Tru Psi
model WP3

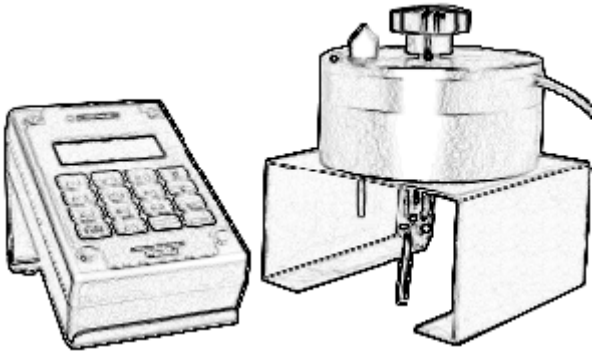
Water Potential Measurement System

Operator's Manual
version 2.1

Contents

Welcome

Welcome to Decagon's Tru Psi psychrometer. This time-saving instrument measures the water potential of soil, plants, seeds, and other organic material. We hope you find this manual useful in understanding and maximizing your instrument's capability to help you in your applications.



1. Introduction

Warranty

As with all Decagon products, Tru Psi carries a 30-day satisfaction guarantee and a one-year warranty on parts and labor from the date of purchase. To validate your warranty, please take some time to fill out the registration card enclosed with this manual and return it to us, or you can mail, fax, telephone, or e-mail your registration information back to us. When doing so, please include all the information requested on the registration card. It is important for us to have your current mailing address and telephone number so we can send you updated product information.

Customer Service and Tech Support

If you have questions about Tru Psi or need assistance with your instrument, don't hesitate to contact us for technical support. This can be done in several ways:

1. Our **toll-free number** is available for our customers in the U.S. and Canada, Monday through Friday, 8a.m.– 5p.m. PST.
1-800-755-2751

Our regular number is (509) 332-2756. This is available for those outside of the U.S. and Canada.

2. **Fax us** at (509) 332-5158. Please include your name, current address, phone number and return fax number as well as the serial number of your instrument.

3. **E-mail.** You can e-mail us with your question or problem at **tru_psi@decagon.com.** Again, please include as part of your message your name, address, phone and fax numbers, and serial number. This will better help us to be able to contact you and meet your needs.

4. Visit our website at **www.decagon.com/tru_psi** for information about Tru Psi and applications.

Seller's Liability

Seller warrants new equipment of its own manufacture against defective workmanship and materials of a period of one year from date of receipt of equipment (the results of ordinary wear and tear, neglect, misuse, accident, and excessive deterioration due to corrosion from any cause not to be considered a defect); but Seller's liability for defective parts shall in no event exceed the furnishing of replacement parts FOB the factory where originally manufactured. Material and equipment covered hereby which is not

manufactured by Seller shall not be liable to Buyer for loss, damage, or injuries to persons (including death), or to property or things 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 constitutes Buyer's acceptance of the terms set fourth in this warranty. There are no understandings, representations, or warranties of any kind, express, implied, statutory or otherwise (including, but without limitation, the implied warranties of merchantability and fitness for a particular purpose), not expressly set forth herein.

2. Read This First!

Registration Code

The first time you turn Tru Psi on, the screen will read ENTER REGISTRATION CODE.

Before you can take measurements or use your Tru Psi at all, you must enter a four-digit registration code. This code is easy to get. Just call Decagon at 1-800-755-2751 in the USA or Canada (Internationally 509-332-2756). Give us your name, address, phone number, and instrument serial number. We'll give you the registration code. Write the code here for future reference: (There is also a space at the top of the calibration certificate to record the code).

Tru Psi

Serial Number:_____

Registration Code:_____

The registration code is only necessary the first time you turn on your Tru Psi and following any time when the operating program is loaded into your

instrument. Keep your code here and on the calibration certificate so when you do receive an updated program and download it to your instrument you will have the code to start it again.

Once you register your instrument, you activate the warranty, and it provides us the ability to send you free program upgrades when they become available. If you move, please let us know your new address.

By Fax

Fax us a copy of the completed registration card at 509-332-5158 and we will fax your registration code back to you. This will also register your instrument and activate the warranty.

By Email

Email all of the information to us at tru_psi@decagon.com. We will respond in the same manner with your registration code. This again registers your instrument and activates the warranty

3. Opening the Box

Using this Manual

This manual is designed for several different types of users. Everyone should read (or at least skim) this introduction for general information. “Hands on” types can then head for the field, learning as they go. Thorough, methodical types may want to read on. The Method chapter gives step-by-step instructions, warning against potential problems and sources of error. The rest of the manual can be referenced when needed. It includes detailed information on menu options, care and maintenance, the theory of operation, and answers to commonly asked questions. The Menu and Maintenance sections are primarily reference sections. Each sub-section is intended to be complete. The result: lots of repetition. If you read these sections straight through, you may become bored.

Contents of the Tru Psi Kit

No doubt you have opened the box and pushed a few buttons already. Before you go on, make sure you have all pieces of the Tru Psi kit. You should have the following:

Nanovoltmeter/Microcontroller

1. Meter enclosed in a protective bag
2. One PsiLink software diskette

Sample Changer

1. SC10X
2. Neoprene sleeve
3. 10 stainless steel sample cups (9 stainless steel sample cups and one water reservoir with a Richards Thermocouple system, special order)
4. One Delrin plug to seal the loading chamber

Miscellaneous

1. Aluminum microcontroller stand
2. AC Adapter/Battery Charger
3. RS-232 interface cable
4. One pkg. precut filter paper strips
5. One 1/8" hex driver (for opening sample changer for cleaning)
6. 12 vials of 0.5 Molal KCL (note: this is not Molar)
7. Manual
8. 9-25 pin adapter
9. Material safety data sheet
10. Certificate of Calibration
11. EC Certificate (for Europe only)
12. 10 Texwipe cleaning swabs

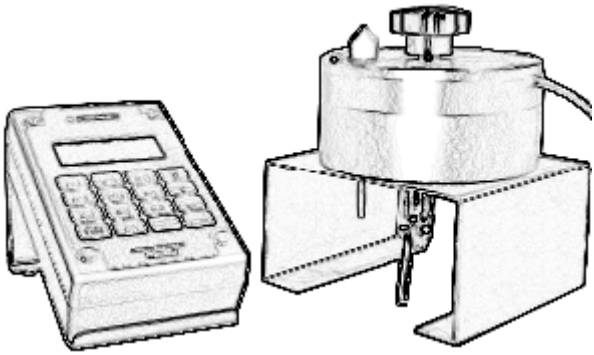


Figure 1: Tru Psi System

The SC10X Thermocouple Psychrometer/Sample Changer (also referred to as the SC10) is a solid cylindrical block of anodized aluminum on a square metal base. A Peltier thermocouple is mounted inside the block. Beneath the thermocouple sits a sample ring with room for ten samples. The round knob on top rotates the samples into position. A rubber-coated lever on the right hand side clamps samples under the thermocouple. Sample cups are inserted and removed through the load chamber. Use the cup lifter to raise and lower samples through the chamber.

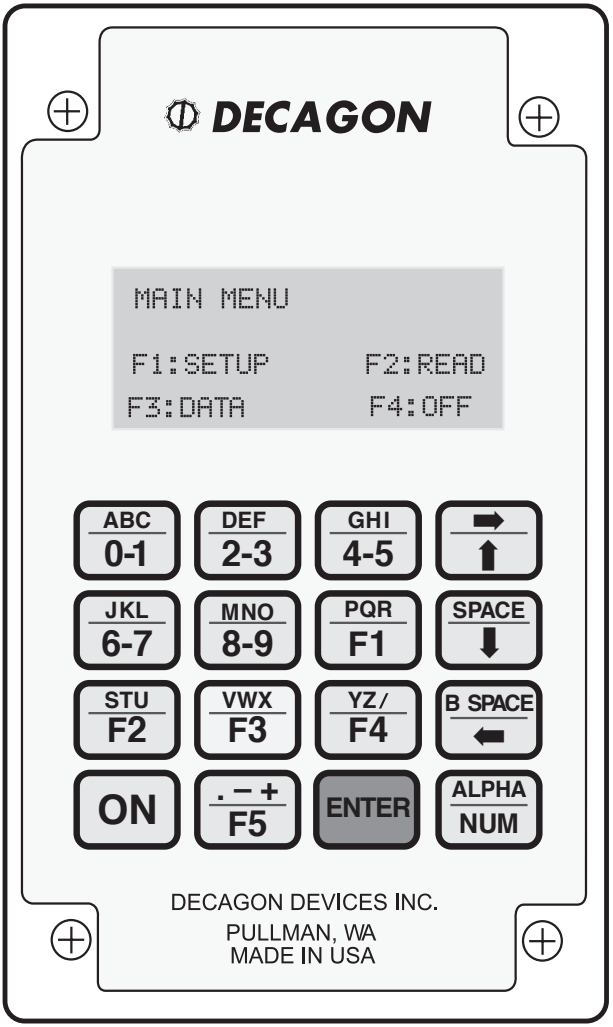


Figure 2: Microcontroller Keypad

The microcontroller consists of Tru Psi's microprocessor, an alpha-numeric keypad, and

display. The controller program is contained in RAM and can be updated as water potential measurement techniques change. Decagon will provide free program upgrades to all registered users. Two connectors are situated at the controller's top end. The connecting cable from the SC10 plugs into the center one. The RS-232 cable can be plugged into the outer one. The RS-232 cable connects Tru Psi to a PC for downloading data and uploading operating program upgrades. The controller is powered by two rechargeable battery packs. The program and user data are backed up by semi-permanent lithium cells. For information on charging and changing the batteries, see the Care and Maintenance section.

Tru Psi is shipped with ten **stainless steel sample cups** and a **white delrin plug** for the load chamber.

A white delrin **water reservoir** is included if a Richards thermocouple was special ordered. It fits in one of the sample positions when using this type of thermocouple.

The **aluminum controller stand** holds the controller at an angle.

The **RS-232 interface cable** connects the controller to a PC for down- and up-loading.

The **charging cable and adapter** allow the controller's batteries to be recharged.

The **neoprene sleeve** insulates the SC10 from changes in temperature during sampling.

0.5 M KCl standard solutions for calibration and **Filter Papers** precut to fit the sample cups are also included.

1/8" allen wrench is included for changing the thermocouple.

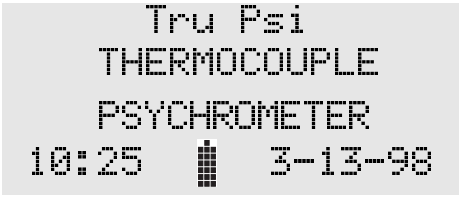
A **9-25 pin adapter** has also been included for connecting to a computer, should it be required.

Brief Tour

Turn Tru Psi on using the ON key on the controller. The following screen will appear:

```
Tru Psi ver 2.1
COPYRIGHT 95-96
DECAGON DEVICES
SN#TPXXXX
```

Then:



The controller will check its RAM and batteries. Icons will appear for each test:

- for the battery check
- for the ram check.

Then the screen will ask you to call Decagon's toll-free customer service number and register your instrument. When you call to register, we will give you a four digit registration code. Type in this code and press enter.

Note: the registration screen will only reappear when the Tru Psi firmware (operating system) is reloaded or upgraded from a PC. You won't need to use the registration code on a day-to-day basis.

How Tru Psi works

Tru Psi holds ten samples in its enclosed sample ring. Each sample separately equilibrates with the water vapor in the air around it. After an equilibration

time, the water potential of the sample and the air will be equal. A sample is clamped up and sealed to the thermocouple mount. Tru Psi uses a Peltier thermocouple to measure the water potential of the air. Then, algorithms in the controller compute the water potential of the sample. The equations used are detailed in the Theory section of this manual.

Tru Psi is also able to use Richards-type thermocouples. See Appendix A for information on how Richards thermocouples work and when to consider using one.

Data

Data is displayed at the end of each water potential reading. You can then decide whether to save or discard it. All saved data is stored in the microprocessor memory. The DATA menu gives you access to stored data. You can also download the data to a PC for analysis and long-term storage.

Each data readout includes the sample's water potential, temperature, optional comments, and the time and date. If you want to do the hard work yourself, you can set Tru Psi to display the thermocouple voltage in microvolts. These readings can be saved, either at a single point or continuously at the rate of two per second, and then viewed or downloaded to a computer.

The downloaded data file is a comma delimited file. The PsiLink program, provided on the disk with your system, allows you to easily download the file to your computer. The data can be directly imported by most spreadsheet and statistical programs from the file made in PsiLink. The manual for your spreadsheet or statistics software should describe how to import data from a comma delimited file. For more information on the process of downloading to a PC, see Downloading Data in the Method section.

Memory Size

The rate at which memory fills up depends on both the size and number of readings you make. You should be able to log 3 or 4 days' worth of data with no difficulty. If you want to know how much memory is left, from the Main Menu go to the F3: DATA menu.

The number displayed in the top right corner indicates how much room is left in memory. You can use this to gage how much space a reading takes

when sampling. An empty memory will display 52K available for storage.

The Controller Keypad

The controller keypad has full alpha-numeric capabilities on 16 keys. The ALPHA/NUM key acts like a shift-lock. Press once to enter letters and symbols, use the space and backspace keys, and move forward without overwriting. Press again to enter numbers, use the function keys, and move up, down, and back without overwriting.
Each screen where input is desired or available will show either an A or N in the lower right hand corner. The A means keys pushed will enter the letters or perform the functions on the upper half of the keys, N means that keys will enter the numbers or perform the functions on the bottom half of the keys. Push the Alpha/Num key to toggle between modes.

Typing in numbers:

Numbers are grouped two to a key. Push the key once for the first number, twice for the second. Keep pushing the key to toggle back and forth between the numbers. Similarly, letters are grouped in threes. Push once for the first letter, twice for the second, and three times for the third. If you push a fourth time, you will rotate back to the first letter. When you

press a different key, the cursor will move forward and you can select the next letter. The only hitch comes when you need to type letters or numbers located on the same key consecutively (e.g., the number "45," the word "bad"). Before putting in the second letter or number, use the ⇒ key to move the cursor to the next space.
Note: when typing in numbers, you have to hit the ALPHA/NUM key before using the ⇒.

The **function keys**, F1- F5, are mainly used to select menu options or designate preset comments (assigned in the Function Key option of the Setup/System menu).

The ⇐ and ⇒ keys move the cursor around the screen without overwriting text.

The ⇑ and ⇓ keys are used in the View Data option of the Data menu to scroll up and down through screens of saved data.

The ⇑ key is also used to move back to the previous menu.

The SPACE and BSPACE keys move the cursor forward and back, writing over characters underneath it.

Menus

Tru Psi's main menu offers four options. Setup, Read, and Data are the principal sub-menus. F4 turns Tru Psi off.

Setup Menu

The Setup menu lets you set Tru Psi's time and date functions and establish macros for the function keys. You can also designate the units in which water potential is read out, the number of SC10s to be connected to the controller (it accommodates up to four), the type of thermocouple used, the default equilibrium time, and the default cooling time for Peltier thermocouples. Any change of default time requires a new calibration to be performed.

Read Menu

The Read menu is Tru Psi's working menu. Use this menu to initially calibrate Tru Psi. You can then measure a sample's water potential or take a direct reading of the voltage changes across the thermocouple. Finally, save or discard your data.

Data Menu

Use the Data menu to view, download, and discard data stored in Tru Psi's memory.

A Few Definitions

Peltier thermocouple: this type of thermocouple is cooled until water condenses on it, then the wet bulb temperature depression is found from the corresponding voltage output. It is accurate in the range of -3 to -35 bars.

Relative humidity: the ratio of the amount of water vapor actually present in the air to saturated vapor pressure at the same temperature.

Richards thermocouple: this type of thermocouple is first dipped in water. The water evaporates until it reaches equilibrium with the water vapor in the air. The wet bulb temperature depression is found from the corresponding voltage output. It is accurate over a larger range of water potentials (at least -3 to -1000 bars). It requires some skill in order to obtain accurate measurements

Thermocouple: a welded junction between two dissimilar metals over which a voltage is generated when the temperature changes at the junction. Measuring the voltage gives the temperature.

Water potential: measures the freedom of water in any system compared with pure water. Since pure water is assigned a water potential of zero, sample water potential values will be negative.

4. Method

This section explains normal Tru Psi operation. It's a good place to start getting comfortable with the instrument. For better, more accurate measurements, read it all the way through.

How Tru Psi Works

Tru Psi's functional component is a thermocouple — a small electrical thermometer used to measure temperature differences. Two wires of dissimilar metals are joined at their ends to form two junctions. If the junctions are at different temperatures, current will begin to flow. The voltage produced is proportional to the temperature difference. In a Tru Psi, one junction is kept at a stable, known temperature inside the sample changer. Current is passed through the thermocouple to cool the other junction (this is known as the Peltier effect) until dew forms on it. After the dew forms, the wet junction becomes a wet bulb. As the water evaporates, the temperature difference between the junctions is related to the relative humidity of the air around the sample.

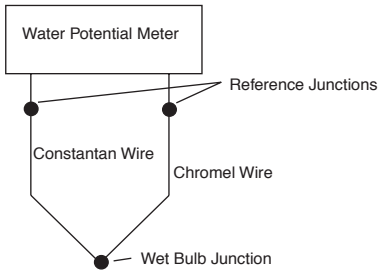


Figure 3: Thermocouple

Tru Psi holds ten samples in its enclosed sample ring. Each sample equalizes the temperature of the sample changer. After half an hour, the temperature of the sample and the changer should be equal. A sample is clamped up and sealed to the thermocouple mount. After a short wait for vapor equilibrium (2 minutes), the thermocouple is cooled for about 15 seconds. Tru Psi determines the voltage produced when the condensed water on the thermocouple junction evaporates. Then, algorithms in the microcontroller use that voltage to compute the water potential of the sample. The equations used are detailed in the Theory section of this manual.

Getting Ready to Measure

Location

Tru Psi is very temperature-sensitive. Accurate water potential readings depend on tiny temperature differences between the reference temperature and

the wet bulb temperature. To make good measurements, find a good location. Make sure the temperature stays fairly constant, and minimize air flow around the instrument. Even people walking in and out of the room can have an effect.

Setting up the Microcontroller

Check Batteries: Tru Psi uses two rechargeable battery packs. If batteries are low, you will see the message "Low Batteries. Shutting down." Recharge the batteries regularly (at least 10 hours for a full charge), to avoid the warning message. (Before the warning message appears the screen will dim.) The batteries will last about 16 hours of continuous measurement. If you batteries are low, they will prematurely abort logging in the unattended mode.

Recharge the Batteries (if necessary): Tru Psi uses two NiCad battery packs. They can be recharged hundreds of times. The charging adapter connects to Tru Psi's RS232 interface cable. Plug the five pin end of interface cable into the connector at the top end of the microcontroller (figure 4). Connect the AC adapter to the interface cable. Plug the adapter into any standard outlet. A full charge takes 10 hours. It charges best overnight.
ALERT!! Maintain the NiCad batteries. Don't charge them longer than 16 hours. It helps to use the batteries until they are almost drained before

recharging, and then recharging them completely on a regular basis. This can help in maintaining the batteries. Note: if the batteries will no longer hold a charge, contact Decagon (1-800-755-2751) for replacements.

NOTE: Tru Psi will not operate while recharging.

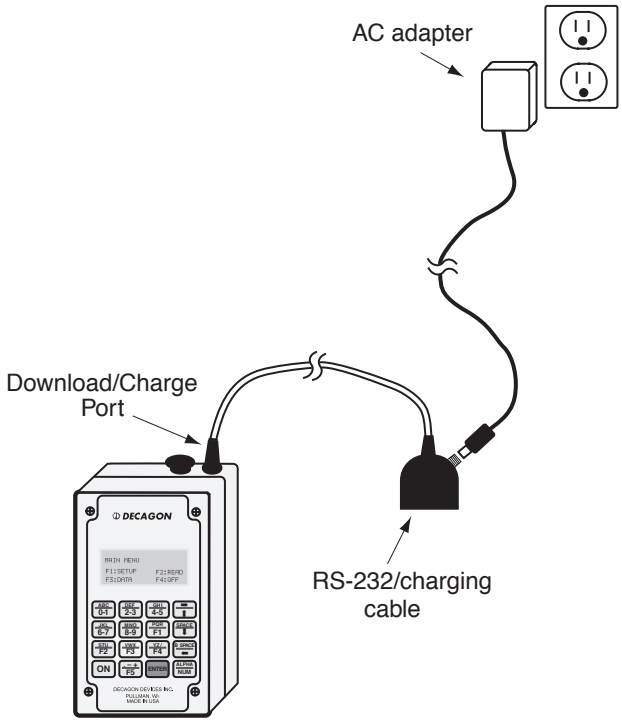


Figure 4: Recharge setup

Setting Clock and Date

To set Tru Psi's internal clock, from the Main Menu select F1: Setup>System> Clock. Move the cursor under

the hour or minutes displayed. Increase ⇑ or decrease ⇓ the reading until it is correct. Use the BSPACE key to move between hours and minutes. Push ENTER to reset the clock and return to the System menu.

Tru Psi is factory preset to use the standard US date format: MM/DD/YEAR. If you prefer this format, always set the date using the Setup: System: US Date option. To reset the date, move the cursor under the day, month, or year to be changed using the BSPACE key. Increase ⇑ or decrease ⇓ the number until it is correct. Push ENTER to reset the date and return to the System menu. To use the international date format (DD/MM/YEAR), select Setup: System: Int'l Date.

Selecting Units of Measure

Water Potential is a measure of potential energy in a unit of mass. Its standard units are joules per kilogram (J/kg). But other units are also frequently used in expressing water potential. Bars (a unit of pressure; one bar equaling one million dynes per square centimeter) are particularly convenient. Water potentials in soil and organic materials tend to be between -1 and -100 bars. Megapascals (MPa) and kilopascals (kPa) are also used. When measuring

water potential, these units are directly related.

Table 1: Water Potential Units

	Bar	J/Kg	kPa	MPa	Atm	cmH_20
Bar	1	0.01	0.01	10	1.01	0.00098
J/Kg	100	1	1	1000	101	0.098
KPa	100	1	1	1000	101	0.098
MPa	0.1	0.001	0.001	1	0.101	0.000098
Atm	.99	0.0099	0.0099	9.9	1	0.00097
cmH_2O	1020	10.2	10.2	10200	1030	1

Note: Atm and cmH_20 are not available as reading units on Tru Psi.

Choose the units you prefer in the System: Read: Units menu. Tru Psi will use these units by default until you change the setting.

Setting Up the SC10

Connect the SC10 to the center connector of the microcontroller.

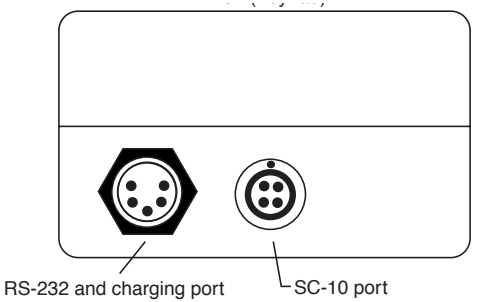


Figure 5: Microcontroller Ports

Selecting Thermocouple Type

Specify the thermocouple you are using by selecting F1: SETUP from the Main menu. Choose F2: READ OPTIONS, then F2: CONFIG SC10. Pick F1 to configure the first SC10 and press ENTER. Choose F1 to set thermocouple type. Unless you have special-ordered a Richards thermocouple, your SC10 uses a Peltier thermocouple. Press F1: Peltier. When you have finished, select F4 to return to the Main Menu.

Calibration

A perfect psychrometer, in which no heat is lost or gained from the environment, has a constant of .067. The constant for a real-world psychrometer must be determined empirically. Tru Psi is calibrated using a standard salt solution with a known water potential. The psychrometer constant for each instrument will be slightly different. Your SC10 was calibrated at the factory. Its psychrometer constant is given on the

calibration certificate included with your Tru Psi. This value should stay fairly constant over the life of the thermocouple. (Please note, this constant will change with changes in altitude.) If you get a very different constant, check the Sources of Error listed at the end of this chapter, or read the chapter on troubleshooting.

Tru Psi calibrates itself to a salt solution of 0.5 molal KCl. For calibration, take a strip of filter paper 12 mm by 45 mm and use it to line the inside of a sample cup. Push the paper down until the space between the paper and the cup rim is 1 mm. Filter paper strips are shipped with your Tru Psi. Additional strips can be obtained from Decagon.

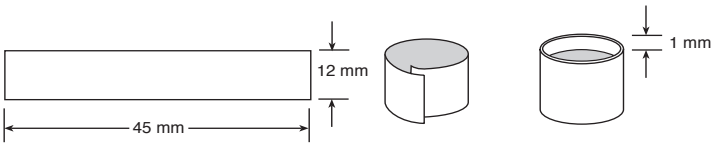


Figure 6: Filter paper use

Pour some KCl into the sample cup. Add just enough to cover the bottom and wet the filter paper. Do not overfill. Too much solution can slop and contaminate the thermocouple and chamber. It is also important to wipe off the top of the sample cup before it is loaded into the chamber. Fingerprints are oily enough to contaminate the chamber over time. Therefore, try to use a lint-free tissue or sterile gloves when preparing samples and handling the sample cups.

Turn to position 0 to load the calibration. Quickly slide the sample cup down the loading chamber and put the delrin plug in. This minimizes error due to evaporation. Gently rotate the knob so that the thermocouple (which lies under the "Read" arrow) is over an empty chamber. This prevents condensation on the thermocouple mounting plate if the sample happens to be warmer than the chamber.

Let the KCl come to temperature equilibrium with the with the changer. It should equilibrate within 20 minutes. When equilibration is complete, choose F2: READ from the Main menu. Select F3: Cal to begin calibration. The following screen will appear:

```
CLAMP 0.5MKCL
UNDER TC
PRESS <ENTER>
TO CALIBRATE
```

As you rotate the knob of the SC10, the sample ring, which looks like the dial on a rotary phone, is also turning. It rides on two ball bearings. It will slide between positions, then drop into place with a metallic click. If you turn the knob slowly, the sample ring will stop as each sample lines up. The Read arrow will indicate which sample lies under the

thermocouple. You can then pull up on the Read lever to clamp that sample into place under the thermocouple.
Note: if the sample cup is not lined up under the thermocouple, it will get jammed in when you pull up on the read lever. Solution: turn the knob slowly and stop at the click.

Rotate to sample 1. Carefully raise the Read lever and clamp the cup into place. It will snap into place. Press ENTER. Tru Psi will heat the thermocouple for ten seconds to drive off any water that may be on the thermocouple, then will wait two minutes for vapor equilibration. The screen will then read "Cooling peltier thermocouple." The thermocouple will be cooled for 15 seconds. These default times are required for accurate calibration.

When calibration is complete, Tru Psi will display a calibration constant. Check this constant against the factory calibration constant. If they are fairly close (• .03), your instrument is fine. This change is most likely due to difference in altitude between your location and Decagon's factory. Large changes, particularly when your altitude has not changed, indicate chamber contamination (see Maintenance, chapter 7, for cleaning instructions). Press F1 to accept this value and continue. You will return to the Read menu. If it is very far off, wait 2 minutes for

further equilibration. Then press F2 to recalculate. If the value still looks bad, press F3 to discard and read about "Sources of Error" at the end of this section or read the troubleshooting chapter at the end of the manual.

Reading Sample Water Potential

Prepare the samples you want to measure (read the section on preparing samples later in this chapter). Load the SC10. Be careful to avoid evaporating water from the samples. Plug the loading chamber. Rotate the knob to leave the thermocouple over the driest sample (or an empty chamber). This minimizes the chance that water will condense on the thermocouple mounting plate. Wait 20 minutes while the samples to come to thermal equilibrium.

Setting Up to Read

After a sample is clamped up to be read, Tru Psi heats the thermocouple for 10 seconds, then waits for vapor equilibrium. The default waiting time is 2 minutes. It then cools the thermocouple for 15 seconds.

Tru Psi has two read modes. The first is single read mode, in which it takes one reading of the sample and stops. The second is the unattended logging mode, whereby it can take a user specified number of readings on one sample. This allows you to monitor the change in water potential over a period of time.

Samples such as pine needles or leaves require differing equilibrium times. Therefore, monitoring a sample over a sufficient amount of time can lead to a better estimation of the required equilibrium time. To do this, run a calibration cycle. Then select F1: H2O Potential in the READ menu and select F4: UNATTENDED. When the data has been logged, reviewing the resulting data will show the best equilibrium time. (See Appendix C.)

Measuring Water Potential

Tru Psi is now calibrated and configured. It is ready to read samples.

Select F2: Read from the Main menu. Choose F1: H2O Potential. Rotate to sample 1. Raise the lever and clamp the cup into place. Press ENTER. Tru Psi will heat the thermocouple for 10 seconds, then wait 2 minutes for vapor equilibrium. The thermocouple will then be cooled for 15 seconds.

The reading will be taken as water evaporates from the thermocouple. Tru Psi will display the sample's water potential and the sample temperature in Celsius. If you choose, you can save the reading with a comment. To save without, just press F1.
Note: Tru Psi does not mark the data as "Sample #1" "Sample # 2" and so on. Data will be easier to read with comments added. Save the data with a

comment by pressing F2. The following screen will appear:

Type in the comment at the prompt. If you find yourself typing the same phrase over and over again, you may wish to assign that phrase to a function key (also called macro keys) in the Fn Key option of the Setup: System menu. Pressing ENTER will save the data. To discard the comment, press F4. You will be ready to read the next sample.

Clamp Sample 2 into place. Press ENTER to begin reading. Continue until all samples have been read; press the ⇑ key to return to the Read menu.

You can put a new batch of samples in, equilibrate them, and read them. You should re-calibrate the Tru Psi after each batch, and especially if conditions change.

Preparing Samples for Reading

The sample water potential must fall within 300 to 3500 J/kg (-3 to -35 bars). Samples drier than this do not provide enough water vapor for condensation on the thermocouple. Use the Richards thermocouple option for samples drier than -35 bars.

Good sample preparation gives accurate results. Here are some tips to follow and remember when preparing samples:

1. Always remember that exposing samples to air will cause some evaporation. Serious errors can result.

2. Samples should be prepared in a humid glove box.

3. Always wipe the top lip of each sample cup before putting a sample into the Tru Psi.

4. Oils from fingerprints as well as sample material on the rim build up on the thermocouple mount in the instrument and errors result. Use a lint-free tissue or sterile gloves when handling these items.

5. If you feel that you are getting false readings, check the calibration constant and clean the instrument if necessary (see chapter 7, Care and maintenance) or read the troubleshooting chapter at the end of this manual.

Preparing Soil Samples

Fill the cup with soil. Pack it enough so that an indentation will hold its shape. Clean the cup rim. The white loading chamber plug has a dual function. The pointed end will make a depression in the sample just deep enough for the thermocouple. Hold the plug on the flat end, insert the pointed end into the sample cup, and twist. make sure the cup edges are clean before the cup is put in the SC10.

Preparing Leaf Samples

In order to measure a leaf with Tru Psi, you must cut the leaf. This can lead to serious errors, due to the fact that water and ions are taken up at cut surfaces. Cells expand during equilibration, the tissue

deteriorates, respiration heats the sample, and water is absorbed by cuticle covered surfaces. Take steps to minimize these errors.

Clean all surfaces to minimize water absorption. Gently abrade the cuticle with 600 grit sandpaper. Use a sharp blade to cut a strip out of the prepared leaf. The strip should be the same size as the filter paper used in calibration. Wrap the strip around the inside of a sample cup. Load the samples quickly to prevent evaporation. Put the sample tissue in good contact with the sample cup walls to maximize heat exchange. This will increase the odds that the sample temperature and the reference junction temperature are equal. Carefully monitor the waiting time for equilibrium. Changes due to equilibration may be compounded by actual tissue deterioration. You will need to use some judgement in deciding how long to wait for thermal equilibrium. Use the unattended mode to establish equilibrium time. For more details on using Tru Psi for measuring plant tissues, contact Decagon for a copy of an article written on this topic.

Plant Osmotic Potential

Prepare the sample cups as if for calibration by wrapping filter paper around the inside walls. Then prepare the plant tissue. Put the tissue in a short length of Tygon tubing. Stopper the ends. Freeze the samples with liquid nitrogen or dry ice. Quickly thaw

the sample. Express the solution by rolling the tubing between two steel rollers. Put enough solution in the cup to cover the bottom and wet the filter paper.

Seeds

Different species of seeds reach vapor equilibration at different rates. This is a good time to use the Tru Psi's data logging capacities. Be careful to minimize evaporation. Fill the sample cups half full of the seeds, any more will damage the thermocouple. Make sure the cone on the end of the sample changer plug does not meet with any resistance when you are assuring the cups are not overfilled.

Other Materials

With every sample, cover the bottom of the cup. Wetter samples should also cover the walls, if possible. Use the filter paper technique with liquid samples. Make a depression in the sample with the plug if the material will hold its shape. With all samples, carefully wipe the cup rim. Do everything possible to avoid contaminating the thermocouple mounting plate, as this will cause erroneous readings (see chapter 7: Care and Maintenance).

Sources of Error

Tru Psi is measuring very small temperature differences. You will make most measurements at very high humidities. A change in water potential of

20 J/kg (0.2 bars) reflects a change in wet bulb depression of just 0.0017 degrees.

Be aware of sources of error. Minimize these errors with careful handling. Most errors come from two sources: bad reference temperature or bad wet bulb temperature.

Bad Reference Temperature

The reference temperature is measured in the thermocouple mounting plate. For an accurate measurement, this temperature needs to be as close as possible to the actual temperature of the sample. Temperature gradients can have a serious effect. Gradients come from environmental influence and chamber contamination. Here are some typical problems with straightforward solutions:

Fluctuating environmental temperature: from drafts, heaters, people moving through, etc. Locate Tru Psi in an isolated room. Make sure the temperature stays constant. Always use the neoprene insulating sleeve. Wait a full 20 minutes for temperature equilibrium.

Heat from the operator: heat can be transferred to Tru Psi from the user. The top knob and the read lever are insulated. While making readings, don't touch any other part of the SC10. Handle the knobs

and levers as little as possible.

Bad Wet Bulb Reading

The wet bulb is measured at the thermocouple junction. This junction measures relative humidity in the sample chamber. Materials and deposits in the sample chamber absorb water. This prevents vapor equilibrium.

Contamination of the sample chamber: clean the sample cups and prevent sample splashes.

Water condensation from a sample: during long sample equilibration, let the thermocouple rest over an empty chamber or over a fairly dry sample. A contaminated thermocouple is indicated by an abnormally high gamma or psychrometer constant. Values above 0.18 indicate that the thermocouple needs to be cleaned.

Special Interest

Using the Microvolt Setting

This option lets you use Tru Psi's microcontroller like a microvoltmeter. This mode is like the "manual" setting on an automatic camera. Some people can't understand why it's there. Some people want to use it all the time. This mode turns off all Tru Psi's "higher functions." It won't stop the reading at a preset point or calculate water potential.

Equations for converting voltages into water potential are given in the Theory section.

Using the Richards Thermocouple

If you are reading dry samples (with water potentials drier than -35 bars), you will need to use a Richards thermocouple. These samples will give an erroneous reading when read with a Peltier thermocouple. For more information about the Richards thermocouple, see Appendix A.

Other Calibration Standards

Tru Psi is calibrated to 0.5 molal KCl. The water potential of this standard solution is -21.9 bars, or -2190 J/kg. This is a mid-range water potential value. If you are measuring very wet or very dry samples, you may wish to measure other standard solutions. A table of standard solutions with their water potential values is given in Appendix B. These samples can be used for verifying that your Tru Psi is reading the right water potential, but they are NOT for calibration. The calibration routine in the Tru Psi ONLY works with 0.5 molal KCl. Decagon Devices sells pre-made verifying solutions. They are accurate and easy to use. Contact Decagon for more information.

5. Tru Psi's Menus

Main Menu

```
MAIN MENU
F1:SETUP  F2:READ
F3:DATA   F4:OFF
```

Tru Psi's main menu offers four options. Setup, Read, and Data are the principal sub-menus. F4 turns Tru Psi off.

F1: Setup

```
SETUP
F1:SYSTEM
F2:READ OPTIONS
```

The F1: System option in the Setup menu lets you set Tru Psi's time and date functions and preset comments for the function keys. The F2: Read Options menu lets you set the thermocouple type and

thermocouple equilibration time for each SC10 connected to the microcontroller.

F1: System

```
F1:SYSTEM CLOCK
F2:USDATE •
F3:INTL DATE
F4:FUNCTION KEYS
```

The small dot following USDATE indicates that Tru Psi is currently using the US date format. The format will change when the set up function is used to reset the date. On other screens the small dot will follow the currently selected functions.

F1: TIME

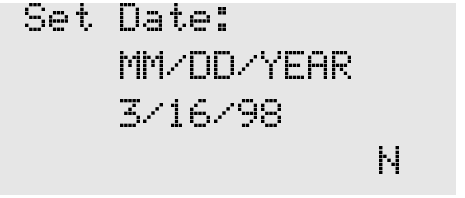
```
Set Time:

      15:36
                  N
```

Set Tru Psi's internal clock to standard local time. Move the cursor under the hour or minutes displayed. Increase [up arrow] or decrease [down arrow] the reading until it is correct. Use the B SPACE

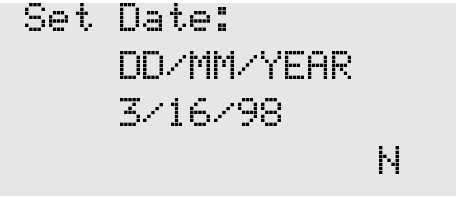
(Backspace) key to move between hours and seconds. Push ENTER to accept the clocked time and return to the System menu.

F2: US DATE:



Tru Psi is factory preset to use the standard US date format: MM/DD/YEAR. If you prefer this format, always set the date using the US Date option. To reset the date, move the cursor under the day, month, or year to be changed. Increase (up arrow) or decrease (down arrow) the number until it is correct. Use the B SPACE (backspace) key to move between month, day and year. Push ENTER to accept the date and return to the System menu.

F3: INTL DATE:



Tru Psi can be set to use the International Date format (DD/MM/YEAR). However, it is factory preset to use the standard US date format. If you prefer international format, you must reset the date using the Intl Date option. Tru Psi uses the format last set in the Setup: System menu. To reset the date, move the cursor under the day, month, or year to be changed. Increase [up arrow] or decrease [down arrow] the number until it is correct. Use the B SPACE (backspace) key to move between month, day and year.Push ENTER to accept the date and return to the System menu.

F4: FUNCTION KEY

After each reading, you are given the option of adding comments. If you find that you are repeatedly using the same comment, you may wish to assign that comment to a function key to make it more convenient. Therefore, at the "Comment" prompt, you could then press the programmed function key to recall your comment.

For example: Say you are measuring the water potential of soil samples from different plots under different conditions, and there are 30 or so samples per plot that you want to read. After the first 5 or 6 readings you get tired of typing "Plot 1" after each reading. Therefore, you decide to assign that term to

the F1 button. Thereafter, you just press the F1 button at the comment prompt.

To program the function key, press F4: FUNCTION KEYS. The following screen will appear:

```
Set Fn Key:
Select F-Key
                    N
```

At this point, enter the function key that you want to use as your macro. Any of the five function keys may be used. For this illustration we'll use F1. The following screen will then appear:

```
Set F1 Key:
Enter macro:
_                   A
```

Type in your desired comment at the prompt and then press ENTER. Each comment may be up to 15 characters long. The key will be programmed and then it will take you back to the main menu.

Caution!: If you already have a comment assigned to this function key, it will not be displayed here.

Therefore, if you don't wish to overwrite the current comment (if any) that is assigned to this key, press ENTER to escape this menu and use a different F-key.

System: F2: Read Options

Use the Read menu to configure each SC10 connected to the microcontroller. You can also change the water potential units used in Tru Psi's data displays.

```
READ OPTIONS

F1:UNITS  [BARS]
F2:CONFIG SC10 1
```

F1: Units

Water Potential is a measure of potential energy in a unit of mass. The Ψ (Psi) units are joules per kilogram (J/kg). But other units are also frequently used in expressing water potential. Bars (a unit of pressure; one bar equaling one million dynes per square centimeter) are particularly convenient. Water potentials in soil and organic materials tend to be between -1 and -100 bars. Megapascals (MPa) and kilopascals (kPa) are also used. When measuring water potential, these units are directly related. (See "Units of Water Potential" in the Method section for a conversion table.)

Tru Psi is factory preset to use bars. The current unit setting is shown in brackets beside the F1: Units option To change the setting, select F1: Units. The following screen will appear:

```
WATER POTENTIAL
UNITS
F1:BARS•   F2:J/Kg
F3:aw      F4: MPa
```

The dot shows which units are currently being used. Keep that default by pressing ENTER. Or, change the setting. Choose F1 for bars, F2 for joules per kilogram, F3 for water activity units, or F4 for megapascals. You will return to the main menu.

F2: Config SC10

```
PICK SC10

F1:#1•     F2:#2
F3:#3      F4:#4
```

The microcontroller can operate up to four SC10s. Push F3 to configure the third SC10, for example. The currently selected SC10 is marked with a dot. If you have multiple sample changers, you configure each

one with this menu option. If you don't want to change the selected SC10, you can either select the one it's already using, or press ENTER. When you select the sample changer you want, the following screen will appear:

```
CONFIGURE SC10 3
F1:TC TYPE [P]
F2:TIME
F4:TO MAIN MENU
```

The [P] following TC TYPE indicates that this SC10 is configured for a Peltier thermocouple. This is the default setting. Choosing F1 will show this screen:

```
PICK TYPE OF
THERMOCOUPLE
F1:PELTIER•
F2:RICHARDS
```

Choose F1 for Peltier thermocouple, F2 for Richards. For more information on thermocouple types, see "Choosing a Thermocouple" in the Method chapter. Tru Psi will return you to the configure SC10 menu when a TC type is chosen.

In the "Configure SC10" menu, push F2 to set the vapor equilibrium time. The following screen will appear:

```
ENTER DELAY TIME
FOR EQUILIBRIUM
2 :00 <ENTER>
MN:SEC          N
```

Tru Psi will wait a preset time before cooling the thermocouple. This delay time allows the sample chamber to reach vapor equilibrium. To set this time, select F2: Time. The default time is two minutes. Press ENTER to accept the minutes value. You will then be prompted to accept the value for seconds. Press ENTER to accept the value. Tru Psi will then prompt for a cooling time.

```
ENTER COOLING TIME

15 SECONDS
<ENTER>          N
```

The thermocouple is cooled to condense water vapor or dew. Tru Psi measures the temperature difference across the thermocouple at this dew point to determine sample water potential. If the thermocouple is not cooled long enough, dew may not form. Press ENTER to accept the value for seconds.

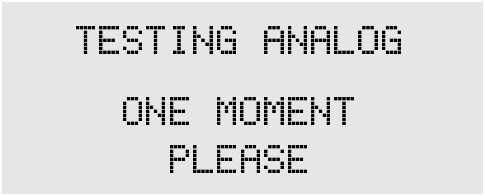
Note: the default times of 2 minutes and 15 seconds

are standard for most applications. If you would like to change these default times, please consult Decagon first.

To configure a second SC10, press the up arrow. You will return to the Pick SC10 menu. Choose the next SC10 to be configured. Be sure to configure all SC10s to be used. Number the SC10s to correspond with their configuration number.

F2: Read

The Read menu is Tru Psi's working menu. Use this menu to Calibrate an SC10, measure water potential (H2O Potential), and read thermocouple Voltage directly. If more than one SC10 is connected to the microcontroller, you can also Pick which SC10 to use. When you select F2: READ from the Main Menu, the following screen will appear:



Then:

```
READ
F1: H20 POTENTIAL
F2:uVOLT    F3:CAL
F4:PICK SC10 [4]
```

F1: H20 Potential

This option will read the water potential of a sample. Note: Readings will be inaccurate if you have not prepared the SC10 and the sample. Before choosing this option, make sure to:

- calibrate the SC10.
- set the thermocouple type correctly.
- let the samples come to temperature equilibrium inside the SC10 (20 - 30 minutes).

Complete instructions on these steps are given in the Method section.

Press F1 to begin the measurement process. If the sample changer has not been calibrated, the following screen will appear:

```
ERROR: SC10 1 IS
NOT CALIBRATED
CHOOSE F3:CAL TO
CALIBRATE SC10 1
```

If calibration has been completed the screen will read:

```
   READ WATER
   POTENTIAL
F1: SINGLE READ
F2: UNATTENDED
```

F1: SINGLE READ
If you want to do sample in single read mode, select F1. The following screen will appear:

```
CLAMP SAMPLE
UNDER TC
PRESS <ENTER> TO
BEGIN READ CYCLE
```

As you rotate the knob of the SC10, the sample ring, which looks like the dial on a rotary phone, is also turning. It rides on two ball bearings. It slides between positions, then drops into place with a metallic click. If you turn the knob slowly, the sample ring will stop as each sample lines up. The Read arrow will indicate which sample lies under the thermocouple. You can then pull up on the read lever to clamp that sample into place under the

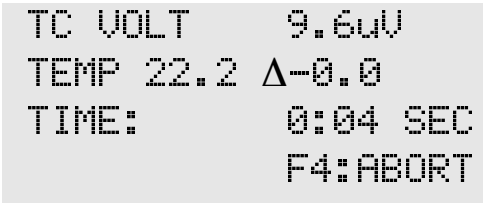
thermocouple.
Note: If the sample cup is not lined up under the thermocouple, it will get jammed in when you pull up on the read lever. Solution: turn the knob slowly and stop at the click.

Gently turn the changer knob until the Read arrow points to the one on the knob. Raise the Read lever and clamp the cup into place. Press ENTER. The screen will read:

```
HEATING PELTIER
THERMOCOUPLE
TIME:       0:03 SEC
            F4:ABORT
```

```
 EQUILIBRATING...
 TIME:      0:07 SEC
            F4:ABORT
```

```
COOLING PELTIER
THERMOCOUPLE
TIME:       0:07 SEC
            F4:ABORT
```



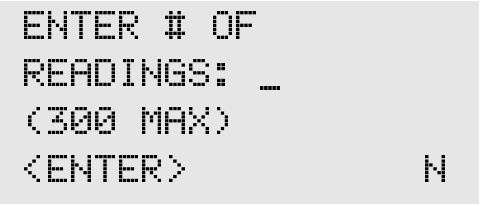
Tru Psi will read the voltage on the thermocouple and determine the wet bulb temperature depression. Tru Psi will then display the sample's water potential and the sample temperature in Celsius. You can save the reading with or without a comment. To save without, just press F1. If you do not wish to save the reading F4 will discard it. F1 and F4 will both return you to water potential menu where you can clamp another sample (or the same one) under the thermocouple and start the reading cycle again. F2 will allow you to save a comment with your reading. Note: Tru Psi will not mark the data as "Sample #1" "Sample # 2" and so on. The data will also not be labeled as to which sample changer it was measured in, this may be another comment you will wish to add.

To save the data with a comment, press F2. The following screen will appear:

Type in the comment at the prompt. If you find yourself typing the same phrase over and over again, you may wish to assign that phrase to a function key in the Fn Key option of the Setup: System menu. Pressing ENTER will save the data and return you to the water potential read menu, and you will be ready to read the next sample.

F2: UNATTENDED

If you want to do unattended logging of your sample, select F2: UNATTENDED from the H20 Potential menu. The following screens will appear:



Enter the number of readings you wish to make for your sample and press ENTER.

```
ENTER # OF
MINUTES BETWEEN
READINGS: _
(3-30 MINUTES)   N
```

When the minutes between samples has been entered, the following screen will appear:

```
LOGGING...       1
Ψ-21.8 BARS
TEMP 22.1°C
F4:ABORT
```

As Tru Psi takes a reading it will show all of the steps on the screen. Between readings it will look like above, with the reading number in the upper right hand corner and the proper water potential and temperature readings. When it has finished logging to appropriate number of readings it will show:

```
   DONE LOGGING
       DATA
   PRESS ANY KEY
    TO CONTINUE
```

When any key is pressed, Tru Psi returns to the read

menu.

Caution: If your microcontroller quits logging data while running in unattended mode, the battery levels were too low and the program was discontinued. You will need to recharge the batteries before sampling again.

F2: uVolt

This option lets you use Tru Psi's microcontroller like a microvoltmeter. This mode is like the "manual" setting on an automatic camera. Some people can't understand why it's there. Some people want to use it all the time. This mode turns off all Tru Psi's "higher functions." It won't stop the reading at a preset point or calculate water potential. It can help you determine an appropriate thermocouple equilibrium time for Richards thermocouple readings.

Press F2 and the microcontroller screen will read:

```
CLAMP SAMPLE
UNDER TC
PRESS <ENTER> TO
BEGIN READ CYCLE
```

As you rotate the knob of the SC10, the sample ring, which looks like the dial on a rotary phone, is also

turning. It rides on two ball bearings. It slides between positions, then drops into place with a metallic click. If you turn the knob slowly, the sample ring will stop as each sample lines up. The Read arrow will indicate which sample lies under the thermocouple. You can then pull up on the read lever to clamp that sample into place under the thermocouple.
Note: if the sample cup is not lined up under the thermocouple, it will get jammed in when you pull up on the read lever. Solution: turn the knob slowly and stop at the click.

Turn the knob until the arrow points to sample 1. Raise the Read lever and clamp the cup into place. Press ENTER. The screen will show thermocouple voltage (in microvolts) as it changes. It will also show the thermocouple temperature and the elapsed time in seconds.

For the Richards thermocouple, watch the microvolt reading as it drifts downward. It represents, in voltage, evaporation from the thermocouple. At thermocouple equilibrium, the reading will be relatively steady. Push F1 to freeze the reading and the elapsed time. You have the option of saving the endpoint value or all voltages. If you wish to comment, do so before choosing a save option. Press F4, then type in your comment at the prompt. If you

find yourself typing the same phrase over and over again, you may wish to assign that phrase to a function key in the Fn Key option of the Setup: System menu. You will return to the Save menu.

Press F1 to save the final microvolt value, the sample temperature, the elapsed time, and the actual time and date. If you typed in a comment, it will be attached to the data set.

With the Peltier Thermocouple, the following screen will appear when the reading is complete:

```
F1:SAVE PEAK
F2:SAVE ALL
F4:COMMENTS
```

Press F1 to save the peak voltage. The peak voltage represents the wet-bulb temperature depression. Sample temperature, elapsed time, actual time, date, and comment (if typed in) will also be saved.

Tru Psi reads and stores a voltage twice per second. You can save all those values by pressing F3. This option stores a lot of data. Tru Psi's memory capacity is about 100 minutes of data stored using the "Save All" option. Temperature, date, actual time and comment, if made, will be stored with the first data

point. Voltage and elapse time will be saved for all the half-second intervals following.

F3: Calibrate

Tru Psi has a one-point calibration process. Calibrate and re-calibrate to get accurate water potential readings. Calibrate before the sample set if you are measuring just a few samples. Calibrate Tru Psi at least every few hours if you are running samples over an extended period of time.

Tru Psi calibrates itself to a salt solution of 0.5 molal KCl. For calibration, a strip of filter paper 12 mm by 45 mm is wrapped inside a sample cup. Push the paper down until the space between the paper and the cup rim is 1 mm.

Pour some KCl into the sample cup. Add just enough to cover the bottom and wet the filter paper.

Quickly slide the sample cup down the loading chamber and put the teflon plug in. This minimizes error due to evaporation.

The KCl should equilibrate within 20 minutes. When equilibration is complete, press F3 to begin calibration.

```
CLAMP 0.5M KCL
UNDER TC
PRESS <ENTER>
TO CALIBRATE
```

As you rotate the knob of the SC10, the sample ring, which looks like the dial on a rotary phone, is also turning. It rides on two ball bearings. It slides between positions, then drops into place with a metallic click. If you turn the knob slowly, the sample ring will stop as each sample lines up. The Read arrow, located on the neoprene sample changer sleeve, will indicate (generally speaking) which sample lies under the thermocouple. You can then pull up on the read lever to clamp that sample into place under the thermocouple.
Note: if the sample cup is not lined up under the thermocouple, it will get jammed in when you pull up on the read lever. Solution: turn the knob slowly and stop at the click.

Rotate to sample 1. Raise the Read lever and clamp the cup into place. Press ENTER. The following screens will appear in sequence:

```
HEATING PELTIER
THERMOCOUPLE
TIME:       0:03 SEC
            F4:ABORT
```

(Heating the thermocouple drives any moisture off that may have previously condensed on the junction.)

```
EQUILIBRATING...
TIME:       0:17 SEC
            F4:ABORT
```

```
COOLING PELTIER
THERMOCOUPLE
TIME:       0:07 SEC
            F4:ABORT
```

```
TC VOLT     9.3uV
TEMP 22.2 Δ-0.0
TIME:       0:04 SEC
            F4:ABORT
```

```
CAL CONST  0.1150
F1:ACCEPT
F2:RECALC
F4:DISCARD
```

When calibration is complete, Tru Psi will display a calibration constant. This represents the psychrometer constant. In the absence of heat exchange, this constant is 0.067. Because in all real situations, heat is exchanged, the calibration constant of your instrument will not be 0.067. But it should be between 0.08 and 0.18. If it is, press F1 to accept this value and continue. You will return to the Read menu. If it is very far off, wait two more minutes for further equilibration. Then press F2 to recalculate. If the value still looks bad, press F3 to discard and read "Sources of Error" in the Methods section, or refer to the troubleshooting chapter.

F4: Pick SC10

```
PICK SC10

F1:#1*    F2:#2
F3:#3     F4:#4
```

In this menu you can choose which SC10 is connected

to the controller. The small dot following the SC10 number indicates the SC10 currently chosen.

F3: Data Menu

From the main menu, you can use the Data menu to view, download, and discard data stored in Tru Psi's memory.

```
DATA          [15.8K]
F1:DOWNLOAD
F2:CLEAR DATA
F3:VIEW DATA
```

F1: Download

Tru Psi can be linked to the serial port of any personal computer. You can then send data to a computer file for further analysis.

Using Terminal for Windows 3.0 and 3.11

1. Connect the RS-232 cable between the Tru Psi and your computer. Remember which COM port you are using, and make sure the shorting block is not on both program pins.

2. Double-click on the Accessories icon in Program Manager. Open the icon labeled "Terminal."

3. Select "Communications" from the Settings menu. Set the baud rate to 9600, and make sure the

other settings are as follows: 8 data bits, 1 stop bit, no parity. Select the COM port that you will be using. Click OK.

4. Select "Receive text file" from the Transfers menu. A pop-up window will appear. Type in a name for this terminal session and click OK.

5. From the Main Menu of the Tru Psi, select F3: DATA and then press F1: DOWNLOAD. The data will then appear on the computer screen.

6. When it has finished downloading, click on the "Stop" button on the bottom left corner of the screen. Terminal will save your data to the file-name you indicated earlier.

7. If you wish, you can open this file in a spread-sheet program and analyze the data further.

Using Hyperterminal for Windows 95

1. Press the Start button and select Programs > Accessories > Hyperterminal and click the Hyper-terminal icon.

2. At the prompt, choose a name for this program (Tru Psi is a good one) and choose an arbitrary icon above to represent it. In future downloads, you will be able to click on this icon in have it already set up for you to download. Click the OK button.

3. A pop-up menu labeled “Connect To” will appear. Click on the scroll bar on the bottom of the screen labeled “Connect Using” and select the COM Port your RS-232 cable is connected to.

4. A pop-up menu labeled “COM Properties” will appear, showing the port settings for the COM port you selected. Make sure the settings are the following: Bits per second, 9600; 8 databits, no parity, 1 stop bit, and flow control set to hardware. Click OK.

5. Plug your RS-232 cable to the COM port you selected and connect it to your Tru Psi. Make sure the shorting block is not on both program pins in the RS-232’s connector.

6. From the Main Menu of the Tru Psi, select F3: DATA and then press F1: DOWNLOAD. The data will then appear on the computer screen.

7. When it has finished downloading, you can print the data in the terminal session, or save it.

Downloading with PsiLink

Before downloading information, install the PsiLink communications software shipped with your computer. Insert the PsiLink disk in drive a or b. Make a directory on your chosen hard drive by typing “MD PSILINK” at the disk prompt (i.e. "C:\"). Then copy the contents of the PsiLink disk into this directory

(PSILINK.EXE, PSILINK.CFG, TRUPSI1_0.HEX, TPXXXX.HEX).

1. In this directory, double-click on "psilink.exe" to start the program.

2. Specify the com port and baud rate. Select Options: Communications. When downloading data to your Tru Psi, always use a baud rate of 9600. If you are not sure whether your serial port is com 1 or com 2, try one, then the other. (Be sure not to erase any data until you have checked the computer file for successful download.)

3. At the main menu, press F4 to turn the Tru Psi off. Plug the RS-232 cable's connector into the far right port of the microcontroller (nearest the edge). Plug the 25 pin end of the cable into your serial port. If your serial port has a 9 pin connector, use the 25 to 9 pin adapter shipped with the Tru Psi. (If you've lost the adapter, contact Decagon or your local computer store).

4. Turn the Tru Psi on. On the computer terminal, select File: Download. PsiLink will ask for a file name. Unless you specify otherwise, the file will be stored in the PsiLink directory. Type in a file name and choose OK. When working with a specific spreadsheet program it is a good idea to use a file extension that is common to that program (like .prn or .txt). This will help in being able to open the file with your program.

5. From the main menu of the Tru Psi microcontroller, select F3: Data, then F1: Download. All data stored in Tru Psi's memory will be downloaded to the specified file.

WARNING: Before you press F2: Clear Data, check the file. At the computer, choose File: Exit and then check the directory. You may want to start a spreadsheet, statistics, or text program and import the data file before you clear Tru Psi's memory.

Tru Psi data is downloaded in a quote and comma delimited format. This format is recognized by most spreadsheets and statistical programs and can be directly imported. If directly printed, the file looks like this:

"BARS", "Temp", "Time", "Date", "Comment"
-21.7, 21.5, 19:42:21, 5/3/1998, 20E 3C
-22.3, 21.4, 11:22:36,5/4/1998,
-22.1, 21.4, 12:20:23,5/4/1998,
-22.3, 21.4, 12:42:10,5/4/1998,
-22.5, 21.4, 13:21:57,5/4/1998,
-21.7, 21.4, 14:10:44,5/4/1998,
-22.5, 21.6, 14:41:31,5/4/1998,

Headings read across the top. Then data is listed in rows. If read into a spreadsheet, the data will align in columns under the proper headings.

F2: Clear Data

Use this function after downloading data to a computer or printer. Press F2 to clear memory and return to the main menu. Tru Psi will prompt you for confirmation.

F3: View Data

Press F3 to begin scrolling through Tru Psi's data memory. Sample data is stored in the order that it was read. Data saved in the water potential mode will appear in the following format:

```
-21.8 BARS      1
22.1°C
(Comment appears Here)
15:38     10/20/1998
```

The actual time displayed is the time when the reading was saved. The temperature is taken at the beginning of the reading process.

Data saved in the microvolt mode will be displayed in the following format:

```
1.90 uV          1
22.1°C
(Comment appears Here)
15:38     10/20/1998
```

The actual time displayed is the endpoint time; the temperature is the endpoint temperature.

If all voltage points were saved (using save all), you will need to download the stored data in order to view the points.

Page through the data screens with the ⇓. Return to previous screens with ⇑. Press ENTER to return to the Main menu.

F4: Off

F4, from the main menu, turns the power off. Data stored will be maintained when the power is off.

6. Theory

Are you unfamiliar with thermocouples, psychrometers, and water potential? If so, read on. This section explains how and why Tru Psi works. It gives important equations. It also gives potential sources of error. If you are looking for more technical information, check the references listed under "Further Reading."

Defining Water Potential

Water Potential is the potential energy of water per unit mass. Water content tells how much water is in a sample. Water potential tells how available the water is. The total water potential of a sample is the sum of four component potentials: gravitational, matric, osmotic, and pressure. Gravitational potential depends on the position of the water in a gravitational field. Matric potential depends on the adsorptive forces binding water to a matrix. Osmotic potential depends on the concentration of dissolved substance in the water. Pressure potential depends on the hydrostatic or pneumatic pressure on the water.

Depending on circumstances, some of these component potentials may be zero. For example,

when evaluating a soil sample, the pressure and gravitational potentials for a sample of soil are zero. Unless the sample is salty, the osmotic potential is also zero. Therefore, a water potential reading for that sample is measuring only matric potential.

Measuring Water Potential

The water potential of a solid or liquid sample can be measured through a series of relationships. The first is the relationship of the sample water potential reading to the vapor pressure in the air around the sample. The sample must be in an enclosed space. The sample and the water vapor in the air need time to come to vapor equilibrium. Then, the water potentials of the sample and the water vapor are equal. The relationship between vapor phase water potential (Ψ) and the relative humidity (h_r) of the air is:

$$\Psi = \frac{RT_a}{M} \cdot \ln h_r$$

where R is the gas constant (8.31 J/mol K), T_a is the Kelvin temperature of the air, and M is the molecular weight of water. The relative humidity of the air can be measured by a thermocouple.

Thermocouples

A thermocouple is a small electrical thermometer used to measure temperature differences. Two wires of dissimilar metals are joined at their ends to form

two junctions. If the junctions are at different temperatures, current will begin to flow. The voltage produced is proportional to the temperature difference.

In a psychrometer, one junction is kept at a constant temperature. The other is wetted. As water evaporates from it, it will be cooled to a lower temperature. When the evaporation rate is steady, the temperature difference is related to the relative humidity of the air. The temperature at the wet junction is called the temperature depression of the wet bulb (or wet bulb temperature).

Once the wet bulb temperature is known, use Teten's equation to find a value for the saturation vapor pressure at that temperature. Then, the relative humidity of the air can be calculated from this equation:

$$h_r = \frac{ew' - \gamma(T_a - T_w)}{e'}$$

where e_w is the saturation vapor pressure at the wet bulb temperature, e is the saturation vapor pressure at the reference temperature, T_a is the reference temperature, T_w is the wet bulb temperature, and g is the psychrometer constant.

γ, the Psychrometer constant

A perfect psychrometer, in which no heat is lost or gained from the environment, has a constant of .067. The psychrometer constant for a thermocouple psychrometer in a chamber is determined by the rates of diffusion of heat and water vapor to and from the thermocouple measuring junction. If the thermocouple is very small, and the measuring junction of the thermocouple is completely wet, the psychrometer constant approaches the ideal psychrometer constant. The constant for a real psychrometer is determined empirically. The relative humidity of standard salt solutions can be found from the concentration. One of these solutions is measured. The above equation is then solved for γ.

How Tru Psi Works

The Thermocouple

Tru Psi's thermocouple is made of chromel and constantan. At one junction, the wires are welded together. Current is passed through the junction of the Peltier thermocouple, causing moisture to condense on it as it cools below the dewpoint of the air. The Richards thermocouple is made wet by dipping the ceramic bead that covers the welded junction in water. This junction becomes the wet bulb. The other junction is in the thermocouple mount plate. By the laws of thermocouples, you can

break the thermocouple circuit and insert other wires and measuring devices, as long as they balance on each side of the circuit. In this case, the chromel and constantan are connected to gold-plated pins in the mount plate. The pins are then connected to copper wires. The copper wires are connected to (actually through) the microcontroller.

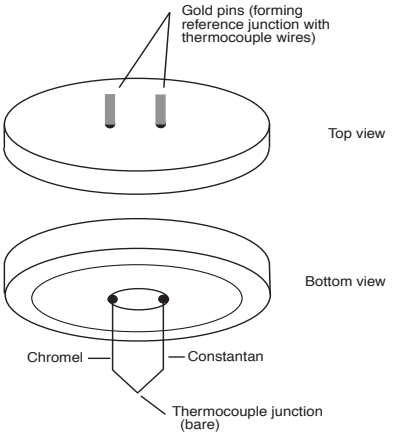


Figure 7: Peltier thermocouple

The copper wires and gold pins are present on both sides of the circuit. The voltages at the junctions sum up as if these wires were not there. For all practical purposes, the other thermocouple junction is at the thermocouple mount plate. That is where the

reference temperature is measured via a thermister.

The Sample Changer

Raise the SC10 sample lever and clamp it into place. You have now created a sealed sample chamber. The sides and bottom of the chamber are the sample cup. The top is the thermocouple mounting plate. The thermocouple hangs down into the airspace above the sample. To make a good seal: keep the rim of the

sample cup clean.

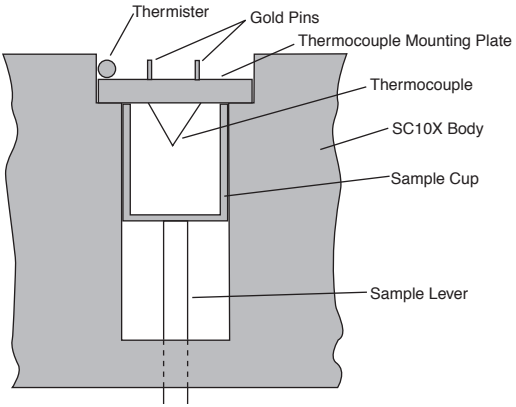


Figure 8: Sample chamber

Start a sample reading. The reference temperature is measured at the thermocouple mounting plate with the thermister. For an accurate measurement, this temperature needs to be as close as possible to the actual temperature of the sample. Keep Tru Psi's environment temperature as constant as possible. Don't hold onto it or move it around. Just use the top knob and the rubber insulated lever. Always use the neoprene insulating sleeve.

The wet bulb temperature is measured at the measuring junction. The Peltier thermocouple needs to be clean and free from solutes. For the Richards thermocouple, the bead should be wet and evaporating water molecules into the airspace. If it wasn't dipped in the water reservoir, the wet bulb

temperature will be completely inaccurate. Here are some possible reasons:

1. The water reservoir is not full enough.

2. The thermocouple is bent and the clay bead doesn't reach the reservoir.

3. The operator forgot to dip between measurements.

Very dry samples can also cause problems. They can actually absorb water from the clay bead.

Calibrating Tru Psi (finding γ)

Tru Psi is calibrated using a 0.5 molal KCl solution. The Calibrate option displays the psychrometer constant. This value should stay relatively constant for your instrument. If you notice a change, check the Sources of Error listed in the Method section.

Microvolt Mode

Using Tru Psi in microvolt mode is like turning off Tru Psi's "brain". You have to do all the calculations. Use this mode to estimate thermocouple equilibration time for the Richards thermocouple. It is helpful for understanding the process of water potential readings. As the wet bulb junction is cooled by evaporation, the microvolt reading will decrease quickly. When the evaporation rate nears steady state,

the voltage decrease will slow. F1 can be used to freeze the reading when it becomes fairly steady. There are many other options available in the microvolt mode, changing depending on thermocouple type. See the menu section for greater details.

T_a, the reference temperature, is displayed on the second line of the data screen. The DT displayed is the change in T_a over the read cycle, with a 1.5 second delay at the end. This should be 0 , any change indicates temperature gradients which can cause errors. TC Volts is the T_w which can then be converted to temperature by 60.0 •V = 1 C depression. g was given during calibration. Saturation vapor pressure at any temperature T (the temperature in Kelvin) is computed from:

$$e'(T) = 0.614 \exp\left[\frac{17.502T}{240.97 + T}\right]$$

This equation can be used to find both e_w, the saturation vapor pressure at the wet bulb temperature, and e, the saturation vapor pressure at the reference temperature.

Put all these terms into the relative humidity equation:

$$h_r = \frac{e_w' - \gamma(T_a - T_w)}{e'}$$

Then, using the relative humidity, calculate the water potential (in J/kg) from the equation

$$\Psi = 1.36 \times \ln h_r$$

Reading Water Potential

The conversion equations are important to understand. They are also inconvenient. Tru Psi will read the voltage, calculate water potential, and display it in bars, joules per kilogram, megapascals, or kilopascals. You set the time needed for vapor equilibration (usually around two minutes). Then, choose Read: H2O Potential. Clamp the sample into place. Press ENTER and wait for the reading to appear. You can save the reading (with or without a comment) and move on to the next sample.

Why Ten Samples?

Samples need time to come to temperature equilibrium with the sample chamber. Temperature equilibrium takes 20 minutes or more. Fill the SC10 with samples, put in the plug, and let them all come to equilibrium. Twenty to thirty minutes later, you can make the ten readings.

Temperature Effects

Tru Psi is measuring very small temperature differences. You will make most measurements at very high humidities. A change in water potential of 20 J/kg (0.2 bars) reflects a change in wet bulb depression of just 0.0017 degrees.

The reference temperature junction is in the thermocouple mount plate. Its temperature should be equal to the sample temperature. The SC10 is designed to minimize temperature gradients. It is made of thick aluminum and is designed to exchange heat mainly by contact with air. Minimize temperature changes around Tru Psi. Put it in a room with very little air flow and relatively constant temperature. Handle it as little as possible when making readings. Touch only the knob and the rubber part of the sample lever. Always use the neoprene insulation sleeve.

Water Problems

In psychrometry, cleanliness is critical for good accuracy. Materials and deposits in the sample chamber absorb water. This prevents vapor equilibrium. Keep the sample cups very clean. Don't leave sample material on the walls. Especially wipe off the cup rims! If you suspect that the thermocouple mount has been contaminated, see the

Care and Maintenance section.

The opposite problem is condensation. Water from very wet samples can condense on the thermocouple mount. That water makes your readings go haywire! During long sample equilibration, let the thermocouple rest over an empty chamber or over a fairly dry sample. Never leave it over the water reservoir.

When to use the Richards Thermocouple

The Peltier thermocouple works well for all but the driest samples. It will accurately read samples up to -35 bars. Drier samples do not produce enough water vapor for dew to form on the thermocouple. If you get a water potential reading of 0 for a dry sample, you may need to use the Richards thermocouple. See Appendix A: Richards Thermocouples, for further information.

Further Reading

You can get more information from these resources:

Measurement Methods and Interpretation

Campbell, G.S. and W.H. Gardner. 1971 *Psychrometric measurement of soil water potential: temperature and bulk density effects.* Soil Sci. Soc. Am. Proc. 35: 8-12.

Campbell, G.S. and A. M. Wilson. 1972. *Water potential measurements of soil samples.* p. 142-149 in R. W. Brown and B.P VanHaveren (eds.) Psychrometery in Water Relations Research. Utah Agric. Exp. Stn., Logan, Utah.

Campbell, G.S., W.D. Zollinger, and S.A. Taylor. 1966. *Sample changer for thermocouple psychrometers: construction and some applications.* Agron. Jour. 58:314-318.

Richards, L.A. and G. Ogata. 1958. *Thermocouple for vapor pressure measurement in biological and soil systems at high humidity.* Science. 128: 1089-1090.

Spanner, D.C. 1951. *The Peltier effect and its use in the measurement of suction pressure.* J. Exp. Bot. 2:145-168.

U.S. Salinity Laboratory Staff. 1954. *Diagnosis and improvement of saline and alkali soils.* USDA Agric. Handbook. No. 60.

Theory of Hygrometry and Psychrometry

Papendick, R.I. and G.S. Campbell. 1980. *Theory and measurement of water potential.* p. 1-22 in

Water Potential Relations in Soil Microbiology. Soil Science Society of America, Madison, Wisconsin.

Campbell, E.C., G.S. Campbell, and W.K. Barlow. 1973. *A dewpoint hygrometer for water potential measurement.* Agric. Meteor. 12:113-121.

Peck, A.J. 1968. *Theory of the Spanner Psychrometer: 1, the thermocouple.* Agric. Meteor. 5:433-477.

7. Care and Maintenance

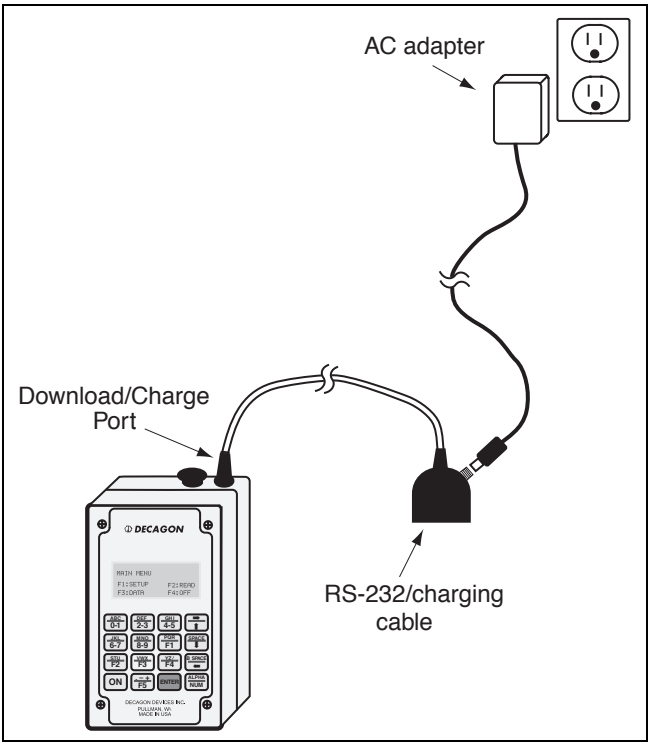
Tru Psi's accuracy depends on good maintenance. Cleanliness really is a critical issue. Take care not to contaminate the SC10. If it becomes contaminated, stop and clean it immediately. Read all the steps for cleaning before you start. Also, keep the microcontroller batteries charged.

Routine Maintenance

Check Batteries: Tru Psi uses two rechargeable battery packs. If batteries are low, you will see the message "Low Batteries. Shutting down." Recharge the batteries regularly (at least 10 hours for a full charge), to avoid the warning message.

Recharge the Batteries (if necessary): Tru Psi uses two NiCad battery pack. They can be recharged hundreds of times. They last for about 16 hours of normal use. The charging adapter connects to Tru Psi's RS-232 interface cable (fig. 7). Plug the five pin end of the interface cable into the connector at the top end of the microcontroller. Connect the AC adapter to the interface cable. Plug the adapter into any standard outlet. A full charge takes 10 hours. It charges best overnight.

ALERT!! Maintain the NiCad batteries. Don't charge them longer than 16 hours. Note: if the batteries will no longer hold a charge, contact Decagon for replacements. WARNING: Tru Psi will not operate while plugged into an outlet for recharging.



When Necessary:

Clean the Inside of the SC10: The thermocouple mounting plate may be contaminated by spilled sample material. It also may gradually get dirty as a

result of normal use. Thermocouple contamination shows up as a change in γ, the psychrometer constant. Check by calibrating before each use. Put one standard and nine samples in for a small batch, or calibrate every two to three hours during an all-day session.

Cleaning the thermocouple mounting plate is not a small job. Read these directions completely before you pick up a screwdriver.

Disassembling the SC10

1. Remove all the sample cups. Leave the knob with position 0 at the loading chamber. Unscrew the three screws on the top of the SC10 using the hex driver provided in the accessories box that came with your system.

2. Hold onto the base and pull up on the knob. The cover plate will come up. Set the knob and cover plate aside.

The next layer of the SC10 is a separate disc. This disc holds the thermocouple mounting plate. The plate, about one inch in diameter, is shiny chrome-plated brass. It is held in place by two screws. The

thermocouple is mounted on the underside.

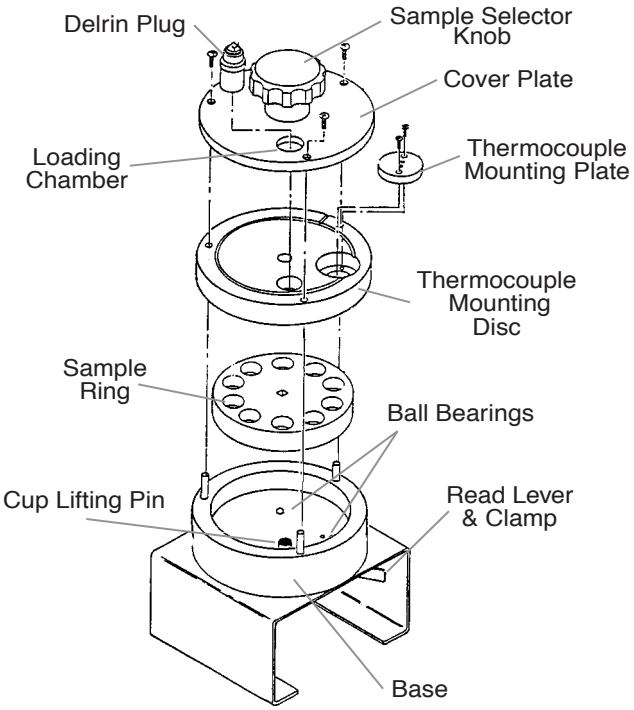


Figure 9: SC10X

3. Hold the disc around its outside edges. Pull up. Lay the disc on a clean surface, thermocouple side down. Remove the two screws.

4. Carefully turn over the disc. The thermocouple mounting plate will drop out.

Common Sense Alert: keep one hand close to the mounting plate to catch it.

5. Locate the thermocouple junction. It is hard to see. It is also easy to damage. The delicate 25 micrometer chromel and constantan wires are easy to break. Clean slowly. Be careful not to bump or bend the thermocouple.

6. Examine the thermocouple mount. It should be clean and uniformly shiny. If not, use one of the Texwipe• swabs included with your system (or wrap a lint-free tissue around tweezers or small forceps) to rub it until it is clean. You can also gently squirt the mount with distilled water from a wash bottle. If some solutes are stuck on and too difficult to rub off, try soaking the swab or tissue in distilled water, then gently rub the mount to remove it.

Common Sense Alert: when working with the mounting plate, always rest it with the thermocouple junction side up!

7. Remove the sample ring. Carefully clean it with a soft cloth.

8. Wipe out the lowest level of the body. Watch out for the ball bearings. If they are accidentally dislodged, reload them spring first, bearing second.

9. If the inside of the SC10 is dirty, wipe it out and re-grease it with a light coat of petroleum jelly. Coat the inside of the base, the outside of the sample ring, and the bottom of the thermocouple disk. **Do not** coat the chrome thermocouple mounting

plate or the area around it, the individual chambers of the sample ring, or the sample cups.

Reassembling the SC-10

1. Replace the sample ring. Make sure it turns freely.

2. Replace the thermocouple mounting plate, thermocouple side down. Screw it in. Replace the disc that holds the mounting plate. Line it up so you can see the black button on top of the cup lifting pin through the loading chamber. (See figure 10).

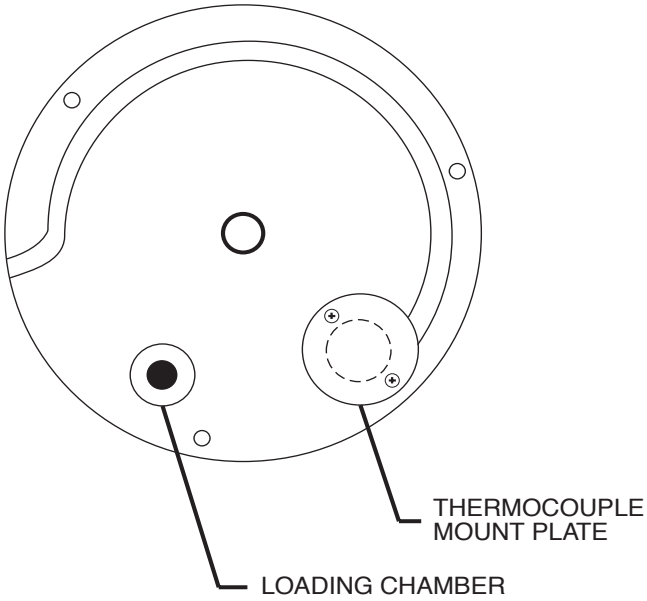


Figure 10: Assembly

Replace the cover plate and knob, lining up position 0

and the loading hole with the loading chamber. Replace the top screws.

Cleaning a Thermocouple

A common source of error in measurements is due to contamination of the thermocouple. Follow these steps to clean your thermocouple if you suspect it has become dirty.

1. Remove the thermocouple mount as described above.

2. Obtain two syringes without needles. Fill one with distilled water and the other with ethyl alcohol (ethanol), if available. If you don't have any ethanol, just use the distilled water.

3. Squeeze the water syringe enough so a bead of water is formed on the end.

4. Holding the thermocouple mount with a lint-free tissue or protective cloth gloves, move the bead of water through the thermocouple junction. The junction should be at a 90 angle. If it is not, refer to the next section on straightening a bent thermocouple.

5. If you are using only water, do this about 6 or 7 times. If you have ethanol as well, alternate between the water and the ethanol, making sure to do a final rinse with water. Leave your system

open to air dry for 20-30 minutes before re-assembling.

6. After re-assembly, make sure to calibrate your system using KCl and your calibration constant.

Straightening a Bent Thermocouple

This job is not for the faint-hearted. It involves teasing the tiny thermocouple wires straight without breaking them. First, disassemble the SC10 as outlined above. Lay the mounting plate down, thermocouple side up. (You might want to use a microscope on low power.) Using a needle or the other end of a texwipe, put the point under the thermocouple. Without putting any pressure on the wires, gently tease them straight.

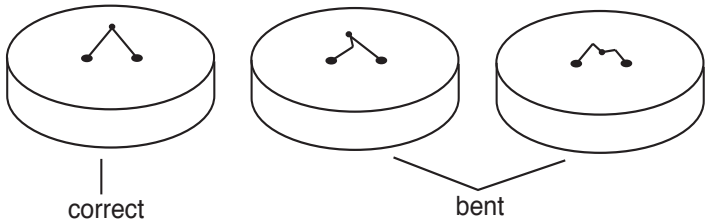


Figure 11: Proper thermocouple position

Replacing a Thermocouple

The thermocouple and mounting plate are replaceable. If the thermocouple is broken or damaged beyond repair, it can be replaced. The instructions for replacing the thermocouple are below. Contact Decagon for further information.

1. Remove the three screws that secure the cover plate and remove it.

2. Remove the two screws securing the thermocouple mount and unwind the grey thermocouple lead wire from the surrounding grooves. Lift the thermocouple mounting plate out of the SC-10.

3. Place the thermocouple mounting plate in a vise or a pair of vice grip pliers, being careful not to scratch the thermocouple mount surface and keeping track of which wires came from which hole. (On the card the red tab indicates the constantan, the white lead wire connects to the constantan.) The lead wires do not need to be unsoldered. Using a pair of forceps or needle nose pliers, remove the pins holding the wires and remove and discard all the pieces of the old thermocouple. Inspect the teflon tubes for stray pieces of wire.

4. The new thermocouple will be shipped taped to a small card with color coded tabs. The red tab indicates the constantan wire and the green tab indicates the chromel wire. It is important to correctly connect these wires.

5. Using a pair of tweezers or forceps and a good light, remove the thermocouple from the shipping card. Do not attempt to remove the colored tabs. Use a sharp razor blade to cut the wires as close to the tabs as possible.

6. With the forceps, place the red-tabbed wire into the red-tabbed hole in the thermocouple mount. The wire should be inserted from the shiny side of the thermocouple mount. Place the green wire in the green-tabbed hole. (If there is no green tab it is the un-tabbed hole.)

7. Thread the two wires through the holes until the small welded junction of the thermocouple is about 1/4" above the shiny surface of the thermocouple mount. Gently pull the red-tabbed wire until the welded junction is just at the entrance to the hole and then bend the wire on the back of the thermocouple mount so that it will not slip out.

8. With a pair of forceps or needle nose pliers, insert the pin with the white wire attached to it into the hole housing the red-tabbed wire. The pin should fit snugly into the hole. If it does not, it should be slightly bent to make a tighter fit. As the pin enters the hole, the wire will be pushed out the other end.

9. Pull the green-tabbed wire through its hole until the junction is at the entrance of the hole and insert the other pin (with the brown wire). After the pins have been inserted, the wires on the shiny side of the thermocouple mount should have been pushed out the same distance, leaving the welded junction in the center. If not, adjust the pins until the junction is centered.

10. Using a razor blade or forceps, carefully clip away the excess thermocouple wire. Excess wire can short the thermocouple to the mount.

11. Place the thermocouple mount into the mount plate with the pins facing up and the thermocouple facing down. Replace the two mount screws and grounding lug.

12. Use an ohm meter to check for continuity and shorts. The resistance between the black wire and the white wire should be about 20 ohms. If this is not the case, remove the thermocouple mount and recheck your work. You may also check for shorts between the pins and the thermocouple mount.

13. Wrap the black thermocouple lead wire into the grooves surrounding the thermocouple mount.

Since each thermocouple is slightly different, it is necessary to re-calibrate the instrument after changing the thermocouple. See the calibration section of this manual for further instructions.

Non-Routine Maintenance

Replace Thermocouple

If the thermocouple has been seriously damaged or broken, you can replace it yourself (instructions above), purchase a thermocouple already mounted in the thermocouple mount (model TM 1), or return the SC10 to Decagon for service. If damage is limited to

the thermocouple alone, repair charges will be minimal.

Replace NiCad Batteries

If your batteries will not hold a charge, Decagon can provide replacements, if you cannot procure them at your location. The replacement cost is minimal.

Replace Lithium Cells

Tru Psi's program and data memory is backed up by semi-permanent lithium cells. These will rarely need changing (about every 10 years or so). When they do the system will no longer work. Return the microcontroller to Decagon for this service.

Loading Firmware

Firmware is the program that the Tru Psi microcontroller runs on. Periodically, Decagon will send upgrades to this firmware to make your instrument better as we discover ways to improve the program. These upgrades are free of charge. It is important to let us know your address so that we can get these to you.

The PsiLink program sent with your Tru Psi (it is the same program used for downloading data to your computer). Connect the microcontroller to the computer as you would for downloading data. Open

the black case and move the jumper to cover both pins instead of just one (see figure 12).

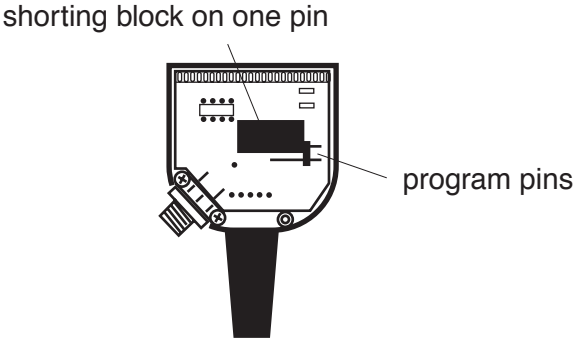


Fig. 12 Programming Pin

In the PsiLink program, under Options select "Firmware". Turn the microcontroller on (the display will remain blank). Load the file titled TRUPSIxx.HEX (xx signifies the version number). This is located on the diskette sent with your system. It will ask for the serial number of your instrument before continuing. Your serial number is found on the start-up screen when you turn on your instrument. It is also found on the inside of the microcontroller enclosure. You (or a previous user) may have recorded the serial number on page 6 of the manual with the registration code. When it is finished, disconnect the cable (now is a good time to replace the programming jumper to just one pin to avoid problems downloading data) and turn on your

instrument. At this time you will again be required to give the registration code that you received when you registered.

Resolving Problems

If Tru Psi needs service for any problem, call Decagon for repair information. When shipping it to us, please include a document giving the complete shipping address, the name and department of the person responsible for the instrument, and a description of the problem. For non-warranty repairs, also include a repair budget, billing information, and a purchase order number.

Pack Tru Psi carefully. Return to:

Decagon Devices
Attn: Tru Psi Repair Dept.
950 NE Nelson Court
Pullman, WA 99163

If possible, ship Tru Psi in its original packing case. If the case is not available, pad the instrument generously.

Repair Costs

Instruments covered by warranty will be repaired at no charge (not including shipping). If the one-year warranty has expired, parts, labor, and shipping costs

will be billed to you. A $50 minimum repair charge applies. An expedite fee is charged for rush work. Decagon will gladly provide an estimated repair cost.

Appendix A: Richards Thermocouple

A thermocouple has two junctions: a reference junction and a wet bulb. The Peltier thermocouple creates a wet bulb by cooling the junction to the point where dew forms. The Richards thermocouple creates a wet bulb by having the user dip the junction in pure, distilled water.

When used with the Richards thermocouple, Tru Psi holds nine samples (one space is used by a water reservoir) in its enclosed sample ring. Each sample separately equilibrates with the water vapor in the air around it. After half an hour, the water potential of the sample and the air will be equal. The thermocouple is dipped in pure, distilled water, and then a sample is clamped up and sealed to the thermocouple mount. As the water evaporates from the thermocouple, Tru Psi records the change in voltage across the thermocouple wires. Then, algorithms in the microcontroller use that voltage to compute the water potential of the sample. The equations used are detailed in the Theory section of this manual.

Range

The Richards thermocouple has a range of -3.0 to -1000 bars. It is effective in measuring drier samples; however, it is more difficult to use than the Peltier thermocouple.

Installation

If you did not request Tru Psi with the Richards option, you will need to order the thermocouple from Decagon. The thermocouple can be ordered either by itself or already installed in a thermocouple mount. Call Decagon for more information. To install the thermocouple, you will need to disassemble the SC10. Please refer to Chapter 7 for information on disassembling the SC10.

The Richards thermocouple also comes with a white delrin water reservoir. This fits in the 0 position of the sample chamber and is used to wet the thermocouple.

Method

To make readings with the Richards thermocouple, set up Tru Psi as described in the Start Up section of this manual.

Calibration

A perfect psychrometer, in which no heat is lost or

gained from the environment, has a constant of .067. The constant for a real-world psychrometer must be determined empirically. Tru Psi is calibrated using a standard salt solution with a known water potential. The psychrometer constant for each instrument will be slightly different. Your SC10 was calibrated at the factory. Its psychrometer constant is given on the calibration page at the end of this manual. This value should stay fairly constant over the life of the instrument. If you get a very different constant, check the Sources of Error listed at the end of this chapter.

First, fill the water reservoir with distilled water. Use pure water from a dropper. The meniscus should be even with the top of the reservoir (figure 13). Line up position 0 with the load chamber and slide the reservoir in.

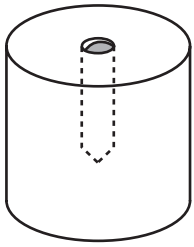
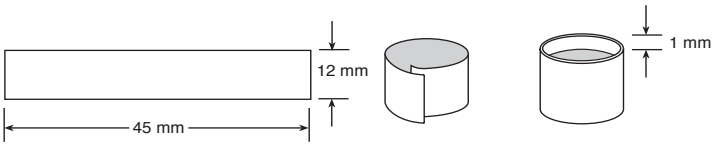


Figure 13: water reservoir

Tru Psi calibrates itself to a salt solution of 0.5 molal KCl. For calibration, a strip of filter paper 12 mm by

45 mm is wrapped inside a sample cup. Push the paper down until the space between the paper and the cup rim is 1 mm. Filter paper strips are shipped with Tru Psi. Additional strips can be obtained from Decagon.



Pour some KCl into the sample cup. Add just enough to cover the bottom and wet the filter paper.

Quickly slide the sample cup down the loading chamber and put the teflon plug in. This minimizes error due to evaporation. Rotate the knob so that the thermocouple (which lies under the "Read" arrow) is over an empty chamber. This prevents condensation on the thermocouple mounting plate.

Leave the KCl to come to vapor equilibrium with the air surrounding it. It should equilibrate within 20 minutes. When equilibration is complete, choose F3: Read from the Main menu. Select F3: Cal to begin calibration. The following screen will appear:

```
DIP TC, CLAMP
0.5M KCL UNDER TC
PRESS <ENTER>
TO CALIBRATE
```

As you rotate the knob of the SC10, the sample ring, which looks like the dial on a rotary phone, is also turning. It rides on two ball bearings. It slides between positions, then drops into place with a metallic click. If you turn the knob slowly, the sample ring will stop as each sample lines up. The Read arrow will indicate which sample lies under the thermocouple. You can then pull up on the read lever to clamp that sample into place under the thermocouple.

Note: if the sample cup is not lined up under the thermocouple, it will get jammed in when you pull up on the read lever. Solution: turn the knob slowly and stop at the click.

Gently turn the changer knob until the Read arrow points to the zero on the knob. The water reservoir is now under the thermocouple. The thermocouple just needs a brief dip in the reservoir. Raise the read lever, then lower it quickly. Be sure to push the lever down completely. Then rotate to sample 1. Raise the Read

lever and clamp the cup into place and immediately press ENTER. The screen will show thermocouple voltage (in microvolts) as it changes. It will also show the reference temperature and the elapsed time in seconds. You can abort the reading by pressing F4.

When calibration is complete, Tru Psi will display a calibration constant. Check this constant against the factory calibration constant. If they are fairly close, Tru Psi is working well. Press F1 to accept this value and continue. You will return to the Read menu. If it is very far off, wait 2 minutes for further equilibration. Then press F2 to recalculate. If the value still looks bad, press F3 to discard and read about "Sources of Error" at the end of this section.

Determining Equilibrium Time

An accurate water potential reading takes time. Not too much, and not too little. If you wait too long to make a reading, the water potential reading will be too low. If you don't wait long enough, water will still be evaporating from the thermocouple and the reading will be too high. We recommend 2 minutes for most applications as a standard time.

The sample water potential must fall within 30 to 30,000 J/kg
(-3 to -1000 bars). Samples wetter than this will cause errors due to condensation. Samples drier than this

will absorb water from the thermocouple's clay bead.

Prepare the samples you want to measure. Load the SC10. Be careful to avoid evaporating water from the samples. Load the water reservoir in position 0. Plug the loading chamber. Rotate the knob to leave the thermocouple over the driest sample (or an empty chamber). This minimizes the chance that water will condense on the thermocouple mounting plate. Wait 20 minutes while the samples equilibrate.

To determine thermocouple equilibrium time, choose F2: Read from the Main menu. Then select F2: uVolt. Dip the thermocouple in the water reservoir (turn the knob until the Read arrow points to position 0; raise and then lower the read lever). Rotate to position 1. Clamp the sample cup under the thermocouple. Press ENTER to begin the read cycle.

Tru Psi displays the changing thermocouple voltage. It also shows the reference temperature and elapsed time. As the wet bulb junction is cooled by evaporation, the microvolt reading will decrease quickly. When the clay bead and the vapor near equilibrium (called "thermocouple equilibrium" in this manual), the voltage decrease will slow. F1 can be used to freeze the reading when it becomes fairly steady. There are also other options associated with the Richards thermocouple. They are described in the

menu section under microvolt mode. Best accuracy is achieved by using a standard time for measurement (like two minutes). Tru Psi will automatically read and stop up to the specified times.

Tru Psi will display a final voltage, temperature, and elapsed time. Record the elapsed time. Choose F4 to discard the value. Tru Psi is ready to read the second sample. Dip the thermocouple again. Rotate to position 2 and start the reading. Freeze the reading when it becomes steady. The elapsed time should be close to that of the first sample. This time is your vapor equilibrium time. It is typically about 2 minutes. It varies with the type of sample being measured. If you are measuring samples of similar water potential, this time value should be the same for all samples. If the water potential of your samples varies greatly, you may want to vary the equilibrium time.

This time value is entered in the Setup: Read Options: Config SC10 menu. Select F1 to configure the first SC10. Select F1 to set the thermocouple type. Choose F2 to set the vapor equilibrium time. Type in the time in minutes and seconds and press ENTER. Press F3 to return to the Main menu.

Measuring Water Potential

Tru Psi is now calibrated and configured. It is ready to read samples.

Select F2: Read from the Main menu. Choose F1: H2O Potential. Rotate to position 0 and dip the thermocouple. Then rotate to sample 1. Raise the Read lever and clamp the cup into place. Press ENTER. The screen will show thermocouple voltage (in microvolts) as it changes. It will also show the reference temperature, the change in temperature (to alert you to possible error), and the elapsed time in seconds. You can abort the reading by pressing F4.

The reading will freeze at the point you set in System/Read/Configure SC10. Tru Psi will display the sample's water potential and the sample temperature in Celsius, You can save the reading with or without a comment. To save without, just press F1.

Note: Tru Psi will not mark the data as "Sample #1" "Sample # 2" and so on. Save the data with a comment by pressing F2.

Type in the comment at the prompt. If you find yourself typing the same phrase over and over again, you may wish to assign that phrase to a function key in the Fn Key option of the Setup: System menu. Pressing ENTER will save the data. You will be ready to read the next sample.

Dip the thermocouple in the water reservoir, then clamp Sample 2 into place. Continue until all samples have been read; press the [up arrow] to return to the Read menu.

You can put a new batch of samples in, equilibrate them, and read them. You don't have to re-calibrate or reconfigure Tru Psi unless conditions change.

Sources of Error

Tru Psi is measuring very small temperature differences. You will make most measurements at very high humidities. A change in water potential of 20 J/kg (0.2 bars) reflects a change in wet bulb depression of just 0.0017 degrees.

Be aware of sources of error. Minimize these errors with careful handling. Most errors come from two sources: bad reference temperature or bad wet bulb temperature.

Bad Reference Temperature

The reference temperature is measured at the thermocouple mounting plate. For an accurate measurement, this temperature needs to be as close as possible to the actual temperature of the sample. Temperature gradients can have a serious effect. Gradients come from environmental influence and chamber contamination. Here are some typical problems with straightforward solutions.

Dirty sample cup rim: contaminates the thermocouple mounting plate. Always wipe off the cup rim carefully.

Sample splashes: the mount plate can be contaminated by splashes from the sample cups. Always use the filter paper method with liquid samples. Fill the cup less than half full. Use the pointed end of the loading chamber plug to shape the sample (but only if the sample material holds its shape!). Move the knob and read lever gently. If you suspect the thermocouple has become dirty, refer to chapter 7 for instructions on cleaning.

Fluctuating environmental temperature: from drafts, heaters, people moving through, etc. Locate Tru Psi in an isolate room. Make sure the temperature stays constant.

Heat from the operator: heat can be transferred to Tru Psi from the user. The top knob and the read lever are insulated. While making readings, don't touch any other part of the SC10. Handle the knobs and levers as little as possible.

Bad Wet Bulb Temperature

The wet bulb is measured at the clay-bead covered thermocouple junction. This junction measures relative humidity in the sample chamber. Materials and deposits in the sample chamber absorb water. This prevents vapor equilibrium.

Dry wet bulb junction:
The bead should be very wet. Possible problems:

1. The water reservoir is not full enough.

2. The thermocouple is bent and the clay bead doesn't reach the reservoir.

3. The operator forgot to dip between measurements.

Very dry samples can also cause problems. They can actually absorb water from the clay bead. The opposite problem is condensation. Water from very wet samples can condense on the thermocouple mount, making your readings inaccurate. Typical causes of these problems (with their solutions)

include:

Dirty sample cup rim:
This contaminates the thermocouple mounting plate. Always wipe off the cup rim carefully.

Sample splashes
The mount plate can be contaminated by splashes from the sample cups. Always use the filter paper method with liquid samples. Fill the cup less than half full. Use the pointed end of the loading chamber plug to shape the sample (but only if the sample material holds its shape!). Move the knob and read lever gently.

Water condensation from a sample
Never put a cup of pure water in the sample changer. During long sample equilibration, let the thermocouple rest over an empty chamber or over a fairly dry sample. Never leave it over the water reservoir. Don't read samples with water potential higher than about -30 J/kg (-0.3 bars).

Underfilled water reservoir
The thermocouple doesn't reach the water reservoir. Fill the reservoir until the water meniscus is even with the reservoir top.

Bent thermocouple

The thermocouple doesn't reach the water reservoir. The bulb is dry when measurements start. Don't overfill the sample cups to avoid bending the thermocouple. See the Care and Maintenance Section if you suspect it has already been bent!

Broken thermocouple

The clay may have been knocked off the junction by an overfilled sample cup. If the damage has occurred, see the Care and Maintenance section.

Appendix B: Salt Standards

Following is a table showing the water potential at given concentrations of NaCl and KCl at 20 C.

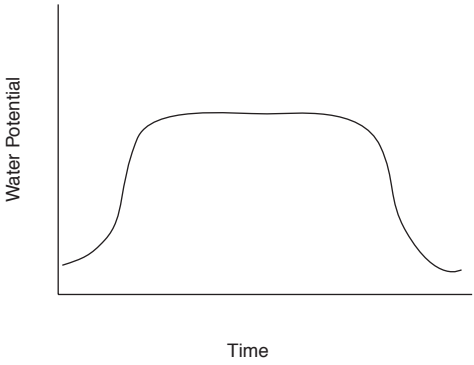
Table 2: Ψ of NaCl and KCl in bars (J/kg x $10^{2)}$

Concentration (Moles/kg)	NaCl	KCl
0.05	-2.32	-2.32
0.10	-4.54	-4.52
0.20	-9.01	-8.88
0.30	-13.49	-13.26
0.40	-17.93	-17.60
0.50	-22.42	-21.90
0.60	-26.99	-26.22
0.70	-31.59	-30.61
0.80	-36.18	-35.01
0.90	-40.87	-39.31
1.00	-45.58	-43.72

Appendix C: Equilibrium Times

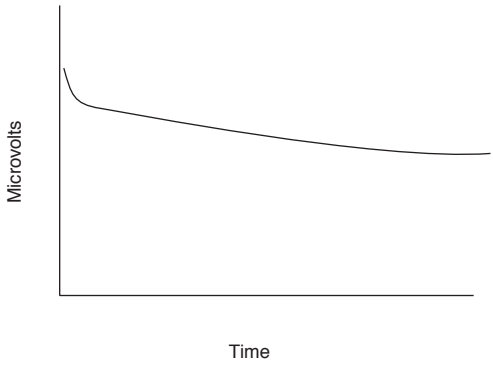
When measuring the water potential it is important to note the equilibrium time. Getting the time right can be critical to obtaining accurate readings. Each sample that is measured shows a different microvolt curve. It is good to know the basic curves that samples show. Following are 3 examples. On each graph, the best equilibrium time is indicated.

When determining an equilibrium time it is also important to remember that for a set of similar samples, the greatest accuracy will be found when a standard equilibrium time is used. Variation of equilibrium times can result in greater uncertainty and operator error. When using the log data mode, it is possible to generate a graph very similar to graph 1. On this graph, it is easy to see the time required to reach the plateau. You will want to select an equilibrium time on the plateau.



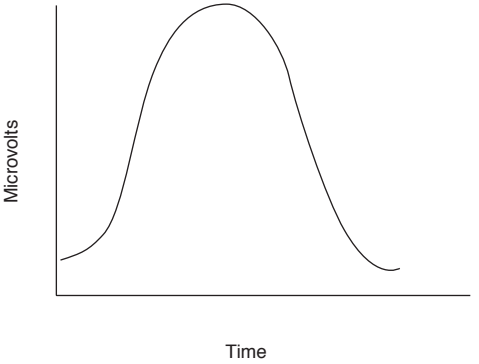
Graph 1

Graph 2 shows the standard curve when microvolts are plotted over time using a Richards thermocouple. The Tru Psi takes a reading at 2 minutes. This yields the most accurate results. When measuring a number of samples, using a set time (like 2 minutes) will make it so the results relate well to each other.



Graph 2

Graph 3 shows the standard microvolt/time curve for a peltier thermocouple. On this curve the peak microvolt reading is used to compute the water potential. Tru Psi watches for this peak and makes the reading.



Graph 3

Appendix D: Troubleshooting

The following is a guide to possible solutions to problems you may encounter when sampling with your Tru Psi system. If you encounter a problem that is not addressed below, or the solutions listed below do not solve your problem, contact Decagon for further assistance.

Sampling Problems

Tru Psi is measuring very small temperature differences. You will make most measurements at very high humidities. A change in water potential of 20 J/kg (0.2 bars) reflects a change in wet bulb depression of just 0.0017 degrees.

Be aware of sources of error. Minimize these errors with careful handling. Most errors come from two sources: bad reference temperature or bad wet bulb temperature.

Bad Reference Temperature

The reference temperature is measured at the thermocouple mounting plate. For an accurate measurement, this temperature needs to be as close as

possible to the actual temperature of the sample. Temperature gradients can have a serious effect. Gradients come from environmental influence and chamber contamination. Here are some typical problems with straightforward solutions.

- **Dirty sample cup rim**: this contaminates the thermocouple mounting plate. Always wipe off the cup rim carefully.

- **Sample splashes**: the mount plate can be contaminated by splashes from the sample cups. Always use the filter paper method with liquid samples. Fill the cup less than half full. Use the pointed end of the loading chamber plug to shape the sample (but only if the sample material holds its shape!). Move the knob and read lever gently. If you suspect the thermocouple has become dirty, refer to chapter 7 for instructions on cleaning.

- **Fluctuating environmental temperature**: from drafts, heaters, people moving through, etc. Keep Tru Psi in an isolated room to minimize this. Make sure the temperature stays constant.

- **Heat from the operator**: heat can be transferred to Tru Psi from the user. The top knob and the read lever are insulated. While making readings, don't touch any other part of the SC10. Handle the knobs and levers as little as possible.

Bad Wet Bulb Temperature

The wet bulb is measured at the thermocouple junction. This junction measures relative humidity in the sample chamber. If there are other materials or deposits in the sample chamber, they will absorb water. This prevents vapor equilibrium.

- **Dry wet bulb junction** (Richards thermocouple only):

The bead should be very wet. Possible problems:

1. The water reservoir is not full enough.

2. The thermocouple is bent and the clay bead doesn't reach the reservoir.

3. The operator forgot to dip between measurements.

- **Very dry samples** can cause problems. If using a Richards thermocouple, they can actually absorb water from the clay bead.

- **Dirty sample cup rim**: This contaminates the thermocouple mounting plate. Always wipe off the cup rim carefully.

- **Sample splashes**: The mount plate can be contaminated by splashes from the sample cups. Always use the filter paper method with liquid samples. Fill the cup less than half full. Use the

pointed end of the loading chamber plug to shape the sample (but only if the sample material holds its shape!). Move the knob and read lever gently.

- **Water condensation from a sample**: Water from very wet samples can condense on the thermocouple mount and make your readings inaccurate. Never put a cup of pure water in the sample changer. During long sample equilibration, let the thermocouple rest over an empty chamber or over a fairly dry sample. Never leave it over the water reservoir (if using a Richards thermocouple). Don't read samples with water potential higher than about -30 J/kg (-0.3 bars).

- **Underfilled water reservoir (Richards thermocouple only)**: The thermocouple doesn't reach the water reservoir. Fill the reservoir until the water meniscus is even with the reservoir top.

- **Bent thermocouple**: Don't overfill the sample cups to avoid bending the thermocouple. See the Care and Maintenance Section if you suspect it has already been bent!

- **Broken thermocouple**: If the thermocouple is improperly handled or the sample cup is overfilled, the thermocouple can break. If this has occurred, contact Decagon.

Inaccurate or inconsistent readings

Possible reasons:

- **No preparation**: user hasn't prepared the SC10 and the sample as described in Chapter 4, including: calibrating the SC10, setting the correct thermocouple type, setting the cooling and vapor equilibrium times (if different from defaults), and letting the sample come to equilibrium before reading.

- **Dirty thermocouple**: the thermocouple can become dirty from improper handling or contamination from samples. Follow the directions in Chapter 7 for directions on cleaning the thermocouple.

- **Sample not clamped**: you may not have clamped the sample up to the thermocouple. Check to make sure the handle is securely clamped in the up position.

Large number for γ when calibrating

If you get an enormous number like 191493... for γ when you are calibrating, there are two possible reasons:

- The thermocouple is broken. Contact Decagon for further instruction.
- The 4-pin connector wires are not plugged in to the Tru Psi motherboard. Unscrew the microcontroller and make sure the connector coming from the 4-pin port is connected to the motherboard.

If you get a number for γ that exceeds your original

gamma by .05, your thermocouple is probably dirty. Refer to Chapter 7 for instructions on cleaning the thermocouple.

N displayed for temperature

- If you are reading a sample and the temperature displays the letter N instead of a number, this indicates that there is a problem with your Tru Psi's ability to accurately measure the sample temperature. Contact Decagon for further directions if this occurs.

NaN displayed for uV

- This message indicates that the value being measured is not an acceptable number. You may either have a broken thermocouple or the 4-pin connector is not plugged into the Tru Psi motherboard. Unscrew the microcontroller and make sure the connector coming from the 4-pin port is connected to the motherboard.

Hardware Problems

Won't Download Data to computer

Possible reasons:

- Make sure the computer's communications settings are correct (9600 baud, no parity, 8 databits, 1 stopbit, correct COM port).
- Make sure the shorting block in the RS-232 cable's circuit board is not connected to both program pins.

- Check the solder connections of the 5-pin connector inside the Tru Psi case from the wires to the solder cups.

Analog Failure

If you encounter this message when sampling or in any menu, there is a problem with the Tru Psi's internal circuits, which requires service from Decagon's technicians. Please contact Decagon for details.

Won't Turn On

- Make sure batteries have been recently recharged.
- Try to re-load the Tru Psi's operating code to the instrument. There is a remote chance that the code has somehow become corrupted and needs to be re-installed.

The Manual

If you have comments, corrections, or suggestions about the manual and its content, please let us know. Contact the Tru Psi Product Manager at 1-800-755-2751 in the US and Canada or at (509) 332-2756. You can also fax your comments at (509) 332-5158 or e-mail them at tru_psi@decagon.com.

Index

S

T

U

W