OPERATION MANUAL

Ultrafine Particle Monitor MODEL 651

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About Teledyne API(TAPI)

Teledyne API (TAPI), a business unit of Teledyne Instruments, Inc., is a world leader in the design and manufacture of precision analytical instrumentation for trace gas analysis. Founded in San Diego, California, in 1988, TAPI introduced a complete line of Air Quality Monitoring (AQM) instrumentation, which complied with the Environmental Protection Administration (EPA) requirements for the measurement of criteria gases consisting of CO, SO_2, NO_X and Ozone.

Since that time, TAPI has introduced many features to these products and has grown to the position of the leading producer of AQM instrumentation, providing state of the art analytical products on a world wide basis. Our instruments comply with US EPA regulations as well as a number of other international requirements.

NOTICE OF COPYRIGHT

TRADEMARKS

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Safety Messages

Important safety messages are provided throughout this manual for the purpose of avoiding personal injury or instrument damage. Please read these messages carefully. Each safety message is associated with a safety alert symbol, and are placed throughout this manual; the safety symbols are also located inside the instrument. It is imperative that you pay close attention to these messages, the descriptions of which are as follows:

WARNING: Electrical Shock Hazard

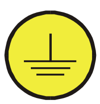
HAZARD: Strong oxidizer

GENERAL WARNING/CAUTION: Read the accompanying message for specific information.

CAUTION: Hot Surface Warning

Do Not Touch: Touching some parts of the instrument without protection or proper tools could result in damage to the part(s) and/or the instrument.

Technician Symbol: All operations marked with this symbol are to be performed by qualified maintenance personnel only.



Electrical Ground: This symbol inside the instrument marks the central safety grounding point for the instrument.

Laser radiation warning. Take appropriate cautionary measures to avoid exposure to radiation.

CAUTION

This instrument should only be used for the purpose and in the manner described in this manual. If you use this instrument in a manner other than that for which it was intended, unpredictable behavior could ensue with possible hazardous consequences.

NEVER use any gas analyzer to sample combustible gas(es)!

Note

For Technical Assistance regarding the use and maintenance of this instrument or any other Teledyne API product, please contact Teledyne API's Technical Support Department:

Telephone: 800-324-5190 Email: sda_techsupport@teledyne.com

or access the service options on our website: http://www.teledyne-api.com/.

Laser Safety

The Ultrafine Particle Monitor – Model 651 is a Class I laser-based instrument. During normal operation, you will not be exposed to laser radiation. To avoid exposing yourself at any time to hazardous radiation in the form of intense, focused visible light (exposure to this light can cause blindness), take these precautions:

- Do ***not*** remove any parts from the instrument unless you are specifically told to do so in this manual.
- Do ***not*** remove the instrument housing or cover 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, which can cause blindness.

Warranty

WARRANTY POLICY (02024F)

Teledyne API (TAPI), a business unit of Teledyne Instruments, Inc., provides that:

Prior to shipment, TAPI equipment is thoroughly inspected and tested. Should equipment failure occur, TAPI assures its customers that prompt service and support will be available.

COVERAGE

After the warranty period and throughout the equipment lifetime, TAPI stands ready to provide on-site or in-plant service at reasonable rates similar to those of other manufacturers in the industry. All maintenance and the first level of field troubleshooting are to be performed by the customer.

NON-TAPI MANUFACTURED EQUIPMENT

Equipment provided but not manufactured by TAPI is warranted and will be repaired to the extent and according to the current terms and conditions of the respective equipment manufacturer's warranty.

PRODUCT RETURN

All units or components returned to Teledyne API should be properly packed for handling and returned freight prepaid to the nearest designated Service Center. After the repair, the equipment will be returned, freight prepaid.

The complete Terms and Conditions of Sale can be reviewed at http://www.teledyne-api.com/terms_and_conditions.asp

CAUTION – Avoid Warranty Invalidation

Failure to comply with proper anti-Electro-Static Discharge (ESD) handling and packing instructions and Return Merchandise Authorization (RMA) procedures when returning parts for repair or calibration may void your warranty. For anti-ESD handling and packing instructions please refer to "Packing Components for Return to Teledyne API's Customer Service" in the *Primer on Electro-Static Discharge* section of this manual, and for RMA procedures please refer to our Website at http://www.teledyne-api.com under Customer Support > Return Authorization.

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About This Manual

This Model 651 manual, PN 07506, is accompanied by a Quick Guide document, PN 07507, which provides critical information that is critical to the proper and safe initial setup and timely maintenance, and proper handling of this instrument.

CAUTION – AVOID WARRANTY INVALIDATION

Failure to comply with proper setup, maintenance and handling of this instrument will void the warranty. Please read both the Quick Guide and this Operation Manual before proceeding with operation of this instrument.

Revision History

2013, June, Model 651 Manual, 07506C, DCN 6727, updates to reflect hardware changes

2012, March, Model 651 Manual, 07506B, DCN 6400, administrative corrections and specs corrections: Inlet pressure, power requirements – max W)

2012, March, Model 651 Quick-guide (separate document), 07507B, DCN 6401, administrative correction.

2011, August, Model 651 Manual, PN 07506 Rev A, DCN 6190, Initial Release

2011, August, Model 651 Quick-Guide (separate document), PN 07507 Rev A, DCN 6190, Initial Release

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Tables

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How This Manual is Organized

Purpose

This is an operation and service manual for the Ultrafine Particle Monitor - Model 651.

Organization

The following information is a guide to the organization of this manual.

- **Chapter 1: Product Overview**
  Contains an introduction to the Model 651, a list of features, the specifications, and a brief description of how the instrument works.
- **Chapter 2: Unpacking and Setting Up the Model 651**
  Contains a packing list and the step-by-step procedures for installing the Model 651.
- **Chapter 3: Moving and Shipping the Model 651**
  Describes how to prepare the Model 651 for moving and shipping.
- **Chapter 4: Instrument Description**
  Describes features and controls that run the Model 651, including the components on the front-panel, back-panel, and inside the instrument. It also covers the basic functions of the instrument.
- **Chapter 5: Instrument Operation**
  Describes the operation of the Model 651.
- **Chapter 6: Technical Description**
  Describes the principle of operation, theory, and performance of the Model 651.
- **Chapter 7: Particle Counting**
  Contains information about the particle counting modes.
- **Chapter 8: Computer Interface, Commands, and Data Collection**
  Describes the computer interface, commands and data collection.

- **Chapter 9: Maintenance, Service, and Troubleshooting**
  Describes the recommended practices for routine maintenance and service, as well as important troubleshooting procedures.
- **Chapter 10: Primer on Electro-Static Discharge**
  Describes how static electricity occurs and why it is so dangerous to electronic components and assemblies, as well as how to prevent that damage from occurring so that the instrument warranty is not invalidated.
- **Appendix A: Firmware Commands**
  Lists the main serial commands for communications between the Model 651 and the computer.

Related Product Literature

TAPI Model 651 Quick Guide *(part number 07507)*

This single-sheet quick guide provides critical information about initial setup, operation, shipping, and maintenance of the instrument.

Getting Help

To obtain assistance with the M651, contact TAPI Technical Support:

Toll-free Phone:	800-324-5190
Phone:	+1 858-657-9800
Fax:	+1 858-657-9816
Email:	sda_techsupport@teledyne.com
Website:	http://www.teledyne-api.com/

CHAPTER 1
Product Overview

This chapter contains an introduction to the Ultrafine Particle Monitor - Model 651 and provides a brief explanation of how the instrument operates.

Product Description

The Model 651 is a continuous laminar flow condensation particle counter that uses water as its working fluid. The Model 651 provides rapid, high-precision measurement of the numbers of ultrafine (down to 7 nm) airborne particles. The instrument delivers robust field performance in both pristine and heavily polluted areas and can be used for a variety of applications including ambient monitoring and research, indoor air quality investigations, atmospheric and climate research, and health effects studies. TAPI recommends annual maintenance and calibration for the Model 651.

Features of the Model 651 include:

- 6-inch color touch screen with a graphical interface displaying particle concentration, total counts, and a plot of concentration vs. time.
- 7-nm detection.
- Single-particle counting to 10^6 particles/cm^3.
- Continuous, live-time, electronic processing for maximum accuracy.
- Adjustable inlet flow (3.0 or 0.6 L/min), inlet location (front or back), and water supply connection (front or back).
- Flexible data acquisition options including USB stick, Ethernet, USB port, and RS-232 port.
- Advanced instrument diagnostics including a novel pulse height analyzer to monitor super-saturation state, wick health, and instrument status.
- Newly designed air flow, wicking, and water handling systems.
- Option to mount in a rack with included hardware.

Figure 1-1
Ultrafine Particle Monitor - Model 651

Specifications

Table 1-1 contains the operating specifications for the Model 651 instrument. These specifications are subject to change without notice.

Table 1-1 Model 651 Specifications

PARAMETER	SPECIFICATION
Particle Size Range	
Min detectable particle (D_{50})	7 nm (verified with DMA-classified sucrose)
Max detectable particle	3 µm
Particle Concentration Range	
Single Particle Counting	0 to 10^6 particles/cm^3, with continuous live-time coincidence correction
Particle Concentration Accuracy	
Measurement Accuracy	±10% at 10^6 particles/cm^3
Response Time (T95)	
High flow mode(3 L/min)	<3 sec to 95% in response to concentration step change
Low flow mode (0.6 L/min)	<5 sec to 95% in response to concentration step change
Flow	
High-flow inlet	3 ±0.3 L/min
Low-flow inlet	0.6 ± 0.06 L/min

PARAMETER	SPECIFICATION
Aerosol flow rate	120 ±12 cm^3/min
False Background Counts	
False background counts	<0.01 particles/ cm^3, one hour average
Aerosol Medium	
Aerosol medium	Air only
Environmental Operating Conditions	
Ambient temp range	10 to 38°C (50 to 100.4°F)
Ambient humidity range	0 to 90% non-condensing
Inlet Pressure Operation	
Inlet pressure operation (absolute)	50 to 110 KPa (0.5 to 1.1 atm)
Inlet pressure gauge	1 to -5 kPa (-20 inch H_20)
Water System	
Condensing liquid	Distilled water
Water system	External 1 liter bottle for up to 4 weeks of operation.
Water consumption	~250 ml/week
Vacuum	
Vacuum	External vacuum pump not included in instrument accessories
Communications	
Protocol	ASCII command set
Interfaces	
RS-232	9-pin, D-Sub connector
USB	Type B connector, USB 2.0 compatible at 12 MB
Ethernet	8-wire RJ-45 jack, 10/100 BASE-T, TCP/IP
Data Logging	
Data logging	USB Flash drive
Averaging interval	Data averaging interval of 1-3600s 1,2,4,5,6,10,12,15,20,30 or 60s software provides more avg options.
Outputs	
Digital display	9-inch QVGA color touch screen with graphical interface. Graph of conc vs. time, concentration, time and total counts, and status
Analog output	BNC connector, 0 to 10V proportional to concentration, or 0 to 7V in LOG concentration mode.
Digital output	Data download using USB, RS-232 serial, or Ethernet interface
Calibration	
Calibration	Recommended annually
Power	
Requirements	100 to 240 VAC, 50/60 HZ, 175 W max

PARAMETER	SPECIFICATION
Physical Features	
Front panel	Display, sample inlet, LED particle indicator
Back panel	Power connector, USB, Ethernet, RS-232, BNC output, fan, water fill connector, pump exhaust port, fill bottle and bracket
HxDxW	20.3 x 48.3 x 30.5 cm (8 x 19 x 12 inches)
Weight	9.9 Kg (22 lbs)

How it Works

The Ultrafine Particle Monitor - Model 651 is designed to measure the concentration of airborne particles. The Model 651 draws in an air sample and counts the number of particles in that sample to provide a particle concentration value that is displayed as the number of particles detected per cubic centimeter of sampled air.

The Model 651 utilizes a patented* laminar-flow, water-based condensation growth technique. Particles which are too small (nanometer scale) to scatter enough light to be detected by conventional optics are grown to a larger size by condensing water on them. In this instrument, an air sample is continuously drawn through the inlet via an external pump and a portion of the flow is sent to the exhaust as transport flow. The stream of aerosol particles is uninterrupted and follows a laminar flow path from the sample inlet to the optical detector.

The Model 651 particle counting process is as follows:

- The aerosol enters the sample inlet.
- In the conditioner, the aerosol sample stream is saturated with water vapor and then temperature-equilibrated.
- The sample passes to a growth tube where the wetted walls (composed of a porous medium) are heated to raise the vapor pressure. The high diffusivity of the water vapor allows the vapor to reach the center of the sample stream at a faster rate than the thermal diffusivity of the vapor can equilibrate to the higher temperatures near the walls—creating a supersaturated condition along the radius of the flow stream. These unstable conditions facilitate water condensation on the sample particles.
- Particles that are larger than the detection limit of the Model 651's minimum critical particle size act as condensation nuclei as they pass up the growth tube.

*US Patent No. 6,712,881, Aerosol Dynamics Inc., Drs. Susanne V. Hering and Mark Stolzenburg.

- The enlarged particles are passed through a laser beam and create a large light pulse. Every particle pulse event is detected and counted. In this technique, particle concentration is measured by counting **each** particle in the air stream.

Figure 1-2 illustrates the flow system of the Model 651.

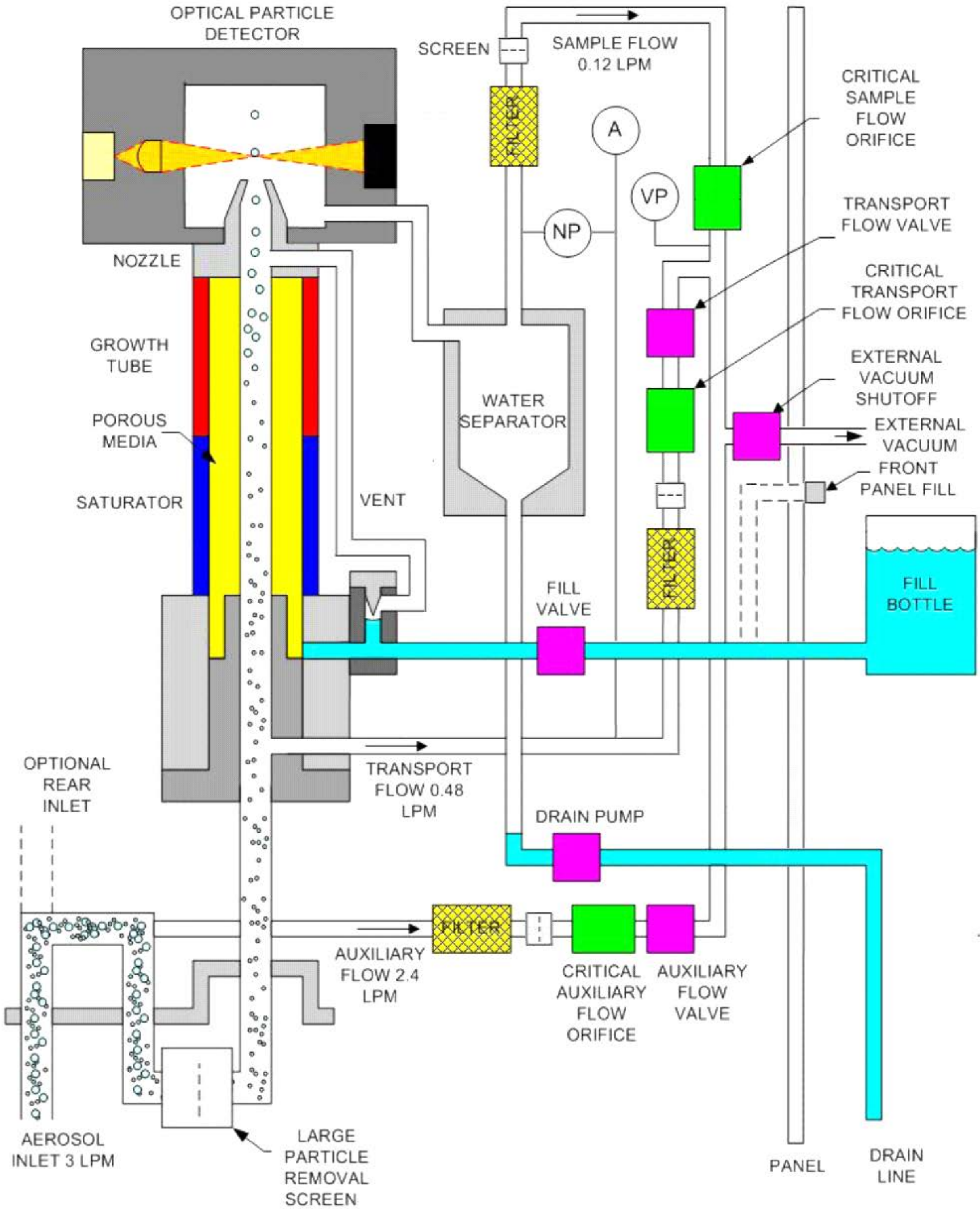

Figure 1-2
Model 651 Flow System Schematic

CHAPTER 2

Unpacking and Setting Up the Model 651

Use the information in this chapter to unpack and set up the Ultrafine Particle Monitor - Model 651.

Packing List

The packing list described in Table 2-1 shows the components shipped with the Model 651.

Table 2-2 shows the components included in the Model 651 Maintenance Kit.

Table 2-1 Model 651 Packing List

Qty.	Part Number/ Model Number	Description
1	081000000	Ultrafine Particle Monitor - Model 651
1	076220000	TAPI Manuals on CD-ROM(KB)
1	075070000	Model 651 Quick Start Guide
1	WR0000008	Power cable, 10A
1	DU0000167	Water supply bottle
1	DU0000168	Water drain bottle
1	DU0000177	Vacuum pump tubing
1	WR0000257	Cable, USB, com
1	WR0000101	RS-232 Serial cable, DB9 M/F
	DU0000175	Vacuum pump, 115V, 60Hz
1	DU0000169	Maintenance Kit (for details see Table 2-2 below)
1	KIT000400	Inlet Mounting Kit

Note: *Some items above and those for future maintenance are available for purchase as kits from TAPI. A complete list of replacement parts is included in the Maintenance section in Chapter 9.*

Table 2-2 Model 651 Maintenance Kit PN DU0000169

Qty.	Part Number	Description
1	DU0000150	Static Dissipative Sample Inlet Tubing (3M)
3	DU0000234	Filter Replacements M651
1	DU0000161	Replacement Critical Flow Control Orifice .005 inch
1	DU0000162	Replacement Critical Transport Flow Control Orifice .0095 inch
1	DU0000163	Replacement Critical Auxiliary Flow Control Orifice .0225 inch
1	DU0000157	3783 Wick Cartridge
12	DU0000158	Wick 3783: Replacement Wicks
1	DU0000178	Three-foot length of 1/8 inch tubing

Unpacking

Carefully unpack the Model 651 from the shipping container (refer to Chapter 10 to avoid damage due to Electro-Static Discharge). Check to ensure there is no damage to the instrument. If any damage is found, contact the carrier. Use the Packing List in Table 2-1 to verify that there are no missing components.

Save the original shipping container to be used for future shipping.

If anything is missing, TAPI Technical Support by phone or by email:

Phone: 1-800-324-5190 (within the US)
001-858-657-9800 (outside the US)
+1 858-657-9800 (local)
E-mail: sda_techsupport@teledyne.com.

See Chapter 9 for instructions on how to return the instrument to TAPI, and Chapter 3 for moving/shipping procedures.

Caution – Prevent Damage and Avoid Warranty Invalidation

The Ultrafine Particle Monitor - Model 651 operates using distilled (<6 ppm) or HPLC water as a working fluid. Do **not** tip the instrument more than 10 degrees during normal operation. Perform the procedures described in Chapter 3 before moving or shipping the instrument.

Do **not**:

- Ship an “undried” instrument.
- Transport an “undried” instrument over long distances.
- Subject an “undried” instrument to freezing temperatures.

Any of the above actions can result in the flooding of the optical system, performance degradation, and possible damage to the instrument. Such neglect is not covered under the manufacturer’s warranty.

Installation

IMPORTANT
The wick used in the M651 must be changed every 4 weeks (800 hours), and distilled (<6 ppm) or HPLC water must be used as the water source. Follow the instructions in Chapter 9 for wick replacement.

This section contains instructions for installing the Model 651 instrument. Follow the instructions in the order given.

The installation procedures, described on the following pages, include the following:

- Removing protective caps.
- Connecting the water supply.
- Connecting the water exhaust tube.
- Connecting the aerosol supply and vacuum line.
- Installing the Model 651 in a rack (if desired).
- Connecting the USB cable.
- Connecting the power and warming up the Model 651.

Equipment

You will need the following equipment to install the Model 651:

- 9/16 inch wrench.
- 7/64 inch hex driver.
- ¼-inch, thick-walled, plastic tubing.
- Water supply.

Note: *Use either distilled (<6 ppm) or HPLC water. Do **not** use tap water.*

Remove Protective Caps

After unpacking the Model 651, remove the protective caps from the **AEROSOL INLET**s on the front and back panels of the instrument and from the **PUMP EXHAUST**. Then remove the covers from the BNC connectors.

Connecting the Water Supply

The Model 651 uses a gravity-fed water fill system.

Note*: To prevent the water from draining back into the bottle during operation, the bottle must always be placed at a higher level than the instrument.*

To connect the water supply, follow these instructions:

1. Using a 7/64 inch hex driver, mount the water supply bottle bracket to the front or back of the particle counter using the provided bottle bracket mounting screws. The figure below shows the bracket mounted on the back.

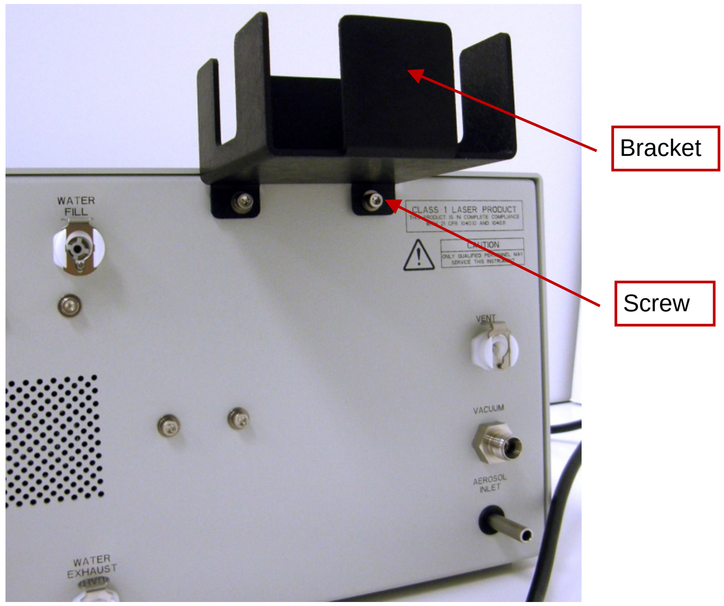

Figure 2-1
Connecting the Water Supply

2. Fill the water supply bottle with either distilled (<6 ppm) or HPLC water and place the bottle in the bracket.

   Note: *A filled water supply bottle will typically allow the Model 651 to operate for more than the 4-weeks wick replacement interval. If water is added between the wick change, it is recommended that the water be added to the bottle without disconnecting it from the Model 651 to avoid adding any bubbles into the water supply line.*

3. Push the connector on the water supply bottle tubing into the **WATER FILL** fitting on either the front or back of the instrument (figure below shows the back).

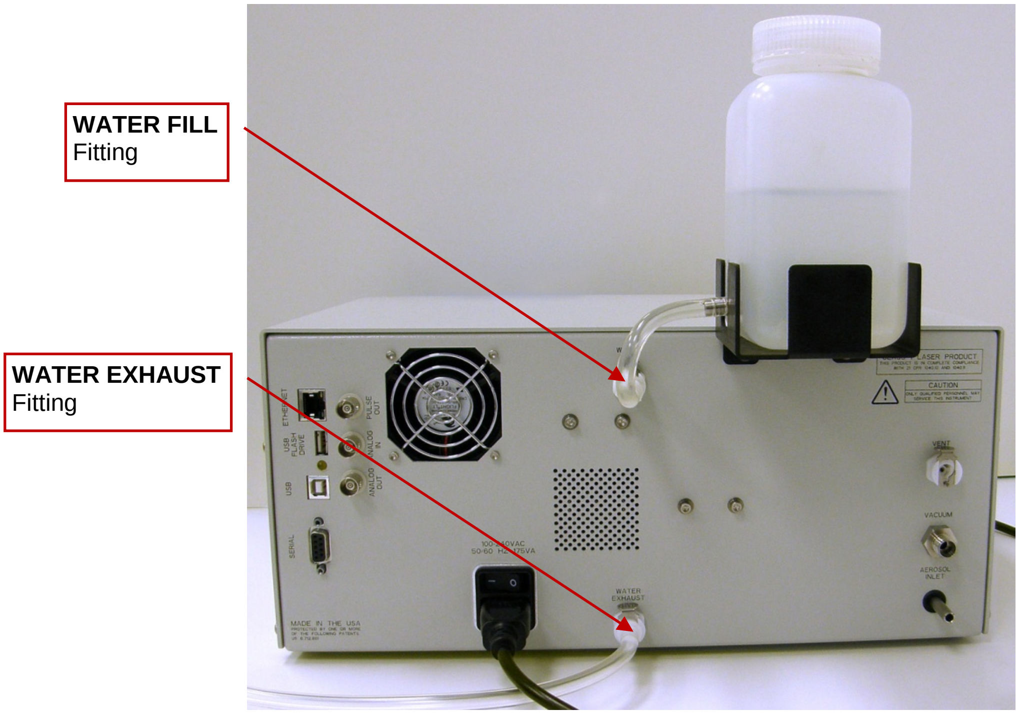

Figure 2-2
Water Fill and Water Exhaust Fittings

Connecting the Water Exhaust Tube

The waste water should pass into a suitable drain such as a floor drain or a vented container. To connect the drain tube:

1. Push the connector on the supplied length of drain tubing into the **WATER EXHAUST** fitting on the back panel.
2. Place the other end of the drain tube in a vented container or over a floor drain.

Connecting the Aerosol Supply

The Model 651 allows you to conduct aerosol sampling from either the front or the back of the instrument. To run the instrument effectively, you need an external vacuum capable of drawing 6 SLPM at 400 mbar absolute pressure.
Sampling options include the following:

- Ambient sampling using the inlet screen assembly (provided with the monitor) connected to the Model 651 inlet. The inlet screen assembly prevents large matter (such as insects and dirt) from entering the instrument.

  Note: *If you are sampling from the back of the instrument, you must use the inlet screen assembly and the flow rate must be 3 L/min when using the inlet screen.*

- Using a sampling system connected directly to the aerosol inlet.
- Environmental monitoring using tubing connected directly to the aerosol inlet.

IMPORTANT
The gauge pressure of the sampled aerosol must be within +4/-20 in. H_2O pressure relative to the ambient pressure. Pressures outside of this range will result in water-handling failures.

To set up the aerosol supply, follow these instructions:

1. Decide whether you will sample from the front or the back of the instrument.
2. Place the aerosol sample inlet cap over the sample port that you will not be using.
3. Determine your sampling method. The instrument is shipped with the inlet screen assembly in place, but if it has been removed and you wish to use it, you must reconnect it to the Model 651 inlet. If you are not using the inlet screen, connect the aerosol sample line to the aerosol inlet.

Figure 2-3
Connecting the Aerosol Supply

4. If you are using the inlet screen assembly and it needs to be connected, line up the two captive screws with the corresponding holes on the front panel. The elbow tube should line up with the nozzle.

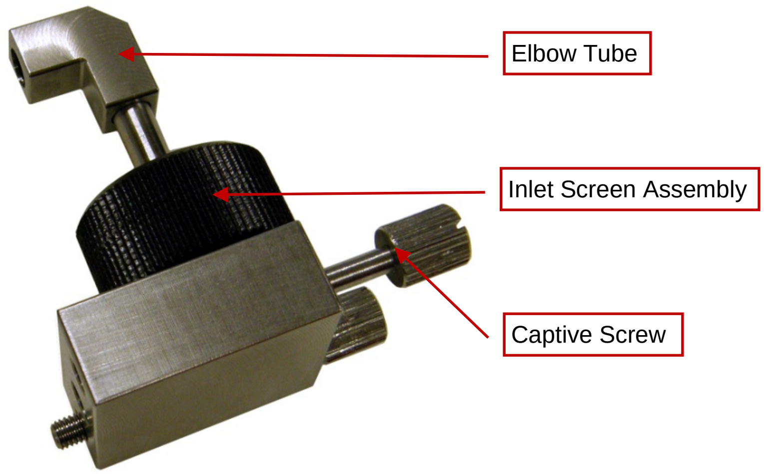

Figure 2-4
Connecting the Aerosol Supply to Inlet Screen Assembly

5. Turn the captive screws to secure the inlet screen assembly in place. Tighten with hex key (supplied with the instrument).

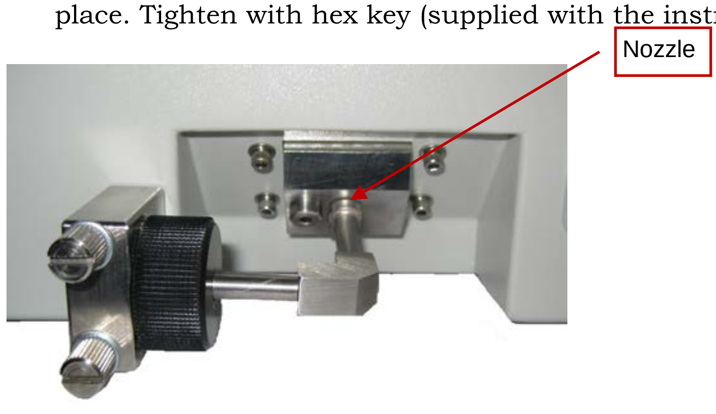

Figure 2-5
Securing Inlet Screen Assembly in Place

6. If you have not already done so, remove the protective cap from the **VACUUM** inlet on the back panel.

7. Connect an external vacuum source to the **VACUUM** inlet using the vacuum tubing provided with the instrument, and a 9/16-inch wrench to tighten the Swagelok® fitting.

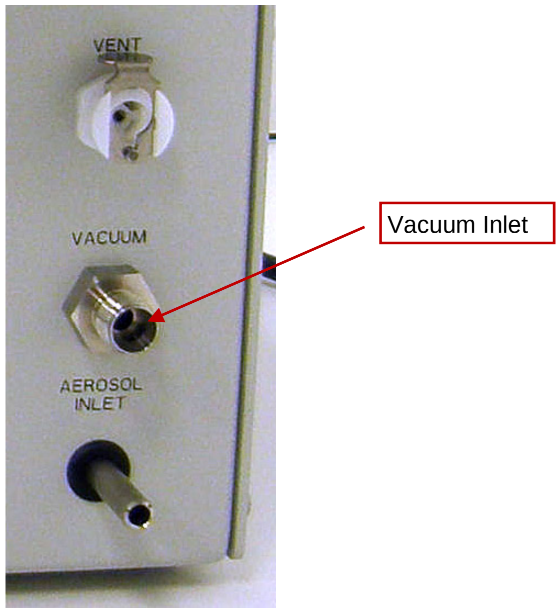

Figure 2-6
Connecting External Vacuum Source

Installing the Model 651 in a Rack

Before you can install the Model 651 instrument in a rack, you must attach the rack-mount brackets. To attach the rack-mount brackets, follow these instructions:

1. Using a 1/8-inch hex driver and the mounting screws provided with the particle monitor, attach the rack-mount brackets to the front sides of the instrument.

   Note *The bracket with the USB port should be attached to the front right of the instrument.*

Swagelok is a registered trademark of Swagelok Company.

Figure 2-7
Installing Model 651 in a Rack

2. Place the Model 651 in the rack.

W A R N I N G
When mounting the instrument in a rack location be certain that the back panel power on/off switch is accessible or that a readily accessible means of disconnecting power is provided.

Connecting the USB Cable

Connect the provided USB cable to the USB connector on the back panel of the Model 651. If you have placed the monitor in a rack, you can use an extension cord to connect the port at the back of the instrument to the port on the rack-mount handle to give you easy access to the USB port.

Connecting Power and Warming up the Model 651

After you connect the power, the warm-up process takes approximately 20 minutes.

Follow these instructions to connect the power and warm up the Model 651:

1. Plug the power cord provided with the Model 651 into the power connector (100 to 240 VAC 50/60 Hz 175 W) on the back panel.
2. Plug the cord into an earth-grounded AC power source (100 to 240 VAC, 50 to 60 Hz, 175 W).

WARNING
Connection to an improperly grounded electrical source may cause a severe shock hazard—ensure that the ground is secure.

3. Turn on the instrument. The Home screen appears on the display and reads **Warmup**. During the warm-up process, status messages are displayed at the top left of the home screen.

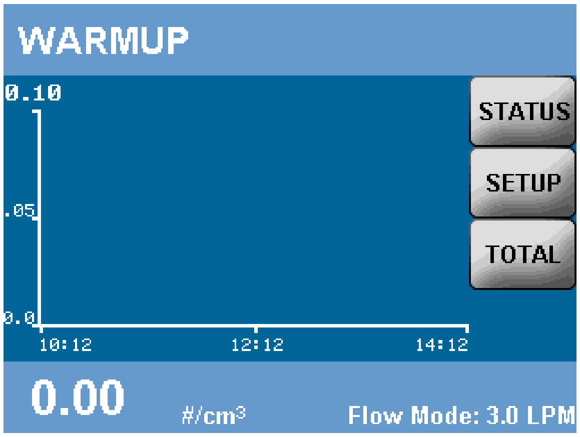

Figure 2-8
Warm-up Screen

4. When the warm-up is complete, if all conditions for operation are in place, the display reads **Ready**. If you do not see the Ready message, check the settings.

CHAPTER 3

Moving and Shipping the Model 651

Use the information in this chapter to prepare the Ultrafine Particle Monitor - Model 651 for moving or shipping.

Caution- Prevent Damage and Avoid Invalidating the Warranty.

The Model 651 operates using water as a working fluid. Do **not** tip the instrument more than 10 degrees during normal operation or you may flood the optical system.

Do **not**:

- Ship an “undried” instrument.
- Transport an “undried” instrument over long distances.
- Subject an “undried” instrument to freezing temperatures.

Any of the above actions can result in the flooding of the optical system, performance degradation, and possible damage to the instrument. Such neglect is not covered under the manufacturer’s warranty.

Moving the Model 651 Short Distances

You can successfully transport the Model 651 short distances from one lab to another, or even a short drive in a vehicle, without draining it first. However, do *not* tip the instrument >45°and do *not* subject it to prolonged freezing temperatures.

Preparing the Model 651 for Shipping and Storage

To prepare the Model 651 for shipping, follow these instructions:

1. Disconnect the water bottle, empty it, and then reconnect it.
2. If you have not already done so, turn on the particle monitor and allow it to warm up (the display screen reads **Ready** when the warm-up is complete and all the settings are correct).
3. Disconnect any connections to the aerosol inlet.
4. Allow the instrument to operate for at least one hour with the water source disconnected.
5. Disconnect the drain tube from the **WATER EXHAUST** outlet.
6. Turn off the power.

7. With the inlet screen assembly securely in place, carefully place the instrument in the original packing materials. (Detailed instructions for attaching the inlet screen assembly are given in Chapter 2, "Connecting the Aerosol Supply".)

The Model 651 is now ready for shipping or storage.

CHAPTER 4

Instrument Description

Use the information in this chapter to become familiar with the location and function of controls, indicators, and connectors on the Ultrafine Particle Monitor - Model 651.

Front Panel

The main components of the front panel are shown in the figure below.

Figure 4-1
Model 651 Front Panel

Display

The QVGA color LCD display provides continuous, real-time display of sample data as well as user menus and status information. Pressing the display "buttons" allows you to move from one screen to another or to record settings.

Status Messages

Status messages display at the top of the home screen. The indicators are as follows:

Status Indicator	Description
Low Water	Water level is low
Warmup	Instrument is warming up
Laser Fault	Laser fault
Inlet Pressure Fault	Inlet pressure is too high/low
Vacuum Fault	Vacuum pressure is too high/low
Nozzle Fault	Plugged nozzle or wet sample flow filter
Absolute Pressure Fault	Barometric pressure is out of range
Optics Temp Fault	Optics temperature is out of range
Growth Tube Temp Fault	Growth Tube temperature is out of range
Conditioner Temp Fault	Conditioner temperature is out of range
Separator Temp Fault	Water Separator temperature is out of range
Pulse Height Fault	Low particle pulse height
Ready	Warm-up process has finished and the instrument is ready for use

***Note**: The status messages on the front-panel display either indicate that the instrument is warming up or that there is a problem with the instrument. However, only one indicator can display at a time. Check the Status screen for more details about potential problems.*

Indicator Light

The blue indicator light on the front panel flashes once for each particle detected. At particle concentrations >100 particles/cm^3, the flashing becomes a continuous glow.

Back Panel

The main components of the back panel are shown in the figure below. Components include power and data connections, analog input/output connections, and water and sample inlets/outlets.

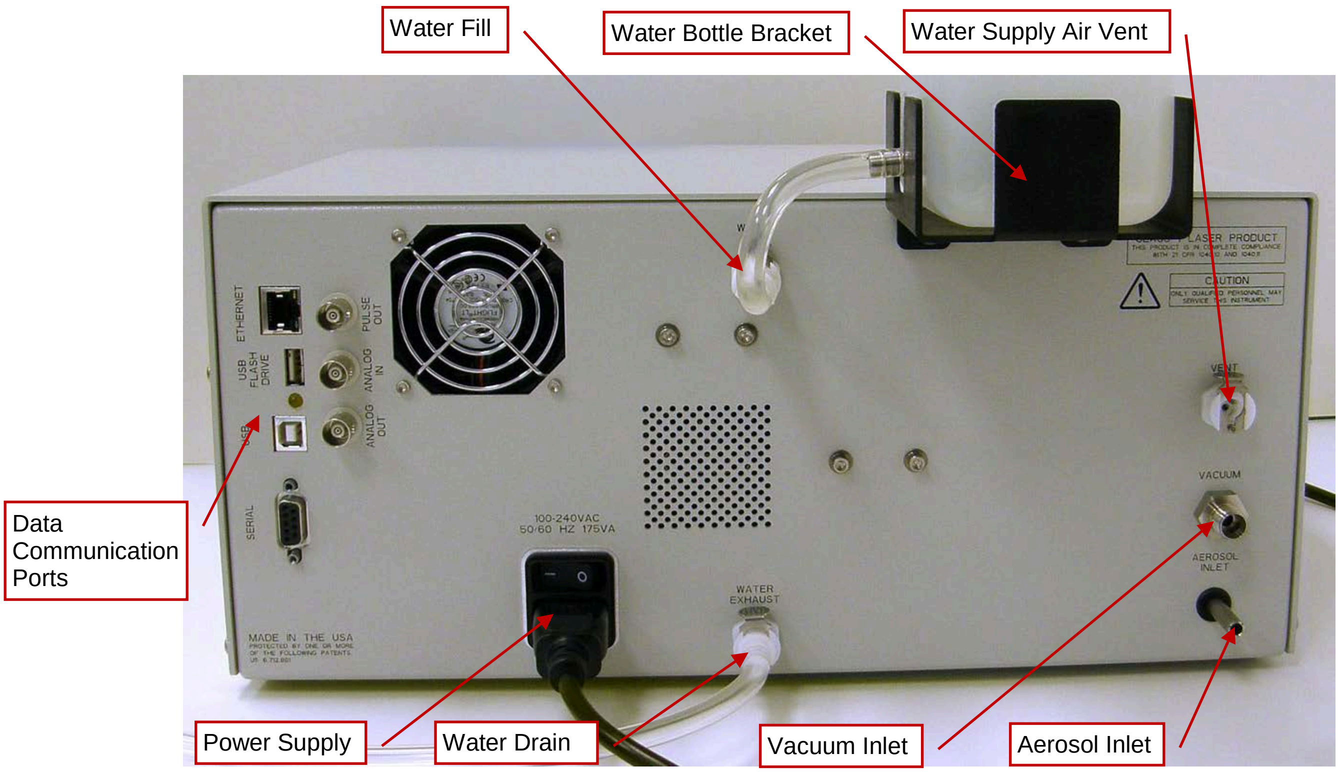

Figure 4-2
Model 651 Back Panel

Internal Instrument Components

Internal components are described in this section and identified in the photos below.

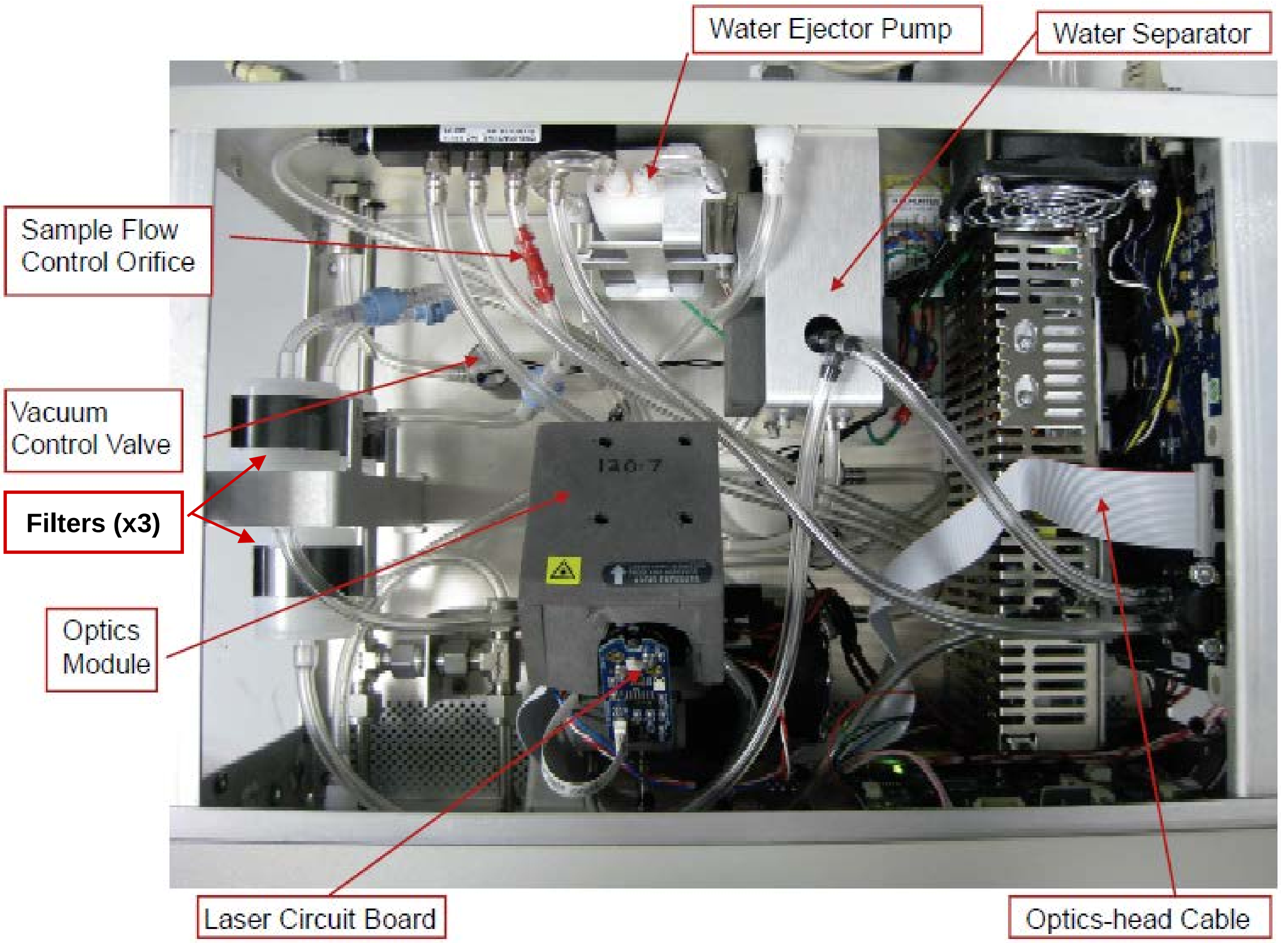

Figure 4-3
Model 651 Internal Components (viewed from instrument front)

Optics Module

The optics module detects particle droplets from the growth tube. The optics module contains a laser, photodetector, and the optics, as well as the detector and optics circuit boards.

Vacuum Supply

An external vacuum supply enables all the flows. The internal vacuum control valve (controlled by parameters available on the

SETUP screen) is an electronic valve used to turn on/off the vacuum from the external source.

Water System

The water separator removes water from the vapor stream coming from the optics head. This prevents water from condensing and blocking the flow orifices. Water from the separator is pumped out by the water ejector pump.

The instrument flow orifices operate under critical pressure with flow determined by the orifice diameter. Each orifice is protected by a glass fiber filter followed by a separate inline screen to remove contamination which can result from an accidental flooding event.

Fans

Two internal fans cool the instrument; one cools the internal electronics and one dissipates the heat generated during cooling of the condenser.

Circuit Boards

The Model 651 contains the following circuit boards:

- Main board
- Laser board
- Detector board

The main circuit board controls all the primary functions. Feedback circuits on the main electronics board control the internal temperatures (displayed on the Status screen).

Internal Clock

The clock used in the Model 651 is a quartz crystal component embedded in the microprocessor. The accuracy is on the order of about a second per day, but time drift during long periods of data logging is possible. If a higher level of time accuracy is needed, one of the following options should be implemented:

1. Send a serial command to the instrument once per day to reset the M651 clock to synchronize with the data collection tool.
2. If collecting data via the USB stick, reset the clock on the instrument as needed.

Data Communication Ports

USB Communication Port

The Model 651 provides a USB port for communications use.

RS-232 Serial Connections

The Model 651 provides one standard, 9-pin RS-232 serial port that allows communication between a computer and the particle monitor. Serial commands are sent to and from the computer to monitor instrument status information, to retrieve and monitor data, and to provide a variety of control functions such as turning the pump on and off. More information can be found in the Computer Interface section of Chapter 8 in this manual.

Analog Input

The Model 651 can monitor the analog voltage from an external source via the analog input BNC connector on the back panel (labeled Analog Input). The input voltage range for these ports is 0 to 10 V. Analog voltages can be displayed together with concentration data on the display screen and can be saved to the removable Flash Drive or a computer. Voltages from connected pressure, flow, or temperature transducers can be correlated to particle concentration in real time.

Amplification must be supplied by the user to bring low voltage signals to the appropriate 0 to 10 V range for best resolution.

DMA/Analog Out and Pulse Out

During normal operation of the Model 651, the Analog Out port provides an analog 0 to 10 V signal proportional (linear or log) to particle concentration. This particle concentration is corrected for coincidence and tracks the displayed concentration.

Pulse Out provides a 5-volt (50-ohm termination) digital pulse for each particle detected. This enables you to use your own counting electronics hardware and provides a particle trigger for special applications. The width of the pulse depends on both the shape of the photo detector pulse and the trigger-level of the pulse threshold. To provide accurate pulse counts, *use a counter that is capable of counting pulses with a width of 50 nanoseconds or less.*

Particle concentrations that have been calculated based on the particle counts from the counting electronics hardware are *not live-time corrected* for particle coincidence. Thus, when particle concentration is high, the concentration provided by this output might be lower than the displayed concentration. Appropriate coincidence correction should be applied when pulse output is used for high concentration measurements.

The pulse output is a way to get raw particle count information. This information is also available through serial command. Using the **SM** or **SSTART,3** command, described in Appendix B, you can read raw, uncorrected, particle counts. TAPI recommends using the serial interfaces for raw counts rather than the pulse output because then all the information used to calculate the corrected concentration is communicated and there are no issues with the monitor's ability to accurately count the pulses.

Ethernet Communication Port

Instrument status, including particle concentration, of the Model 651 can be monitored remotely from a local area network or over the internet using the Ethernet communication port.

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CHAPTER 5

Instrument Operation

This chapter describes the basic operation of the Ultrafine Particle Monitor - Model 651 and describes how to use the controls, indicators, and connectors found on the front and back panels.

Operating Precautions

Read the following before applying power to the particle monitor:

- Review the operating specifications for the Model 651 described in Appendix A.
- Do ***not*** operate the Model 651 at temperatures outside the range of 10°C to 35°C. If the particle monitor is operated outside this range, the displayed concentration may be inaccurate.

WARNING
The Model 651 should not be used with hazardous gases such as hydrogen or oxygen. Using the particle monitor with hazardous gases may cause injury to personnel and damage to equipment.

Recommended Operation Procedures

Outdoor Operation Procedures

When sampling outdoor aerosol, follow these recommendations:

- Place the Model 651 in a conditioned enclosure or shelter to ensure that it is operating within temperature and humidity specifications.
- If the Model 651 is placed in an environment with temperatures lower than the ambient temperature, consider heating the sample line to reduce condensation.
- If you are not using a sampling system, use a cyclone with a cut size no greater than 3 µm on the particle counter inlet.
- Ensure that the pressure differential at the inlet is not greater than 2.5 kPa (10 inches of H_2O). If you are using a cyclone, do not exceed the inlet pressure drop of 2.5 kPa.

- Follow the startup advice contained in the Quick Start Guide (shipped with the instrument).

Standard Operation Procedures

Perform these standard procedures every 4 weeks (800 hours):

- Replace the wick.
- Check the flow using a volumetric flowmeter.
- Fill the water bottle with 1 liter of distilled (<6 ppm) or HPLC water. **Do not use tap water.**
- Verify that the inlet pressure is in the correct operating range relative to the ambient pressure:
    - Check the inlet pressure value on the status screen, then disconnect the aerosol inlet and check the value again. The pressure drop caused by an inlet restriction should not exceed 250 mbars (25 kPa).

      or
    - Check inlet pressure on the status screen, then turn the instrument vacuum off and check the pressure again. The pressure drop caused by an inlet restriction should not exceed 250 mbars (25 kPa).
- Check the status screen to make sure the parameters are still accurate.
- Check the inlet screen and remove any debris collected there.
- Check the time and date on the Flash Drive.

Perform these standard procedures annually:

- Replace the filters.
- Perform a Zero check by placing a HEPA filter on the Model 651 inlet and ensuring that particle concentration is <0.01 particles/cm^3.

Note: *Detailed information about these procedures can be found in the Maintenance section of Chapter 9.*

Warm-up

When you have successfully made all the connections described in the Installation section of Chapter 2, and turned on the power, the Home screen appears on the display and reads **Warmup**. When the warm-up process is complete, and the optics and growth tube temperatures are within two degrees of their standard operating temperatures, the display reads **Ready**. You can then use the menus to do the following:

- Turn flow on and off.
- Set the date and time.
- Set sampling parameters.
- Check flow.
- Collect data.
- Set the network and data collection options.

Display/User Settings

Read this section for details of the screens, how to make selections, and how to change options.

HOME Screen

The Home screen displays a real-time sample graph of the concentration in particles/cm^3, the **STATUS** of the instrument, and the **SETUP** and **TOTAL** options. You can return to the Home screen from any other screen by pressing **HOME**.

The following screens are accessible from the home screen and are described on the following pages:

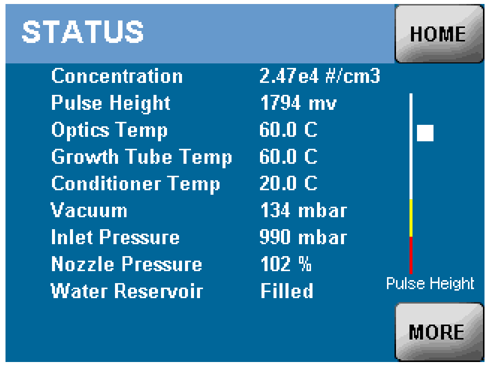
- **STATUS**
- **SETUP**
- **TOTAL**

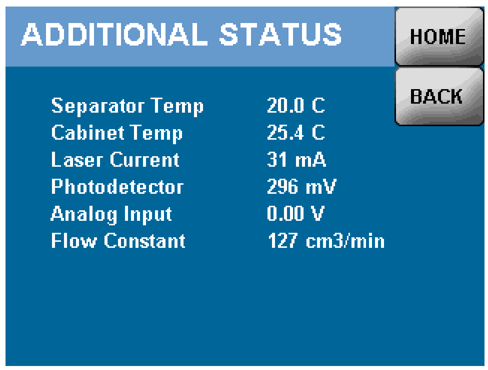
STATUS Screens

The two **STATUS** screens display a variety of real-time readings to give you an instant view of the operational status of the instrument. The following status colors are significant:

- Red indicates a parameter that is “out of range.”
- Yellow indicates something “in process.”
- White indicates “normal” conditions.

Press **MORE** on the first Status screen to see the **ADDITIONAL STATUS** settings. The photos below show the **STATUS** and **ADDITIONAL STATUS** screens.





The Status screens display the following information:

Status	Description
Concentration	Represented in particles/cm^3
Pulse Height	The signal height in mV. The pulse height varies with particle concentration and is useful for indicating problems with the wick.
Optics Temp	Temperature of the Optics in degrees Celsius. A normal Optics temperature is 60°C.
Growth Tube Temp	Temperature of the Growth Tube in degrees Celsius. A normal Growth Tube temperature is 60°C.
Conditioner Temp	Temperature of the Conditioner in degrees Celsius. A normal Conditioner temperature is 20°C.
Vacuum	The vacuum pressure in mbars (must be less than half of the inlet pressure).
Inlet Pressure	The atmospheric pressure in mbars. This parameter is preset and can be used to indicate a blockage.

Status	Description
Nozzle Pressure	The pressure difference upstream and downstream of the optics assembly. Should be 100% - a 10% drop in nozzle pressure indicates a nozzle clog.
Separator Temp	Temperature of the Separator in degrees Celsius. A normal Separator temperature is 7°C.
Cabinet Temp	Temperature inside the Model 651 cabinet.
Laser Current	The operating current of the laser in mA.
Photodetector	Indicates photodetector voltage in mV.
Analog Input	Displays the voltage of the analog input.
Flow Constant	Represented in particles/cm^3. Compensates for any variations in orifice diameter.

SETUP Screens

HOME | SETUP

Pressing the **SETUP** button on the home screen takes you to the **SETUP** screen where you can set the following operating parameters:

Parameter	Description
SAMPLE TIME	Select a sample time for updating the display graph. Choices are 1 sec, 2 sec, 3 sec, 4 sec, 5 sec, 6 sec, 10 sec, 12 sec, 15 sec, 20 sec, 30 sec, 60 sec.
VACUUM	Turn the vacuum valve on/off.
INLET FLOW	Set the inlet flow. Choices are 3 L/min (total flow), 0.12 L/min (sample flow), and 0.6 L/min (transport flow).
SET TIME	Set the time for the internal, real-time clock used for data logging purposes.
MORE	Takes you to the **NETWORK SETUP** screen.
NETWORK SET UP	Set up network connections including **NETWORK, ADDRESS, MASK**, and **GATEWAY**.
MORE	Takes you to the **ADDITIONAL SETUP** screen.
ADDITIONAL SETUP	Specify the **ANALOG OUTPUT** and **LOGGING** time.
ANALOG OUTPUT	Set an analog voltage range for the output.
LOGGING	Choose intervals for logging data.

The following pages contain descriptions of the **SETUP** options.

SAMPLE TIME

SETUP | SAMPLE TIME

Select a sample time in seconds for the on-screen graph. Press the **SAMPLE TIME** button to scroll through the settings. Sample Time choices are 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30, and 60 seconds. If you intend to gather data for long periods of time, use the longer sample times to reduce the number of data files.

VACUUM

SETUP | VACUUM

Select one of the following vacuum settings:

Vacuum Setting	Description
ON AFTER WARMUP	Turns on the vacuum. Message displays during the warm-up process.
ON	Turns on the vacuum valve. Message only displays when warm-up is complete.
OFF	Turns off the vacuum valve.

***Note**: You can toggle between the **ON** and **OFF** settings.*

INLET MODE

SETUP | INLET MODE

Set the inlet flow in liters per minute. Press the **INLET MODE** button to scroll through the settings. Inlet flow choices are:

Inlet Mode Setting	Description
3 L/min	This setting will pull the total flow through the inlet: including sample flow (0.12 lpm), transport flow (0.48 lpm), and auxiliary flow (2.4 lpm), This is flow during normal operation.
0.12 L/min	This setting will include sample flow (0.12 lpm) only through the inlet, transport and auxiliary flows are off.
0.6 L/min	This setting will include only the transport (0.48 lpm) and the sample flow (0.12 lpm) through the inlet and the auxiliary flow is off.

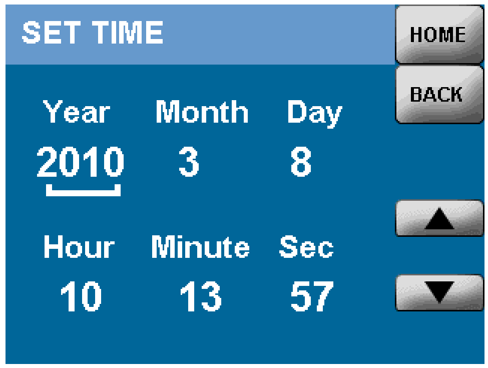
SET TIME

SETUP | SET TIME

Allows you to select the date (year, month, and day) and time (hour, minute, and second) for data collection.

To set the date and time, follow these instructions:

1. Touch the screen option you wish to change. In the photo below, the Year is active (indicated by the line below the number) and ready to be changed.



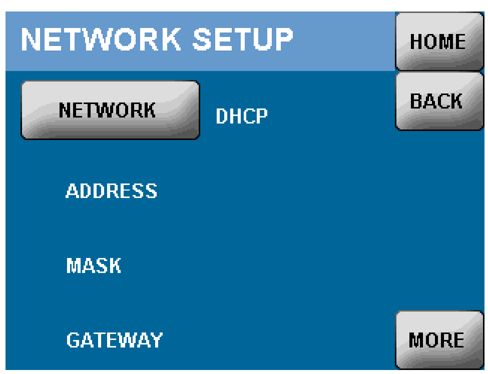
2. Use the ▲▼ arrows to scroll through the different settings.
3. Touch **BACK** to return to the previous screen when you have made your choices.

NETWORK

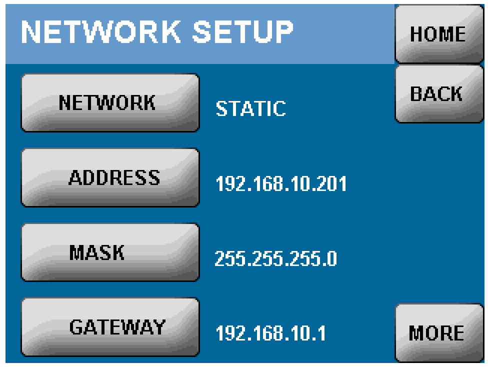
SETUP | NETWORK SETUP | NETWORK

Allows you to specify the network settings. The **NETWORK** button toggles between the settings **STATIC** and **DHCP** (shown below).

Note: *If the network settings have been selected, they are displayed, otherwise they are blank.*



On this screen, only the network setting has been specified.



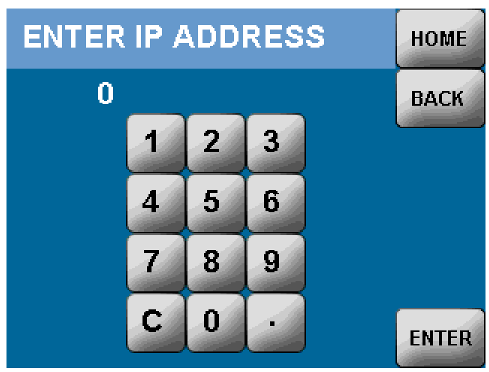
On this screen all network settings have been specified.

ADDRESS

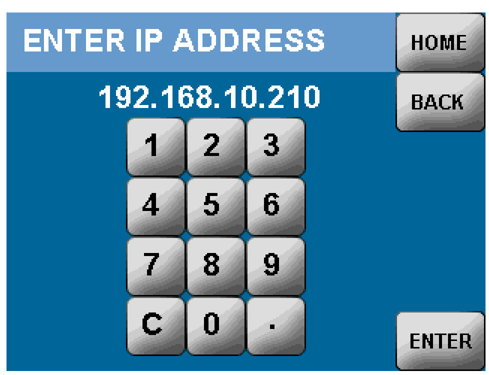
SETUP | NETWORK SETUP | ADDRESS

Allows you to specify an IP address for your network. To set the IP Address, follow these instructions:

1. Press the numbers on the on-screen keypad.



2. When you have selected all the numbers, press **ENTER**. The IP Address is now recorded and displayed on the screen.



3. Press **BACK** to return to the Network setup screen where the IP address is now displayed.

MASK

SETUP | NETWORK SETUP | MASK

Allows you to specify the network mask.

Note*: The Mask must match the size of your network. A typical setting is 255.255.255.0 for a small network.*

To set the Mask, follow the instructions for using the onscreen keypad to set the IP Address.

GATEWAY

SETUP | NETWORK SETUP | GATEWAY

Allows you to specify the network gateway device. To specify the Gateway, follow the instructions for using the onscreen keypad to set the IP Address.

ANALOG OUTPUT

SETUP | NETWORK SETUP | MORE | ADDITIONAL SETUP | ANALOG OUTPUT

Allows you to set the function of the analog output. Press the button to scroll through the options. Settings are 1.00, 100, 1000, 1.0 E^4, 1.0 E^5, 1.0 E^6, 1.0 E^7#/cm^3 FS, LOG OUTPUT (Logarithmic output) and **STATUS OUTPUT** (where a normal Status Output is 0. Abnormal output is 5V).

LOGGING

SETUP | NETWORK SETUP | MORE | ADDITIONAL SETUP | LOGGING

Allows you to choose intervals for logging data to the Flash Memory Card. Logging options are either one hour, or one day. Press the button to toggle between the options.

TOTAL Screen

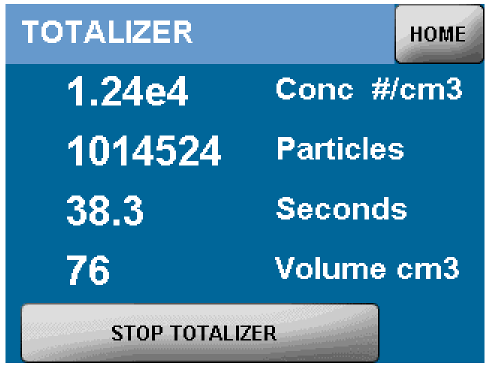
Pressing the **TOTAL** button on the home screen takes you to the **TOTALIZER** screen. The screen displays the following information:

- Current particle concentration in #/cm^3.
- Number of accumulated particles.
- Sample time in seconds.
- Volume based on flow rate and sample time.

This option is useful for manually measuring concentration over a period of time.

There is a toggle button at the bottom of the screen. When you choose **TOTAL** from the Home screen, the toggle button displays **CLEAR TOTALIZER**. When you press **CLEAR TOTALIZER**, the button displays **START TOTALIZER**.

***Note**: If you go to another screen on the display, the **TOTALIZER** continues to run, it can only be stopped by pressing **STOP TOTALIZER**.*



CHAPTER 6

Technical Description

The Model 651 is a continuous-flow, water-based, condensation particle counter that detects particles down to <7 nm at a sample flow rate of 0.12 L/min. This section describes the function of the particle counter, its subsystems and its components. A discussion of operation theory is given first.

Theory

The Model 651 acts very much like an optical particle counter. However, the particles are first enlarged by a condensing vapor to form easily detectable droplets. Portions of the following discussion (focusing on how to condense the vapor onto the particles) are taken from a paper by Keady, et al. [1986].

In *heterogeneous* condensation, the vapor surrounding particles reaches a certain degree of supersaturation and begins to condense onto the particles. In *homogeneous nucleation* (*self-nucleation),* supersaturation is so high that condensation can take place even if no particles are present because molecules of the vapor form clusters (nucleation sites) due to the natural motion of the gas and attractive van der Waals forces. The Model 651 operates below the supersaturation ratio to avoid homogeneous nucleation.

The degree of supersaturation is measured as a saturation ratio (P/P_s), which is defined as the actual vapor partial-pressure divided by the saturation vapor pressure for a given temperature:

$$\text{supersaturation} = \frac{P}{P_s}$$

For a given saturation ratio, the vapor can condense onto particles only if they are large enough. The minimum particle size capable of acting as a condensation nucleus is called the *Kelvin diameter* and is evaluated from the following relationship:

$$\text{saturation ratio} = \frac{P}{P_s} = \exp\frac{(4\gamma M)}{\rho RTd}$$

where γ = surface tension of the condensing fluid
M = molecular weight of the condensing fluid
ρ = density of the condensing fluid
R = universal gas constant
T = absolute temperature
d = Kelvin diameter

The higher the saturation ratio, the smaller the Kelvin diameter.

The saturation vapor pressure P_s is defined for a flat liquid surface. For a curved liquid surface, such as the surface of a droplet, the actual saturation vapor pressure is greater. The smaller the droplet, the easier it is for the vapor molecules to escape the liquid surface. The Kelvin diameter defines the critical equilibrium diameter at which a pure droplet is stable (there is neither condensation nor evaporation). Liquid particles with diameters smaller than the critical equilibrium diameter will evaporate and larger particles will grow even larger by condensation. The larger particle will grow until the vapor is depleted, causing the saturation ratio to fall until it is in equilibrium with the particle droplet. The lower size sensitivity of the counter is determined by the operating saturation ratio.

Design of the Model 651

Submicrometer particles are drawn into the particle counter and enlarged by condensation of a supersaturated vapor into droplets that measure several micrometers in diameter. The droplets pass through a lighted viewing volume where they scatter light. The scattered-light pulses are collected by a photodetector and converted into electrical pulses. The electrical pulses are then counted and their rate (live-time corrected) is a measure of particle concentration.

The basic instrument consists of three major subsystems: the sensor, the microprocessor-based signal-processing electronics, and the flow system. The sensor and the flow system are described below.

Sensor

The sensor contains a conditioner, a growth tube, and an optical detector (shown schematically in Figure 1-2). The sensor grows the sampled aerosol particles into larger droplets that are detected optically.

The sample flow is cooled with a thermoelectric device in the conditioner. The vapor passes into the growth tube where it becomes supersaturated and condenses onto the aerosol particles (acting as condensation nuclei) to form larger droplets. The droplets pass through a nozzle into the optical detector.

The sensor’s optical detector is comprised of a laser diode, collimating lens, cylindrical lens, elliptical mirror, and photodiode detector. The laser and collimating lens form a horizontal ribbon of laser light above the aerosol exit nozzle. The collection mirror focuses the light scattered by the droplets at a 90° angle (side scatter) onto a low-noise photodiode. The main beam is blocked by a light-stop in the back of the sensing chamber. A reference photodiode is used to maintain constant laser power output. The surface temperature of the optics housing is maintained at a higher level than the growth tube to avoid condensation on the optical surfaces.

The Model 651 operates in single particle count mode up to 10^6 particles/cm^3. Rather than simply counting individual electrical pulses generated by light scattered from individual droplets, the Model 651 uses a continuous, live-time correction to improve counting accuracy at high particle concentrations. Live-time correction occurs when the presence of one particle obscures the presence of another particle creating an undercounting error that results in dead time.

Pulse Height

The Model 651 contains an electronic sub-system for monitoring the amplitude (voltage height) of the particle pulse generated by the optical detector. The actual amplitude of the pulse does not affect the particle counting performance as long as it is large enough to intercept the preset discriminator threshold. Typical pulse amplitudes (1 to 2 volts) are 10 to 40 times higher than the discriminator level which is typically 20 times higher than the RMS noise level of the photo-detector electronics. This large magnitude of ‘signal-to-noise’ margin provides robustness in performance in the optical detection of droplets.

Under normal operating conditions, the pulse amplitude decreases with increasing particle concentration. As particle concentration increases, depletion effects within the growth tube cause the nucleated droplets to grow to smaller sizes than they would at lower particle concentrations.

***Note**: The droplet size has been reduced in this instrument compared to those of previous generations - reducing the variation in pulse amplitude with respect to particle concentration to about 2:1 over the concentration range of the instrument.*

Changes in optical alignment, laser power, operating temperatures, flow rates, presence of water, or optical cleanliness can all reduce pulse amplitude, therefore the pulse amplitude indicates the "health" of the WCPC. A peak-sense and hold circuit within the Model 651 measures the pulse amplitude of 50 particles/sec. The average pulse amplitude is displayed both numerically and in a bar graph on the Status screen, and is also included in the data retrieved from the digital interfaces. The limitation of the Pulse Height indication is that is requires the presence of at least 50 particle pulses/sec to provide information. The Pulse Height fault status indication is displayed for particle concentrations over 1000 #/cm^3 with a pulse height of less than 350 mV. When measuring very low concentrations (<10 #/cm^3) the Pulse Height fault may be displayed even though the correct particle concentration is provided.

Flow System

Refer to Figure 1-2 while reviewing the instrument flow information.

The Model 651 relies on an external vacuum supply to maintain constant flows through three critical orifices. These independent flows can be verified by toggling into the different flow modes.

Orifice	Description
0.12 L/min aerosol sample flow mode	Carries the aerosol to be sampled. This is **not** user-selectable.
3.0 L/min auxiliary flow mode	Provides a higher flow rate for use with sampling systems. ***Note**: 2.4 L/min auxiliary flow is removed to leave a transport flow of 0.6 L/min.*
0.6 L/min transport flow mode	Reduces particle losses. ***Note**: 0.48 L/min transport flow is removed to leave a sample flow of 0.12 L/min.*

The flow rate through the sensor is always 0.12 L/min, independent of the inlet flow rate setting. Problems with the aerosol flow can be detected by monitoring the pressure drop across the nozzle and verifying that the critical orifice pressure is maintained.

Critical Flow

To achieve the 0.12 L/min sample flow through the sensor, an orifice is used (operated at the *critical pressure ratio*) to provide a *critical flow*. Critical flow is very stable and is a constant *volumetric* flow, ensuring accurate concentration measurements despite varied inlet pressure.

The critical pressure ratio is found by dividing the absolute pressure downstream of the orifice P_D, by the absolute pressure upstream of the orifice P_U. This ratio must be below 0.528 for air.

$$\text{Critical pressure} = \frac{P_D}{P_U} \leq 0.528$$

The following pressure values are displayed on the Status screen and can affect the Model 651 flow.

Pressure Value	Description
Vacuum	The vacuum pressure
Inlet Pressure	The inlet pressure.
Nozzle Pressure	The differential pressure across the sensor flow orifice

Temperature Control

The temperatures of the conditioner, growth tube, and optics are nominally maintained at 20°C, 60°C, and 60°C, respectively, with specified ambient temperatures in the operating range of 10°C to 40°C. Temperatures are controlled through feedback circuits on the main electronics board and are displayed on the Status screen on the front-panel display.

Note*: For ambient temperatures outside the instrument operating range, the instrument temperature performance may not be maintained. Moderate increases in conditioner temperature will raise* D_{50} *a small amount.*

Vacuum Supply

The external vacuum supply must be sufficient to maintain the sample flow at 0.12 L/min along with the auxiliary and transports flows. The recommended supply is 4 SLPM at 400 mbar absolute pressure.

Inlet Pressure Measurement

With an adequate vacuum supply, the Model 651 can operate at inlet pressures in the range of 75 to 105 kPa. The inlet pressure is measured by an absolute pressure sensor and is equal to the barometric pressure if no inlet restriction is present.

The Inlet Pressure reading is displayed on the Status screen on the front-panel display.

Water Removal System

The Model 651 has a water separator and ejection system to remove water from the vapor stream exiting the optics assembly. The water separator condenses the water vapor and then the collected water is ejected through the **WATER EXHAUST** port on the back panel and away from the internal flow control orifices. A drain tube or bottle is provided to allow the small amount of expelled water to be directed away from the instrument to a suitable drain.

Counting Efficiency and Response Time of the Model 651

The Model 651 has a lower detection curve with a D_{50} of 7 nm. D_{50} is defined as the particle diameter at which 50% of particles are detected. The curve fit shown in Figure 6-1 is based on testing of three Ultrafine Particle monitors using sucrose particles generated by TSI Model 3480 Electrospray Aerosol Generator and size-classified with TSI Model 3080 Electrostatic Classifier and Model 3085 Nano Differential Mobility Analyzer (DMA). The counting efficiency is calculated by comparing the Model 651 readings to TSI Model 3068A Aerosol Electrometer readings.

The particle concentration measured by the particle counter is the total number concentration of all particles that the Model 651 can detect. This measurement provides no size differentiation and it is not corrected using the Model 651 counting efficiency curve.

The Model 651 has a fast response time. T_{95}, defined as the time it takes for the instrument reading to reach 95% of a concentration step change, is < 1.0 sec. Figure 6-2 shows the response time curves, based on the average of three Ultrafine Particle monitors.

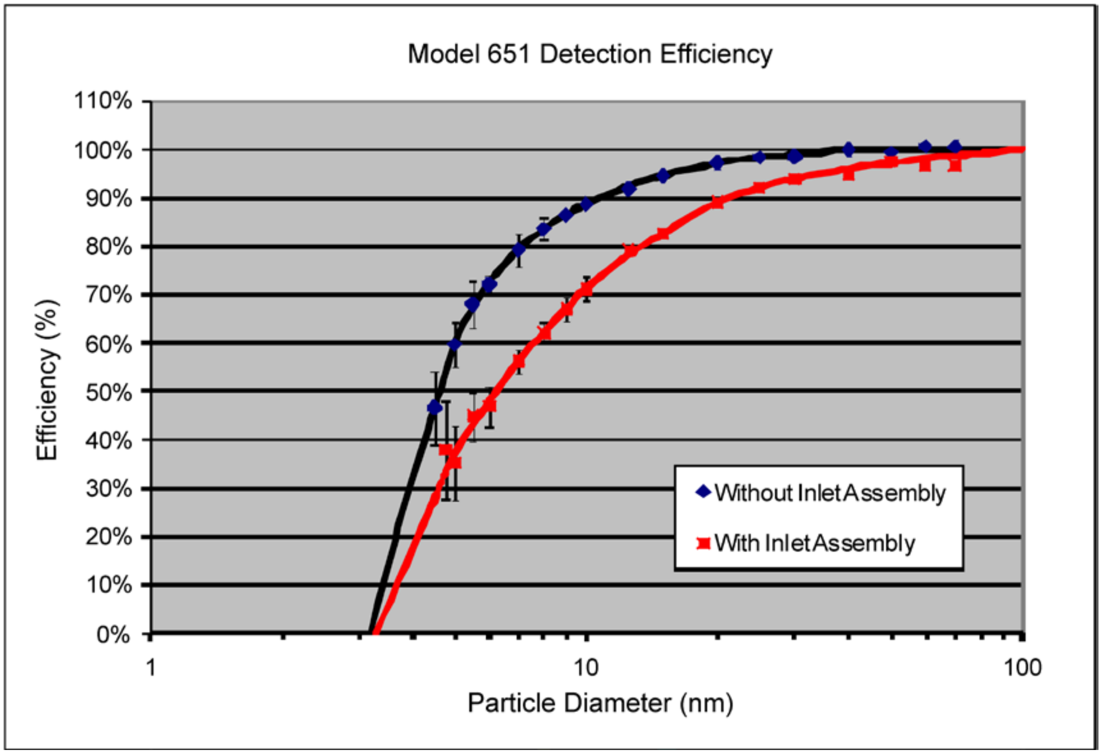


Figure 6-1
Counting Efficiency Curve of Model 651

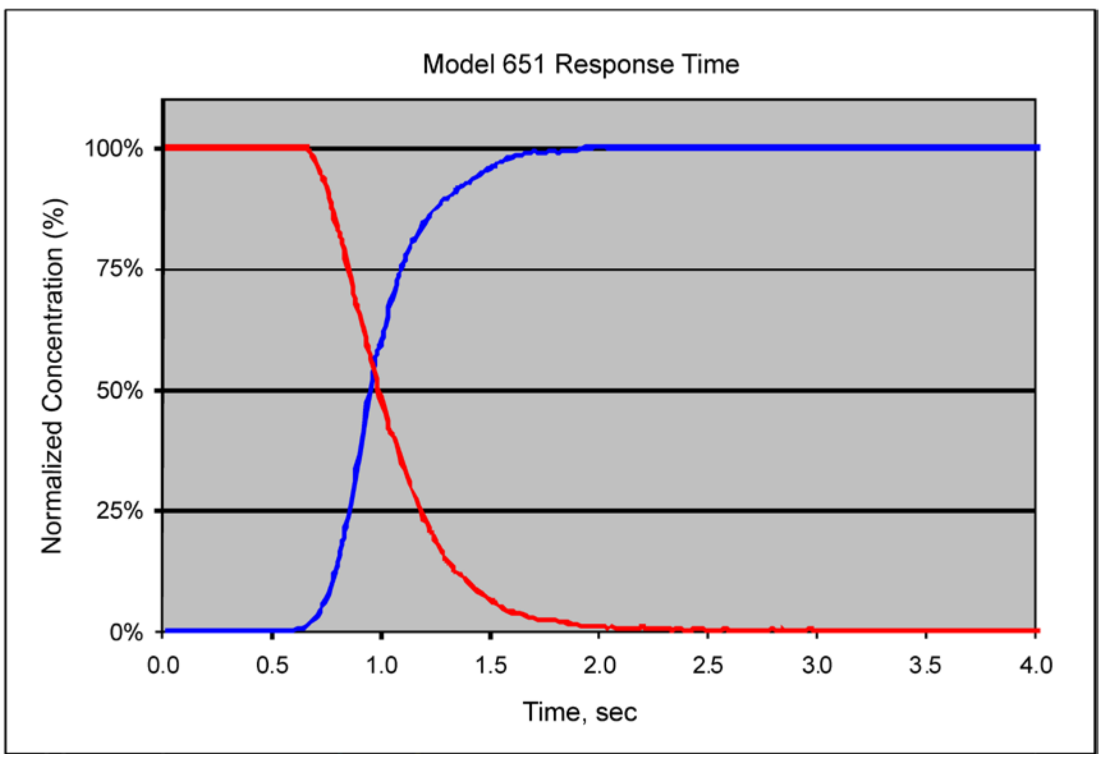


Figure 6-2
Response Time of Model 651

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CHAPTER 7
Particle Counting

This chapter discusses particle counting and particle count measurements performed using the Ultrafine Particle Monitor - Model 651.

The Model 651 has two modes for particle counting:

- Concentration mode, where data is presented as particle concentration in particles/cm^3, updated each second on the display (the maximum time resolution is one second).
- Totalizer mode, where total particle counts are accumulated and presented each second.

Concentration mode is commonly used for most applications and for averaging over a period of time. Totalizer mode is used at very low particle concentrations and includes live-time corrections. Particles can be accumulated until a desired statistical accuracy is achieved.

In the concentration mode, the Model 651 operates in the single count mode with continuous, live-time correction over the range between 0 and 1×10^6 particles/cm^3.

The instrument can display up to 10^6 particles/cm^3. The Model 651 must be calibrated against a concentration reference (e.g., an aerosol electrometer or another Ultrafine Particle Monitor with a dilution bridge with a known dilution ratio) in the range from 3×10^5 to 10^6 particles/cm^3 in order to provide a single dead-time correction calibration (DTC) factor.

Total Count Accuracy

At very low concentrations, the accuracy of the measurement in the single-particle-counting mode is limited by statistical error. If the total number of particles counted in each time interval is very small, the uncertainty in the count is large. The relative statistical error of the count σ_r is related to the total count n by

$$\sigma_r = \frac{\sqrt{n}}{n}.$$

In totalizer mode, the accuracy of the concentration is increased by sampling for a longer period and counting more particles. The concentration is displayed on the front panel in totalizer mode and is calculated by:

$$\text{concentration} = \frac{\text{total counts}}{\text{volume of aerosol flow in the sensor}} = \frac{n}{Q \times t}$$

where
Q = Sample flow rate ration. It is very close to its nominal value of 0.12 L/min.
t = sample time in sec.

Live-Time Counting

Coincidence occurs when more than one particle occupies the optical sensing region simultaneously. The optical detector cannot discriminate between the particles and multiple particles are counted as a single particle. At higher particle concentrations, particle coincidence begins to have a significant impact on the measured concentration.

The Model 651 corrects for coincidence continuously with the instrument electronics performing a “live-time” correction.

Live-time refers to the time between electrical pulses. This is the total measurement time interval minus the time during which the counter is disabled with one or multiple particles in the optical sensing volume (the dead time). The dead time should not be included in the sample time since only the particles already in the viewing column can be counted. The actual particle concentration therefore equals the number of counted particles divided by the live-time (actual sample time) and the aerosol flow rate.

To measure live-time, a high-speed clock and accumulator are used. The accumulator adds up the live time and the counter adds up pulse counts. The particle concentration is then calculated by

$$C_a = \frac{\text{number of counted particles}}{\text{accumulated live - time}} \times \frac{1}{\text{aerosol flow rate}}$$

Note: *At concentrations > 10^6 particles/cm^3, the status reads* ***Over Range****. If this occurs, the Model 651 is outside of the concentration operating range and the number of particles shown on the display could be lower than the actual concentration.*

Concentration Measurement

The Model 651 can report particle concentration values in the following ways:

- On the front-panel display.
- On the Totalizer display.
- Using the data communications ports.

Particle concentration is presented as particles per cubic centimeter (p/cm^3). The following parameters are important for calculating particle concentration:

- The number of particle pulses counted (measured internally by the Model 651).
- The sample time (measured internally by the Model 651).
- The sample flow rate (always assumed to be 0.120 L/min, or (120 cm^3/min).

The basic calculation for the number of particles per volume of air is:

$$Concentration = \frac{N}{Q \times t}$$

where:

Concentration is the particle concentration in #/cm^3
N is the number of particle counted
t is the sample time (corrected for dead-time)
Q is the sample flow rate in cm^3/second

The number of particles in the measured sample is one of the limiting factors of how low a particle concentration can be precisely determined. To calculate low particle concentrations, the Totalizer uses the elapsed time as the sample time in the above calculation.

The formula for this statistical precision is:

$$\sigma_N = \frac{\sqrt{N}}{N} \times 100\%$$

where:

σ_N is the relative standard deviation in percent
N is the number of particle counts in the sample

For a sample of 10,000 particles, the statistical precision is 1% (greater accuracy than that of the instrument). At 100 particles, the statistical uncertainty increases to 10% and becomes a significant factor in determining the aerosol concentration. The Totalizer allows for increased statistical precision at low particle concentrations through the use of longer sample times.

When a particle enters the optical viewing volume and is being detected, no other particles can be counted. As the particle concentration increases, the amount of time blocked by the presence of particles becomes significant. If the particle concentration were computed using elapsed time, the value would be under-reported, therefore the actual sample time needs to be corrected for this blocked or dead time.

To adjust for this particle “coincidence” effect, the Model 651 measures the “dead time” resulting from the presence of particles in the viewing volume and subtracts it from the sample time. This sample ‘live-time’ value is used in place of the elapsed sample time for the concentration calculations for the primary display when not using the Totalizer.

At very high concentrations, the dead-time value grows and the adjustment becomes large. Single particle events may not even be detected since particles are nearly continually in the measurement viewing volume and the accuracy of the ‘live-time’ measurement begins to diminish. When the measured ‘live-time’ value drops below 40% of elapsed (real time), the display will show an “OVER” annotation indicating that the measured concentration exceeds its specified operating range. When the ‘live-time’ value drops below 10% of elapse time, the display will show a concentration of $9.99e^5$ particles/cm^3 indicating an extreme overload condition.

During operation, the Model 651 collects single particle counts and dead-time corrected sample time every tenth of a second. The concentration value reported on the front-panel display is updated each second. It uses data collected over the previous second of elapsed time to calculate concentration. If the concentration is <20.0 particles/cm^3, a 6-second running average of particle count data is used to calculate the displayed value. A single particle counted during this six-second sample is displayed as 0.03 particles/cm^3 which is the minimum value that can be displayed (other than 0.00) without using the Totalizer. Concentration data is also available from the data communications ports and it is ‘aggregated’ or summed from each tenth-second measurement with programmable sample periods from 0.1 second to 3600 seconds.

Totalizer Mode

The Totalizer mode counts the number of particles in a given time period. This mode is used primarily to improve counting resolution at very low particle concentrations, but it can also be used to take an average over a user-specified time period.

The time, number of counts, accumulated sample volume, and particle concentration are shown on the display. The time is the actual sample time and is shorter than the elapsed time (beginning when the Totalizer is started).

The Totalizer automatically stops when 3600 seconds of sample time have been accumulated.

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CHAPTER 8

Computer Interface, Commands, and Data Collection

This chapter provides information about the computer interface, communications information, and data collection for the Ultrafine Particle Monitor - Model 651. Information about using a Flash Drive is also provided.

Computer Interface

The Model 651 provides four interfaces to allow for flexible data collection and instrument control. This section of the manual includes information about the following data interfaces:

- Ethernet
- Flash Drive
- USB
- RS-232 (Serial)

Although four interfaces are provided, you can only use one at a time. The Serial and USB data interfaces share a common communications channel to the Model 651 microcontroller. Data input to the Model 651 from the Serial interface is exclusive from input via the USB interface. Communications can be received from the Serial interface until a connection is linked to the USB port. When the link is established, communications can be received via the USB port but not from the Serial port. When the USB link is terminated, the Serial port can be used.

Ethernet

The Ethernet port on the Model 651 can provide system status information or instrument control over a network. In the instructions below, the client is used. Please note that Telnet feature is not included with Windows Vista® or Windows 7 operating system and must it must be enabled to be used.

To enable Telnet in Windows 7 operating system, follow these instructions:

1. From the **Start** menu, choose **Control Panel** and then choose **Programs and Features**.
2. Choose **Turn Windows features on or off**.
3. Choose **Telnet Client** and then click **OK**. A dialog box appears confirming the installation of new features.

To monitor system status using the Telnet client, follow these instructions:

1. Insert an Ethernet cable into the Ethernet port on the back panel of the M651 and connect the cable to your network or a personal computer.
2. On the M651 home screen, choose **SETUP** then choose **MORE** to view the **NETWORK SETUP** screen.
3. On the **NETWORK SETUP** screen, choose **ADDRESS** and enter a static IP address for this unit that is available on your network. Alternately choose **NETWORK** and select **DHCP**. If your network has a DHCP server, a dynamic address will be selected for you in a few seconds.
4. If you are using a personal computer, from the **Start** menu, choose **Run** then type the command **telnet xx.xx.xx.xx** where **xx.xx.xx.xx** is the IP address determined in step 3.
5. A console screen appears which allows direct entry of firmware of commands.

To test communication between the personal computer (or your network) and the N-WCPC, follow these instructions:

1. From the Start menu, choose **Run**, type **cmd** and press **Enter**.
2. In the resulting window type **ping xx.xx.xx.xx** where **xx.xx.xx.xx** is the IP address determined in step 3 above.
3. The response shows the response from the instrument if the network connection is valid as shown in the figure below.

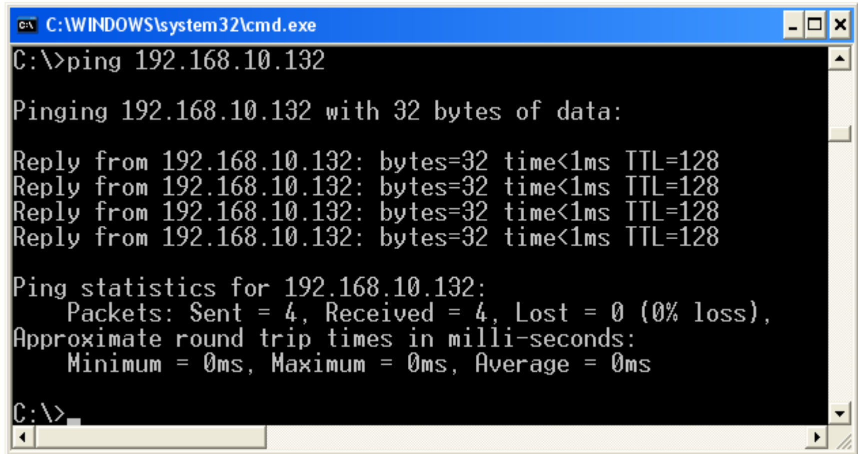

Figure 8-1
Screen Showing Valid Network Connection

Flash Drives

The Model 651 can store particle concentration data and analog input data to a flash drive inserted into the USB slot.

Note*: Flash drives >16 Gigabytes may not be recognized.*

To insert a Flash drive, follow these instructions:

1. Plug the Flash drive into the USB Flash Drive port on the back panel of the Model 651.

   Note*: If the Model 651 is mounted in a rack, you can use the alternative USB port on the rack-mount bracket by running an extension cable from the USB port on the back panel to the USB port on the front.*

2. Check the Home screen. You should see a **START** button displayed beneath the other home screen buttons. If you do not see this button, check that your Flash drive is inserted correctly. You should also see a status message beneath the button. This message reads **Mem Stick** until you begin data collection.

3. Press **START**. The status message changes to **Logging** and the button displays **STOP**. When you press **START**, a directory named **3783** is created on the Flash drive. The data files created within that directory contain either one hour or one day of data (depending upon the **SAMPLE TIME** you chose on the **SETUP** screen), unless you press STOP to discontinue the data logging.

***Notes**: Data records written to the flash drive are also echoed out of the Ethernet interface on the Telnet socket. This allows redundant external data collection to be performed with the Ethernet connection while data is being collected by the flash drive.*

*You cannot change the **SAMPLE TIME** while data is being logged - you must stop logging data first.*

4. Press **STOP** to discontinue data logging at any time.

   ***Note**: Do **not** remove the Flash drive while logging data.*
   *Do **not** restart data logging or go beyond 99 files. If you do, data files may be overwritten.*

5. Remove the Flash drive and connect it to a computer to download the data.

Flash Memory Data Files

The data is stored in files with the "dat" extension and a new file is created either every day or every hour (depending upon the Logging selection you have made). If you stop data collection at any time, the current data file is saved even if it contains less than one hour/day of data.

Every time a new run is started, a unique file is created. Each data file has the following format:

Filename	yymmddxx, where yy is the year (no leading zero), mm is the month (1-12), dd is the day of the month, and xx is a sequence number for the day (01-99). Example: 9110601.DAT where 9 is the Year, 11 is the month, 06 is the day, 01 is the file number and .DAT is the extension.
LINE 1	“TSI CPC DATA VERSION 3”
LINE 2	Time stamp for the file: yy/mm/dd,hh:mm:ss where yy is the year, mm is the month, dd is the day of the month, hh is the hours, mm the minutes, and ss the seconds
LINE 3	Data average period (sample time intervals) in seconds.
LINE 4	Dead-time correction factor, flow calibration constant (mL/min).
LINE 5	Instrument model number, firmware version number, serial number
LINE 6	Header descriptions.
LINE 7	First data record.
LINE 8	Second data record.
LINE X	Last data record.

Example of data record:

```
TSI CPC DATA VERSION 3
1268228469,2010/3/10,13:41:09
60
1.00,120
 Model 651 Ver 1.00 S/N 123456
"Date","Time","Concentration","Count"," Live-
Time","Blank","Abs Press"," Analog In","Pulse Height"," Pulse
STD","Status Flags"
2010/3/10,13:41:57,2.15e4,2522183,58.62,,970,0.00,567,600,0
2010/3/10,13:41:57,2.32e4,2719488,58.51,,970,0.00,607,595,0
2010/3/10,13:42:57,2.15e4,2530791,58.62,,970,0.00,587,609,0
2010/3/10,13:43:57,2.13e4,2505886,58.63,,970,0.00,581,615,0
```

Data fields include:

- Date
- Time
- Particle Concentration (#/cm^3)
- Raw Particle Counts
- Live-time (seconds)
- Comma (reserved field)
- Absoluter Pressure (mbars)
- Analog Input (V)
- Pulse Height average (mV)
- Pulse Height Standard Deviation
- Status flags.

You can select the Sample Time (the period over which data is collected and reported) from one of the following choices: 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30, or 60 seconds. Data is collected internally 10 times/second and is averaged over the selected sample time. The average is displayed on the graph and can be saved to the flash drive. Data is saved to the flash drive every 10 seconds, or at the rate of the data averaging period if it is longer than 10 seconds. The data averaging period is the same as the Sample Time setting. Once the data is being logged to the Flash drive, the Sample Time setting cannot be changed.

IMPORTANT

If power is lost at any time, the instrument should continue data logging when the power is returned. The data files created will have the extension **.rdt** so that the previous files are not overwritten.

USB

USB communications are available with the Model 651. USB driver software must be installed on the host computer. For Windows® operating systems the drivers may be downloaded from the USB chip manufacturer's site at:
http://www.ftdichip.com/Drivers/VCP.htm

To install the USB driver, follow these instructions:

1. Find the appropriate driver for the host computer's operating system.
2. Download the driver to the host computer.
3. Extract (unzip) the driver to a blank folder.
4. Connect the computer to the Model 651 USB port.
5. Follow the **Add New Hardware** wizard steps and browse to the folder containing the extracted driver. If the wizard does not start, use the Add Hardware function on the Control Panel.

When the USB driver is loaded, the operating system recognizes the Model 651 as a new serial device. In Microsoft® Windows® operating system this is a new port (such as COM2 or COM6). If it is not obvious which COM port is being used, you can check in the computer's Device Manager. To check which COM port is being used, follow these instructions:

1. Open the **Control Panel** and choose **System**.
2. In the **System Properties** dialog box, choose the **Hardware** tab and then click **Device Manager**.
3. In the **Device Manager** dialog box, click the **+** sign next to **Ports (COM & LPT)**. The USB Serial Port indicates in parenthesis which COM port is being used.

Connect the supplied USB cable between the Model 651 USB port and a computer running the Windows®-based operating system

RS-232 Serial Communications

The communications port is configured at the factory to work with RS-232-type devices. RS-232 is a popular communications standard supported by many computers. The Model 651 has one 9-pin, D-type subminiature connector on the back panel (labeled Serial). Table 8-1 lists the signal connections.

Note: *This pin configuration is compatible with standard IBM® PC serial cables.*

IBM is a registered trademark of International Business Machines Corporation in the United States, other countries, or both.

Table 8-1
Signal Connections for RS-232 Configurations

Pin Number	RS-232 Signal
2	RXD (Input to Model 651)
3	TXD (Output from Model 651)
5	GND

An external computer can be connected to the Serial or USB ports for basic instrument communications.

Communications Parameters

All serial communications with the Model 651 are accomplished using the following communications parameters:

- Baud Rate: 115,200
- Bits/Character: 8
- Stop bits: 1
- Parity: None

All data communications are performed through ASCII-based character codes.

All multi-field responses are comma separated values (CSV).

All input commands and output responses are terminated with a carriage return.

All input line feeds are ignored.

Terminal Communications

When you have made a Serial or USB connection between the Model 651 and host computer, you can use a terminal emulation program to communicate with the Model 651. You can choose from the following terminal emulation programs:

- Tera Term—a free terminal emulator for Microsoft Windows® operating systems.
- HyperTerminal—included with most Microsoft Windows® operating systems.

You should set up the terminal emulation software so that incoming carriage returns are translated into carriage return line feed sequences and therefore do not overwrite the previous line of data. Also, consider enabling local echoing of characters so that data typed on the keyboard is displayed on the screen.

When the terminal emulation software is connected and running, if you press the **Enter** key you will see an **ERROR** response from the

Model 651 in the terminal emulation software. This is because, although the Model 651 and computer are communicating, the command is not understood. You can ignore this error message – it is only used for testing the connectivity. When data is being reported to the screen of the terminal emulation software, you can either, cut and paste the data into a file, or use the software's data logging capabilities to capture data. Data in the comma-delimited format can be imported into programs such as Microsoft Excel® spreadsheet software for analysis and graphing.

Appendix B, "Firmware Commands" describes the commands that control the operation and data reporting options for the Model 651 instrument.

Commands

It is important to note the following information about the commands and responses:

- Unless specified as binary-encoded, all commands and responses are sent or received as ASCII characters.
- All messages are terminated with a <CR> (0x0D) character.
- All linefeed (0x0A) characters are ignored and none are transmitted.
- Commands are case insensitive. The backspace character (0x08) deletes previous characters in buffer.
- Values enclosed by "<>" indicate ASCII characters/values sent/received. For example, <,> indicates the comma was sent or received via the communications channel.

The firmware commands are divided into the categories described below.

Commands	Description
READ	Used to read parameters from the instrument (such as flow rate, pressure, temperature, etc.). **READ** commands can be identified by a leading "R".
SET	Set an internal parameter to the value(s) supplied with the command (supplied parameters are always delimited by a comma). **SET** commands can be identified by a leading "S". The instrument will reply to all **SET** commands with the string "OK"<CR>.

Note: *When the instrument does not understand a command, it replies with the string "ERROR".*

To use the read and set commands, a program capable of sending and receiving ASCII text commands can be used. A terminal program such as HyperTerm (supplied with Windows® XP operating system) is appropriate. To use Hyperterm, follow the instructions below for Windows® XP operating system. Other OS versions may require that you download a terminal program such as TeraTerm, but the steps are similar.

1. Connect to Serial 1 of the Model 651.
2. Open the HyperTerminal program by selecting: **Start | Programs | Accessories | Communications | HyperTerminal**.
3. Enter a name for the connection, for example, TAPI-651.
4. Enter the communications (COM) port.
5. Enter the following port settings and click **OK**:
   Bits per second: 115200
   Data bits: 8
   Parity: None
   Stop bits: 1
   Flow control: None**.**
6. Under the settings tab, pick the **ASCII Setup** button and check the following boxes:
   - ☐ Send line ends with the feeds
   - ☐ Echo typed characters locally
   - ☐ Append line feeds to incoming line ends
   - ☐ Wrap lines that exceed terminal widths
7. From the **File** menu choose **Save As** and save the file to the desktop for easy access.
8. Close the program and start it again from the desktop. It should automatically open a connection to the instrument.
9. Type in firmware commands to communicate with the Model 651. A list of firmware commands can be obtained using the **HELP** command or from Appendix A.

   To obtain the list from the **HELP** command, select **Transfer | Capture Text**. **HELP ALL** in the terminal window lets you capture all the help commands to a text file for easy reference.

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CHAPTER 9

Maintenance, Service, and Troubleshooting

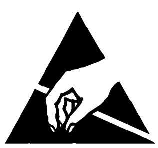
This chapter describes recommended maintenance procedures and is intended to be used by a service technician with skills in both electronics and mechanics. Static preventative measures should be observed when handling any printed circuit board connectors.

Regular maintenance of the Model 651 instrument will help ensure years of useful operation; however, the frequency of service depends upon the frequency of use and the cleanliness of the air measured. TAPI recommends annual maintenance and calibration for the Model 651.

If you need to contact TAPI for assistance, please have the Model 651 close to the telephone when discussing the problem with a TAPI technician.

WARNING
Procedures described on the following pages may require removal of the instrument cover. The instrument must be unplugged prior to service to prevent possible electrical shock hazard**.**

WARNING
Unplug the instrument prior to removing the cover to avoid potential of exposure to laser radiation.



Caution
Whenever performing service on internal components avoid damage to the Model 651 circuitry by not stressing internal wiring, through bumping, snagging or pulling. Also use electrostatic discharge (ESD) precautions: ❑ Use only a table top with a grounded conducting surface. ❑ Wear a grounded, static-discharging wrist strap

Removing the Cover

When you remove the Model 651 cover to perform service or maintenance, follow the instructions below:

1. Read the warnings and cautions at the beginning of this chapter.
2. Unplug the instrument and remove the instrument cover by loosening the eight side panel screws.
3. Lift the cover up.

Replacement Parts Kits

In addition to replacement parts found in your supplied accessory kit, additional replacement items are available from TAPI to keep your Model 651 operating for many years. Parts are available in kits listed below in Table 9-1. Please contact TAPI for details and purchase of these items.

Table 9-1 Model 651 Maintenance and Replacement Kits

Part No.	Name	Description
DU0000169	M651 Maintenance Kit	See Table 2-2 in Chapter 2 for details.
DU0000157	Wick Cartridge	REPLACEMENT WICK CARTRIDGE
DU0000158	Wick	REPLACEMENT WICK (SET OF 12)
DU0000161	Critical Flow Control Orifice	REPLACEMENT CRITICAL FLOW CONTROL ORIFICE (.005 INCH)
DU0000162	Critical Transport Flow Orifice	REPLACEMENT CRITICAL TRANSPORT FLOW CONTROL ORIFICE (.0095 INCH)
DU0000163	Critical Auxiliary Flow Control Orifice	REPLACEMENT CRITICAL AUXILIARY FLOW CONTROL ORIFICE (.0025 INCH)
DU0000164	Rack-mount kit	RACK-MOUNT BRACKETS W SCREWS,& USB ADAPTER CABLE
DU0000165	Inlet screen	INLET SCREEN ASSEMBLY
DU0000166	Inlet cap	INLET CAP
DU0000167	Water supply bottle	WATER SUPPLY BOTTLE
DU0000168	Water drain bottle	WATER DRAIN BOTTLE
DU0000171	Water Separator Assembly	REPLACEMENT WATER SEPARATOR WITH BRACKET
DU0000172	Ejection Pump Assembly	REPLACEMENT EJECTION PUMP WITH BRACKET
DU0000174	Optics Assembly	REPLACEMENT OPTICS ASSEMBLY
DU0000234	Filter	FILTER REPLACEMENT
TU0000034	Inlet tubing	STATIC DISSIPATIVE SAMPLE INLET TUBING

Removing and Installing the Wick

The wick should be replaced every 4 weeks (800 hours). To replace a wick, follow these instructions:

1. Unscrew the top of the spare wick cartridge and insert a new, dry replacement wick.

Figure 9-1
Loading New Wick Into Spare Wick Cartridge

2. With the Model 651 powered on, disconnect the water supply.
3. Press SETUP and turn the VACUUM to OFF.
4. Loosen the thumb screws holding the inlet screen assembly in place and pull off the assembly.

Figure 9-2
Removing Inlet Screen Assembly

5. Loosen the sampling inlet jack-screw using the supplied 1/8" Hex ball driver, and slowly turn the screw. As you turn the screw, the nozzle and wick cartridge will gradually be pushed out of the instrument. Grasp the sampling inlet and carefully pull it from the instrument.

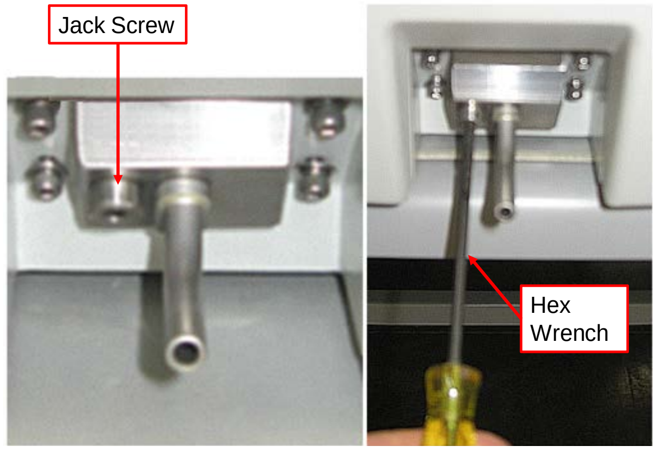


Figure 9-3
Nozzle Jack Screw

6. Insert spare wick cartridge loaded with a new wick (wick inserted in Step 1) into the inlet assembly.

Note
It is important that the flow path through the wick is uniform and clear of obstruction. Visually inspect the flow channel through the cartridge before installing it on the inlet nozzle assembly to ensure that the wick is not twisted and provides a uniform flow path.

7. Reinstall the sampling inlet assembly and the inlet screen assembly (take care to tighten the jack screw so that it is properly seated to avoid flooding of the optics).
8. Reconnect the water supply and turn the VACUUM back to ON in the Setup menu. It will take at least 30 minutes for the new wick to saturate properly. The unit may display a Pulse Height warning during this time.
9. Allow removed wick to dry inside removed wick cartridge
10. Once the old wick is dry, unscrew the end of the wick cartridge and carefully remove the old wick.

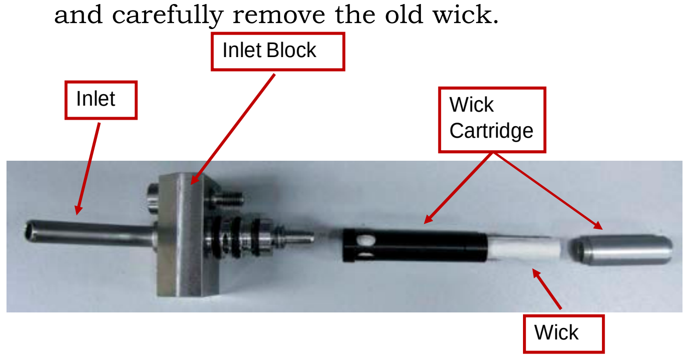


Figure 9-4
Removing Wick

11. For the next required wick replacement, discard the used wick, and insert a new wick into the wick cartridge. Keep this assembly handy.

Changing the Filters

The Model 651 contains three filters. The filters should be replaced as part of the annual service.

To replace a filter, follow these instructions:

1. Turn off the power to the Model 651.
2. Remove the instrument cover.
3. Remove the filter from the filter clip.

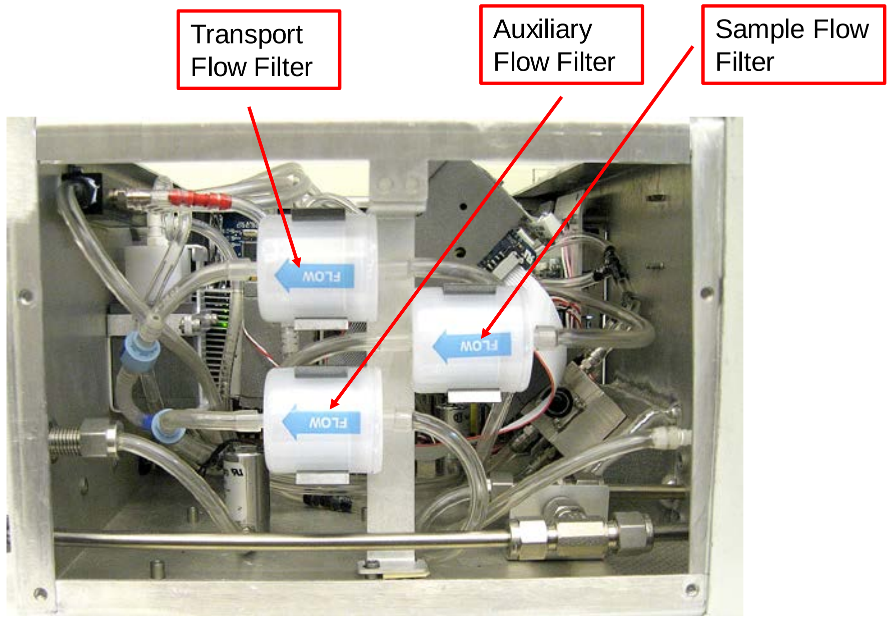


Figure 9-5
Location of Filters

4. Noting the direction of flow, push the ends (easier than pulling) of the tubing off both ends of the filter (Figure 9-6).
5. Attach the tubing to a new filter making sure the flow direction matches that of the filter you removed.
6. Remove the filter inline filter screen.
7. Push the filter into the filter clip.
8. Replace the instrument cover.

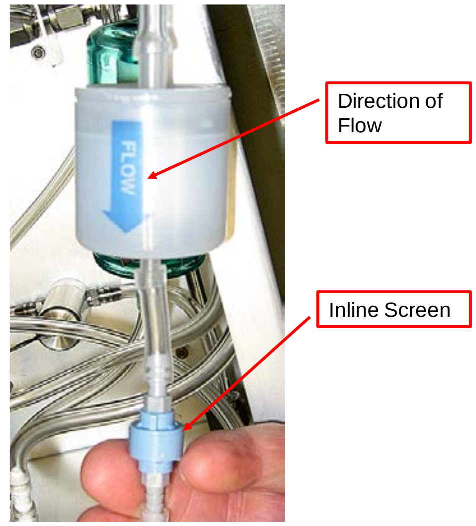


Figure 9-6
Changing Filter

Aerosol Flow Checks

The correct aerosol sample flow rate is essential in the determining of aerosol concentration. For this reason, it is important to periodically verify the sample flow rate. This is especially important after changing the wick or other activity which may result in the contamination of the optics nozzle or orifice (filter change).

To verify aerosol sample flow rate, follow the instructions presented in this section.

The flow schematic below shows the auxiliary, transport and sample flows through the Model 651.

Note: Check each flow after every wick change.

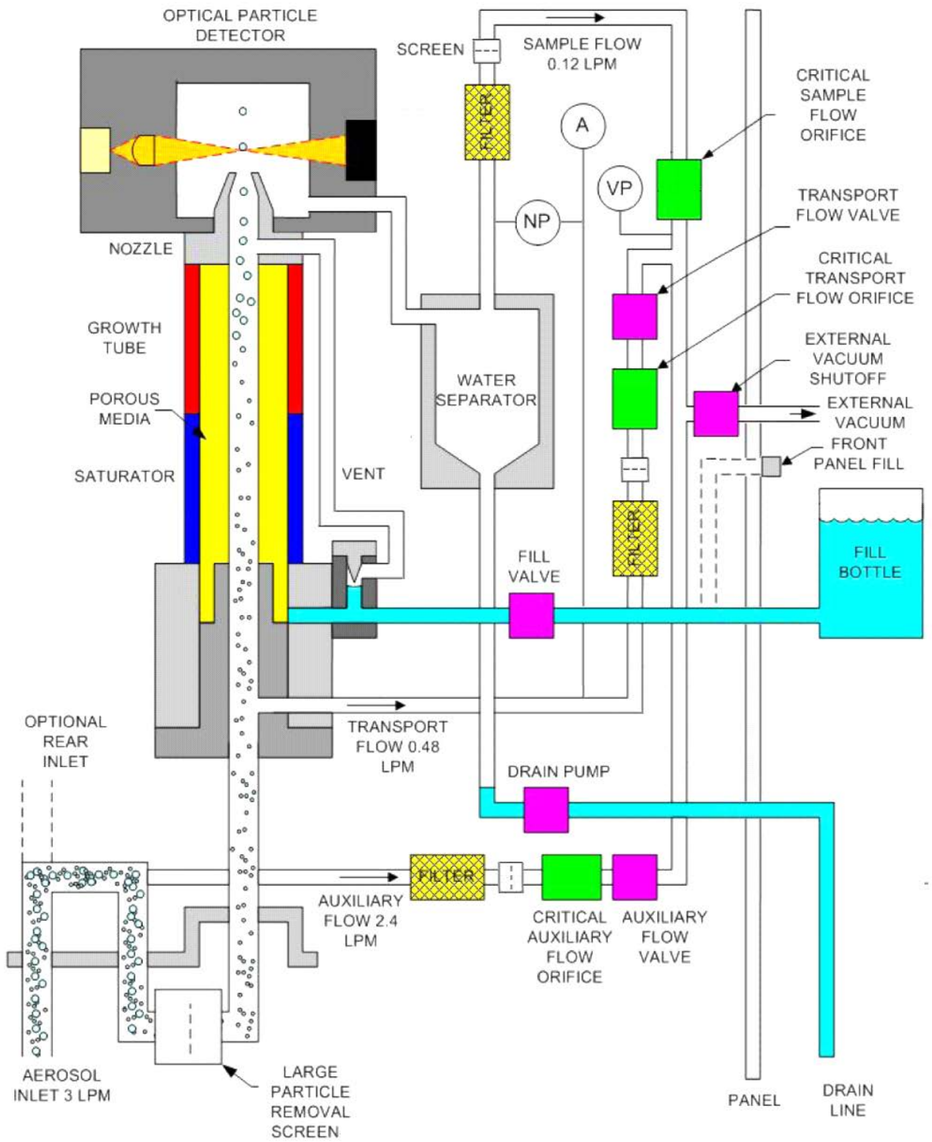


Figure 9-7
Model 651 Flow Schematic

The instructions below describe the procedure for checking the aerosol sample flow. Use a similar procedure to check the auxiliary and transport flows.

To check the aerosol flow, follow these instructions:

1. With the instrument powered on, press **SETUP** on the Home screen, then press **INLET FLOW**.
2. Select 0.12 L/min as the setting. This value is nominal for the aerosol sample flow. Your actual inlet flow value may be slightly different, and depends on characteristics of the critical sample flow orifice. The actual flow for your orifice is displayed as an

instrument Flow Constant status value on the ADDITIONAL STATUS screen.

3. Attach an accurate external flow meter such as a bubble meter, or Gilibrator (brand), or BGI Tetracal (available from TAPI), to either the Model 651 sample inlet or the aerosol inlet and measure the inlet flow.

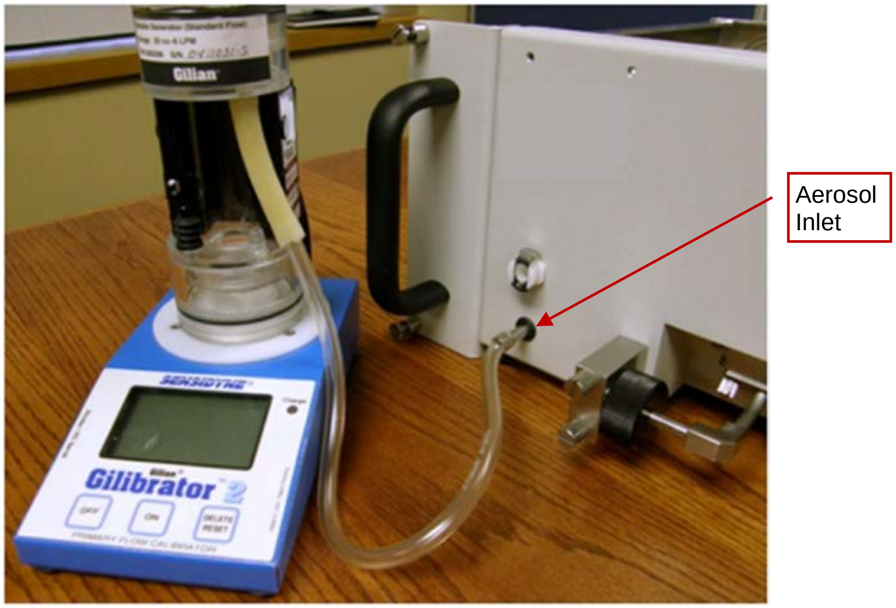


Figure 9-8
External Flow Meter Attached to Model 651

4. From the HOME screen, select STATUS, MORE, ADDITIONAL STATUS. Observe the Flow Constant value. This is the aerosol sample flow for the installed orifice.

5. Verify that the measured flow corresponds with the observed Flow Constant within ±5%, and also add in any uncertainty in the flow measurement resulting from errors in the accuracy of your flow meter. If the measured flow still does not compare with the Flow Constant when the tolerance errors are considered, refer to the Troubleshooting section of this chapter.

Cleaning the Water Bottle

To prevent bacterial growth and potential contamination of the Model 651, clean the water bottle after every use. To clean the water bottle, follow these instructions:

1. Disconnect the water fill tubing from the **WATER FILL**.
2. Empty the water bottle.
3. Wash the water bottle with a mild detergent.
4. Thoroughly rinse out the water bottle.

Inspecting and Cleaning the Fans

The fans should not require much maintenance, but it is beneficial to perform a visual inspection at intervals to check for dust build up. If any of the fans are dusty, blow them clean with compressed air.

Clean/Replace the Orifices

The Model 651 has three orifices:

- Sample flow orifice (0.12 L/min)
- Transport flow orifice (0.48 L/min)
- Auxiliary flow orifice (3 L/min)

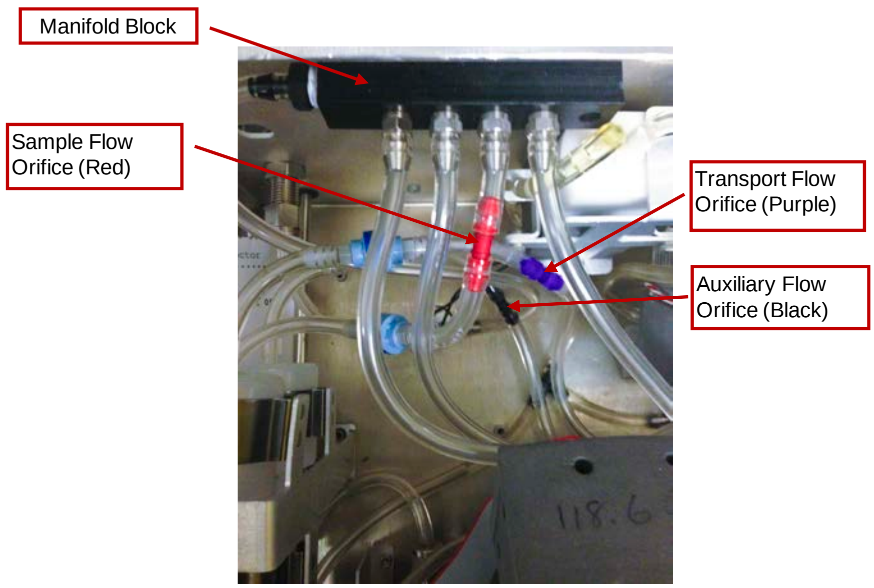


Figure 9-9
Cleaning/Replacing Orifices

To clean or replace an orifice, follow these instructions:

1. Turn off the power to the Model 651.
2. Remove the instrument cover.

Note the orientation of the orifice.

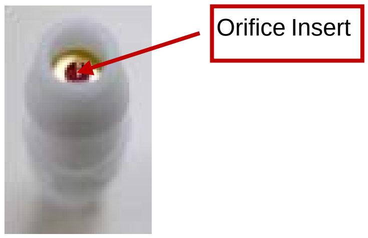


Figure 9-10
Orifice Insert

3. Grasp the tubing on either side of the orifice and pull firmly to detach the tubing from the orifice.
4. Using a microscope, inspect the orifice. If debris is present, soak the orifice in isopropyl alcohol for 20 minutes.

Figure 9-11
Inspect Orifice

5. Using compressed air at <60 psi, blow out the orifice and then re-inspect under the microscope.
6. If the orifice is clean, replace it in the instrument making sure that the orifice insert is positioned closest to the manifold block.
7. If the orifice is not clean, replace it with a new one.
   Note*: replacement orifices are available from TAPI*
8. Replace the instrument cover.

Inspect Liquid Lines

Inspect the water filling lines that flow from the fill connectors located on the front and back panels to the fill valve. Also inspect the water line from the fill valve to the Model 651 engine. Check for cracks, damage, loose fit, or signs of leaking. Replace as necessary or annually, whichever comes first, with tubing supplied in the maintenance kit that comes with the instrument.

Status Messages

Status messages display at the top of the Home screen. The messages are described below.

Status Message	Indicator Description
Low Water	Water level is low
Warmup	Instrument is warming up
Laser Fault	Laser malfunction
Inlet Pressure Fault	Inlet pressure is too high/low
Vacuum Fault	Vacuum pressure is too high/low
Nozzle Fault	Flow obstruction exists
Absolute Pressure Fault	Barometric pressure is outside the operating range
Optics Temp Fault	Optics temperature is out of range
Growth Tube Temp Fault	Growth Tube temperature is out of range
Conditioner Temp Fault	Conditioner temperature is out of range
Separator Temp Fault	Separator temperature is out of range
Pulse Height Fault	Low pulse height
Ready	Warm-up process has finished and the Model 651 is ready for use.
Fault	Unspecified fault (not covered by any of the specific indicators)

Note*: The messages are a warning that there is a problem with the instrument, but only one message can display at a time. Check the Status screen for more details about potential problems.*

Troubleshooting

The **STATUS** screen displays the status of the operating parts in live-time. The table below provides basic information about some status messages and suggestions for corrective action.

Table 9-2 Troubleshooting

Problem	Cause	Suggestions
Nozzle fault indicated on the Home screen and low Nozzle Pressure (<50%) indicated on the Status screen.	Low sample flow. Likely causes: There is an obstruction in the Sample Flow Orifice. The Sample Flow Filter is wet. This may result after a flooding incident, or result from poor performance of the Water Separator. Water present in the pressure transducer sample lines.	Verify 0.12 L/min inlet flow as described in the Flow Checks section of this chapter. If flow is OK, check for the presence of water in the Pressure Transducer sample lines. The Sample Orifice is likely clogged or dirty and needs cleaning or replacement. Replace the Sample filter if it appears wet. A wet filter may indicate flooding or poor performance of the Water Separator. The problem may be seen as presence of water in the tubing immediately upstream of the filter. Replace the Sample Filter. Also mark flow direction with a marker and remove the filter Screen found downstream of the Sample Filter. Use compressed air to blow back through the Screen to remove trapped material. Replace the Screen in its original orientation as indicated by the mark. Poor performance of the Water Separator may result if the instrument is operated outside its temperature and humidity specification range.
Nozzle fault indicated on the Home screen and high Nozzle Pressure (>300%) indicated on the Status screen.	The pressure over the nozzle is high indicating that the nozzle may be plugged or the path ahead of the nozzle is obstructed. Obstruction may be due to an improperly installed, twisted wick or the presence of excess water.	Verify 0.12 L/min inlet flow as described in the Flow Checks section of this chapter. Disconnect the water bottle and remove the inlet block and wick assembly as described earlier in this chapter. If the Nozzle Pressure % remains high, the nozzle is plugged. The nozzle is not user serviceable, contact TSI. If the Nozzle Pressure % drops to near 100% after wick assembly removal, a restriction in the wick cartridge is indicated. Unscrew the wick cartridge from the inlet block and the growth tube from the conditioner. Look through the wick tube to verify an open path. If there is no clear path, (e.g. the wick is twisted causing a blockage), refer to the manual section on replacing the wick. If there appears to be excessive water dripping from the instrument after inlet removal, flooding may have occurred. Disconnect the water fill bottle at the quick disconnect and allow the instrument to run for a few hours without the wick cartridge installed. This will dry the instrument.

Problem	Cause	Suggestions
Home screen displays Inlet Pressure Fault. Status screen displays a low inlet pressure reading (in red).	There is an obstruction in the aerosol or Model 651 inlet.	1. Check that there are no kinks in the tubing upstream of the inlet. 2. Check the inlet screen assembly for obstructions. 3. Remove the inlet screen assembly. 4. Remove the elbow joint.  5. Unscrew the black cap. 6. Remove the screen assembly. ***Note**: Do **not** lose the O-ring.*  7. Blow the screen with compressed air. 8. Reassemble the inlet screen assembly. 9. Replace the inlet screen assembly.
"Temperatures out of range" error messages are displayed for the Water Separator, Optics, Growth Tube or Conditioner. Status screen shows readings in red.	The instrument was flooded. Environmental temperature or humidity is too high or too low. ***Note**: If the instrument was flooded, you will also see water in the tubing and high nozzle pressure readings.*	In the event of flooding: 1. Disconnect the water bottle from the **WATER INLET/DRAIN**. 2. Run the instrument for 6 to 8 hours to dry it out. 3. When the flow returns to normal, the instrument is dry. 4. Reconnect the water bottle. If concentrations do not return to normal, return the instrument to TAPI for repair.
Status screen indicates Water Reservoir Not Filled.	There is no water in the reservoir. The water may not be connected, the water bottle may be empty, or the water bottle has been placed below the level of the instrument.	Check that the water bottle is filled and connected correctly. Make sure that the bottle is placed at a higher level than the instrument to provide for the gravity flow fill mechanism. If the problem persists, return the instrument to TAPI for repair.
Status screen Pulse Height indicator is too low (in the red area).	There is no or very low (<10 #/cm^3) particle concentration. At higher concentrations this indicates: a dry wick, optical alignment problems, dirty optics, or flooded optics.	If the suspected concentration is above 100 #/cm^3 then replace the wick and make sure water is connected to the instrument. If all other status indicators are normal, the optics module must be replaced. Return the instrument to TAPI for replacement of the optics module by a qualified service technician.
The real-time clock does not maintain time when the instrument is turned off. The time is not maintained correctly.	The clock battery needs replacing.	Replace the clock battery located on the main electronics board with a BR1225 Panasonic or equivalent.

Technical Assistance

If this manual and its troubleshooting / repair sections do not solve your problems, technical assistance may be obtained from:

Teledyne API Technical Support
9970 Carroll Canyon Road
San Diego, California 92131-1106USA

Toll-free Phone:	800-324-5190
Phone:	+1 858-657-9800
Fax:	+1 858-657-9816
Email:	sda_techsupport@teledyne.com
Website:	http://www.teledyne-api.com/

Returning the Model 651 for Service

Before returning the Model 651 to TAPI for service, visit our website at http://www.teledyne-api.com and on the left, under Help Center, click Return Authorization for specific return instructions.

TAPI recommends that you keep the original packaging of the Model 651 for use whenever the instrument is shipped, including when it is returned to TAPI for service. Always seal off the sampling inlet to prevent debris from entering the instrument and dry the Model 651 before shipping (refer to moving and shipping instructions for details in Chapter 3).

If you no longer have the original packing material, first protect the Model 651 by following the packing instructions in Chapter 10 Primer on Electro-Static Discharge. Then package the unit with at least 5" (13 cm) of shock absorbing/packaging material around all six sides of the instrument.

Chapter 10

Primer on Electro-Static Discharge

Teledyne API considers the prevention of damage caused by the discharge of static electricity to be extremely important part of making sure that your analyzer continues to provide reliable service for a long time. This section describes how static electricity occurs, why it is so dangerous to electronic components and assemblies as well as how to prevent that damage from occurring.

How Static Charges Are Created

Modern electronic devices such as the types used in the various electronic assemblies of your analyzer, are very small, require very little power and operate very quickly. Unfortunately, the same characteristics that allow them to do these things also make them very susceptible to damage from the discharge of static electricity. Controlling electrostatic discharge begins with understanding how electro-static charges occur in the first place.

Static electricity is the result of something called triboelectric charging which happens whenever the atoms of the surface layers of two materials rub against each other. As the atoms of the two surfaces move together and separate, some electrons from one surface are retained by the other.

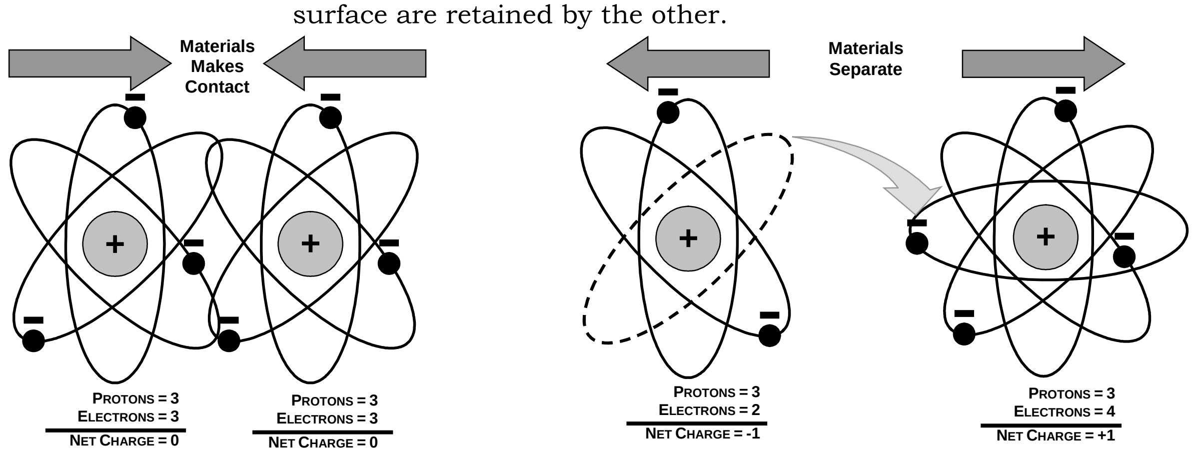


Figure 10-1
Triboelectric Charging

If one of the surfaces is a poor conductor or even a good conductor that is not grounded, the resulting positive or negative charge cannot bleed off and becomes trapped in place, or static. The most common example of triboelectric charging happens when someone wearing leather or rubber soled shoes walks across a nylon carpet or linoleum tiled floor. With each step, electrons change places and the resulting electro-static charge builds up, quickly reaching significant levels. Pushing an epoxy printed circuit board across a workbench, using a plastic handled screwdriver or even the constant jostling of StyrofoamTM pellets during shipment can also build hefty static charges.

Table 10-1 Static Generation Voltages for Typical Activities

MEANS OF GENERATION	65-90% RH	10-25% RH
Walking across nylon carpet	1,500V	35,000V
Walking across vinyl tile	250V	12,000V
Worker at bench	100V	6,000V
Poly bag picked up from bench	1,200V	20,000V
Moving around in a chair padded with urethane foam	1,500V	18,000V

How Electro-Static Charges Cause Damage

Damage to components occurs when these static charges come into contact with an electronic device. Current flows as the charge moves along the conductive circuitry of the device and the typically very high voltage levels of the charge overheat the delicate traces of the integrated circuits, melting them or even vaporizing parts of them. When examined by microscope the damage caused by electro-static discharge looks a lot like tiny bomb craters littered across the landscape of the component’s circuitry.

A quick comparison of the values in Table 15 1 with the those shown in the Table 15 2, listing device susceptibility levels, shows why Semiconductor Reliability News estimates that approximately 60% of device failures are the result of damage due to electro-static discharge.

Table10-2 Sensitivity of Electronic Devices to Damage by ESD

DEVICE	DAMAGE SUSCEPTIBILITY VOLTAGE RANGE	
	DAMAGE BEGINS OCCURRING AT	CATASTROPHIC DAMAGE AT
MOSFET	10	100
VMOS	30	1800
NMOS	60	100
GaAsFET	60	2000
EPROM	100	100
JFET	140	7000
SAW	150	500
Op-AMP	190	2500
CMOS	200	3000
Schottky Diodes	300	2500
Film Resistors	300	3000
This Film Resistors	300	7000
ECL	500	500
SCR	500	1000
Schottky TTL	500	2500

Potentially damaging electro-static discharges can occur:

- Any time a charged surface (including the human body) discharges to a device. Even simple contact of a finger to the leads of a sensitive device or assembly can allow enough discharge to cause damage. A similar discharge can occur from a charged conductive object, such as a metallic tool or fixture.
- When static charges accumulated on a sensitive device discharges from the device to another surface such as packaging materials, work surfaces, machine surfaces or other device. In some cases, charged device discharges can be the most destructive.

  A typical example of this is the simple act of installing an electronic assembly into the connector or wiring harness of the equipment in which it is to function. If the assembly is carrying a static charge, as it is connected to ground a discharge will occur.
- Whenever a sensitive device is moved into the field of an existing electro-static field, a charge may be induced on the device in effect discharging the field onto the device. If the device is then momentarily grounded while within the electrostatic field or removed from the region of the electrostatic field and grounded somewhere else, a second discharge will occur as the charge is transferred from the device to ground.

Common Myths About ESD Damage

- **I didn't feel a shock so there was no electro-static discharge**: The human nervous system isn't able to feel a static discharge of less than 3500 volts. Most devices are damaged by discharge levels much lower than that.
- **I didn't touch it so there was no electro-static discharge**: Electro-static charges are fields whose lines of force can extend several inches or sometimes even feet away from the surface bearing the charge.
- **It still works so there was no damage**: Sometimes the damaged caused by electro-static discharge can completely sever a circuit trace causing the device to fail immediately. More likely, the trace will be only partially occluded by the damage causing degraded performance of the device or worse, weakening the trace. This weakened circuit may seem to function fine for a short time, but even the very low voltage and current levels of the device's normal operating levels will eat away at the defect over time causing the device to fail well before its designed lifetime is reached.

  These latent failures are often the most costly since the failure of the equipment in which the damaged device is installed causes down time, lost data, lost productivity, as well as possible failure and damage to other pieces of equipment or property.
- **Static Charges can't build up on a conductive surface**: There are two errors in this statement.

  Conductive devices can build static charges if they are not grounded. The charge will be equalized across the entire device, but without access to earth ground, they are still trapped and can still build to high enough levels to cause damage when they are discharged.

  A charge can be induced onto the conductive surface and/or discharge triggered in the presence of a charged field such as a large static charge clinging to the surface of a nylon jacket of someone walking up to a workbench.
- **As long as my analyzer is properly installed, it is safe from damage caused by static discharges**: It is true that when properly installed the chassis ground of your analyzer is tied to earth ground and its electronic components are prevented from building static electric charges themselves. This does not prevent discharges from static fields built up on other things, like you and your clothing, from discharging through the instrument and damaging it.

Basic Principles of Static Control

It is impossible to stop the creation of instantaneous static electric charges. It is not, however difficult to prevent those charges from building to dangerous levels or prevent damage due to electro-static discharge from occurring.

General Rules

Only handle or work on all electronic assemblies at a properly set up ESD station. Setting up an ESD safe workstation need not be complicated. A protective mat properly tied to ground and a wrist strap are all that is needed to create a basic anti-ESD workstation (refer to Figure 10-2).

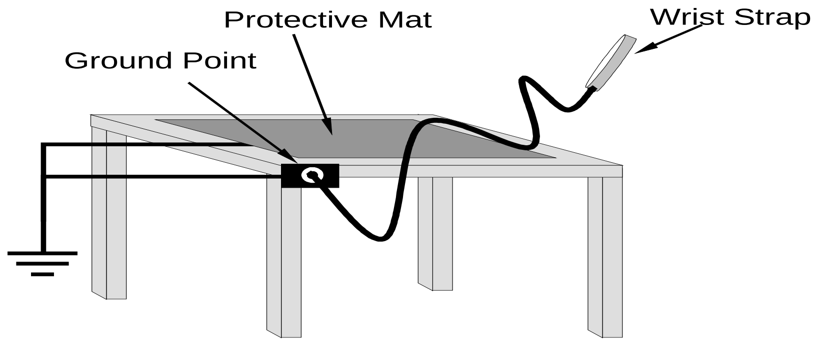


Figure 10-2
Basic Anti-ESD Work Station

For technicians that work in the field, special lightweight and portable anti-ESD kits are available from most suppliers of ESD protection gear. These include everything needed to create a temporary anti-ESD work area anywhere.

- Always wear an Anti-ESD wrist strap when working on the electronic assemblies of your analyzer. An anti-ESD wrist strap keeps the person wearing it at or near the same potential as other grounded objects in the work area and allows static charges to dissipate before they can build to dangerous levels. Anti-ESD wrist straps terminated with alligator clips are available for use in work areas where there is no available grounded plug.

  Also, anti-ESD wrist straps include a current limiting resistor (usually around one meg-ohm) that protects you should you accidentally short yourself to the instrument's power supply.

- Simply touching a grounded piece of metal is insufficient. While this may temporarily bleed off static charges present at the time, once you stop touching the grounded metal new static charges will immediately begin to re-build. In some conditions, a charge large enough to damage a component can rebuild in just a few seconds.

- Always store sensitive components and assemblies in anti-ESD storage bags or bins: Even when you are not working on them, store all devices and assemblies in a closed anti-Static bag or bin. This will prevent induced charges from building up on the device or assembly and nearby static fields from discharging through it.
- Use metallic anti-ESD bags for storing and shipping ESD sensitive components and assemblies rather than pink-poly bags. The famous, "pink-poly" bags are made of a plastic that is impregnated with a liquid (similar to liquid laundry detergent) which very slowly sweats onto the surface of the plastic creating a slightly conductive layer over the surface of the bag.

  While this layer may equalizes any charges that occur across the whole bag, it does not prevent the build up of static charges. If laying on a conductive, grounded surface, these bags will allow charges to bleed away but the very charges that build up on the surface of the bag itself can be transferred through the bag by induction onto the circuits of your ESD sensitive device. Also, the liquid impregnating the plastic is eventually used up after which the bag is as useless for preventing damage from ESD as any ordinary plastic bag.

  Anti-Static bags made of plastic impregnated with metal (usually silvery in color) provide all of the charge equalizing abilities of the pink-poly bags but also, when properly sealed, create a Faraday cage that completely isolates the contents from discharges and the inductive transfer of static charges.

  Storage bins made of plastic impregnated with carbon (usually black in color) are also excellent at dissipating static charges and isolating their contents from field effects and discharges.

- Never use ordinary plastic adhesive tape near an ESD sensitive device or to close an anti-ESD bag. The act of pulling a piece of standard plastic adhesive tape, such as Scotch® tape, from its roll will generate a static charge of several thousand or even tens of thousands of volts on the tape itself and an associated field effect that can discharge through or be induced upon items up to a foot away.

Basic Anti-ESD Procedures for Instrument Repair and Maintenance

Working at the Instrument Rack

When working on the instrument while it is in the instrument rack and plugged into a properly grounded power supply.

1. Attach your anti-ESD wrist strap to ground before doing anything else.
   - Use a wrist strap terminated with an alligator clip and attach it to a bare metal portion of the instrument chassis. This will safely connect you to the same ground level to which the instrument and all of its components are connected.
2. Pause for a second or two to allow any static charges to bleed away.
3. Open the casing of the analyzer and begin work. Up to this point, the closed metal casing of your analyzer has isolated the components and assemblies inside from any conducted or induced static charges.
4. If you must remove a component from the instrument, do not lay it down on a non-ESD preventative surface where static charges may lie in wait.
5. Only disconnect your wrist strap after you have finished work and closed the case of the analyzer.

Working at an Anti-ESD Work Bench

When working on an instrument of an electronic assembly while it is resting on an anti-ESD work bench:

1. Plug your anti-ESD wrist strap into the grounded receptacle of the work station before touching any items on the work station and while standing at least a foot or so away. This will allow any charges you are carrying to bleed away through the ground connection of the workstation and prevent discharges due to field effects and induction from occurring.
2. Pause for a second or two to allow any static charges to bleed away.
3. Only open any anti-ESD storage bins or bags containing sensitive devices or assemblies after you have plugged your wrist strap into the workstation.
   - Lay the bag or bin on the workbench surface.
   - Before opening the container, wait several seconds for any static charges on the outside surface of the container to be bled away by the workstation's grounded protective mat.
4. Do not pick up tools that may be carrying static charges while also touching or holding an ESD Sensitive Device.
   - Only lay tools or ESD-sensitive devices and assemblies on the conductive surface of your workstation. Never lay them down on any non-ESD preventative surface.

5. Place any static sensitive devices or assemblies in anti-static storage bags or bins and close the bag or bin before unplugging your wrist strap.
6. Disconnecting your wrist strap is always the last action taken before leaving the workbench.

Transferring Components from Rack to Bench and Back

When transferring a sensitive device from an installed Teledyne API analyzer to an Anti-ESD workbench or back:

1. Follow the instructions listed above for working at the instrument rack and workstation.
2. Never carry the component or assembly without placing it in an anti-ESD bag or bin.
3. Before using the bag or container allow any surface charges on it to dissipate:
   - If you are at the instrument rack, hold the bag in one hand while your wrist strap is connected to a ground point.
   - If you are at an anti-ESD workbench, lay the container down on the conductive work surface.
   - In either case wait several seconds.
4. Place the item in the container.
5. Seal the container. If using a bag, fold the end over and fastening it with anti-ESD tape.
   - Folding the open end over isolates the component(s) inside from the effects of static fields.
   - Leaving the bag open or simply stapling it shut without folding it closed prevents the bag from forming a complete protective envelope around the device.
6. Once you have arrived at your destination, allow any surface charges that may have built up on the bag or bin during travel to dissipate:
   - Connect your wrist strap to ground.
   - If you are at the instrument rack, hold the bag in one hand while your wrist strap is connected to a ground point.
   - If you are at a anti-ESD work bench, lay the container down on the conductive work surface
   - In either case wait several seconds
7. Open the container.

Opening Shipments from Teledyne API'S Customer Service

Packing materials such as bubble pack and Styrofoam pellets are extremely efficient generators of static electric charges. To prevent damage from ESD, Teledyne API ships all electronic components and assemblies in properly sealed anti-ESD containers.
Static charges will build up on the outer surface of the anti-ESD container during shipping as the packing materials vibrate and rub

against each other. To prevent these static charges from damaging the components or assemblies being shipped ensure that you always unpack shipments from Teledyne API's Customer Service by:

1. Opening the outer shipping box away from the anti-ESD work area.
2. Carry the still sealed ant-ESD bag, tube or bin to the anti-ESD work area.
3. Follow steps 6 and 7 of Section 15.5.3 above when opening the anti-ESD container at the work station.
4. Reserve the anti-ESD container or bag to use when packing electronic components or assemblies to be returned to Teledyne API.

Packing Components for Return to TAPI's Customer Service

Always pack electronic components and assemblies to be sent to Teledyne API's Customer Service in anti-ESD bins, tubes or bags.

Caution - Avoid Damage and Invalidating Warranty

- **DO NOT use pink-poly bags.**
- **NEVER allow any standard plastic packaging materials to touch the electronic component/assembly directly.**
- **This includes, but is not limited to, plastic bubble-pack, Styrofoam peanuts, open cell foam, closed cell foam, and adhesive tape.**
- **DO NOT use standard adhesive tape as a sealer. Use ONLY anti-ESD tape.se electrostatic discharge (ESD) precautions:**
  - ☐ Use only a table top with a grounded conducting surface.
  - ☐ Wear a grounded, static-discharging wrist strap

1. Opening the outer shipping box away from the anti-ESD work area.
2. Carry the still sealed ant-ESD bag, tube or bin to the anti-ESD work area.
3. Follow steps 6 and 7 of Section 15.5.3 above when opening the anti-ESD container at the work station.
4. Reserve the anti-ESD container or bag to use when packing electronic components or assemblies to be returned to Teledyne API.
5. Never carry the component or assembly without placing it in an anti-ESD bag or bin.
6. Before using the bag or container allow any surface charges on it to dissipate:
   - If you are at the instrument rack, hold the bag in one hand while your wrist strap is connected to a ground point.
   - If you are at an anti-ESD workbench, lay the container down on the conductive work surface.
   - In either case wait several seconds.

7. Place the item in the container.
8. Seal the container. If using a bag, fold the end over and fastening it with anti-ESD tape.
   - Folding the open end over isolates the component(s) inside from the effects of static fields.
   - Leaving the bag open or simply stapling it shut without folding it closed prevents the bag from forming a complete protective envelope around the device.

IMPORTANT
If you do not already have an adequate supply of anti-ESD bags or containers available, Teledyne API's Customer Service department will supply them. Follow the instructions listed above for working at the instrument rack and workstation.

APPENDIX A Firmware Commands

The firmware commands are divided into the categories described below.

Commands	Description
READ	Used to read parameters from the instrument (such as flow rate, pressure, temperature, etc.). **READ** commands can be identified by a leading "R".
SET	Set an internal parameter to the value(s) supplied with the command (supplied parameters are always delimited by a comma). **SET** commands can be identified by a leading "S". The instrument will reply to all **SET** commands with the string "OK"<CR>.

Note*: When the instrument does not understand a command, it replies with the string "ERROR".*

Table A-1 is a quick reference of all the firmware commands. More detailed information about each command can be found on the following pages.

Note*: The commands are not case sensitive.*

Table A-1 Model 651 Firmware Commands

Command	Explanation
Read Commands	
RAI	**R**ead **A**nalog **I**nput **V**oltage
RALL	**R**ead Operating Condition
RCT	**R**ead **C**urrent **T**ime
RD	**R**ead **D**isplayed **C**oncentration
RIE	**R**ead **I**nstrument **E**rrors
RIF	**R**ead **I**nlet **F**low Rate
RIS	**R**ead **I**nstrument **S**tatus
RL	**R**ead **L**aser Current
RLL	**R**eads **L**iquid **L**evel
RPA	**R**ead **A**bsolute **P**ressure
RPN	**R**ead **N**ozzle **P**ressure
RPV	**R**ead **V**acuum **P**ressure
RRD	**R**ead **D**ata **R**ecord
RRS	**R**ead **S**tatus **R**ecord
RTA	**R**ead **C**abinet **T**emperature
RTC	**R**ead **C**onditioner **T**emperature
RTG	**R**ead **G**rowth **T**ube **T**emperature
RTO	**R**ead **O**ptics **T**emperature
RV	**R**ead **V**ersion
Set Commands	
SM	**S**et **M**ode **x**=mode **t**=sample time in tenth of second
SA	**S**et **A**uxiliary Flow
SFC	**S**et **F**low Rate **C**alibration Constant
SP	**S**et **P**ump On/Off
SR	**S**et **R**eal Time Clock
SSTART	**S**tart a New **S**ample
ST	**S**et **T**ransport Flow On/Off
SW	**S**et **W**ater Separator Temperature Control On/Off
SWS	**S**et **W**ater Separator Temperature **S**et Point

READ Commands

Read Commands are used to display specific data values. The values, associated parameters, responses returned by the Model 651, and examples are given on the following pages.

RAI – Read Analog Input Voltage

RAI reads the analog input voltage in V.

RAI		
Command	RAI	
Response	X	X = analog input ZZAs (a floating point number from 0.00 to 10.00)
Example		
Command	RAI	Read Analog Input Voltage
Response	5.22	Voltage = 5.22 V

RALL – Read Operating Condition

RALL reads the Model 651's operating condition, calibration parameters, and diagnostic parameters.

RALL		
Command	RALL	
Response	X	X = a list of operating condition, calibration parameters, and diagnostic parameters (see below)
Example		
Command	RALL	Read Analog Input Voltage
Response		

```
Model 651 Ver 1.01 S/N 83031002
ROM Checksum,                       356E
Service Date Cal_Reminder Num       0101-30,0101-30,6
On time Las time,                   497:10,389:30
Laser SP mA,                        750,0
Detect Offset Thrsh HV Photo,       3700,125,1000,0
Ejection Rate,                      60
Cap Flow SP Offset Value,           2500,3,5
Nozzle SP Offset Val Flow,          254,128,121,0
ABS Raw Mbar Inlet_Cap,             3267,991,0
Deadtime  Corr   Val%,              117,84
Inlet SP Temp Drive Cal,            100,221,0,221
Optics SP Temp Drive,               600,509,1023
GT SP Temp Drive,                   600,512,1023
Cond SP Temp Drive Zero Current(ma),200,200,103,134,59
Sep SP Temp Drive Zero Current(ma), 200,200,66
Fill Cond_Thresh GT_Thresh,         850,700
Analog Output DAC Span Offset,      217950,1291
Analog Input ADC Span Offset,       9801,100
Cabinet SP Temp(bits) Temp,         1722,1722,25.0
Particle Conc,                      0.00
Pulse Height Threshold,             150
Network Setting (DHCP State),       STATIC
MAC Address,                        0:55:3:4:F3:DA
IP Address,                         192.168.20.201
Subnet Mask,                        255.255.255.0
Gateway Address,                   192.168.20.1
```

RCT – Read Current Time

RCT reads the current time.

RCT		
Command	RCT	
Response	yyyy/mm/dd,hh:mm:ss	yyyy = year mm = month (1 – 12) dd = day (1 – 31) hh:mm:ss = time (hours, minutes, seconds)
Example		
Command	RCT	Read Current Time
Response	2012/12/18,20:22:19	Year = 2012 Month = December Day = 18 Hour = 8 pm Minutes = 22 Seconds = 19

RD – Read Displayed Concentration

RD is a legacy command that reads the displayed concentration in particles/cm^3.

RD		
Command	RD	
Response	x	X = #/cm^3, floating point number (0.00 – $1.00e^6$)
Example		
Command	RD	Read Displayed Concentration
Response	$3.16e^4$	

RIE – Read Instrument Errors

RIE reads the instrument errors (displayed as a 16-bit integer in hexadecimal format). The number may be a combination of the values of more than one flag.

RIE		
Command	RIE	
Response	Bit 0 x XXXX	Bit = Hexadecimal character A-F. When the bit is set, the parameter is in error. XXXX = 4-digit number 0x0001 = Conditioner Temperature 0x0002 = Growth Tube Temperature 0x0004 = Optics Temperature 0x0008 = Vacuum Level 0x0020 = Laser Status 0x0040 = Water Level 0x0080 = Concentration Over-range 0x0100 = Pulse Height Fault 0x0200 = Absolute Pressure 0x0400 = Nozzle Pressure 0x0800 = Water Separator Temperature 0x1000 = Warmup 0x2000 = Reserved 0x4000 = Service Reminder 0x8000 = Reserved
Example		
Command	RIE	Read Instrument Errors
Response	C00	Water Separator Temperature and Nozzle Pressure faults (Nozzle Pressure = hexadecimal 4. Water Separator = hexadecimal 8. Added together they make hexadecimal C.)

Note: *Hexadecimal is a numerical system using a base of 16. The symbols 0-9 represent the values zero to nine, and the letters A-F represent the values ten to sixteen. It is a useful "shorthand" for computer engineering because each hexadecimal digit represents four binary digits.*

RIF – Read Aerosol Flow Rate

RIF reads the inlet flow rate in liters per minute (L/min).

RIF		
Command	RIF	
Response	X	X = Floating point number either 0.12, 0.6, or 3.0
Example		
Command	RIF	Read Inlet Flow Rate
Response	0.3	3.0 L/min

RIS – Read Instrument Status

RIS reads the instrument status (displayed as 13 comma-separated fields).

RIS		
Command	RIS	
Response	X	X = 1-13 1 = Concentration (#/cm^3) 2 = Livetime (%) 3 = Not used in Model 651 4 = Inlet Pressure (mBar) 5 = Nozzle Pressure (%) 6 = Inlet Flow Mode (0.12, 0.6, 3.0) 7 = Analog Input Voltage (mV) 8 = Pulse Height (mV) 9 = Optics Temp (°C) 10 = Growth Tube Temp (°C) 11 = Conditioner Temp (°C) 12 = Water Separator Temp (°C) 13 = Water Reservoir (Filled/Not Filled, 0/1)
Example		
Command	RIS	Read Instrument Errors
Response	0.00, 100, blank 1002, 100, 0.12, 0.00, 0, 60.0, 60.0, 20.0, 7.0, 0	Particle Concentration Livetime Not used in Model 651 Inlet Pressure Nozzle Pressure Inlet Flow Mode Analog Input Voltage Pulse Height Optics Temp Growth Tube Temp Conditioner Temp Water Separator Temp Water Reservoir (Filled)

RL – Read Laser Current

RL reads laser current in mA.

RL		
Command	RL	
Response	X	X = 0 - 50
Example		
Command	RL	Read laser current
Response	30	30 mA

RLL – Read Liquid Level

RLL reads the liquid level.

RLL		
Command	RLL	
Response	FULL/NOTFULL X	X = ADC reading from 0 to 4095
Example		
Command	RLL	Read Liquid Level
Response	FULL (2471)	FULL – water level ADC - 2471

RPA – Read Absolute Pressure Transducer

RPA reads the absolute pressure transducer in mbars.

RPA		
Command	RPA	
Response	X	X = A floating point number from 150 to 1150
Example		
Command	RPA	Read Absolute Pressure
Response	1001	

RPN – Read Nozzle Pressure Transducer

RPN reads the nozzle pressure transducer in percent.

RPN		
Command	RPN	
Response	X	X = A floating point number from 0 to 2050
Example		
Command	RPN	Read Nozzle Pressure
Response	100	

RPV – Read Vacuum Pressure

RPV reads the vacuum pressure transducer in mbars.

RPV		
Command	RPV	
Response	X	X = A floating point number from 0 to 1150
Example		
Command	RPV	Read Vacuum Pressure
Response	408	

RRD – Read Data Record

RRD returns the current data values in the “D” record format. Data records are collected according to the time period you have specified for the data collection interval.

RRD		
Command	RRD	
Response	D record (see below)	
	D	Record identifier
	Date	Date in yyyy/mm/dd format
	Time	Time in hh:mm:ss format
	Flags	Status Flags (see information in RIE command description)
	Conc	Aggregated concentration calculated by dividing the accumulated aggregate counts by the live-time of the sample flow rate (2 cm^3/sec). The aggregated counts and live-times are accumulated each 1/10th second interval. The overflow flag is set when the concentration value exceeds the maximum specified concentration.
	AT	Elapsed sample time 0.1 sec resolution (0.1 to 3600)
	LT	Live time 0.001 sec resolution (0.001 to 3600)
	CNT	Accumulated particle counts
	Photo	Average photodetector value in mV
	Reserved	Blank reserved space
	PH	Average pulse height in mV
	PSTD	Pulse height standard deviation

Example D Record:
D,2012/11/2,08:01:21,0,1.04e4,6.0,4.4,769424,140,,0,0

Record Type	Date	Time	Flags	Conc	AT	LT	CNT	Photo	PH	PSTD
D	2012/11/2	08:01:21	0	1.04e4	6.0	4.4	769424	140	0	0

RRS – Read Status Record

RRS returns the current raw analog values in "S" record format for diagnostic use.

RRS		
Command	RRS	
Response	S record (see below)	
	S	Record identifier
	AP	Absolute pressure in mbars
	ST	Conditioner Temperature in degrees Celsius
	GT	Growth Tube temperature in degrees Celsius
	OT	Optics temperature in degrees Celsius
	WT	Water Separator temperature in degrees Celsius
	FL	Sample flow rate in cm^3/min

Example S Record:
S,1003,20.0,60.0,60.0,20.0,124.0

Record Type	AP	ST	GT	OT	WT	FL
S	1003	20.0	60.0	60.0	7.0	124.0

RTA – Read Cabinet Temperature

RTA reads the cabinet (ambient) temperature in degrees Celsius.

RTA		
Command	RTA	
Response	X	X = A floating point number from 0.0 to 60.0
Example		
Command	RTA	Read Cabinet Temperature
Response	23.8	23.8 °C

RTC – Read Conditioner Temperature

RTC reads the conditioner temperature in degrees Celsius.

RTC		
Command	RTC	
Response	X	X = Floating point number from 0.0 to 50.9
Example		
Command	RTC	Read Conditioner Temperature
Response	20.0	20.0°C

RTG – Read Growth Tube Temperature

RTG reads the Growth Tube temperature in degrees Celsius.

RTG		
Command	RTG	
Response	X	X = Floating point number from 0.0 to 80.0
Example		
Command	RTG	Read Growth Tube Temperature
Response	60.0	60.0°C

RTO – Read Optics Temperature

RTO reads the optics temperature in degrees Celsius.

RTO		
Command	RTO	
Response	X	X = Floating point number from 0.0 to 80.0
Example		
Command	RTO	Read Conditioner Temperature
Response	60.0	60.0°C

RV – Read Firmware Version Number

RV returns the instrument model number, firmware version number, and serial number.

RV		
Command	RV	
Response	Model 651 Ver v.vv S/N nnnn	v.vv = ranges from 0.01 to 9.99 (3 digits) nnnn ranges from 100-99999999)
Example		
Command	RV	Read Version Number
Response	Model 651 Ver 1.00 S/N 1004	Model 651 = Model # Ver 1.00 = Version # S/N 1004 = Serial Number

SET Commands

Set commands are used to set instrument parameters and data collection modes. You will use the **Set Mode** (SM) command to control data collection.

SM – Set Mode

SM is used to set the data collection mode and the sample interval. At the end of each sample interval, the data are reported and, if in a continuous mode, the data are cleared internally and the next sample is started. The four available modes are shown in the list below.

0	Idle. No data collection.
1	Continuously collects data and reports data (“D” record) at end of every sample interval.
2	Continuously collects data and reports data (“S” record) at end of every sample interval.
3	Continuously collects data and reports data (“D” record) at end of every sample interval. Concatenates “S” record to the “D” record.

SM		
Command	SM,n,tttt	n = mode (0,1,2,3) ttttt – sample interval in 1/10 of a second
Response	OK	Response issued after parameters changed.
Example		
Command	SM,1,60	Continuous data collection (response mode 1) at 6-second sample intervals.
Response	OK	
Command	SM	Parameters not changed.
Response	1,60	Continuous data collection (response mode 1) at 6-second sample intervals.

Note: *To stop data collection, enter SM,0 in the Firmware Command field.*

SA – Set Auxiliary Flow Valve

SA is used to turn the auxiliary flow valve on or off. When the Model 651 is powered off, the setting is saved (it does not revert to the default).

SA		
Command	SA,x	x = 0 turns valve off x = 1 turns valve on
Response	OK	Response issued after parameters changed.
Example		
Command	SA,0	Turns the valve off.
Response	OK	
Command	SA	
Response	0	Parameter not changed – current setting displayed on record.

SFC – Set Flow Rate Calibration Constant

SFC is used to set the flow rate calibration constant or to return the value of the current setting if no parameter is supplied. When the Model 651 is powered off, the setting is saved (it does not revert to the default).

SFC		
Command	SFC,cccc	cccc = 1000-1400
Response	OK	Response issued after parameters changed.
Example		
Command	SFC,1205	Changes the flow rate constant to 120.5 cm^3/min.
Response	OK	
Command	SFC	
Response	1205	Parameter not changed. Current setting displayed on record.

SP – Set Pump Vacuum

SP is used to turn the pump vacuum on or off. The default setting at power-up is On. When the Model 651 is powered off, the setting is saved (it does not revert to the default).

SP		
Command	SP,x	x = 0 turns vacuum off x = 1 turns vacuum on
Response	OK	Response issued after parameters changed.
Example		
Command	SP,0	Turns the vacuum off.
Response	OK	
Command	SP	
Response	0	Parameter not changed – current setting displayed on record.

SR – Set Real-time Clock

SR is used to set the clock. When the Model 651 is powered off, the setting is saved (it does not revert to the default).

SR		
Command	SR,yy,mm,dd,hh,mm,ss	yy = year (2 or 4 digits) mm = month (1-12) dd = day (1-31) hh = hour (0-23) mm = minutes (0-59) ss = seconds (0-59) Note: mm and ss are 0 if not included.
Response	OK	Response issued after parameters changed.
Example		
Command	SR,12,5,6,15,34	Clock is set to May 6, 2012, 3:34 pm
Response	OK	
Command	SR	
Response	12,5,6,15,34	Parameter not changed – current setting displayed on record.

SSTART – Starts a New Sample

SSTART is used to start a new sample routine.

SSTART		
Command	SSTART,x	X = 0,1,2,3 0 = Stop 1 = Start data type 1 (not used) 2 = Start data type 2 (not used) 3 = Start new sample
Response	OK	Response issued after parameters changed.
Example		
Command	SSTART,0	Stops sample.
Response	OK	
Command	SSTART,3	Starts new sample.
Response	OK	
Command	SSTART	
Response	3	Parameter not changed – current setting displayed on record. U records are displayed when the **SSTART,3** command is entered. The records are returned once per second (see below).
	U	Record type
	X	Elapsed time in seconds (integer)
	C	Concentration in 1/10th second intervals (float)
	R	Raw counts in 1/10th second intervals (integer)
	X	No value represented between commas for the Model 651
	T	Live time in 1/10th seconds (float)
	D	DTC value (float)
	P	Absolute pressure in millibars (integer)
	AN	Analog input
	HM	Pulse height mean in millivolts (integer)
	HS	Pulse standard deviation in millivolts (integer)
	IS	Instrument status (use RIE command to see a list of statuses)

Example U record:
UX,C,C,C,C,C,C,C,C,C,C,R,R,R,R,R,R,R,R,R,R,,T,T,T,T,T,T,T,T,T,T,D,P,AN,HM,HS,IS

```
U1,2.13e3,1.97e3,2.18e3,2.24e3,2.34e3,2.29e3,2.26e3,2.31e3,
2.35e3,2.17e3,466,430,475,489,510,500,493,505,512,474,,,,,,,,
,,,0.099,0.099,0.099,0.099,0.099,0.099,0.099,0.099,0.099,0.09
9,1.17,990,0.000,1179,421,0
U2…
```

ST – Set Transport Flow

ST is used to turn the transport flow on or off. The default setting at power-up is On. When the Model 651 is powered off, the setting is saved (it does not revert to the default).

ST		
Command	ST,x	x = 0 turns flow off x = 1 turns flow on
Response	OK	Response issued after parameters changed.
Example		
Command	ST,0	Turns the flow off.
Response	OK	
Command	ST	
Response	0	Parameter not changed – current setting displayed on record.

DATA Reporting Records

The Model 651 displays data in real time on the front panel display. You can also collect data records over time. Data records include the following:

D Records	Used for data collection
S Records	Used for data collection

D Record

D records contain the following information:

D	Record identifier
Date	Date in yyyy/mm/dd format
Time	Time in hh:mm:ss format
Flags	Status Flags (see information in RIE command description)
Conc	Aggregated concentration calculated by dividing the accumulated aggregate counts by the live-time of the sample flow rate (2 cm^3/sec). The aggregated counts and live-times are accumulated each $1/10^{th}$ second interval. The overflow flag is set when the concentration value exceeds the maximum specified concentration.
AT	Elapsed sample time 0.1 sec resolution (0.1 to 3600)
LT	Live time 0.001 sec resolution (0.001 to 3600)
CNT	Accumulated particle counts
Photo	Average photo-detector value in mV
Reserved	Blank reserved space
PH	Average pulse height in mV
PSTD	Pulse height standard deviation

Example D Record:
D,2012/11/2,08:01:21,0,1.04e4,6.0,4.4,769424,140,,0,0

Record Type	Date	Time	Flags	Conc	AT	LT	CNT	Photo	PH	PSTD
D	2012/11/2	08:01:21	0	1.04e4	6.0	4.4	769424	140	0	0

S Record (Status)

S records are displayed on the Text tab when you enter the command RRS in the Firmware Command field. They display status information.

S	Status record identifier
Pinlet	Inlet pressure in millibars
Pvac	Vacuum pressure in millibars
Tcond	Temperature of the conditioner in °C
Tgrowth	Growth tube temperature in °C
Toptics	Optics temperature in °C
Tsep	Water separator temperature in °C
Tinlet	Inlet temperature in °C

Example S Record:
S,990,282,20.0,59.9,60.0,7.0,23.2

Record Type	Pinlet	Pvac	Tcond	Tgrowth	Toptics	Tsep	Tinlet
S	990	282	20.0	59.9	60.0	7.0	23.2

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