

L e a f P o r o m e t e r

Operator's Manual

Version 9



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1. Introduction

Thank you for purchasing Decagon Devices' Leaf Porometer. The Leaf Porometer is a device used to measure stomatal conductance in leaves. This manual is designed to help you understand the functions of your Leaf Porometer, make high-quality stomatal conductance measurements, and help you get the most out of your Leaf Porometer.

Customer Support

When contacting us, via fax or e-mail, include your Leaf Porometer's serial number (this can be found on the inside of the battery cover), the firmware version you are currently using, your name, address, phone and fax number, and a description of your problem.

Phone:

United States/Canada (toll free): **1-800-755-2751.**

Outside of the U.S./Canada: **1-509-332-2756.**

Fax: 1-509-332-5158

E-Mail: support@decagon.com

NOTE: *If you purchased your Leaf Porometer through a distributor, please contact them for assistance.*

Warranty

The Leaf Porometer is covered by a standard, one-year warranty on parts and labor, and is activated upon the arrival of the instrument at your location.

Seller's Liability

Seller warrants new equipment of its own manufacture against defective workmanship and materials for a period of one year from the date of receipt of equipment (the results of ordinary wear and tear, neglect, misuse, accident and excessive deterioration due to corrosion from any cause are not considered to be a defect); but Seller's liability for defective parts shall, in no event, exceed the furnishing of replacement parts f.o.b. the factory where originally manufactured. Material and equipment covered hereby which is not manufactured by the Seller shall be covered only by the warranty of its manufacturer. Seller shall not be liable to Buyer for loss, damage, or injuries to persons (including death), or to property or things of whatsoever kind (including, but not without limitation, loss of anticipated profits), occasioned by or arising out of the installation, operation, use, misuse, nonuse, repair, or replacement of said material and equipment, or out of the use of any method or process for which the same may be employed. The use of this equipment constitute's Buyer's acceptance of the terms set forth in this warranty. There are no understandings, representations, or warranties of any kind, express, implied, statutory or otherwise, (including, but not without limitation, the implied warranties of merchantability and fitness for a particular purpose), not expressly set forth herein.

Repair Instructions

If your Leaf Porometer should ever require a repair, call Decagon at **(509) 332-2756** or **1-800-755-2751** (United States and Canada). We will ask you for your address, phone number, your Leaf Porometer's serial number, and your current firmware version. For non-warranty repairs, we will also ask for a method of payment.

Before shipping your instrument to Decagon, please contact Decagon to obtain a Request Maintenance Authorization Number (RMA). This will allow Decagon's repair staff to keep track of your Porometer. Once you have acquired an RMA, send your Leaf Porometer to Decagon. Please include a document listing the complete shipping address, name, and department of the person responsible for the instrument, as well as a description of the problem. This will better help our technicians and shipping department to expedite repair on your Leaf Porometer, and ship it back to you.

Please pack your Leaf Porometer carefully. Ship it back in the carrying case, preferably inside a cardboard box. Ship to:

**Decagon Devices Inc.
2365 NE Hopkins Court
Pullman, WA 99163**

Repair Costs

Manufacturer's defects and instruments under warranty will be repaired at no cost. For non-warranty repairs, costs for parts, labor, and shipping will be billed to you.

2. About the Leaf Porometer

The Leaf Porometer is a battery-operated, menu-driven device used to measure stomatal conductance of leaves. Stomatal conductance is a function of the density, size, and degree of opening, of stomata, which are pores in plants that open to the outside air. The Leaf Porometer measures stomatal conductance by putting the conductance of a leaf in series with two known conductance elements, and comparing the humidity measurements between them. It can display information in three selectable units:

- **mmol/m²s** (millimoles per meter squared seconds)
- **m²s/mol** (meters squared seconds per mole)
- **s/m** (seconds per meter)

The first is a unit of conductance, while the other two are units of resistance. To change between them, use the arrow keys when taking a reading (see “Making a Measurement,”). They can also be altered by using the Units screen under the Configuration Menu.

Specifications

Operating Environments: 5 - 40° C; 0-100% relative humidity with desiccant chamber.

Accuracy: 10%

Sample Chamber Aperture: 6.35mm (0.25 in)

Measurement Range: 0 to 1000 mmol/m²s¹

Microcontroller Dimensions: 15.8 x 9.5 x 3.3 cm
(6.2 x 3.75 x 1.3 in)

Data Storage: 4095 measurements

Data Retrieval: Direct via RS-232

Keypad: Six-key, menu-driven

Clock: 24-hour, +/- one minute per month

Interface Cable: RS-232 serial cable (included)

Power Supply: Four type "AA" batteries (included)

Overview of the Leaf Porometer

The Leaf Porometer features an easy-to-use, six-button, menu-driven interface. There are three primary menus: the Main Menu, Data Menu, and Configuration Menu (See "Menus," page 38). You can navigate between each of these by pressing the Menu button.

Components of the Leaf Porometer

The Leaf Porometer and its components come to you in a foam-padded carrying case. You should find the following items inside when your Leaf Porometer arrives:

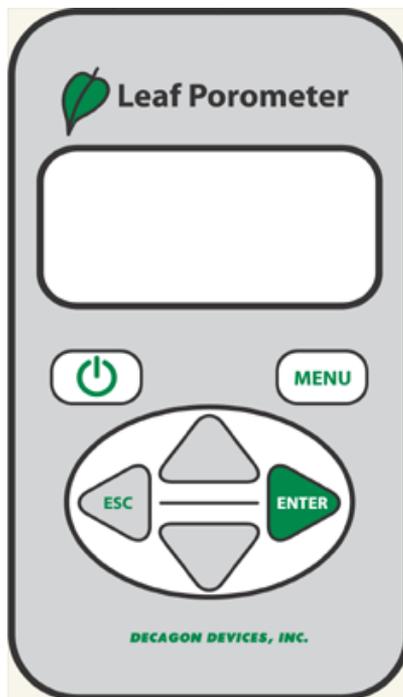
- Leaf Porometer controller
- RS-232 cable
- Operator's manual, including a CD-ROM with the Leaf Porometer Utility
- Sensor head
- Teflon filter disks
- Replacement leaf pad/outer leaf pad (see p. 8)
- Calibration plate
- Bottle of distilled water

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2. About the Leaf Porometer

- Tweezers
- Calibration filter paper disks (Whatman grade #3 filter Paper)
- Bottle of Desiccant (DrieRite 10-20 mesh indicating desiccant)
- Dispensing Cap
- Spacer pin
- White Fluoropolymer agitation beads
(Part# 9660K13 from McMaster Carr)

Keyboard Functions



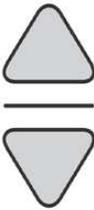
Here is a brief overview of each key's function:



Power: This key activates and deactivates the Leaf Porometer. (*NOTE: The device will automatically turn off if not used for more than 10 minutes or 60 minutes if running in manual mode.*)



Menu: This key cycles between the three menus at the top of the screen. *NOTE: Pressing Menu while changing a setting will cancel any operations.*



Arrow Keys: These keys navigate within menus and sub-menus, and modify numerical values in sub-menus, as well as select different units. Holding down an arrow key allows you to scroll between different options quickly.



Escape: This key backs out of sub-menus and can be used to cancel certain actions.



Enter: This key is used to make selections within menus and sub-menus, and also begins taking measurements.

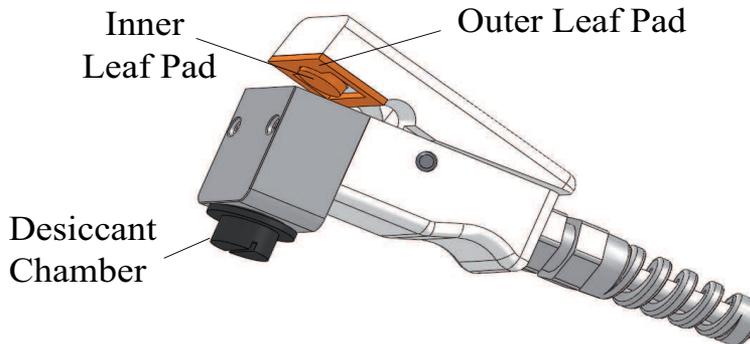
The Sensor Head

The Leaf Porometer cannot take measurements without the aid of the sensor head. This sensor head is responsible

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2. About the Leaf Porometer

for gathering the information (vapor pressure, humidity, etc.) that the Leaf Porometer uses to calculate stomatal conductance in a leaf. The following illustration shows the external components of the sensor head.



Setting the Time

You should make sure that the system time on the Porometer is correctly set. This will make sure the timestamps on downloaded readings are accurate (see “How Saved Data Are Organized,” page 53). You can do this manually in the Porometer (see “Time” page 45,), or by using the Leaf Porometer Utility (see “Setting The Date & Time”, on page 55).

Calibration Number

Each sensor head comes with a default 7 digit calibration number that can be found on the tag on the sensor head cable and on the calibration certificate. The default calibration is for use with desiccant. This default calibration number has been entered into the Leaf Porometer readout unit and will be applied to each measurement until a user initiated calibration is performed. When a user initiated cali-

bration is performed, a new calibration number is generated and stored. This new calibration number will be applied to all subsequent measurements instead of the default calibration until a new user initiated calibration is performed or the user requests a reset to the default calibration.

3. Sensor Head Calibration

For the Leaf Porometer to make accurate readings of stomatal conductance, the two humidity sensors in the sensor head must behave in a very repeatable manner. Over the past several years, we have found that the sensors occasionally change characteristics over time. While the end-point humidity measurement may still be accurate, the response time of the sensors can change subtly which creates inaccurate conductance measurements. The best way to ensure accurate conductance measurements is to calibrate the Porometer before taking measurements. We recommend that the Porometer be calibrated every day that it is used or every time it is used under a different set of environmental conditions (i.e. $> 15^{\circ}$ C temperature change). It is especially important to re-calibrate the Porometer after you install or remove the desiccant chamber. It is also recommended that fresh desiccant be used for each day of measurement. Visit our website at www.decagon.com/porocal for an online video tutorial of the calibration process.

Requirements

All Leaf Porometers with firmware Revision 1.30 or greater have the ability to be calibrated by the user. If your Porometer has firmware lower than Revision 1.30, you may upgrade the firmware. For instructions on how to upgrade your firmware to the latest version see “Upgrading Firmware” on page 77.

In addition to current firmware, you will need a calibration kit from Decagon to perform the calibration. If you do not have a calibration kit, please contact Decagon (support@decagon.com) for a kit. Please have your sensor head serial number available when you contact Decagon for the kit.

The kit contains:

- Calibration plate
- Tweezers
- Bottle of DI water
- Calibration filter paper disks
- Spacer pin
- White fluoropolymer agitation beads

Procedure

1) Equilibrate to Field Conditions

It is critical that the Porometer sensor head is in thermal equilibrium with the environment where measurements will be taken. If you bring the Porometer from an air conditioned environment into hot field conditions, it can take 10 minutes or more for thermal equilibrium to be reached. You can check for thermal equilibrium by putting the Porometer in "manual" mode or using the diagnostic screen to monitor temperature readings until they are steady. It is also important that the DI water and calibration plate are also in thermal equilibrium. For example, do not keep the bottle of DI water in a pants pocket or hold the calibration block for extended periods of time.

2) Check Desiccant

Remove the black plastic desiccant chamber from the bottom of the leaf clip by unscrewing it (counterclockwise).

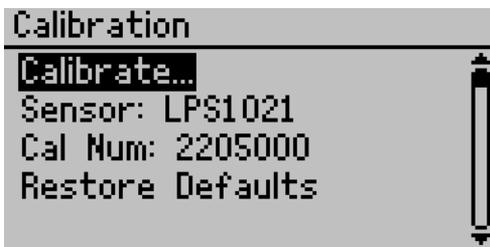
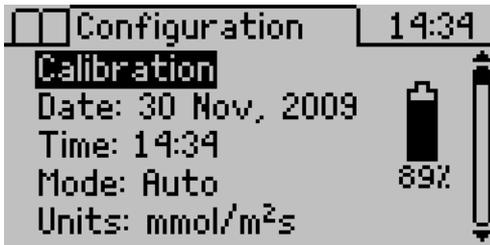
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3. Sensor Head Calibration

Check to see that the desiccant is blue meaning that it is not exhausted. If the desiccant is purple, discard the exhausted desiccant and refill the desiccant chamber with fresh desiccant from the included desiccant storage container. It is typical to change the desiccant each day that measurements are made to ensure that it is not exhausted over the course of the day's measurements.

3) Start Calibration

To start calibration, select the "Calibrate" option on the Configuration/Calibration submenu.



4) Verify Sensor Head Equilibrium

You will be reminded to make sure the sensor head is in thermal equilibrium with its surroundings (see #1 above).

Press Enter to move to the next step.

WARNING

The sensor head must be in thermal equilibrium with it's surroundings before continuing.

5) Enter Serial Number

You will be prompted to enter the sensor head serial number. This number can be found on a tag attached to the sensor head. Select the number by pressing the up and down arrow keys to select a number and pressing enter after each digit.

Sensor Serial Number

LPS0004

6) Sensor Offset/Stability

The sensors must give similar humidity readings for accurate stomatal conductance measurements. Before beginning a calibration, the Leaf Porometer checks to make sure that the two sensors in the sensor head agree well

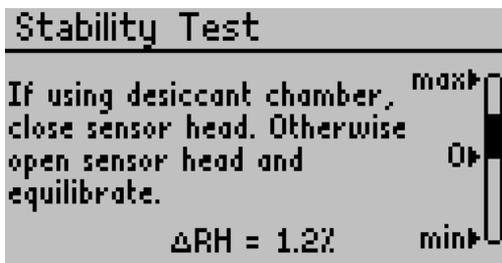
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3. Sensor Head Calibration

with each other. For the sensors to agree, the air in the diffusion path should be well mixed.

One of the white Fluoropolymer agitation beads can be used to mix the air in the diffusion path. To use the bead, simply open the leaf clip, insert the bead into the diffusion path in the Aluminum block, and close the leaf clip. Now the air in the diffusion path can be mixed by shaking the bead. Shaking the leaf clip in a vertical orientation results in the most efficient mixing.

As the sensors come to equilibrium, you should see the indicator bar move closer to the 0% offset line. **DO NOT** open the clip. The water vapor in the ambient atmosphere will slow the equilibration process.

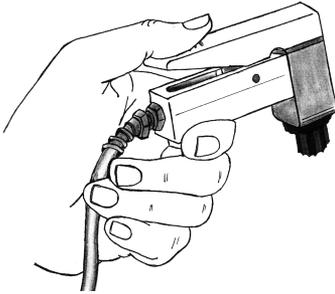


Once the sensor readings stabilize and are confirmed to be within 2% relative humidity of each other, the calibration routine automatically advances to the next screen. If the sensors don't equilibrate to similar humidity values, check for water on the sensor head. If no water is found, then the sensors may have been chemically contaminated or be otherwise malfunctioning. If this case occurs, you should recondition the sensors. See page 75 for more details on re-conditioning the sensors.

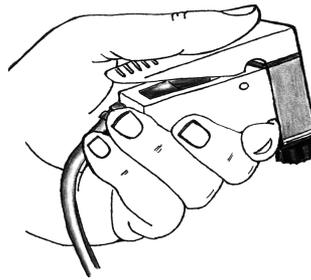
Holding the Sensor Head

Holding the sensor head in the correct manner is very important for maintaining thermal equilibrium. The pictures below illustrate the correct way to hold the external sensor.

Correct



Incorrect



7) Preparing Calibration Apparatus

The Leaf Porometer calibration apparatus consists of a plastic calibration plate with a precisely drilled hole with known conductance of $240 \text{ mmol m}^{-2} \text{ s}^{-1}$. For the conductance value of the calibration plate to be correct, a flat, moist surface must be placed across the hole on the side marked "Filter Paper." This condition is achieved with a circular disk of wet filter paper that is included in your calibration kit. Additional filter disks may be purchased if you run out.

NOTE: Do not touch the calibration filter paper disk with your fingers because oils in your skin will contaminate the disk and result in improper readings. To aid in handling the filter paper disk and to keep it clean, use the

tweezers included in the calibration kit to hold the calibration filter paper disk.

Wetting the filter paper

The wetness state of the filter paper is critical for an accurate calibration. The paper must be wet enough to provide a 100% humidity surface, but must not be too wet. If the paper is too wet, free water will be pulled into the hole on the calibration plate by surface tension and will change the effective dimensions of the hole thereby changing the conductance. The best method of ensuring the proper wetness state is to use the "wet and flick" method. Use tweezers to pick up the filter disk and then add one drop of the DI water to the filter disk to saturate it. Allow the water a couple moments to fully absorb into the filter. Then, while holding the disk with the tweezers, give the filter paper several sharp flicks of the wrist to knock off any excess water. The resulting paper should glisten, but there should be no drop of excess water clinging to the disk. Please see the video of proper Leaf Porometer calibration technique on the Decagon website (www.decagon.com) for visual representation of the dip and flick technique and the proper filter paper wetness state.

NOTE: If you need to obtain a Material Safety Data Sheet (MSDS) for DI water, a printable version is available on our website at www.decagon.com/msds.

After wetting the filter paper, using tweezers, lay it flat over the hole in the calibration plate on the side marked "Filter Paper." It is critical that the filter paper lay flat over the hole. Make sure that the paper is not caved into the hole or bubbled out from the hole. The filter paper

also has to cover the entire hole. Turn the calibration plate over and carefully examine the hole to make sure that no meniscus of excess water is present in the hole. If excess water is observed, remove the filter paper, dry the calibration plate, and repeat the wet and flick procedure with more aggressive flicks.

If during the calibration the filter paper becomes too dry to adhere to the calibration plate, then it needs to be re-wet. If this occurs during a calibration, you will need to re-start the calibration procedure. Note that the first reading after re-wetting the filter paper will be artificially low.

8) Attach Sensor Head to Calibration Plate

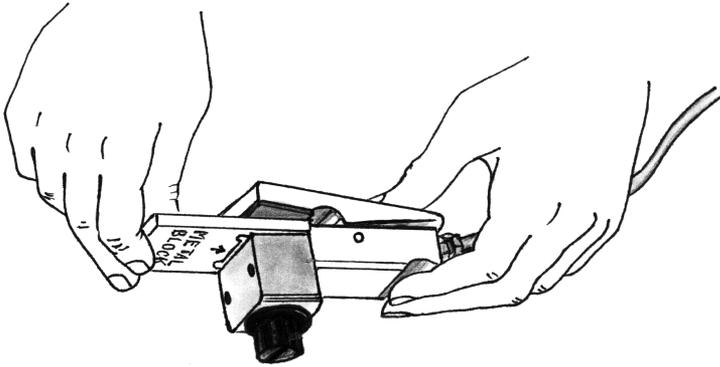
Once the sensors have equilibrated, the Attach Sensor Head screen will automatically appear.



With the moist filter paper in place, slide the calibration plate into the sensor head, making sure you've oriented the side of the plate marked "Metal Block" toward the aluminum block side of the sensor head.

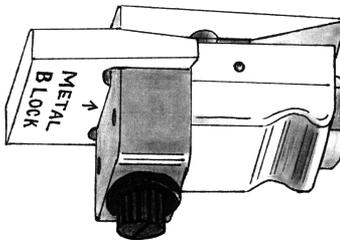
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3. Sensor Head Calibration

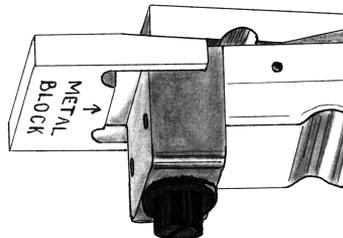


Be sure that the calibration plate is inserted until the aluminum block is seated firmly against the hard stop on the calibration plate.

Correct



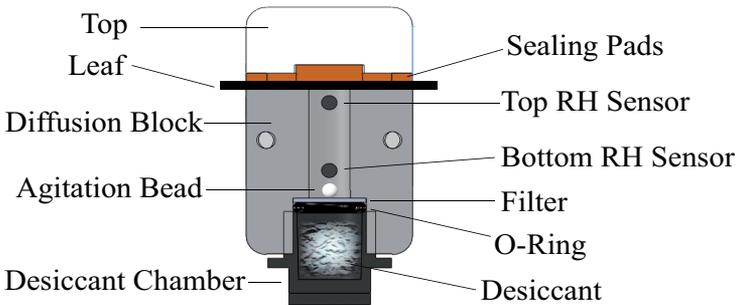
Incorrect



This will ensure that the hole is properly aligned with the diffusion path in the sensor head. Once the sensor head is attached to the calibration plate, the Leaf Porometer will automatically sense the calibration plate and begin the first reading.

If the agitation bead is used during a calibration or regular measurement it is important that the sensor head be ori-

ented with the desiccant cap facing downward so that the agitation bead sits on the Teflon filter and does not interfere with the water vapor diffusion from the leaf to the two sensors (see diagram below). The sensor can be held in this orientation by hand, or the entire sensor head and calibration plate assembly can be set on top of the Leaf Porometer Controller with the desiccant cap hanging off the edge. It is also critical that the sensor head remain still during the calibration or regular measurement if the agitation bead is in the diffusion path. The stomatal conductance measurement relies on water vapor transfer from purely molecular diffusion (no air movement) and any air mixing from agitation bead movement will cause a substantial loss of accuracy.

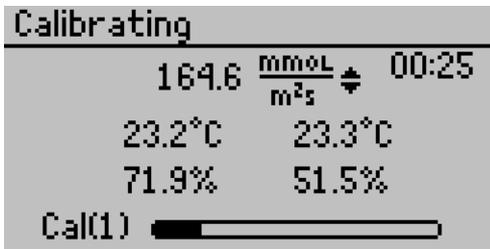


9) Calibration Measurements

Once the sensor head is attached to the calibration plate, the Leaf Porometer will automatically sense the calibration plate and begin the first calibration measurement.

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3. Sensor Head Calibration



Each calibration measurement will take 30 seconds. The indicator bar at the bottom of the screen and timer at the top right of the screen indicate the status of the calibration measurement. Once the measurement is finished, you will be prompted to Equilibrate Sensors (#10 below) and then Attach Sensor Head (#8 above). This will begin another calibration measurement.

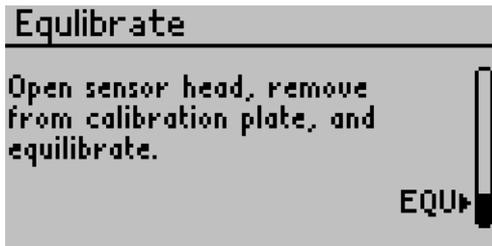
The Leaf Porometer will continue to take calibration measurements until three consecutive measurements are all within 7.5% of each other. This ensures that the Porometer measurements have stabilized. Normally, the calibration should end after 3-5 calibration measurements are performed. The routine will continue for a maximum of 10 measurements. If stable readings haven't been achieved in 10 readings, then there is a problem with the calibration and the following screen will appear.



The most common problem is that thermal equilibrium hasn't been reached. Let the Porometer equilibrate for a few minutes and repeat the calibration process. If you still can't achieve a good calibration, contact Decagon for help (support@decagon.com).

10) Equilibrate Sensors

Once a reading is complete, you will be prompted to remove the sensor head and equilibrate the sensors.

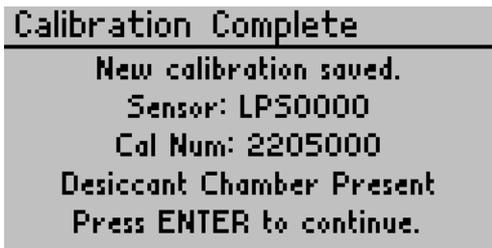


Remove the sensor head from the calibration plate and close the clip. If you are using the agitation bead, shake the sensor head to mix the air in diffusion path to speed up the equilibration process. As the sensors come to equilibrium, you should see the indicator bar move closer to

the "EQU" line. Once the sensors have equilibrated, the Attach Sensor Head screen will automatically re-appear and steps 8-10 can be repeated.

11) Calibration Complete

Once the calibration is complete, the new calibration number is automatically saved into the handheld unit and the following screen is displayed. At this point, you are ready to take measurements with your Leaf Porometer. Note that the most recent saved calibration number will be applied to all subsequent measurements until a new calibration is completed or you request that the factory default calibration number be applied.



```
Calibration Complete
-----
New calibration saved.
  Sensor: LPS0000
  Cal Num: 2205000
Desiccant Chamber Present
Press ENTER to continue.
```

12) Accuracy Verification

It is always a good idea to verify that the calibration was effective. If you wish to do this, go to the measurement menu and make a few measurements on the calibration plate. The measured conductance should be close to $240 \text{ mmol m}^{-2}\text{s}^{-1}$.

If possible, do not re-wet the filter paper for the verification readings. If re-wetting is necessary, disregard the first measurement taken.

Calibration without Desiccant

It is recommended that desiccant is always used to take readings, but if the user wishes to make non-desiccated readings, an ambient humidity of less than 30% is recommended.

For calibrating without desiccant, follow steps 1-11 with a few exceptions:

- Remove the black desiccant chamber to expose the Teflon filter to ambient conditions.
- Do not use an agitation bead in the diffusion path.
- There will be a 3 minute hydration period before calibration readings are taken. During this period, the sensor head is clipped on the cal block with moist filter paper applied.
- The initial stability test (step 6) and subsequent equilibration between calibration measurements (step 9) are performed at ambient humidity. To speed equilibration at these steps, open the clip and wave the sensor head to mix air in the diffusion path.

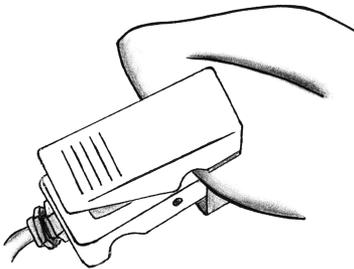
4. Making Measurements

Before Making a Measurement

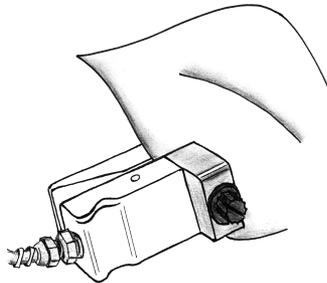
Before beginning a measurement, make sure that the Leaf Porometer is turned on and that the sensor head is clean and properly connected. Also it is critical to make sure that the sensor head is equilibrated to the ambient temperature as thermal disequilibrium will cause highly inaccurate measurements.

NOTE: It is important to consider if you will be measuring adaxial conductance (on the top of the leaf) or abaxial (the bottom). Since the stomates of most leaves are on the bottom of the leaf, most measurements will be abaxial. If the agitation bead is present in the chamber it is required that readings be taken with the black cap facing downward so the bead is not in the diffusion path

Abaxial (Bottom)

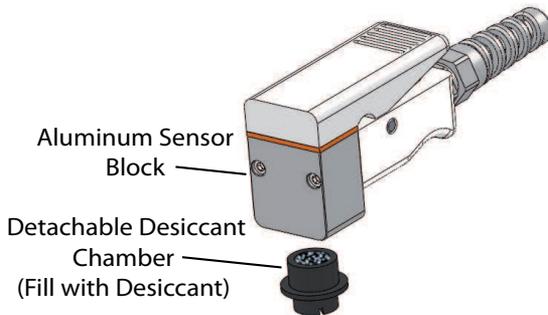


Adaxial (Top)



Desiccant

It is highly recommended that the desiccant chamber is used when making measurements. The Leaf Porometer relies on a measurement of the humidity gradient between the leaf evaporating surface and the ambient atmosphere. As the ambient humidity increases the gradient becomes smaller which causes small errors in the measurement of the humidity gradient to result in very large errors in the calculated conductance. The use of the desiccant chamber lowers the ambient humidity to near zero, thus ensuring a steep humidity gradient between the leaf and ambient conditions and preventing the problems mentioned above. We recommend that the desiccant chamber be used for the most consistent readings.



To use the desiccant chamber, simply fill the detachable chamber with DrieRite Indicating Desiccant (included) and screw it into the bottom of the aluminum sensor block. Make sure that the chamber is screwed in far enough to compress the o-ring on the desiccant chamber and ensure a good vapor seal. If your Porometer sensor block doesn't have threads to accommodate the desiccant chamber, then you have an earlier version of the Leaf

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4. Making Measurements

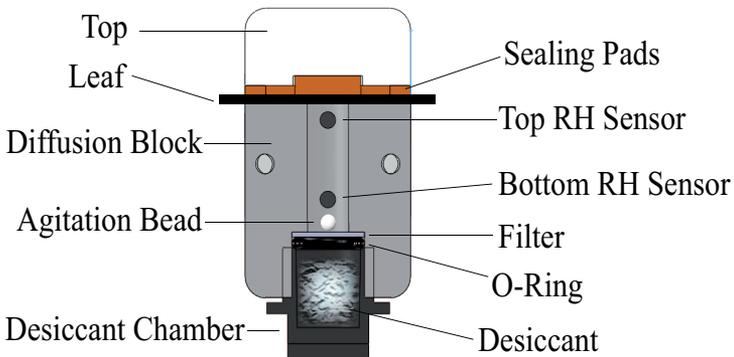
Porometer and will need to contact Decagon to have your Porometer retrofitted with an updated sensor block.

Note: If you need to obtain a Material Safety Data Sheet (MSDS) for DrieRite indicating desiccant, a printable version is available on our website at www.decagon.com/msds.

Although several different desiccants will work in the Porometer (we have had some success with silica gel and molecular sieve), we recommend DrieRite 10-20 mesh because it has the best combination of sorption rate and total water sorption properties for this application. DrieRite can be refreshed by baking at 210 C for 1 hour and re-used. However, from our experience, refreshed DrieRite doesn't sorb as much water as virgin material and therefore doesn't last as long in the Porometer.

When using the desiccant chamber, it is necessary to close the leaf clip in order to re-equilibrate the sensors in preparation for the subsequent measurement. This results in a still-air environment in the diffusion path, so re-equilibration is achieved through molecular diffusion, which is a relatively slow process. At high temperatures, diffusion coefficients are high and the process is relatively rapid. However, at mid to low temperatures, the process can be unacceptably long (several minutes). These long equilibration times can be reduced considerably by using the white fluoropolymer agitation beads that are included with the Porometer to mix the air in the diffusion path. To speed equilibration, simply open the leaf clip, insert one of the beads into the diffusion path, and close the clip. Now, you can shake the leaf clip and the bead will mix the

air in the diffusion path more quickly and speed the re-equilibration time significantly. The presence of the bead will not affect the stomatal conductance measurement as long as the bead doesn't move during the measurement and the leaf clip is oriented with the desiccant chamber down so that the bead rests on the Teflon filter as shown in the illustration below. The bead should not be used if the adaxial (top) surface of the leaf is being measured because the bead will rest on the leaf and distort the diffusion of water vapor from the leaf through the diffusion path.



It is well known that low humidity conditions will induce stomatal closure in most plant species, so prolonged exposure to the desiccated leaf clip should cause inaccurate stomatal conductance measurements. However, it is suggested in the literature that the minimum time necessary for the onset of stomatal closure in response to a change in environmental conditions is 2 minutes. Since the SC-1 Leaf Porometer makes an auto mode measurement in 30 seconds, the presence of the desiccated leaf clip should not cause stomatal closure unless multiple measurements are

made in quick succession on the same location of the same leaf.

Manual Mode vs. Auto Mode

When the Porometer is in Manual Mode, the stomatal conductance is measured directly from the theory presented on page 62 and displayed continuously. The real time conductance measurement can be saved at any time during a Manual Mode measurement. **Manual mode should only be used at low conductances (i.e. < 100 mmol m⁻²s⁻¹).** At higher conductances, the readings become inaccurate and can take an exceptionally long time to complete. For the theory in Chapter 7 to accurately predict the stomatal conductance using the steady state diffusion technique, true steady state conditions must exist in the diffusion path. The amount of time necessary to reach steady state conditions is proportional to the conductance. At conductances less than 20 mmol m⁻²s⁻¹, steady state conditions are generally reached in less than 5 minutes. At higher conductances, steady state conditions can take up to 30 minutes. Please note that leaving the sensor head on the leaf surface for more than a few minutes can cause the stomatal conductance to change in response to the presence of the sensor head clip. Some common uses for manual mode are measuring dark conductance in plants and measuring conductance of static conductance materials (e.g. fruit peels, waterproof fabric).

Auto Mode makes an accurate stomatal conductance measurement in 30 seconds. To do this, the Porometer

takes the first 30 seconds of stomatal conductance data and applies a “look ahead” algorithm to predict the final stomatal conductance reading that would be achieved if unlimited time were allowed for true steady state conditions to occur. Auto Mode has several advantages over Manual Mode and other Porometers. First, the 30 second Auto Mode measurement duration ensures that stomatal conductance doesn't change due to the presence of the sensor head. Second, Auto Mode takes only 30 seconds per measurement, ensuring that your measurements are completed in a timely manner. Finally, Auto Mode sets a definite endpoint for the measurement, meaning that the user doesn't have to pick an arbitrary endpoint, as is common with other diffusion Porometers and with Manual Mode measurements.

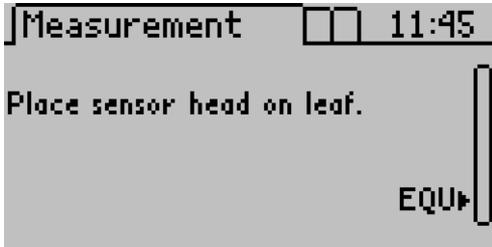
For the Porometer to “detect” the presence of a transpiring leaf and begin the Auto Mode measurement, the measured stomatal conductance must climb to $5 \text{ mmol m}^{-2}\text{s}^{-1}$. So, if you are making measurements on leaves with extremely low conductances, it may be necessary to make the measurements in Manual Mode.

Making a Measurement in Auto Mode

1. Select Auto mode from the configuration menu.
2. Return to the Measurement Menu. You will be prompted to press Enter to begin a reading.
3. After pressing Enter, the following screen will be displayed:

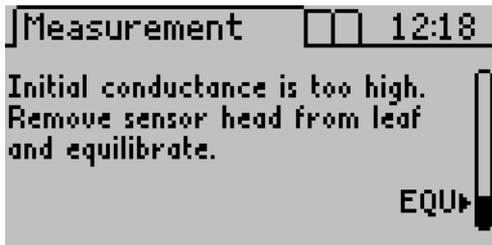
Leaf Porometer Operator's Manual

4. Making Measurements



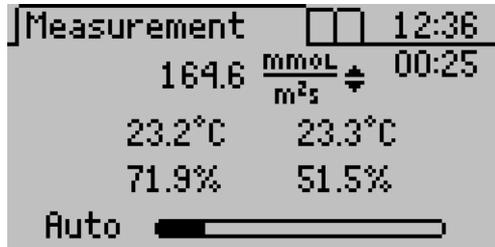
4. The reading will begin once the sensor head is placed on a leaf, and a conductance value greater than $5 \text{ mmol m}^{-2} \text{ s}^{-1}$ is detected. A progress bar will also indicate the reading is underway.

Note: If the desiccant chamber is attached, the reading will begin shortly after opening the leaf clip regardless of whether it is clipped on a leaf. It is critical to slip the leaf clip onto a leaf within 5 seconds of opening the clip or unacceptable errors may be introduced into the conductance measurement.



If you see the screen above, close the clip and allow the sensor to re-equilibrate. If an agitation bead is in place shake the sensor head to more quickly equilibrate. Once the sensors are re-equilibrated, you will be prompted to place the sensor head on leaf.

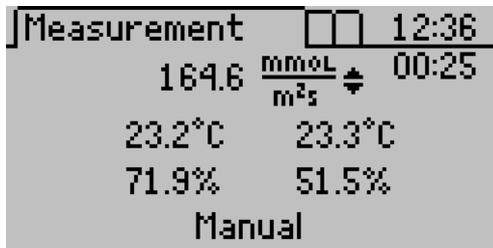
5. The measurement screen will resemble the following.
NOTE: In Auto mode, a timer will appear in the upper right hand corner of the screen that indicates how many seconds remain.



6. Once the 30 second measurement has been completed, the Porometer will display the final conductance. You may save or discard your data. See “Saving Data” section on page 38 for instructions.

Making a Manual Mode Measurement

1. Select Manual mode from the Configuration Menu. Please note that manual mode is only for special situations with conductances below $100 \text{ mmol m}^{-2} \text{ s}^{-1}$. See the section “Manual Mode vs. Auto Mode” earlier in this chapter.
2. Return to the Main menu and press Enter.
3. Place the sensor on a leaf. Unlike Automatic mode, there is no time limit for taking readings, and the elapsed time is displayed directly below the system time.



Measurement		12:36
164.6	$\frac{\text{mmol}}{\text{m}^2\text{s}}$	00:25
23.2°C	23.3°C	
71.9%	51.5%	
Manual		

4. You may save your data at any point during the reading by pressing Enter. See “Saving Data” section on page 38 for instructions.

Measurements without Desiccant

Note: It is recommended that desiccant is always used but if the user wishes to make non-desiccated readings an ambient humidity of <30% is recommended. The following should be noted for measurements without desiccant.

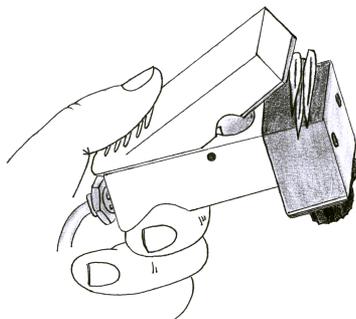
- When not using desiccant, remove the desiccant chamber from the sensor head and do not cover the hole in the bottom of the sensor head. Keep your fingers away from the diffusion path when taking measurement.
- The factory calibration is with desiccant so you will need to re-calibrate without desiccant as described on page 23. If you try to measure without the desiccant after having calibrated with desiccant, the Porometer will prompt you to re-calibrate without desiccant before continuing.
- Without desiccant, the equilibration between measurements is performed at ambient humidity.
- To speed equilibration time, open the clip and wave the sensor head to mix the air in the diffusion path.

Do not insert an agitation bead into the diffusion path.

- If the desiccant chamber is not being used, the first reading in Auto mode after the sensor has been removed from a leaf for more than five minutes will always read low. Discard this reading and begin recording with the second. This is not an issue if the desiccant chamber is in use.

Measuring Small Leaves & Needles

When measuring small needles or leaves, they should be inserted into the sensor as shown below. This is because single needles or small leaves (including blades of grass) may not adequately cover the aperture of the sensor.



For an accurate measurement it is critical that the entire cross sectional area of the diffusion path be covered with leaf material. Sometimes it is necessary to remove the leaves/needles from the plant in order to arrange them over the opening in the diffusion path. This will result in an accurate measurement as long as the measurement is completed within 2 minutes of leaf/needle removal,

because the stomatal aperture should remain unchanged for at least that long after disturbance.

Averaging Readings

A leaf's stomatal conductance depends on the amount of shade and sunlight it receives, the age of the leaf, and its position on the plant. To obtain a plant's stomatal conductance average, you must take a variety of readings from different positions on the plant. The average is proportional to the type of readings taken. For example, if you know your plant receives 70% sunlight, you might consider taking seven readings from the sunny part, and three from the part in the shade.

You can also obtain the average readings for a field of plants. For example, if you had a field of corn, you might decide to take a reading from the third leaf from the top on each stalk of corn on that particular plot. These readings together would give you the average for that field.

Measurement Precautions

General Precautions

- Before using the sensor, allow it to equilibrate to the ambient temperature. This may take 10 minutes or longer to complete if the temperature of the Porometer is very different from the sampling environment, e.g. from a cool air conditioned room to a hot outdoor environment.
- Avoid leaves that are wet or covered with dew; never take readings in the rain.
- If you blow into the sensor head, it will take a few minutes for the stomatal conductance reading to return to normal.

- Clean the sensor periodically to keep it free of dirt and pollen that can build up during use and affect readings. See section on cleaning for more details. (See “Cleaning the Sensor Block,” on page 71.)
- Avoid chemical fumes. Fumes can be extremely harmful to the sensor (i.e. alcohol, gasoline, volatile organics).
- It is recommended that desiccant is always used, but if the user wishes to make non-desiccated readings an ambient humidity of <30% is recommended.

If the stomatal conductance reaches a value beyond the recommended range of the instrument (0 to 1000 mmol/m²s), an “approximate” symbol will appear to the left of the reading. If the stomatal conductance reaches a value greater than or equal to 6000 mmol/m²s, an “infinity” symbol is shown in place of the measurement. Most often, the excessively high values are caused by water on the leaf surface. If you consistently are getting high readings, check your leaf surface for the presence of water.

Chemical Effects

Chemical vapors can interfere with the polymer layers used to form the humidity sensors. These fumes can diffuse through the sensor and compromise the sensor's accuracy. It is a good idea, therefore, to never bring the sensor into contact with any sort of chemical vapor (i.e. glue, alcohol, gasoline, volatile organics). See section on “Sensor Head Reconditioning” if you suspect your sensors have been affected by chemical contamination.

Environmental Effects

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4. Making Measurements

When making a measurement, the following effects must be accounted for.

Light. The amount of CO₂ required for a plant changes depending on the amount of sunlight available to it. In broad daylight, more CO₂ is required, so the stomata remain open. At dusk, the stomata close, and in darkness they are often closed completely. Readings taken on overcast days, for example, generally have lower conductances than those taken on sunny ones. Additionally, leaves in shadow or in shade usually have lower conductances than those in greater light. Therefore, make sure to consider the lighting conditions you will be measuring in.

Temperature. A plant's stomatal conductance is also affected by temperature. For most plants, on a very hot or a very cold day, photosynthesis will slow down or stop, and the stomata will narrow or will not open, to prevent internal water loss. Therefore, be sure to consider the temperature before conducting measurements.

Humidity. A factor that will cause the stomatal conductance to change is the humidity at the leaf's surface. As the outside humidity increases, the stomata will open. Porometers that dry the air around the stomata decrease conductance; likewise, those that allow surface humidity to increase do the opposite. Be sure not to make repeated measurements on the same spot on a single leaf especially if the desiccant chamber is used.

Carbon Dioxide (CO₂). One purpose of the stomata is to regulate the leaf's usage of CO₂, which is important to controlling the balance of humidity. An increase in CO₂

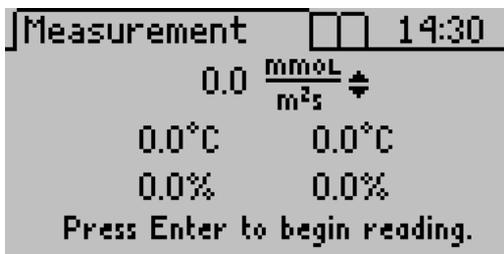
will cause stomata to close, while a decrease will cause them to open. Thus, it is important to consider the CO₂ levels of your measuring environment. You, the Leaf Porometer operator, can adversely affect readings by exhaling CO₂ directly on the plant you are measuring. This is particularly important in growth chambers or greenhouse, where CO₂ from an operator's breath can double or triple ambient levels.

5. The Menus

The Leaf Porometer features three main menus, designed for easy navigability and use.

The Measurement Menu

The Leaf Porometer displays the Measurement Menu when first powered on.

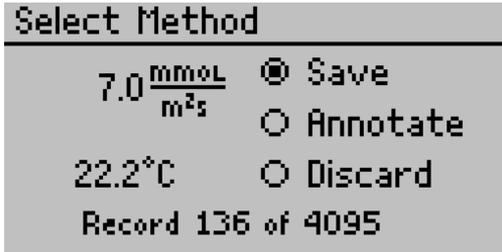


At the top of the screen is the stomatal conductance number at left, and the currently selected unit of measurement at right. Below are two columns of numbers. The left is the sensor closest to the leaf, and the right is the sensor farthest from the leaf. Each column has the temperature of that sensor, and its percent humidity. The Leaf Porometer uses these to calculate the stomatal conductance value.

Saving Data

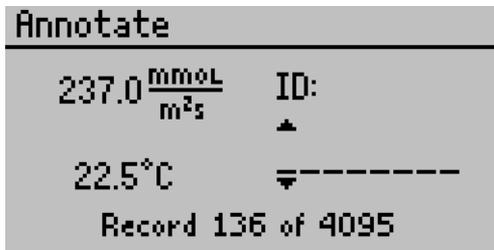
In Automatic mode, you can save data as soon as the timer has expired; in Manual mode, you save your data without interrupting your reading. To save your data in either mode,

1. The following screen will appear (you have to press Enter in Manual mode to access it):



2. You have three options:
 - 1) Select “Save” and press Enter to save your information as-is.
 - 2) Select “Discard” and press Enter to return to the main screen and start over with a new reading
 - 3) Select “Annotate” and press Enter to give your data a file name.

3. **How to annotate a reading:** Selecting “Annotate” will cause the following screen to appear:



You will see a series of lines, with a set of arrows above and below the first. If you have annotated a previous reading, the old annotation will remain to be

changed or deleted. Use the arrow keys to select a letter or number and press Enter to move to the next character.

4. Repeat this until you reach the last character. If you wish to stop before the end, you will still have to press Enter until you reach the end of the row.

The Data Menu

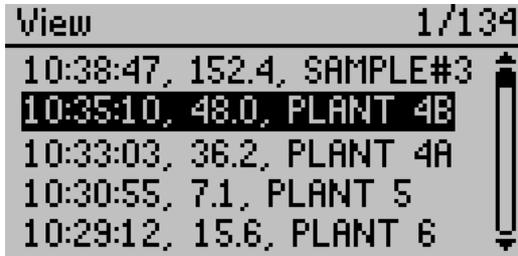
In this menu, you can view any saved data, download data to a computer, and erase all data stored in the Porometer's memory. This menu features three sub-menus.



View

Here you can view measurement data stored on your Porometer. To do this:

1. Press Enter to select the view sub-menu.



2. For each measurement, you will see the time acquired, stomatal conductance/resistance value (depends on which unit you have set as your default) and its annotation (if that measurement was saved with an annotation).

Download

This menu option sends the data saved in the Porometer to the terminal software running on your computer.

NOTE: Your Leaf Porometer comes with the Leaf Porometer Utility software for Microsoft Windows. The Utility makes downloading data to your computer very easy. In general, you should use the Leaf Porometer Utility to download data instead of this menu option on the Porometer. See page 50 for more information.

If you are unable to use the Leaf Porometer Utility, you can use terminal software to transfer the data from your Porometer to your computer. The following steps should apply to most terminal software programs:

1. Configure your terminal software with the following settings:
 - 9600 baud
 - 8 data bits, 1 stop bit, no parity

Leaf Porometer Operator's Manual

5. The Menus

- No software/hardware flow control
 - Append line feeds to incoming line ends
 - Echo typed characters locally.
2. Connect your Leaf Porometer to an available serial port on your computer using the included RS-232 serial cable.
 3. Set your terminal software to capture received data if you want to save the data.
 4. Select "Download" from the Data Menu of the Leaf Porometer.

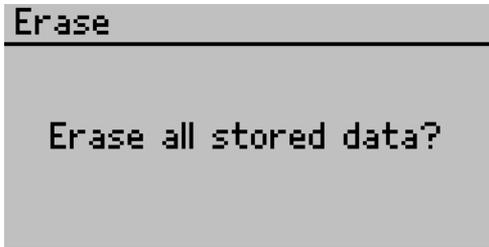
Erase

This will erase **all** your stored data records in your Leaf Porometer memory.

WARNING! Once this feature is activated, all data will be permanently deleted from the Porometer, and cannot be recovered!

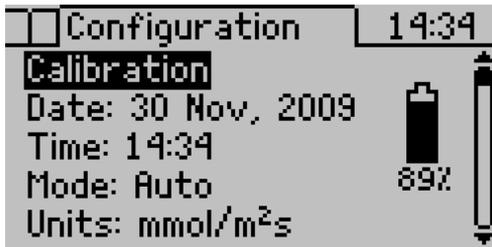
To erase data:

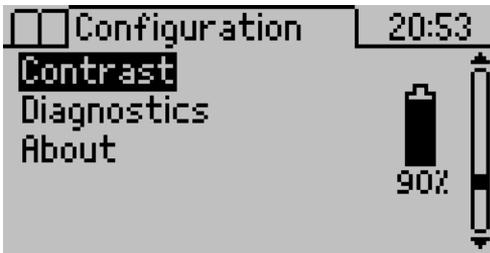
1. Press Enter to select the Erase sub-menu. The following screen will appear.



2. Press Enter again to erase the memory, or ESC if you decide not to erase the data. "Erasing..." will be displayed as data is being removed, which usually takes about 6 seconds.
3. When this is complete, you will be returned to the Data Menu.

The Configuration Menu





This menu allows you to alter system settings, such as the current time, date, and operating mode, select the appropriate units for your readings, and view information about your Leaf Porometer. There is also a battery icon to the right, indicating how much battery power is currently available. This menu features seven sub-menus:

Calibration

See Sensor Head Calibration Procedure on page 11 for a thorough explanation of the calibration menu.

Date

1. To change the current date, Press Enter to select the Date display.
2. The current date will appear in the center of the screen, in day/month/year format. A pair of arrows will be present (above and below) the first number.



3. Use the arrow keys to change this number. (Holding down the up/down arrow will allow you to scroll quickly between values.)
4. Press Enter to move to the next value, and repeat step #3. If you need to return to the previous number, press Escape.
5. When you have finished changing the last number, press Enter and you will be returned to the Configuration Menu.

Time

To change the current time,

1. Press Enter to select the Time display.
2. The current time will appear in the center of the screen, in 24-hour format. A pair of arrows will be present (one above and below) the first number



3. Use the arrow keys to change this number. (Holding down the up/down arrow will allow you to scroll quickly between values.)
4. Press Enter to move to the next number, and repeat step #3. If you need to return to the previous number, press Escape.
5. When you have finished changing the last number, press Enter and you will be returned to the Configuration Menu.

Mode

The Mode Menu allows you to choose which type of measurement mode to use in the Main menu. Press Enter to select a mode. See page 28 for the descriptions of Manual and Auto Modes. Here is a description of how to use each:

- **Auto mode.** Takes readings automatically for 30 seconds. You must press Enter before placing the sensor on the leaf for Auto mode to work properly. In this mode, you are unable to save your informa-

tion mid-reading. You must wait until the timer runs out after 30 seconds, then you may save your reading. Also, if initial conductance is less than 5 mmol/m² s, you will see a screen prompting you to place the sensor on a leaf. Conversely, if the initial conductance is too high, a warning screen will appear.

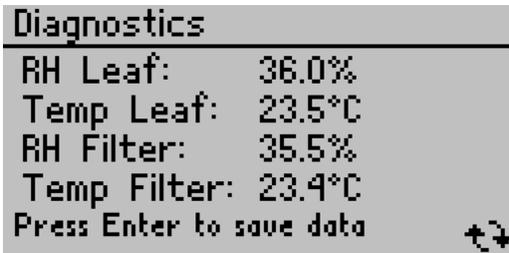
- **Manual mode.** Continuously measures conductance and updates the screen. This mode is only suitable for low conductances (<100 mmol m⁻²s⁻¹). The user can decide when equilibrium has been reached. Pressing Enter will give you the option to save your data at any point during the reading.

Units

Data in the Leaf Porometer can be displayed in three units. These can be accessed on the Main Screen, as well as under the Configuration Menu. When in the Configuration Menu, select “Units” and press Enter to select a unit.

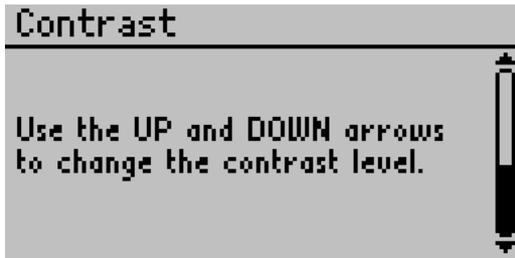
Diagnostics

This menu allows you to view and save real time sensor values from your sensor head. An error message will pop up next to a reading if the value is out of range. Pressing Enter during this screen will save a Scan Record that you can view or download at a later time.



Contrast

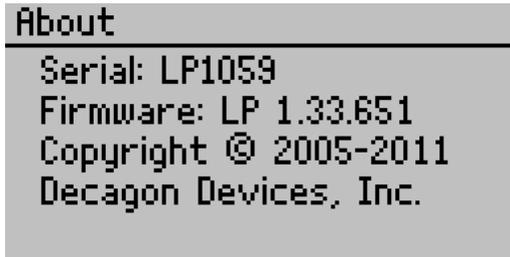
This menu allows you to alter the screen contrast settings. To access it, use the Down arrow key to scroll to it and press Enter. The following screen will appear:



Use the arrow keys to alter the contrast level. Press Enter to save or Escape to cancel adjustments.

About Screen

This menu displays your Leaf Porometer's serial number and firmware version.



```
About
-----
Serial: LP1059
Firmware: LP 1.33.651
Copyright © 2005-2011
Decagon Devices, Inc.
```

6. Leaf Porometer Utility



Leaf Porometer Utility main screen

The Leaf Porometer Utility is a program designed specifically for interfacing with the Leaf Porometer. Use this program to download measurement data to your computer, erase the Leaf Porometer's data, set the date and time, and see information about your Leaf Porometer.

SYSTEM REQUIREMENTS: To use the Leaf Porometer Utility, you must meet the following minimum system requirements:

- Microsoft Windows 98 or NT 4 (SP 5) or better
- Intel Pentium Pro or better processor

- One available serial port *or* one available USB port
- Microsoft Excel 97 or better (for viewing data as .xls files)

You can install the Leaf Porometer Utility using the included CD-ROM (found in the inside cover of the Leaf Porometer Operator's Manual). You can also download and install the latest version of the Utility from <http://www.decagon.com/home/downloads.php> .

Downloading Your Data

This will transfer all saved measurement data on the Leaf Porometer to your computer. Do the following:

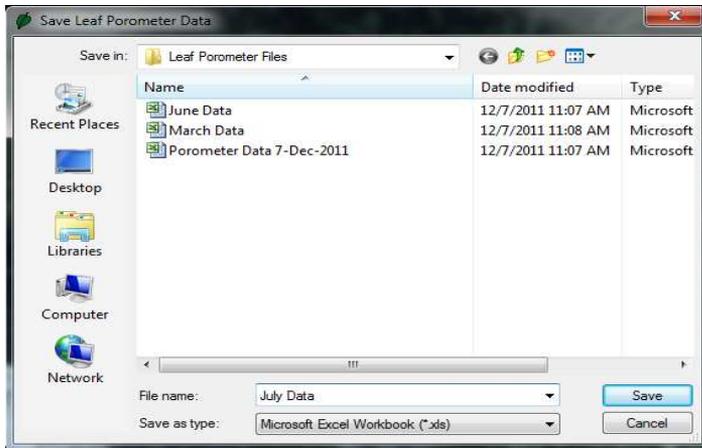
1. Make sure the RS-232 cable is connected to the Leaf Porometer, and to a serial communication (COM) port on your computer.
2. Open the Leaf Porometer Utility.
3. Choose the appropriate COM port from the "Use computer communication port" control on the main screen.
4. Click the "Download" button in the lower right-hand corner, or "Download Data" in the File Menu.

If you encounter an error message after clicking this button, please refer to the Troubleshooting section for instructions.

5. The following screen will then appear:

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6. Leaf Porometer Utility



Save Leaf Porometer data dialog

Name your data file, select where it will be saved to, and in what format. You may choose between the following formats:

- Microsoft Excel Workbook (*.xls);
- Text (Tab delimited) (*.txt);
- CSV (Comma delimited) (*.csv);
- Raw data (Comma delimited) (*.txt)

6. Click “Save” to download your data to the specified location. The progress bar shows the status of the download process.

NOTE: You can cancel a download in progress using the cancel button. If you cancel, no downloaded data are saved.

How Saved Data Are Organized

Data are organized in the same way regardless of what format it was saved in. The information will be divided into six columns:

1. **Measurement time**
2. **Stomatal conductance/resistance**
3. **Temperature in °C or °F**
4. **Sample ID** (if saved with measurement)
5. **Sensor head serial number**
6. **Calibration number**

NOTE: The utility formats measurement dates according to the Windows Local settings found in the Control Panel under “Regional and Language Options” (“Regional Settings” in Windows 98). You may override this and set the format to day/month/year by going to the Edit Menu, click Preferences, Units tab, and by clicking “Use template” under Date/Time Format for Data Files.

Scan Records

Scan records have additional columns than other data records. They show a snapshot of the sensor values at the time of measurement. In all file types, the scan records are interleaved with the normal data records and can be identified because their annotations are labelled “Scan”. Their additional columns are as follows:

7. Leaf Relative Humidity in %RH

8. Leaf Temperature in °C or °F
9. Filter Relative Humidity in %RH
10. Filter Temperature in °C or °F

Erasing Your Data

This will erase all data stored on your Leaf Porometer.

WARNING! Once this feature is activated, all data will be permanently deleted from the Leaf Porometer, and cannot be recovered!

To erase your data, do the following:

1. Make sure that the RS-232 cable is connected to the Leaf Porometer, and to a COM port on your computer.
 2. Choose the appropriate COM port from “Use computer communication port” control on the main screen.
 3. Click “Erase,” in the lower left-hand corner, or “Erase Data...” in the File Menu. **If you encounter an error message after clicking this button, please refer to the Troubleshooting section for instructions.**
 4. The progress bar shows the status of the erase process.
-

Setting the Date and Time

You can set the Leaf Porometer's date and time by selecting "Set Porometer Date/Time" from the Actions Menu. This will automatically synchronize the Leaf Porometer's date and time to your computer's date and time.

Retrieving Leaf Porometer Information

Choose "View Porometer Information..." from the Actions Menu to see information about your Leaf Porometer:



Leaf Porometer Information screen

If you encounter an error message after clicking this button, please refer to the Troubleshooting section for instructions.

This is a good way to find the serial number, firmware version, battery status, and number of stored measurements for your Leaf Porometer.

The Menus and Their Functions

The four menus across the top of the screen allow you to change program settings, and settings on the Leaf Porometer. Below is a brief overview of the options each menu contains.

File

Download Data. Saves measurement data stored in your Leaf Porometer as a data file on your computer (see instructions above).

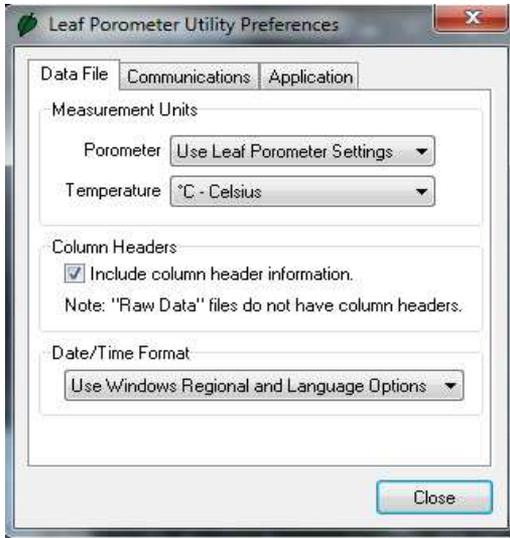
Erase Data. Erases all data in your Leaf Porometer (see instructions above).

Exit. Quits the program.

Edit

Preferences... This consists of three sections:

1. Data File



Preferences - Units screen

Measurement Units: If you select “Get units from Leaf Porometer settings,” this will save all downloaded measurement data in the units used on the Leaf Porometer. You can also choose to override the settings in the Leaf Porometer and save your measurement data in one of three units:

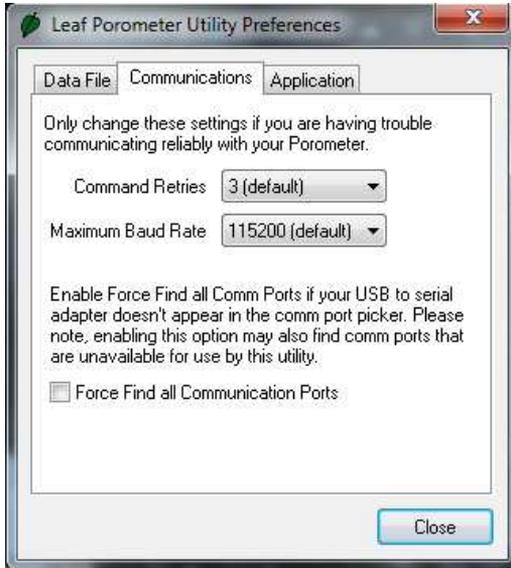
- **mmol/m² s** - stomatal conductance
(millimoles per meter squared seconds);
- **m² s/mol** - stomatal resistance
(meters squared seconds per mole);
- **s/m** - stomatal resistance
(seconds per meter).

Temperature Units: This allows you to choose what unit of temperature data files will be saved with, °C (Celsius) or °F (Fahrenheit).

Column Headers: This option sets column headers (i.e. "Date/Time," "Temperature") for saved data files. This feature is on by default. It does not apply to raw data files, which do not have column headers.

Date/Time Format: Here you can set the format with which the date and time will be displayed in saved data files. By default, the program will use Windows Regional and Language Options (accessible in the Control Panel in Windows), the system settings on your computer.

2. Communications



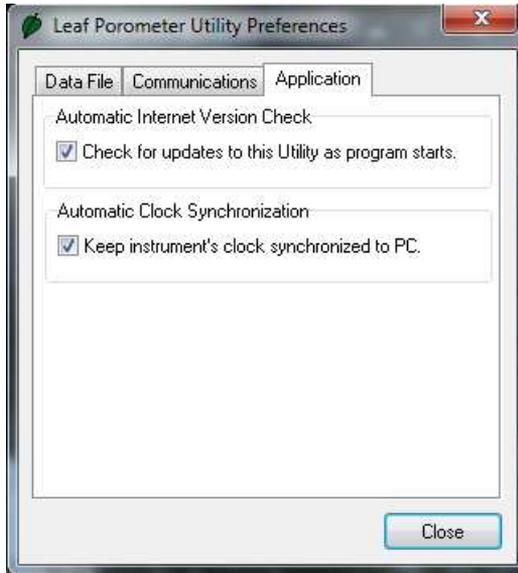
Preferences - Communications screen

Command Retries: If you encounter difficulty communicating with your Leaf Porometer, you can set the number of times the computer should automatically try re-sending communications commands (up to 10).

Maximum Baud Rate: You can set the maximum baud rate for talking to your Leaf Porometer. Choose a lower baud rate if you are not getting reliable communications from your device.

Force Find all Communication Ports: This will detect all COM ports on your computer, and should be used if your serial-to-USB adapter does not appear in the drop-down menu.

3. Application



Automatic Internet Version Check: When selected, the utility will automatically check for utility updates for the Leaf Porometer Utility when you are connected to the Internet. You can also check for these manually by selecting “Check for Updates...” from the Help Menu.

Automatic Clock Synchronization: Automatically sets the Leaf Porometer's time to your computer's time, when you are connected to it. (See instructions above for setting this manually.)

Actions

Set Porometer Date/Time... See the section on “Setting Date and Time” above.

View Porometer Information... This shows the serial number, firmware version, the number of stored readings in the Leaf Porometer, the firmware status, battery status, current date and time, and the sensor calibration number.

Help

Help... Accesses the Leaf Porometer Utility help file, which provides detailed information on how to use the program.

Send Feedback to Decagon... Provides the user with a way to submit feedback to Decagon.

Check for Utility Updates... Goes online and checks for utility updates.

Check for Firmware Updates... Goes online and checks for firmware updates for the Leaf Porometer controller.

About... Displays the current program version and Decagon contact information.

7. Theory Leaf Porometer

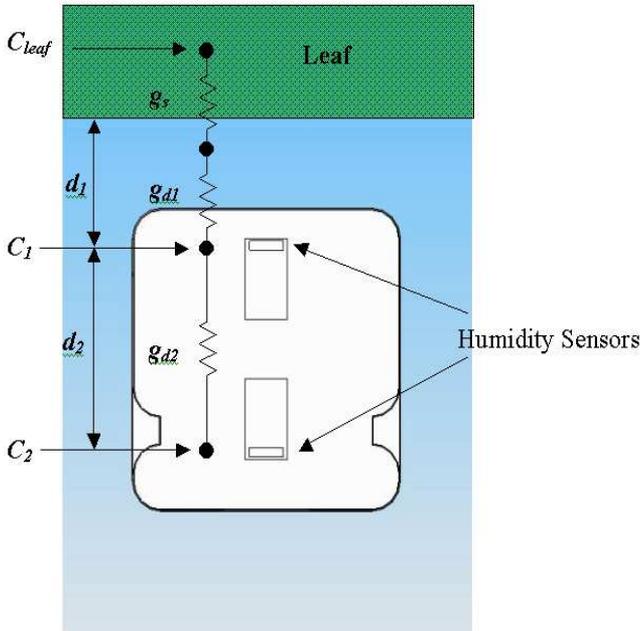
Stomatal Conductance

By definition, stomatal conductance is the measure of the rate of passage of carbon dioxide (CO₂) or water vapor through the stomata of a leaf. Stomata are small pores on the top and bottom of a leaf that are responsible for taking in and expelling CO₂ and moisture from and to the outside air. The Leaf Porometer measures the rate at which this happens.

How the Leaf Porometer Works

The Leaf Porometer measures the stomatal conductance of leaves by putting the conductance of the leaf in series with two known conductance elements. By measuring the humidity difference across one of the known conductance elements, the water vapor flux is known. The conductance of the leaf can be calculated from these variables.

We know the humidity at three places: inside the leaf, and at both of the humidity sensors. The Leaf Porometer effectively calculates the resistance between the inside and outside of the leaf: the stomatal conductance. Resistance is measured between the leaf and the first humidity sensor, and the first and second sensors. The following diagram schematically illustrates this:



insert new screen shot ??

The parameters listed above represent the following:

- C_{leaf} The mole fraction of vapor inside the leaf
- C_1 The mole fraction of vapor at node 1
- C_2 The mole fraction of vapor at node 2
- g_s Stomatal conductance of the leaf surface
- g_{d1} Vapor conductance of the diffusion path between leaf surface and node 1
- g_{d2} Vapor conductance of the diffusion path between node 1 and node 2
- d_1 Distance between the leaf surface and the first humidity sensor
- d_2 Distance between the two humidity sensors

The variable of interest is g_s or the stomatal conductance. First the vapor flux along the diffusion path will be determined using the relative humidity difference between nodes 1 and 2 as follows:

$$F_{vapor} = g_{d2} (C_1 - C_2) \quad (1)$$

Where the C 's are related to relative humidity by

$$C_i = \frac{h_r e_s(T_a)}{P_{atm}} \quad (2)$$

where h_r is the relative humidity, $e_s(T_a)$ is the saturated vapor pressure at air temperature, and P_{atm} is atmospheric pressure. Saturated vapor pressure is calculated by the Tetens formula with appropriate coefficients for water vapor:

$$e_s(T_a) = 0.611 \exp\left(\frac{17.502T}{T + 240.97}\right) \quad (3)$$

NOTE: T must be in degrees Celsius.

Next we must determine the value of gd_2 by the equation

$$g_{d2} = \frac{\rho D_{vapor}}{d_2} \quad (4)$$

where $\hat{\rho}$ is the molar density of air and D_{vapor} is the diffusivity of water vapor. Both of these quantities are temperature and pressure dependent, however when multiplied together as in equation (3) some of this dependency drops out:

$$\hat{\rho} = 44.6 \frac{P_a}{101.3} \left(\frac{273.15}{T} \right) \quad (5)$$

$$D_{vapor}(T, P_a) = D_{ref}(273.15, 101.3) \left(\frac{101.3}{P_a} \right) \left(\frac{T}{273.15} \right)^{1.75} \quad (6)$$

If

$$D_{ref}(273.15, 101.3) = 2.12 \times 10^{-5} \text{ (m}^2 / \text{s)}$$

Then

$$\hat{\rho} D_{vapor} = (44.6)(2.12 \times 10^{-5}) \left(\frac{T}{273.15} \right)^{0.75} \quad (7)$$

Using these C and g values we can now solve equation 1 for the flux:

$$F_{vapor} = \left[\frac{\hat{\rho} D_{vapor}}{d_2} \right] \frac{1}{P_{atm}} [h_{r1} e_s(T_{a1}) - h_{r2} e_s(T_{a2})] \quad (8)$$

Now that the vapor flux has been determined, the stomatal conductance, g_s , can be found. This requires some assumptions. First, we assume that the relative humidity within the leaf tissue is 1.0, so by equation

$$C_{leaf} = \frac{e_s(T_a)}{P_{atm}} \quad (9)$$

Next, we assume that all conductance values are in series so that the flux is constant between any two nodes. **We also assume that the temperature of the leaf is equal to the temperature of the first humidity sensor.** (The sensor block head has been constructed from aluminum to eliminate the temperature difference.) This means that we can write equation (1) for node 1 and the leaf node and then set it equal to equation (8):

$$F_{vapor} = g_{s+d1}(C_{leaf} - C_1) \quad (10)$$

$$F_{vapor} = g_{s+d1} \left(\frac{1}{P_{atm}} \right) [e_s(T_{a1})(1 - h_{r1})] \quad (11)$$

$$\frac{g_{s+d1}}{P_{atm}} [e_s(T_{a1})(1 - h_{r1})] = \frac{1}{P_{atm}} \left(\frac{\hat{\rho}D}{d_2} \right) [h_{r1}e_s(T_{a1}) - h_{r2}e_s(T_{a2})] \quad (12)$$

Solving for g_{s+d1} :

$$g_{s+d1} = \frac{\left(\frac{\hat{\rho}D}{d_2} \right) [h_{r1}e_s(T_{a1}) - h_{r2}e_s(T_{a2})]}{e_s(T_{a1})(1 - h_{r1})} \quad (13)$$

Using the rule for series combination of conductance, we can solve for g_s :

$$\frac{1}{g_s} = \frac{1}{g_{s+d1}} + \frac{1}{g_{d1}} \quad (14)$$

Hence,

$$\frac{1}{g_s} = \frac{e_s(T_{a1})(1-h_{r1})d_2}{\hat{\rho}D[h_{r1}e_s(T_{a1})-h_{r2}e_s(T_{a2})]} + \frac{d_1}{\hat{\rho}D} \quad (15)$$

so:

$$g_s = \frac{\hat{\rho}D_{vapor}}{\frac{[e_s(T_{a1})(1-h_{r1})]d_2}{h_{r1}e_s(T_{a1})-h_{r2}e_s(T_{a2})} - d_1} \quad (16)$$

Therefore, g_s is a function of the distances between humidity sensors, temperature, and the two relative humidity readings.

When the conductance is small, the humidities are nearly the same, and the denominator of the denominator of eq. 6 goes to zero, causing problems. Multiplying top and bottom by the denominator gives

$$g_s = \frac{\hat{\rho}D_{vapor}[h_{r1}e_s(T_{a1})-h_{r2}e_s(T_{a2})]}{[e_s(T_{a1})(1-h_{r1})]d_2 - [h_{r1}e_s(T_{a1})-h_{r2}e_s(T_{a2})]d_1} \quad (17)$$

NOTE: *The resulting g_s is in units of mol/m²s.*

From the Leaf Porometer, the two distances are:

$$d_1 = 3.35 \text{ mm}$$

$$d_2 = 11.43 \text{ mm}$$

Cooling of the evaporating surface. The equations developed so far assume that the evaporating surface temperature is equal to the sensor 1 temperature. A more realistic assumption is that it cools in proportion to the flux of water vapor, which is proportional to the vapor pressure difference between 1 and 2. The effect of this cooling is to reduce the apparent humidity at the evaporating surface. The actual vapor pressure at the evaporating surface is

$$e_o = e_s(T_{a1}) - sP_{atm}(T_{a1} - T_{ao}) \quad (18)$$

Where s is the slope of the saturation vapor concentration function. The temperature difference can be computed from an energy balance for the evaporating surface:

$$H = c_p g_H (T_{a1} - T_{ao}) = \lambda F_{vapor} = \lambda g_{d2} (C_1 - C_2) \quad (19)$$

Where λ is the latent heat of vaporization, so then

$$T_{a1} - T_{ao} = \frac{\lambda g_{d2}}{c_p g_H} (C_1 - C_2) = \frac{C_1 - C_2}{\gamma^*} = \frac{\Delta_1}{\gamma^* P_{atm}} \quad (20)$$

Where

$$\gamma^* = \frac{c_p g_H}{\lambda g_{d2}}$$

Is an apparent psychrometer constant and c_p is the specific heat of air.

And

$$\Delta_1 = [h_{r1} e_s(T_{a1}) - h_{r2} e_s(T_{a2})] \quad (21)$$

Substituting this into eq. 18 gives

$$e_o = e_s(T_{a1}) - \frac{s}{\gamma^*} \Delta_1 \quad (22)$$

The vapor pressure difference between the leaf surface and the first humidity sensor then becomes

$$e_o - e_1 = e_s(T_{a1}) \left(1 - \frac{s \Delta_1}{\gamma^* e_s(T_{a1})} - h_{r1} \right) \quad (23)$$

The equation therefore becomes

$$g_s = \frac{\hat{\rho}D_{\text{vapor}}\Delta_1}{e_s(T_{a1})(1 - q\Delta_1 - h_{r1})d_2 - \Delta_1d_1} \quad (24)$$

Where q is

$$q = \frac{s}{\gamma^* e_s(T_{a1})} = \frac{sP_{\text{atm}}}{P_{\text{atm}}\gamma^* e_s(T_{a1})} = \frac{0.071 - 4.3 \times 10^{-4}T}{P_{\text{atm}}\gamma^*} \quad (25)$$

Both the saturation vapor pressure and its slope have strong temperature dependence, but their ratio is a weak linear function of temperature, so the final form of the equation for q gives a value which is fairly constant with temperature (though the temperature correction is made in code). At room temperature a value of $q = 0.25$ appears to work well.

8. Care and Maintenance

Changing the Batteries

Although the Leaf Porometer has been designed to provide an excellent battery lifespan, the batteries will eventually require changing. When this happens, a low-battery indicator will appear in the upper left hand corner of the screen.

1. Carefully turn over the Leaf Porometer and locate the battery cover.
2. Place your thumb on the grooves and push upward to loosen the cover.
3. Remove the old batteries and insert new ones. Be sure to orient the fresh batteries properly.
4. Use the Leaf Porometer or the Leaf Porometer Utility to update the time and date.

Cleaning the Sensor Block

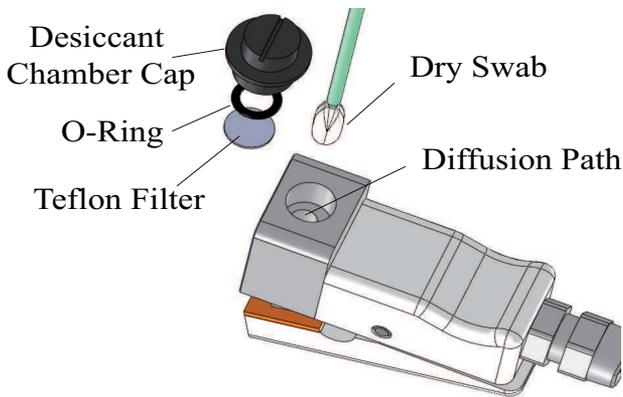
It is necessary to clean the Sensor Block periodically to remove contamination that can build up during routine use. Follow these instructions to clean the Sensor block.

Minor Contamination (dust and pollen)

1. Remove the desiccant chamber.

Leaf Porometer Operator's Manual

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2. Use the tweezers included with the calibration kit to remove the o-ring that secures the Teflon disk.
3. Carefully remove the Teflon disk with the tweezers. The Teflon Disk should be handled around the edges as much as possible, and always kept free of dust and moisture.
4. Hold the sensor head open and use a dry swab to clean out the diffusion path. Swabs are included with your kit. Do not use a damp swab, alcohol or other organic liquids to clean the diffusion path! Direct contact with water on the sensors as well as chemical vapors can cause damage!
5. Reinsert the Teflon Disk. Remember to handle around edges as much as possible. If the Teflon Disk becomes damaged discard and replace. Five replacement disks are included, if additional disks are need please contact Decagon Devices.
6. Replace the O-ring Retainer.

Cleaning the Sensor Block of Major Contamination

When making stomatal conductance measurements on some plant types, the sensor block can become contaminated with sap and leaf exudates that can lead to inaccurate conductance measurements. This type of contamination often cannot be removed with a dry swab procedure so the following cleaning steps should be followed.

1. Remove the two machine screws from the front of the aluminum sensor block using a 3/32" hex key (Allen wrench).
2. Carefully pull the aluminum sensor block off of the sensor assembly. This may take some force as the sensor assembly is press-fit into the block.
3. Remove the desiccant chamber from the bottom of the aluminum sensor block (if it is being used).
4. Use a pair of tweezers (included in calibration kit) to remove the o-ring that secures the Teflon filter inside the desiccant chamber cavity. Use a thin implement to press the Teflon disk out of the aluminum sensor block. Inspect the Teflon disk and discard if it is worn.
5. Now the aluminum sensor block should be free from all accessories and can be cleaned without damaging the sensors. Generally, a solvent like Isopropyl Alcohol is sufficient to dissolve most types of contamination, which can then easily be removed from the sensor block with a cotton swab or piece of paper towel. **Caution:** Make sure that the humidity sensors are not exposed to solvent vapors. Use any

solvents far from the humidity sensors. Avoid scrubbing the aluminum sensor block with abrasive materials as they can remove the hydrophobic finish on the block and affect conductance measurements.

6. Rinse the aluminum sensor block thoroughly with water and allow to dry before re-assembling the Porometer.
7. Re-install the Teflon filter and o-ring retainer. Make sure not to contaminate the Teflon filter with skin oils.
8. Align the aluminum sensor block correctly with the sensor assembly. There is a small oval tab on the sensor assembly that should face downwards and align with an oval cutout on the aluminum sensor block.
9. Press the aluminum sensor block onto the sensor assembly, firmly seating the sensor assembly in place.
10. Re-attach the sensor block assembly using the machine screws that were removed in step 1.

Maintaining the Seals & Teflon Disk

When you clean your sensor head, be sure to check the condition of the seals, and make sure that they are making full contact with the leaf. If the seals require replacement, a spare set has been included in your Leaf Porometer shipment. Also, the Teflon disk should be replaced if it be-comes excessively dirty. If you need more replacements of either component, contact Decagon.

Replacing the Seal. In the event a seal falls off, you can simply replace it by peeling off the adhesive paper on the back and replacing the old seal. If the seal is very loose, it is best to peel it off and replace it in the same manner. When you replace a seal, look to see if the area you will be applying has dirt or soil particles, as these can prevent the adhesive from applying fully. You might try wiping the area with a slightly damp cloth before applying the new seal.

Replacing the Teflon filter disk. A spare set of Teflon filter disks have also been included. To replace the disk, use tweezers to remove the o-ring and then *carefully* remove the disk. Then, handling the disk around the edges (using tweezers is advised), insert the spare and replace the o-ring.

Porometer Sensor Re-Conditioning

In some situations, the humidity sensors in the Leaf Porometer can be adversely affected by exposure to chemicals. This is most commonly encountered when the Leaf Porometer has been exposed to vapors from volatile organic compounds. We have confirmed reports of sensors being affected by obvious sources of volatile organics such as storing the Porometer in a shed with gasoline cans. The signs of sensor "poisoning" can be manifest as a lack of agreement in humidity measurements between the two sensors, or as nonsensical humidity values from one or both sensor (e.g. >100%).

If you suspect that your Leaf Porometer has been affected by chemical exposure, then the sensors can be re-condi-

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8. Care and Maintenance

tioned to return them to their natural state using the following procedure:

1. Remove the sensor head from the hand held readout unit as well as the desiccant chamber.
2. Use the metal pin from the calibration kit to hold the leaf clamp open.
3. Place the entire sensor head (and cable) into an oven with good temperature control.
4. Bake the sensor head in dry heat at 80° C for at least 24 hours.
5. Remove the sensor head and let cool.
6. Re-hydrate the sensor head by exposing it to 70-80% relative humidity at 20-35° C for 12 hours. A 75% humidity atmosphere can be conveniently generated by a saturated NaCl solution. To hydrate with saturated NaCl, the Porometer head should be placed in a sealed container above a slurry of NaCl (table salt is fine) and water. There should be both liquid water and plentiful salt crystals present in the slurry.
7. After hydration, the sensor should be left at ambient conditions for 8 hours before calibrating the sensor. Please note that re-conditioning the sensors will change the sensor calibration, so the sensor must be calibrated prior to using.

General Precautions

While the Leaf Porometer has been designed for quality and durability, it should be kept clean and the batteries

always fresh to ensure proper working condition. Here are a few things to remember when using this device:

- Allow the sensor head to equilibrate to the ambient temperature before using.
- While this device is water-resistant, do not use it in rain, and do not use it on leaves covered with dew or water droplets.

Upgrading Firmware

From time to time Decagon will release firmware updates for the Leaf Porometer that contain bug fixes and new features to improve the performance of your instrument. You can view and download firmware updates by going to our website (www.decagon.com) and navigating to the Software Downloads page. Once there, scroll down to the Leaf Porometer section and download the latest Firmware Updater.



Precautions:

- Any data records on the instrument will be erased during a firmware update so make sure to download any data you wish to save before loading new firmware.
- If upgrading to the latest firmware, you will need to verify your Porometer is equipped with a desiccant chamber. If your Porometer does not have a desiccant chamber, please contact support@decagon.com, or call 1-800-755-2751 for a free upgrade.
- Do not turn off or disconnect your instrument from the communications port while the firmware is updating.

Updating Firmware:

1. Open the firmware updater application.
2. Connect you Leaf Porometer to an available communications port on your computer.
3. Select the same communications port in the drop down list on the firmware updater application.
4. Click Start to begin updating the firmware.
5. Wait for the firmware updater to finish before disconnecting your Leaf Porometer and closing the firmware updater application.

9. Troubleshooting

The Leaf Porometer is a high performance, low maintenance instrument, designed to have few problems if used with care. Unfortunately, some-times even the best operators using the best instruments encounter technical difficulties. Below is quick reference guide that will direct you to detailed solutions of some problems that may occur. If these remedies still don't resolve your problem, then please contact Decagon for help (see Customer Support in Chapter 1). Here is a list of some problems that may occur.

NOTE: If you purchased your Decagon instrument from one of our international distributors, please contact them for local service and support.

Troubleshooting Quick Guide

<u>If this problem occurs:</u>	<u>Refer to:</u>
Instrument won't turn on	Problem #1
Display is difficult to see	Problem #2
Sensor head failure message	Problem #3
Low battery message	Problem #4
Date & time were reset message.....	Problem #5
Invalid Cal Num message	Problem #6

Troubleshooting Quick Guide (continued)

<u>If this problem occurs:</u>	<u>Refer to:</u>
Missing bootstrap loader message	Problem #7
Firmware corrupted message	Problem #8
Communication port is already in use	Problem #9
USB to Serial Port adapter not shown	Problem #10
Download data to the utility failed	Problem #11
No information is being displayed.....	Problem #12
Conductance is not as expected	Problem #13
Porometer will not calibrate.....	Problem #14
Reequilibrate time it too long	Problem #15
(when using desiccant chamber)	
Low RH reading	Problem #16
High RH reading-replace desiccant	Problem #17
High RH reading-use desiccant chamber ..	Problem #18

1. PROBLEM:

Instrument won't turn on.

SOLUTION: Make sure that the batteries are inserted correctly, and/or if they have enough power to activate the machine.

2. PROBLEM:

The display is difficult to see.

SOLUTION: Turn off the Leaf Porometer and then turn it on again. If this does not fix the problem, the Leaf Porometer features a built-in screen for changing screen contrast. See "Contrast" page 48 for details. You may be able to fix the contrast manually, which can be done using a terminal port program. Contact Decagon for information regarding this procedure.

3. PROBLEM:

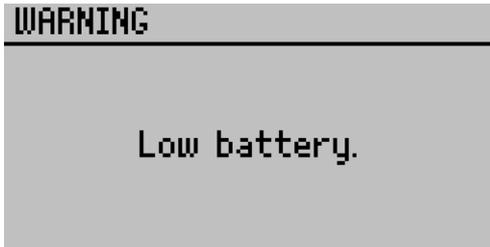
Message on screen displays the following:

```
Sensor Head Failure
RH Leaf:      -4939.4%  ERROR
Temp Leaf:    603.8°C   ERROR
RH Filter:    -4939.4%  ERROR
Temp Filter:  603.8°C   ERROR
Check connection!  ↵
```

SOLUTION: Verify that the sensor head is securely connected to the Leaf Porometer's serial port receptacle and restart the reading. If this screen continues to reappear, it is possible that the cable or sensor is faulty and needs to be replaced. To expedite the troubleshooting process, save a Scan record by pressing Enter and then contact Decagon for further options.

4. PROBLEM:

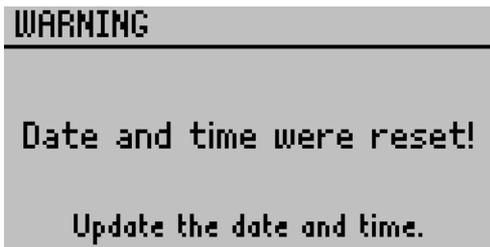
Message on screen displays the following:



SOLUTION: The batteries in the instrument may not be properly inserted in the battery holder or they may need to be replaced. If the batteries aren't inserted properly, reseal the batteries into the battery holder and cycle the power on the instrument.

5. PROBLEM:

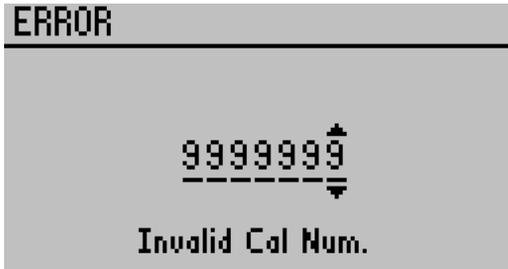
Message on screen displays the following:



SOLUTION: After changing the batteries or loading new firmware onto an instrument, this message may appear. Navigate to the configuration menu and verify that the date and time are set properly.

6. PROBLEM:

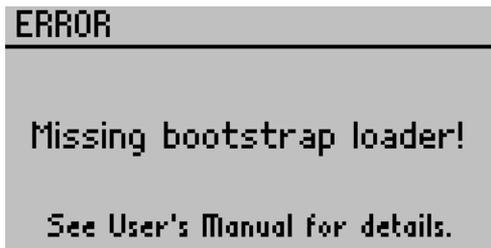
Message on screen displays the following:



SOLUTION: This screen will only be displayed when manually entering a calibration number. The best solution to this problem is to perform a user initiated calibration. Another option is to enter the default calibration from the sensors head's label.

7. PROBLEM:

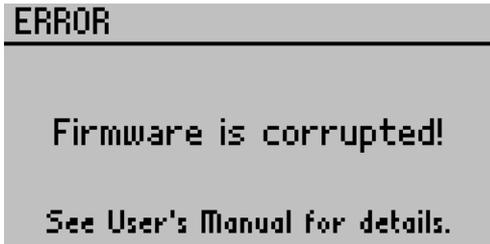
Message on screen displays the following:



SOLUTION: The instrument cannot download new firmware updates. To down-load new firmware to the Leaf Porometer, or to stop this message from displaying, the instrument must be serviced by Decagon.

8. PROBLEM:

Message on screen displays the following:



SOLUTION: This screen means that your firmware was not loaded properly, and that an update is needed. (The firmware for the Leaf Porometer is user-upgradeable.) To obtain this, visit Decagon's website to see if new updates are available; if not, contact Decagon for the newest firmware version. Note: You will lose any saved data records when you install the new firmware. Therefore, download any data you wish to save before re-loading the new firmware. If this is not an option, contact Decagon for further help. To obtain new firmware for your Leaf Porometer, see the section on "Updating Firmware" on page 77 for more information.

9. PROBLEM:

The Leaf Porometer Utility tells me the communication port I want to use is in use by another application, but I don't think any other programs are running.

SOLUTION: Some PDA synchronization software monitor serial communication ports. Disable Microsoft's

ActiveSync or Palm's HotSync system software while using the serial port with the Leaf Porometer Utility.

10. PROBLEM:

My USB to Serial adapter is not showing in the communication port picker.

SOLUTION: Enable "Force find all Communication Ports" in the Preferences Menu by going to the Edit Menu, clicking Preferences, then the Communication tab, and enabling the check box at the bottom of the screen. Enabling this option may find other serial ports that are not available for use by the Leaf Porometer Utility (for example, modems installed in your computer).

11. PROBLEM:

Downloading data stops in the middle with an error message saying the utility lost connection with the Leaf Porometer.

SOLUTION: A noisy serial connection can disrupt the connection between the Utility and the Leaf Porometer. If this error happens regularly, you can try setting your baud rate lower or increasing the number of times a command is sent to the Leaf Porometer. Choose the "Communications" tab in Preferences to alter this.

12. PROBLEM:

No information is being displayed.

SOLUTION: Any conductivity that is lower than $5 \text{ mmol/m}^2\text{s}^1$ will not be displayed in Automatic mode. Therefore, check to see what mode you're in before

beginning. It is advisable to use Manual mode if you know that your leaf has a conductivity that is lower than the minimum threshold for Auto mode. Also, remember that you must press "Enter" in Automatic mode before you begin taking a reading. You may also have gotten moisture inside the sensor assembly or Teflon disk by touching it with your finger. This will distort the sensor's abilities to take accurate readings.

13. PROBLEM:

You are not getting the conductance reading you expected.

SOLUTION: Try recalibrating the sensor head. Navigate to the Calibration option in the configuration menu to begin a calibration. If you're still having problems, the inside of the sensor assembly may be dirty. Remove the Teflon disk and clean it thoroughly (see Cleaning the Sensor Block on page 71). The Teflon disk also may either be wet or dirty and may need to be dried out or replaced. Additionally, if your sensor was exposed to any out gassing materials, it may require repairs or re-conditioning (see section on re-conditioning sensors).

14. PROBLEM:

Your Porometer will not calibrate, even after multiple attempts.

SOLUTION: A Porometer that will not calibrate using the user initiated calibration sequence is generally a symptom of one of two things. The first is thermal non-equilibrium. The Porometer leaf clip temperature must

remain somewhat stable during the calibration sequence for the calibration to succeed.

Another problem that can prevent calibration is contaminated sensors. If the sensors are exposed to volatile organic compounds, their accuracy and dynamic response can be profoundly affected, which can cause the two sensors to read quite differently from each other during a measurement, and can cause the calibration to fail. If you find that your sensors are not well matched, we recommend that you re-condition the sensors as described on page 75.

15. PROBLEM:

When using the desiccant chamber, the time required for the sensors to re-equilibrate between measurements is excessively long.

SOLUTION: Insert one of the white fluoropolymer agitation beads that were included with your Porometer into the diffusion path and close the clip. Now, you can shake the leaf clip and the bead will mix the air in the diffusion path more quickly and speed the re-equilibration time significantly. The presence of the bead will not affect the stomatal conductance measurement as long as the bead doesn't move during the measurement and the leaf clip is oriented with the desiccant chamber down so that the bead rests on the Teflon filter.

16. PROBLEM:

Message on screen displays the following:

WARNING

Low RH Reading. Please recalibrate
with desiccant before continuing.

SOLUTION: This displays only if the calibration was conducted using no desiccant and the internal sensors have equilibrated at a humidity less than 10%. If you wish to use desiccant for future readings, please re-calibrate.

17. PROBLEM:

Message on screen displays the following:

WARNING

Desiccant not detected.
Replace desiccant or recalibrate
before proceeding.

SOLUTION: This displays only if the calibration was conducted using desiccant and the internal sensors have equilibrated at a humidity greater than 10%. Please ensure that desiccant is in place and replace with a fresh batch.

18. PROBLEM:

Message on screen displays the following:

WARNING

Desiccant exhausted or not present.
Replace or add desiccant to avoid
unstable measurements.

See User's Manual for details.

SOLUTION: This displays when the internal sensors have equilibrated at greater than 10% humidity to remind you that measurements with desiccant are generally more accurate and stable. We recommend that the desiccant chamber is always used, but most importantly when ambient humidity is greater than 30%. See the section "Desiccant" on page 25. You can press enter after seeing this display to proceed with non-desiccant measurements.

Further Reading

For more information on porometry, stomatal conductance, and how Porometers work, consider reading:

Campbell, G. S and Norman, J.M. An Introduction to Environmental Biophysics. Springer-Verlag: New York, Heidelberg, Berlin. Second Ed. 1998. pp. 90-92

Jones, H.G. Plants and Microclimate. Cambridge University Press: Cambridge. 1983.

Marshall, B. and Woodward, F.I. Instrumentation for Environmental Psychology. Cambridge University Press: Cambridge. 1985.

Pearcy, R.W. et al. Plant Physiological Ecology: Field-Methods and Instrumentation. Chapman and Hall: New York, London. 1989. Pp. 137-158.

CE Compliance

DECLARATION OF CONFORMITY

Application of Council Directive: **89/336/EEC**

Standards to Which Conformity is Declared: **EN61326 : 1998**
EN55022 : 1998

Manufacturer's Name: **Decagon Devices, Inc.**

Type of Equipment: **Leaf Porometer**

Model Number: **SC-1**

Year of First Manufacture: **2005**

This is to certify that the Leaf Porometer, manufactured by Decagon Devices, Inc., a corporation based in Pullman, Washington, USA, meets or exceeds the standards for CE compliance as per the Council Directives noted above. All instruments are built at the factory at Decagon and pertinent testing documentation is freely available for verification.

Appendix A - Send Feedback

Decagon Software makes it easy to send feedback, bug reports, and feature requests to Decagon or your Decagon Distributor. Choose “Send Feedback to Decagon...” from the help menu. This opens the window shown below.

Send Feedback to Decagon

Name (required) Company Name
User Name User Company

Email Address Telephone (include area code)
user@example.com 555-555-5555

Type of feedback Please respond via
General Feedback Email

Please describe the feedback below
My software is working great...}

Send the following file (file size can be up to 8 MB):
[File Selection] [Folder Icon]

Include Leaf Porometer Utility error log files

Send the feedback to my Decagon Representative's email address:
[Email Address Field]

Send

Enter your name, and other contact information. Tell us what type of feedback you are sending (General Feedback, Feature Suggestions, Bug Report, or Other). Indicate how you want us to respond to your feedback (E-mail or telephone).

Use the description area to give details for your feedback. If you are reporting a bug, it is very helpful for you to tell us what steps you took for the bug to happen and any error message you saw. By default, bug reports also include the software error files.

You can send Decagon a file using this form too. This is useful for sending data files that you have questions about.

If you work directly with a Decagon representative, put their E-mail address in the field at the bottom of the form. This sends the contents of the form to them. Your Decagon representative can follow-up with you directly.

Leaf Porometer Operator's Manual

Appendix A - Send Feedback

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