	Possible Problem	Refer to
"Error" message after pressing <**Enter**>	An invalid command; command does not exist.	Figure C-2 in this section.
	An invalid parameter, which includes too many parameters or a parameter that is out-of-range.	The command showing the range and an example.
	Incorrect syntax	"Input Guidelines" in this section.
No response after pressing <**Enter**>	In unpolled mode	Use the U0 command to disable unpolled mode. Enter U1 if an "OK" is returned.
	Serial cable	Check the cable and the cable connection. See Chapter 2, "Unpacking and System Setup."
	Incorrect COM port	Check the COM port specified in the software.
	Incorrect baud rate	Software must be set at 9600, 19200, or 38400 baud to match instrument setting. Also check computer hardware.
	RS232 chip on the Model 3321	Contact TSI. Refer to "Contacting Customer Service."
	Model 3321 is locked up	Remove power from the Model 3321, then apply power to the instrument. If the problem continues, contact TSI.

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APPENDIX D

Model 3321 Specifications

The following specifications—which are subject to change—list the most important features of the Model 3321.

Table D-1
Specifications of the Model 3321 Aerodynamic Particle Sizer® (APS™) Spectrometer

Measurement technique	The time-of-flight of individual particles is measured in an accelerating flow field. Processing electronics measure the time-of-flight of the particle using a single high-speed timing processor. Phantom particle rejection is achieved through the use of a patent pending double crested optical system. The particle size binning is based on an internally stored calibration curve.
Particle Type	Airborne solids and non-volatile liquids.
Particle Size Range	0.5 to 20 μm aerodynamic size, 0.3 to 20 μm optical size (PSL equivalent)
Maximum Particle Concentration	1000 pt/cm^3 at 0.5 μm with less than 5% coincidence. 1,000 pt/cm^3 at 10.0 μm with less than 10% coincidence. Usable data up to 10,000 pt/cm^3.
Display Resolution	32 channels per decade of particle size (logarithmic). This results in 52 channels total. 1,024 bins of raw time-of-flight data (4 nsec per bin) in uncorrelated mode.
Resolution	0.02 μm at 1.0 μm diameter. 0.03 μm at 10 μm diameter.
Sampling Time	Programmable from 1 second to 18 hours.
Flow Rates	Total flow: 5.0 L/min ±1%, Sheath flow 4.0 L/min ±1%, Aerosol Sample 1.0 L/min ±10% (feedback controlled).
Atmospheric Pressure Correction	Automatic correction between 400 and 1,030 mbar (full correction between 700 and 1,030 mbar).
Concentration Accuracy	±10% of reading plus variation from counting statistics.
Operating Temperature	10 to 40°C (50 to 104°F).
Operating Humidity	10 to 90% RH non-condensing.
Laser Source	30 mW, 655 nm laser diode.
Detector	Avalanche photodetector (APD).
Front Panel Display	320 by 240 pixels.
Power	100 to 240 VAC, 50–60 Hz, 100 W, single phase or 24 VDC.
Communications	RS232 (9-pin) port, 7 bits, even parity, 9600:19200:38400 baud.
Outputs	Digital I/O: 15-pin port (3 input, 3 output). Analog and digital pulse: BNC. Configurable analog: BNC.
Dimensions (HWD)	18 cm × 30 cm × 38 cm (7 in. × 12 in. × 15 in.)
Weight	10 kg (22 lb.).

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Fuse *(not replaceable by user) (internal to power supply -- not accessible by operator).....*	~T 6.3A SB/250V

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