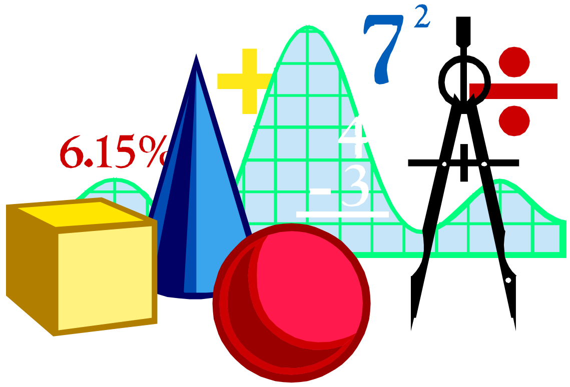

BI-APR100

Burns Instruments

Automated Psychrometer

Reader

User's Guide

v1.2

Revision Date: December 14, 1997

Warning: This instrument is not to be used with human subjects.
The BI-APR100 is not to be used in any system for use with human subjects and the manufacturer will not be responsible for the results of such misapplication of this device.

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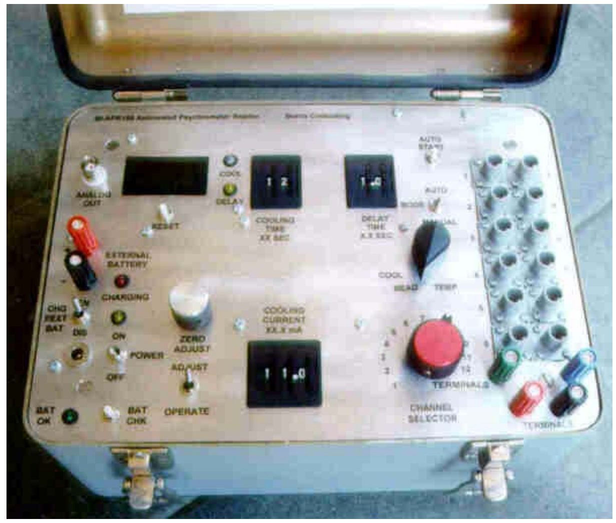

Congratulations!

You have just purchased a field portable precision instrument capable of amplifying microvolt signals (10^{-6}) and supplying currents of up to 59.9mA for Peltier cooling of psychrometers. This affordable combined instrument, the BI-APR100, will allow you to observe small signals from twelve psychrometers operated in the psychrometric mode[1]. Examples of psychrometers compatible with the BI-APR100 are the Wescor C-52, C-30, L-51, L-51A, PCT-55 and PST-55 models as well as the Merrill 75-2C and similar models. The BI-APR100 manually multiplexed psychrometer reader allows the user to control the analog zero offset voltages, inject cooling current, and switch between up to twelve psychrometers. The Bi-APR100 allows the user to run fully manually whereby the operator controls each aspect of a psychrometer reading, or the operator can automate much of the measurement process, thus reducing random errors associated with psychrometer readings.

1 Psychrometric mode is also know as the "Wet Bulb" or "Peltier" mode.

I. Setting Up the Psychrometer Reader

The first step in operating your psychrometer reader is to be sure you have all of the necessary equipment. Below we list the components that are provided with BI-APR100. They are as follows:

- the BI-APR100 unit,
- 120 Volt AC adapter,
- Automobile cigarette lighter 12 volt adapter with 0.75 amp GGS 5 x 20mm type fuse[2]
- SUREFAST™ (Viking) connector to banana plug adapter

In addition, you will need to supply the following:

- psychrometers (sources are listed in Section VIII),
- fresh ***sterile*** sucrose solutions of known molality
- strip chart recorder (if manual or semiautomatic operation will be used)

Before measuring a tissue sample, one must calibrate the behavior of each psychrometer by using sucrose solutions of known water potential. An approximate equation for the molality (m) of a sucrose solution of osmotic potential Ψ_S can be found in the excellent book, "Measuring the Water Status of Plants and Soils, 2nd Edition", John S. Boyer, (Academic Press, New York, 1995) page 99:

$$m = -5.6067 + \sqrt{31.4355 - \frac{11236\ \Psi_S}{8.3143\text{x}10^{-6} D T}}$$

[2] The automobile cigarette lighter 12 volt adapter is supplied configured with color coded banana plugs to be connected to the **EXTERNAL BATTERY** posts (#8 in Figure II.1). Do not replace these banana plugs with a ϕ2.1x5mm power plug for use with the ϕ2.1x5mm power jack (#10 in Figure II.1) unless you want the unit to *always* attempt to charge its internal battery using, and possibly depleting, the automobile battery if the engine is not running.

where *T* is the temperature in Kelvin, D is the density of water[3] at temperature *T* in g/m^3, Ψ_S is the osmotic potential in MPa, and m has units of mole*(kg H_2O)$^{-1}$.

[3] Tables of the density of water as a function of temperature may be found in the *CRC Handbook of Chemistry and Physics*. (CRC Press, Cleveland Ohio)

II. Operating the BI-APR100 Psychrometer Reader

In this section, we explain how to assemble the various parts of BI-APR100 Psychrometer Reader system. The instructions refer to the various controls and connectors on the BI-APR100 electronics box with the numbers shown in Figure II.1 below:

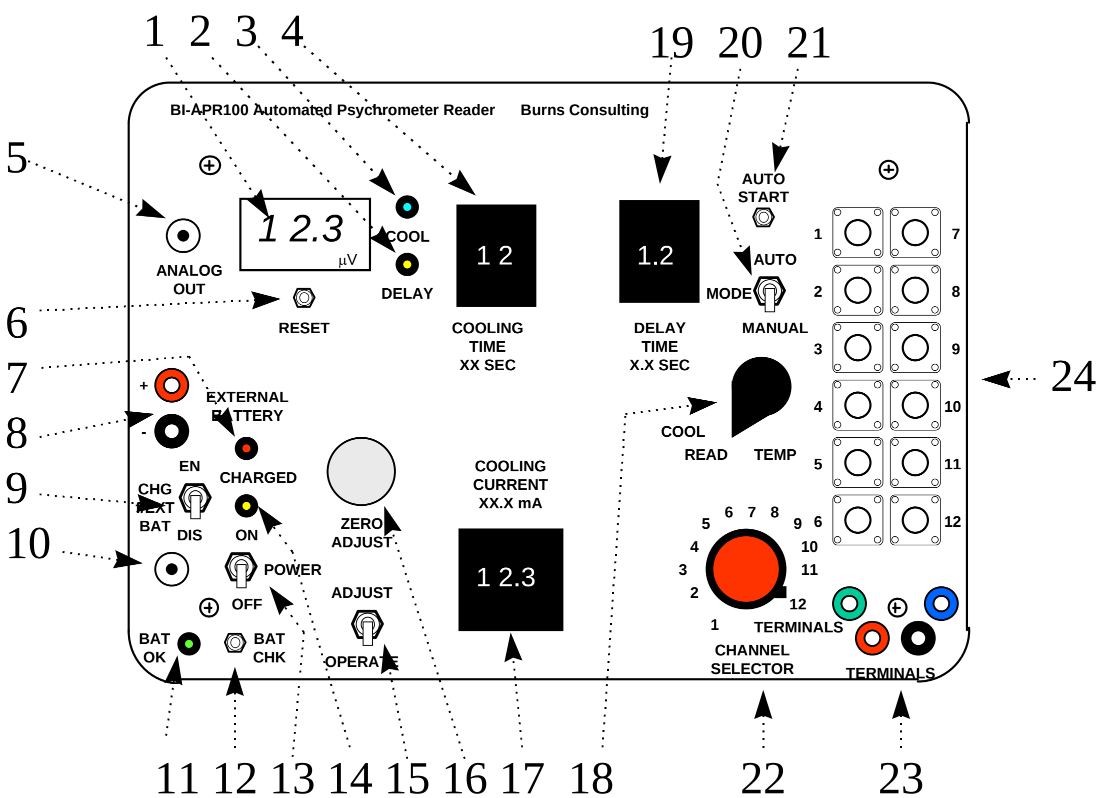

Figure II.1 – Instrument panel.

Preparing for operation powered by the internal battery

STEP 1: Verify Battery Status

Press the battery check (**BAT CHK**) button in the lower left corner of the BI-APR100 panel (12). Verify that the battery OK (**BAT OK**) **green** LED (11) lights. If not, then charge the unit using one of the charging procedures below, or operate the unit from an external power source using one of the procedures below. The power switch (13) does not need to be in the ON position for the battery check procedure to function correctly.

STEP 2: Warming up the unit

Switch the **ZERO ADJUST** switch (15) to the **ADJUST** position.

Set the **MODE** switch (20) to **MANUAL**.

Set the **MANUAL** rotary switch (18) to **READ**.

Switch the **POWER** switch (13) to the **ON** position.

The yellow power LED (14) should be on. Allow the unit to warm up for at least 20 minutes.[4]

Preparing for operation powered by the 120 VAC adapter (charging)

*Note: The order of completing step 1 before step 2 is important in order to set the power management logic into the charge cycle state, as opposed to a only a trickle charge state. If the order is reversed, the power management unit logic may erroneously assess the battery as being fully charged, go into the trickle charge state, and light the **red CHARGED** LED (7) immediately. No damage will occur, however the unit will only be trickle charging the battery.*

STEP 1: Setting the unit's switches

Switch the **ZERO ADJUST** switch (15) to the **ADJUST** position.

Set the **MODE** switch (20) to **MANUAL**.

Set the **MANUAL** rotary switch (18) to **READ**.

Switch the **POWER** switch (13) to the **ON** position.

STEP 2: Connect the 120 VAC adapter

Connect the 120 VAC adapter to a 120 VAC source, and the output plug of the adapter to the ϕ2.1x5.5mm power jack receptacle indicated as 10 in Figure II.1.

The yellow power LED (14) should be on. Allow the unit to warm up for at least 40 minutes.[4] It should be noted that when operating from the 120 VAC adapter, the power management circuit will automatically assess the state of the internal battery and run the internal battery through a charge cycle if needed. The **red CHARGED** LED (7) will be off if the battery is being fast charged by the power management circuit. Note that the BI-APR100 cannot charge a battery connected to the **EXTERNAL BATTERY** terminals (8).

The power management circuitry will assess the battery's charge state and start a controlled charge/condition cycle. The battery itself will be 90% charged usually within 8-10 hours of the start of a cycle. Details of the battery conditioning and charge cycle are described in Section VI. The battery is fully conditioned and in a float state when the **red CHARGED** LED (7) turns on. This may take 8-24 hours depending on the initial depletion state of the battery. The user may remove the unit from charging for use after 8-10 hours even though the **red CHARGED** LED (7) has not turned on and still expect ~100 hours of operation, however repeatedly not allowing the power management circuitry to fully complete the charge/condition cycle will reduce the useful life of the battery.[5]

[4] A fully charged internal battery should provide over 100 hours of operation.
[5] Properly conditioned, the battery should last 6-10 years.

During the initial stages of charging, the power management circuit may dissipate several watts inside the BI-APR100 case and cause thermal gradients which will decrease as the battery approaches a fully charged state. These gradients can, under certain circumstances, cause drifts over time in the psychrometer readings if the zero offset is not checked frequently. If possible, we recommend allowing the unit to charge the internal battery fully before operating the unit off the 120VAC adapter, as indicated by the **red** **CHARGED** LED (7) turning on.

The BI-APR100 does not require the internal battery to be present in order to operate off the 120 VAC adapter or an external battery. If circumstances warrant, the internal battery may be removed per the instructions in Section VI.

Preparing for operation powered by the 120 VAC adapter (no charging)

Note: The order of completing step 1 before step 2 is important in order to set the power management logic into only a trickle charge, as opposed to a fast charge state. The trickle charge state will be indicated by the ***red CHARGED*** *LED (7) being on from the start.*

STEP 1: Connect the 120 VAC adapter

Connect the 120 VAC adapter to a 120 VAC source, and the output plug of the adapter to the ϕ2.1x5.5mm power jack receptacle indicated as 10 in Figure II.1.

STEP 2: Setting the unit's switches

Switch the **ZERO ADJUST** switch (15) to the **ADJUST** position.

Set the **MODE** switch (20) to **MANUAL**.

Set the **MANUAL** rotary switch (18) to **READ**.

Switch the **POWER** switch (13) to the **ON** position.

The yellow power LED (14) should be on, as should the **red** **CHARGED** LED (7). Allow the unit to warm up for at least 40 minutes.[4]

The BI-APR100 does not require the internal battery to be present in order to operate off the 120 VAC adapter or an external battery. If circumstances warrant, the internal battery may be removed per the instructions in Section VI.

Preparing for operation powered by the external battery terminals (no charging)

STEP 1: Connect the external battery

The BI-APR100 will draw about 40mA continuously, and as much as 100mA intermittently (40mA + cooling current), depending on the **COOLING CURRENT** settings. When picking an external direct current (DC) power source such as a lantern battery, automobile battery, automobile cigarette lighter[6], or other DC source, the source must be able to supply at least 7 volts DC, and no more than 30 volts DC, at the current levels mentioned above for operation, and at least 14 volts DC[7], and no more than 30 volts DC. The externally supplied power does not need to be regulated and can drift without affecting the accuracy of the BI-APR100, however if the external voltage source contains large amounts of noise or voltage spikes, as can sometimes come from poorly built or ancient automobile alternators, the timing circuitry in the BI-APR100 *might* occasionally false trigger.

Connect the external battery or DC power source to the **EXTERNAL BATTERY** terminals (8) observing the correct polarity. *Connecting an external power source to the* ***EXTERNAL BATTERY*** *terminals (8) with the polarity reversed will result in damage to the BI-APR100 unit and void the warrantee.*

STEP 2: Warming up the unit

[6] The automobile cigarette lighter 12 volt adapter is supplied configured with color coded banana plugs to be connected to the **EXTERNAL BATTERY** posts (#8 in Figure II.1). Do not replace these banana plugs with a ϕ2.1x5mm power plug for use with the ϕ2.1x5mm power jack (#10 in Figure II.1) unless you want the unit to *always* attempt to charge its internal battery using, and possibly depleting, the automobile battery if the engine is not running.

Switch the **ZERO ADJUST** switch (15) to the **ADJUST** position.

Set the **MODE** switch (20) to **MANUAL**.

Set the **MANUAL** rotary switch (18) to **READ**.

Switch the "charge from external battery" switch labeled **CHG f/EXT BAT** (9) to the disable (**DIS**) position.

Switch the **POWER** switch (13) to the **ON** position.

The yellow power LED (14) should be on. Allow the unit to warm up for at least 20 minutes.[8]

Preparing for operation powered by the external battery terminals (charging)

*Note: The order of completing step 1 before step 2 is important in order to set the power management logic into the charge cycle state, as opposed to a only a trickle charge state. If the order is reversed, the power management unit logic may erroneously assess the battery as being fully charged, go into the trickle charge state, and light the **red CHARGED** LED (7) immediately. No damage will occur, however the unit will only be trickle charging the battery.*

STEP 1: Setting up the unit

Switch the **ZERO ADJUST** switch (15) to the **ADJUST** position.

Set the **MODE** switch (20) to **MANUAL**.

Set the **MANUAL** rotary switch (18) to **READ**.

Switch the "charge from external battery" switch labeled **CHG f/EXT BAT** (9) to the enable (**EN**) position.

Switch the **POWER** switch (13) to the **ON** position.

STEP 2: Connect the external DC power source

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[7] The cigarette lighter in a modern automobile will put out 14 volts when the engine is idling with no other loads (such as the head or tail lights), or will put out 14 volts with additional loads when the engine is operating well above idle as in highway driving.

[8] A fully charged internal battery should provide over 100 hours of operation.

The BI-APR100 will draw about 40mA continuously, and as much as 100mA intermittently (40mA + cooling current), depending on the **COOLING CURRENT** settings, during normal operation. When picking an external direct current (DC) power source such as a lantern battery, automobile battery, automobile cigarette lighter[9], or other DC source, the source must be able to supply at least 7 volts DC, and no more than 30 volts DC, at the current levels mentioned above for operation. If the external DC power source is also to be used for charging the BI-APR100's internal battery, then it needs to supply at least 14 volts DC[10], and no more than 30 volts DC at up to 500mA, in order to use the external power source to fully charge the BI-APR100 internal battery. Partial charging of the BI-APR100 internal battery may be achieved with the externally supplied voltage as low as 12 volts and 100mA.[11] The externally supplied DC power does not need to be regulated and can drift without affecting the accuracy of the BI-APR100, however if the external voltage source contains large amounts of noise or voltage spikes, as can sometimes come from poorly built or ancient automobile alternators, the timing circuitry in the BI-APR100 *might* occasionally false trigger.

Connect the external battery or DC power source to the **EXTERNAL BATTERY** terminals (8) observing the correct polarity. *Connecting an external power source to the* ***EXTERNAL BATTERY*** *terminals (8) with the polarity reversed will result in damage to the BI-APR100 unit and void the warrantee.*

[9] The automobile cigarette lighter 12 volt adapter is supplied configured with color coded banana plugs to be connected to the **EXTERNAL BATTERY** posts (#8 in Figure II.1). Do not replace these banana plugs with a ϕ2.1x5mm power plug for use with the ϕ2.1x5mm power jack (#10 in Figure II.1) unless you want the unit to *always* attempt to charge its internal battery using, and possibly depleting, the automobile battery if the engine is not running.

[10] The cigarette lighter in a modern automobile will put out 14 volts when the engine is idling with no other loads (such as the head or tail lights), or will put out 14 volts with additional loads when the engine is operating well above idle as in highway driving.

[11] The cigarette lighter in a modern automobile will put out about 12.5 volts when the engine is off but the electrical system is activated with no other loads (such as the head or tail lights), if the car battery is fully charged..

The yellow power LED (14) should be on. Allow the unit to warm up for at least 40 minutes.[12] It should be noted that when operating from the external DC power source, the power management circuit will automatically assess the state of the internal battery and run the internal battery through a charge cycle if needed. The **red** **CHARGED** LED (7) will be off if the battery is being charged by the power management circuit.

The power management circuitry will assess the battery's charge state and start a controlled charge/condition cycle. The battery itself will be 90% charged usually within 8-10 hours of the start of a cycle. Details of the battery conditioning and charge cycle are described in Section VI. The battery is fully conditioned and in a float state when the **red** **CHARGED** LED (7) turns on. This may take 8-24 hours depending on the initial depletion state of the battery. The user may remove the unit from charging for use after 8-10 hours even though the **red** **CHARGED** LED (7) has not turned on and still expect ~100 hours of operation, however repeatedly not allowing the power management circuitry to fully complete the charge/condition cycle will reduce the useful life of the battery.[13]

During the initial stages of charging, the power management circuit may dissipate several watts inside the BI-APR100 case and cause thermal gradients which will decrease as the battery approaches a fully charged state. These gradients can, under certain circumstances, cause drifts over time in the psychrometer readings if the zero offset is not checked frequently. If possible, we recommend allowing the unit to charge the internal battery fully before operating the unit off the 120VAC adapter, as indicated by the **red** **CHARGED** LED (7) turning on.

The BI-APR100 does not require the internal battery to be present in order to operate off the 120 VAC adapter or an external battery. If circumstances warrant, the internal battery may be removed per the instructions in Section VI.

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[12] A fully charged internal battery should provide over 100 hours of operation.
[13] Properly conditioned, the battery should last 6-10 years.

Connecting psychrometers to the BI-APR100

The BI-APR100 comes with twelve SUREFAST™ connector receptacles (24) and one general purpose connector composed of **TERMINALS** (23) capable of accommodating wires or wires with banana plugs.

If the psychrometer has a SUREFAST™ connector, simply plug it into one of the twelve connector receptacles (24). If the psychrometer does not have a connector and only have bare wires, strip the last centimeter of insulation from each wire and connect it to the screw **TERMINALS** (23) according to the tables in Cheaper VII.

Since many people add the SUREFAST™ connectors to their psychrometers themselves, there is the possibility that the SUREFAST™ connector is incorrectly wired. This is especially true if the psychrometer is old or if the user did not realize that psychrometer made by different manufacturers use different wire color coding. A SUREFAST™ to banana plug adapter, which allows the user to connect the wires of a psychrometer which already has a SUREFAST™ connector to any of the **TERMINALS** (23), has been provided in case the user has to test for or compensate for this possibility. The pin to color assignment of the adapter follows the Wescor convention shown in Section VII.

Making a psychometric measurement

Manual psychometric measurements

From the warm-up, the **ZERO ADJUST** switch (15) should be in the **ADJUST** position, the **MODE** switch (20) in the **MANUAL** position, and the **MANUAL** rotary switch (18) in the **READ** position. If the HOLD indicator in the LCD display (1) is on, press for 1 second and release the **RESET** button (6). The HOLD indicator should turn off. If it does not, repeat pressing and releasing the **RESET** button (6) again. Alternatively, the HOLD indicator may be cleared by momentarily turning the **POWER** switch (14) to **OFF**, and then back to **ON** again.

Connect a strip chart recorder to the **ANALOG OUT** (5) of the unit, and set the recorder scale to a level sufficient to handle your anticipated psychrometer reading for the sample. The **ANALOG OUT** (5) outputs 1mV/μV when the **MANUAL** rotary switch (18) is in the **READ** and **COOL** positions, and outputs 1mV/°C when the **MANUAL** rotary switch (18) is in the **TEMP** position.

Adjust the **ZERO ADJUST** knob (16) until the reading in the display and on the strip chart recorder is as close to zero as you can make it. It usually is easy to adjust it to be less than 1μV.[14] The **μV** indicator should be on in the lower right of the LCD display (1). Record the remaining reading in the LCD display (1) in the same lab notebook and location that the psychrometer readings will be recorded. This is called the ***residual instrument zero reading (μV)***.

Switch the **CHANNEL SELECTOR** rotary switch (22) to the channel of the psychrometer of interest. Switch the **ZERO ADJUST** switch (15) to the **OPERATE** position. Record the remaining reading in the LCD display (1) in the same lab notebook and location that the psychrometer readings will be recorded. This is called the ***psychrometer baseline reading (μV)***. Switch the **MANUAL** rotary switch (18) to the **TEMP** position. The temperature of the psychrometer, in degrees C will be displayed in the LCD display (1). Depending on the physical condition of the psychrometer (i.e. dirty, corroded, etc.) it may take up to several minutes to settle to the correct reading. If the psychrometer is too corroded, it may never read the correct temperature.[15] The **°C** indicator should be on in the upper right of the LCD display (1). Record the temperature indicated for the psychrometer in the LCD

[14] For each 1μV that you fail to zero out in this step will result in 0.025°C of error in the temperature measurement.

[15] Systematic errors in the thermoelectric voltages generated within the psychrometer are less of a problem for psychrometer readings than they are for absolute temperature readings for two reasons. 1. For psychrometric readings, calibrated solutions are run in the psychrometer thus making the reading of the unknown specimen a differential measurement against the known solutions. 2. The corrosion potentials (electrochemical potentials) of the chromel-copper and constintan-copper junctions in the circuit used for psychrometric readings are of comparable size, but due to the circuit topology are of opposite polarity. Hence for psychrometer readings these two corrosion potentials pretty much cancel each other. However the corrosion potential of the constintan-copper junction used for the temperature reading is additive with the thermoelectric potential of that junction, thus making the temperature readings more susceptible to offsets due to corrosion in the psychrometer.

display (1) in the same lab notebook and location that the psychrometer readings will be recorded. This is will be referred to as the ***temperature reading (°C)***.

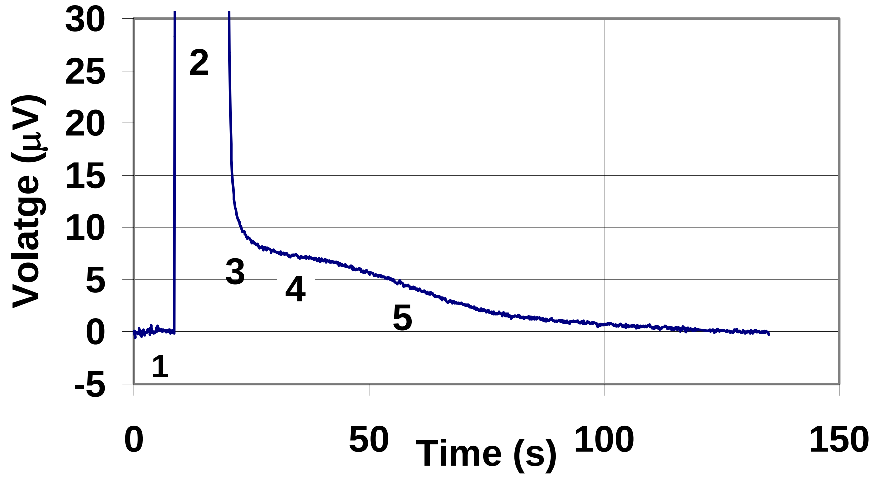

Figure II.2 - Chart recording of a 1M sucrose solution using somewhat contaminated psychrometer from J.R.D. Merrill Specialty Equipment (Model 75-2C) with 8.0 mA cooling current, and 10 seconds of cooling time, recorded in semiautomatic mode.

Select the level of cooling current between 59.9mA and 00.0mA using the **COOLING CURRENT** thumb wheel switches (17). Usually between 03.0mA and 10.0mA is the optimal range.[16]

Switch the **MANUAL** rotary switch (18) to **COOL** for the length of time you wish the psychrometer to cool, then switch it back over to **READ**. The strip chart recorder should display something like that shown in Figure II.2. ***Mark the strip chart with the voltage scale, time scale, identity of the psychrometer, cooling current level, and sample identity.***

The chart recording displayed in Figure II.2 is for a real psychrometer which is not perfectly clean. This is recording is sufficient for reading, but also displays some nonideal behavior due to residual contamination of the psychrometer. The region marked **1** is the baseline before application of the cooling current. This is the

[16] Merrill generally recommends 3.5mA to 5 mA. The Wescor HR-33T Dew Point Microvoltmeter uses 8mA. The Burns Consulting BC-MPNV100 uses 8mA.

reading one used the zero adjust to minimize. The region marked **2** is the region where the cooling current was applied. The reason the curve is off the top of the chart in this region is that the voltage across the psychrometer thermocouple is on the order of hundreds, possibly thousands, of microvolts. The cooling current is on the order of several mA, possibly as much as 59.9mA. The psychrometer junction resistance and leads or on the order of 1 tenth of an ohm, possibly as much as a couple of ohms if the psychrometer is on the end of long cables. This current and resistance, multiplied by each other (V=I*R) produce the large voltage seen by the amplifier during cooling (region **2**). Region **3** indicates the depressed temperature of the psychrometer junction after the cooling current has been removed. This region (3) or the relatively flat region is the ***psychrometer reading (μV)***. This temperature is determined by the rate of evaporation of the water condensed on the junction during the cooling stage (region **2**), back into the air inside the psychrometer chamber. Ideally this region will be flat until all of the water has evaporated, at which point the temperature will return the original baseline (region **5**). Reality is usually somewhat different from the "ideal". The droop (region **4**) in the plateau in Figure II.2 is typical of real psychrometers after they have been used for a while, even after cleaning. The place to take the reading is as close to the beginning of region **3** as possible, however since with Peltier psychrometers the readings of the tissue samples must be calibrated against known solutions *for each individual psychrometer*, consistency in picking the length of time after cessation of the cooling current to read the psychrometer is the more important factor.

In Figure II.3 we show a trace from a new clean psychrometer using the same sucrose solution as that in Figure II.2. The major difference is that the plateau shows less droop (region **4**) and when the last of the condensed water evaporates from the thermocouple junction , to drop towards the baseline is sharper (region **5**).

A few comments are in order. The optimal level for the cooling current depends how large a Peltier effect the thermocouple material used in the psychrometer produces, the ohmic heating in the junction when the cooling current is applied, and the thermal conductance between the junction and the rest of the psychrometer. This latter is itself a complex function of the psychrometer construction and also contamination in the psychrometer. Thus the optimal amount of cooling current will vary from psychrometer to psychrometer, even amongst the same models from a given manufacturer manufactured at the same time. History of use, contamination and variations in manufacture will cause differences between the "optimal" cooling current for psychrometers. We recommend that the user label each psychrometer with a water proof tag containing a unique inventory serial number, and the user should experiment to determine the optimal cooling current settings for that psychrometer. Those settings can then also be placed on the psychrometer's tag.

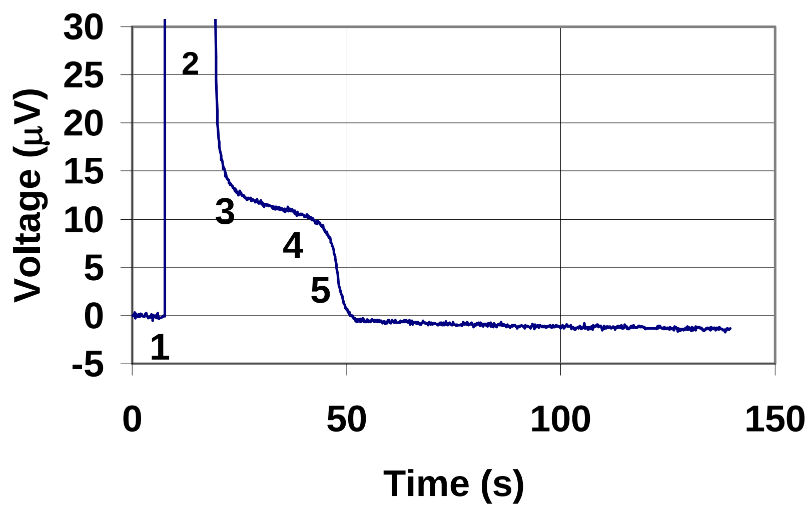

Figure II.3 - Chart recording of a 1M sucrose solution using a new clean psychrometer from Wescor (Model L51) with 10 mA cooling current, and 10 seconds of cooling time, recorded in semiautomatic mode. The continued drift after region 5 is due to the psychrometers temperature drifting.

Semi-automatic psychometric measurements

From the warm-up, the **ZERO ADJUST** switch (15) should be in the **ADJUST** position, the **MODE** switch (20) in the **MANUAL** position, and the **MANUAL** rotary switch (18) in the **READ** position. If the HOLD indicator in the

LCD display (1) is on, press for 1 second and release the **RESET** button (6). The HOLD indicator should turn off. If it does not, repeat pressing and releasing the **RESET** button (6) again. Alternatively, the HOLD indicator may be cleared by momentarily turning the **POWER** switch (14) to **OFF**, and then back to **ON** again.

Connect a strip chart recorder to the **ANALOG OUT** (5) of the unit, and set the recorder scale to a level sufficient to handle your anticipated psychrometer reading for the sample. The **ANALOG OUT** (5) outputs 1mV/μV when the **MANUAL** rotary switch (18) is in the **READ** and **COOL** positions, and outputs 1mV/°C when the **MANUAL** rotary switch (18) is in the **TEMP** position.

Adjust the **ZERO ADJUST** knob (16) until the reading in the display and on the strip chart recorder is as close to zero as you can make it. It usually is easy to adjust it to be less than 1μV.[17] The **μV** indicator should be on in the lower right of the LCD display (1). Record the remaining reading in the LCD display (1) in the same lab notebook and location that the psychrometer readings will be recorded. This is called the ***residual instrument zero reading (μV)***.

Switch the **CHANNEL SELECTOR** rotary switch (22) to the channel of the psychrometer of interest. Switch the **ZERO ADJUST** switch (15) to the **OPERATE** position. Record the remaining reading in the LCD display (1) in the same lab notebook and location that the psychrometer readings will be recorded. This is called the ***psychrometer baseline reading (μV)***. Switch the **MANUAL** rotary switch (18) to the **TEMP** position. The temperature of the psychrometer, in degrees C will be displayed in the LCD display (1). Depending on the physical condition of the psychrometer (i.e. dirty, corroded, etc.) it may take up to several minutes to settle to the correct reading. If the psychrometer is too corroded, it may never read the correct temperature.[18] The **°C** indicator should be on in the upper right of the LCD

[17] For each 1μV that you fail to zero out in this step will result in 0.025°C of error in the temperature measurement.

[18] Systematic errors in the thermoelectric voltages generated within the psychrometer are less of a problem for psychrometer readings than they are for absolute temperature readings for two reasons. 1. For psychrometric readings, calibrated solutions are run in the psychrometer thus making the reading of the unknown specimen a differential measurement against the known solutions. 2. The corrosion potentials

display (1). Record the temperature indicated for the psychrometer in the LCD display (1) in the same lab notebook and location that the psychrometer readings will be recorded. This is will be referred to as the ***temperature reading (°C)***.

Select the level of cooling current between 59.9mA and 00.0mA using the **COOLING CURRENT** thumb wheel switches (17). Usually between 03.0mA and 10.0mA is the optimal range. [19] Select the length of the length of the **COOLING TIME**, between 0 and 99 seconds, using the thumb wheel switches (4).

Press the **AUTO START** button (21) to start the sequence. The strip chart recorder should display something like that shown in Figure II.2. During the cooling cycle, the **blue** **COOL** LED (3) will be lighted, and during the delay portion the yellow **DELAY** LED (2) will light. The LCD display (1) reading will freeze at a time after the cessation of the cooling current specified by the **DELAY TIME** thumb wheel switches (19), and the HOLD indcator will turn on in the LCD display (1). We will not be using this reading in the semiautomatic mode. Press for 1 second and release the **RESET** button (6). The HOLD indicator should turn off. If it does not, repeat pressing and releasing the **RESET** button (6) again. Alternatively, the HOLD indicator may be cleared by momentarily turning the **POWER** switch (14) to **OFF**, and then back to **ON** again. ***Mark the strip chart with the voltage scale, time scale, identity of the psychrometer, cooling current level, and sample identity.***

The chart recording displayed in Figure II.2 is for a real psychrometer which is not perfectly clean. This is recording is sufficient for reading, but also displays some nonideal behavior due to residual contamination of the psychrometer. The region marked **1** is the baseline before application of the cooling current. This is the reading one used the zero adjust to minimize. The region marked **2** is the region

(electrochemical potentials) of the chromel-copper and constintan-copper junctions in the circuit used for psychrometric readings are of comparable size, but due to the circuit topology are of opposite polarity. Hence for psychrometer readings these two corrosion potentials pretty much cancel each other. However the corrosion potential of the constintan-copper junction used for the temperature reading is additive with the thermoelectric potential of that junction, thus making the temperature readings more susceptible to offsets due to corrosion in the psychrometer.

[19] Merrill generally recommends 3.5mA to 5 mA. The Wescor HR-33T Dew Point Microvoltmeter uses 8mA The Burns Consulting BC-MPNV100 uses 8mA.

where the cooling current was applied. The reason the curve is off the top of the chart in this region is that the voltage across the psychrometer thermocouple is on the order of hundreds, possibly thousands, of microvolts. The cooling current is on the order of several mA, possibly as much as 59.9mA. The psychrometer junction resistance and leads or on the order of 1 tenth of an ohm, possibly as much as a couple of ohms if the psychrometer is on the end of long cables. This current and resistance, multiplied by each other (V=I*R) produce the large voltage seen by the amplifier during cooling (region **2**). Region **3** indicates the depressed temperature of the psychrometer junction after the cooling current has been removed. This region (3) or the relatively flat region is the ***psychrometer reading (μV)***. This temperature is determined by the rate of evaporation of the water condensed on the junction during the cooling stage (region **2**), back into the air inside the psychrometer chamber. Ideally this region will be flat until all of the water has evaporated, at which point the temperature will return the original baseline (region **5**). Reality is usually somewhat different from the "ideal". The droop (region **4**) in the plateau in Figure II.2 is typical of real psychrometers after they have been used for a while, even after cleaning. The place to take the reading is as close to the beginning of region **3** as possible, however since with Peltier psychrometers the readings of the tissue samples must be calibrated against known solutions *for each individual psychrometer*, consistency in picking the length of time after cessation of the cooling current to read the psychrometer is the more important factor.

In Figure II.3 we show a trace from a new clean psychrometer using the same sucrose solution as that in Figure II.2. The major difference is that the plateau shows less droop (region **4**) and when the last of the condensed water evaporates from the thermocouple junction , to drop towards the baseline is sharper (region **5**).

A few comments are in order. The optimal level for the cooling current depends how large a Peltier effect the thermocouple material used in the psychrometer produces, the ohmic heating in the junction when the cooling current is applied, and the thermal conductance between the junction and the rest of the psychrometer. This latter is itself a complex function of the psychrometer construction and also contamination in the psychrometer. Thus the optimal amount of cooling current will vary from psychrometer to psychrometer, even amongst the same models from a given manufacturer manufactured at the same time. History of use, contamination and variations in manufacture will cause differences between the "optimal" cooling current for psychrometers. We recommend that the user label each psychrometer with a water proof tag containing a unique inventory serial number, and the user should experiment to determine the optimal cooling current settings for that psychrometer. Those settings can then also be placed on the psychrometer's tag.

Automatic psychometric measurements

From the warm-up, the **ZERO ADJUST** switch (15) should be in the **ADJUST** position, the **MODE** switch (20) in the **MANUAL** position, and the **MANUAL** rotary switch (18) in the **READ** position. If the HOLD indicator in the LCD display (1) is on, press for 1 second and release the **RESET** button (6). The HOLD indicator should turn off. If it does not, repeat pressing and releasing the **RESET** button (6) again. Alternatively, the HOLD indicator may be cleared by momentarily turning the **POWER** switch (14) to **OFF**, and then back to **ON** again.

Adjust the **ZERO ADJUST** knob (16) until the reading in the display and on the strip chart recorder is as close to zero as you can make it. It usually is easy to adjust it to be less than 1μV.[20] The **μV** indicator should be on in the lower right of the LCD display (1). Record the remaining reading in the LCD display (1) in the same lab notebook and location that the psychrometer readings will be recorded. This is called the ***residual instrument zero reading (μV)***.

Switch the **CHANNEL SELECTOR** rotary switch (22) to the channel of the psychrometer of interest. Switch the **ZERO ADJUST** switch (15) to the **OPERATE** position. Record the remaining reading in the LCD display (1), called the ***psychrometer baseline reading (μV)***, in the same lab notebook and location that the psychrometer readings will be recorded. Switch the **MANUAL** rotary switch (18) to the **TEMP** position. The temperature of the psychrometer, in degrees C will be displayed in the LCD display (1). Depending on the physical condition of the psychrometer (i.e. dirty, corroded, etc.) it may take up to several minutes to settle to the correct reading. If the psychrometer is too corroded, it may never read the correct temperature.[21] The **°C** indicator should be on in the upper right of the LCD display (1). Record this ***temperature reading (°C)*** indicated for the psychrometer in the LCD display (1) in the same lab notebook next to the ***residual instrument zero reading (μV)*** and ***psychrometer baseline reading (μV)***.

Select the level of cooling current between 59.9mA and 00.0mA using the **COOLING CURRENT** thumb wheel switches (17). Usually between 03.0mA and 10.0mA is the optimal range.[22] Select the length of the length of the **COOLING TIME**, between 0 and 99 seconds, using the thumb wheel switches (4).

Select the **DELAY TIME** for the reading, between 0.0 and 9.9 seconds, using the thumb wheel switches (19). This is the length of time after the cessation of the cooling current that you want the unit to read the psychrometer. We suggest that you familiarize yourself with the behavior of each psychrometer read while operating the BI-APR100 in the fully manual mode, and tag the

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[20] For each 1μV that you fail to zero out in this step will result in 0.025°C of error in the temperature measurement.

[21] Systematic errors in the thermoelectric voltages generated within the psychrometer are less of a problem for psychrometer readings than they are for absolute temperature readings for two reasons. 1. For psychrometric readings, calibrated solutions are run in the psychrometer thus making the reading of the unknown specimen a differential measurement against the known solutions. 2. The corrosion potentials (electrochemical potentials) of the chromel-copper and constintan-copper junctions in the circuit used for psychrometric readings are of comparable size, but due to the circuit topology are of opposite polarity. Hence for psychrometer readings these two corrosion potentials pretty much cancel each other. However the corrosion potential of the constintan-copper junction used for the temperature reading is additive with the thermoelectric potential of that junction, thus making the temperature readings more susceptible to offsets due to corrosion in the psychrometer.

[22] Merrill generally recommends 3.5mA to 5 mA. The Wescor HR-33T Dew Point Microvoltmeter uses 8mA. The Burns Consulting BC-MPNV100 uses 8mA.

psychrometer with the **DELAY TIME** that works best for it. (Please see the section titled "Preparing for field use" later in this section.)

Press the **AUTO START** button (21) to start the sequence. During the cooling cycle, the **blue** **COOL** LED (3) will be lighted, and during the delay portion the yellow **DELAY** LED (2) will light. The LCD display (1) reading will freeze at a time after the cessation of the cooling current specified by the **DELAY TIME** thumb wheel switches (19), and the HOLD indicator will turn on in the LCD display (1). This is the ***psychrometer reading*** which you should record in your lab notebook next to the ***psychrometer baseline reading (μV)*** and ***temperature reading (°C)*** for the psychrometer. ***Along with these readings, record the identity of the psychrometer and the sample.*** After you have recorded the ***psychrometer reading (μV)***, press for 1 second and release the **RESET** button (6). The HOLD indicator should turn off. If it does not, repeat pressing and releasing the **RESET** button (6) again. Alternatively, the HOLD indicator may be cleared by momentarily turning the **POWER** switch (14) to **OFF**, and then back to **ON** again.

The chart recording displayed in Figure II.2 is for a real psychrometer which is not perfectly clean. This is recording is sufficient for reading, but also displays some nonideal behavior due to residual contamination of the psychrometer. The region marked **1** is the baseline before application of the cooling current. This is the reading one used the zero adjust to minimize. The region marked **2** is the region where the cooling current was applied. The reason the curve is off the top of the chart in this region is that the voltage across the psychrometer thermocouple is on the order of hundreds, possibly thousands, of microvolts. The cooling current is on the order of several mA, possibly as much as 59.9mA. The psychrometer junction resistance and leads or on the order of 1 tenth of an ohm, possibly as much as a couple of ohms if the psychrometer is on the end of long cables. This current and resistance, multiplied by each other (V=I*R) produce the large voltage seen by the amplifier during cooling (region **2**). Region **3** indicates the depressed temperature of the psychrometer junction after the cooling current has been removed. This temperature is determined by the rate of evaporation of the water condensed on the junction during the cooling stage (region **2**), back into the air inside the psychrometer chamber. Ideally this region will be flat until all of the water has evaporated, at which point the temperature will return the original baseline (region **4**). Reality is usually somewhat different from the "ideal". The droop in the plateau in Figure II.2 is typical of real psychrometers after they have been used for a while, even after cleaning. The place to take the reading is as close to the beginning of region 3 as possible, however since with Peltier psychrometers the readings of the tissue samples must be calibrated against known solutions *for each individual psychrometer*, consistency in picking the length of time after cessation of the cooling current to read the psychrometer is the more important factor.

In Figure II.3 we show a trace from a new clean psychrometer using the same sucrose solution as that in Figure II.2. The major difference is that the plateau shows less droop (region **4**) and when the last of the condensed water evaporates from the thermocouple junction , to drop towards the baseline is sharper (region **5**).

A few comments are in order. The optimal level for the cooling current depends how large a Peltier effect the thermocouple material used in the psychrometer produces, the ohmic heating in the junction when the cooling current is applied, and the thermal conductance between the junction and the rest of the psychrometer. This latter is itself a complex function of the psychrometer construction and also contamination in the psychrometer. Thus the optimal amount of cooling current will vary from psychrometer to psychrometer, even amongst the same models from a given manufacturer manufactured at the same time. History of use, contamination and variations in manufacture will cause differences between the "optimal" cooling current for psychrometers. We recommend that the user label each psychrometer with a water proof tag containing a unique inventory serial number, and the user should experiment to determine the optimal cooling current settings for that psychrometer. Those settings can then also be placed on the psychrometer's tag.

Charging the internal battery from the 120 VAC adapter

*Note: The order of completing step 1 before step 2 is important in order to set the power management logic into the charge cycle state, as opposed to a only a trickle charge state. If the order is reversed, the power management unit logic may erroneously assess the battery as being fully charged, go into the trickle charge state, and light the **red** **CHARGED** LED (7) immediately. No damage will occur, however the unit will only be trickle charging the battery.*

STEP 1: Unit Settings

Switch the **ZERO ADJUST** switch (15) to the **ADJUST** position.

Set the **MODE** switch (20) to **MANUAL**.

Set the **MANUAL** rotary switch (18) to **READ**.

Switch the **POWER** switch (13) to the **ON** position.

STEP 2: Connect the 120 VAC adapter

Connect the 120 VAC adapter to a 120 VAC source, and the output plug of the adapter to the receptacle indicated as 10 in Figure II.1.

The yellow power LED (14) should be on. The **red** **CHARGED** LED (7) will be off if the battery is being charged by the power management circuit. When the **red** **CHARGED** LED (7) turns on, the internal battery is fully charged and the power management circuit is maintaining the internal battery. The unit may be left in connected to the 120 VAC adapter in this maintenance mode indefinitely. Leave the cover on the BI-APR100 unit open at all times while the unit is charging or maintaining the internal battery. Also note that while the BI-APR100 cannot charge a battery connected to the **EXTERNAL BATTERY** terminals (8), we recommend that all connections to the **EXTERNAL BATTERY** terminals (8) be disconnected while the 120 VAC adapter is in use.

The power management circuitry will assess the battery's charge state and start a controlled charge/condition cycle. The battery itself will be 90% charged usually within 8-10 hours of the start of a cycle. Details of the battery conditioning and charge cycle are described in Section VI. The battery is fully conditioned and in a float state when the **red** **CHARGED** LED (7) turns on. This may take 8-24 hours depending on the initial depletion state of the battery. The user may remove the unit from charging for use after 8-10 hours even though the **red** **CHARGED** LED (7) has not turned on and still expect ~100 hours of operation, however repeatedly not allowing the power management circuitry to fully complete the charge/condition cycle will reduce the useful life of the battery.[23]

During the initial stages of charging, the power management circuit may dissipate several watts inside the BI-APR100 case. The unit may become slightly warm during the initial stages of charging.

Charging the internal battery from the external battery terminals

*Note: The order of completing step 1 before step 2 is important in order to set the power management logic into the charge cycle state, as opposed to a only a trickle charge state. If the order is reversed, the power management unit logic may erroneously assess the battery as being fully charged, go into the trickle charge state, and light the **red** **CHARGED** LED (7) immediately. No damage will occur, however the unit will only be trickle charging the battery.*

STEP 1: Unit Settings

Switch the **ZERO ADJUST** switch (15) to the **ADJUST** position.

Set the **MODE** switch (20) to **MANUAL**.

Set the **MANUAL** rotary switch (18) to **READ**.

[23] Properly conditioned, the battery should last 6-10 years.

Switch the "charge from external battery" switch labeled **CHG f/EXT BAT** (9) to the enable (**EN**) position.

Switch the **POWER** switch (13) to the **ON** position.

STEP 2: Connect the external DC power source

The BI-APR100 can draw as much as 500mA during charging. When picking an external direct current (DC) power source such as a lantern battery, automobile battery[24], or other DC source for charging the BI-APR100's internal battery at least 14 volts DC[25], and no more than 30 volts DC, at up to 500mA in order to use the external power source to fully charge the BI-APR100 internal battery. Partial charging of the BI-APR100 internal battery may be achieved with the externally supplied voltage as low as 12 volts and 100mA.[26] The externally supplied DC power does not need to be regulated.

Connect the external battery or DC power source to the **EXTERNAL BATTERY** terminals (8) observing the correct polarity. *Connecting an external power source to the **EXTERNAL BATTERY** terminals (8) with the polarity reversed will result in damage to the BI-APR100 unit and void the warrantee.*

The yellow power LED (14) should be on. The **red** **CHARGED** LED (7) will be off if the battery is being charged by the power management circuit. When the **red** **CHARGED** LED (7) turns on, the internal battery is fully charged and the power management circuit is maintaining the internal battery. The unit may be left connected to the external DC power source in this maintenance mode indefinitely

[24] The automobile cigarette lighter 12 volt adapter is supplied configured with color coded banana plugs to be connected to the **EXTERNAL BATTERY** posts (#8 in Figure II.1). Do not replace these banana plugs with a ϕ2.1x5mm power plug for use with the ϕ2.1x5mm power jack (#10 in Figure II.1) unless you want the unit to *always* attempt to charge its internal battery using, and possibly depleting, the automobile battery if the engine is not running.

[25] The cigarette lighter in a modern automobile will put out 14 volts when the engine is idling with no other loads (such as the head or tail lights), or will put out 14 volts with additional loads when the engine is operating well above idle as in highway driving.

without damaging the BI-APR100 unit, however doing so may drain the external source. Leave the cover on the BI-APR100 unit open at all times while the unit is charging or maintaining the internal battery.

The power management circuitry will assess the battery's charge state and start a controlled charge/condition cycle. The battery itself will be 90% charged usually within 8-10 hours of the start of a cycle. Details of the battery conditioning and charge cycle are described in Section VI. The battery is fully conditioned and in a float state when the **red** **CHARGED** LED (7) turns on. This may take 8-24 hours depending on the initial depletion state of the battery. The user may remove the unit from charging for use after 8-10 hours even though the **red** **CHARGED** LED (7) has not turned on and still expect ~100 hours of operation, however repeatedly not allowing the power management circuitry to fully complete the charge/condition cycle will reduce the useful life of the battery.[27]

During the initial stages of charging, the power management circuit may dissipate several watts inside the BI-APR100 case. The unit may become slightly warm during the initial stages of charging.

NOTE: If the DC power source has too low a voltage to cause the **red** **CHARGED** LED (7) to turn on, we recommend that the user either simply use a timed charge (i.e. charge for, say, 12 hours) or better, place a DVM in amp meter mode inline between the external source and the BI-APR100. The user should then monitor the current draw with time, which should decrease as the internal battery is charged. The BI-APR100 will draw a baseline of about 40mA.

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[26] The cigarette lighter in a modern automobile will put out about 12.5 volts when the engine is off but the electrical system is activated with no other loads (such as the head or tail lights), if the car battery is fully charged..

[27] Properly conditioned, the battery should last 6-10 years.

Reading the BI-APR100's internal ambient temperature

The internal temperature of the BI-APR100 can be read out by the following procedure assuming the BI-APR100 has already been warmed up using the appropriate procedure at the beginning of this section.

Switch the **ZERO ADJUST** switch (15) to the **ADJUST** position.

Set the **MODE** switch (20) to **MANUAL**.

Set the **MANUAL** rotary switch (18) to **READ**.

If the HOLD indicator in the LCD display (1) is on, press for 1 second and release the **RESET** button (6). The HOLD indicator should turn off. If it does not, repeat pressing and releasing the **RESET** button (6) again.

Adjust the **ZERO ADJUST** knob (16) until the reading in the display and on the strip chart recorder is as close to zero as you can make it. It usually is easy to adjust it to be less than 1μV.[28] The **μV** indicator should be on in the lower right of the LCD display (1).

Set the **MANUAL** rotary switch (18) to **TEMP**.

The reading in the LCD display (1) with the °C indicator in the upper right corner, is the internal temperature of the BI-APR100 unit.

Preparing for field use

Like any other field portable measurement system, familiarizing oneself with its operation and maintenance should be done ***before*** taking it into the field. The scientific literature is full of suspect scientific articles because the expedition personnel went into the field without first checking out and familiarizing themselves with their equipment while in the lab, where controlled cross checks could be made. After gathering data with faulty or misapplied instruments, there is an intense pressure to publish the results, no matter how poor or suspect the data may be, due to the great financial expense of an expedition. And in many

[28] For each 1μV that you fail to zero out in this step will result in 0.025°C of error in the temperature measurement.

cases, the expedition personnel are so unfamiliar with their equipment, they do not even realize their data is problematical.

To prepare the BI-APR100 for field use *each* user should run though each of the operations above for operating the BI-APR100 from every possible power source that may need to be utilized in the field. Using fresh sucrose calibration solutions, each user should operate the BI-APR in each of its modes (automatic, semi-automatic, and manual) enough to be able to recognize when some reading in the field does not make sense, thus indicating a problem. (The time to recognize measurement problems is when they occur, so they may be corrected.) In addition, measurements using calibration sucrose solutions should be made on each psychrometer that will be taken into the field. Copies of the data from such measurements should be brought with the user into the field to help determine if the field measurements are making sense.

Most importantly, each psychrometer should be tagged with an identification tag containing:

1. Some unique identity code that allows one to uniquely identify each psychrometer and its data (e.g. BIP#1, BIP#2, BIP#3, …)
2. The best cooling current setting for that specific psychrometer as determined through tests using the BI-APR100, or the psychrometer manufacturer's recommended nominal value.[29]
3. The best delay time setting for that specific psychrometer as determined through tests using the BI-APR100.

The unit does not require any preparation for packing. The lid should be closed and latched. ***No items of any kind should be stored inside the BI-APR100's cover as their motion may damage the unit or turn on its power.*** The adapters and psychrometers should be stored separately in the convenient case supplied by Burns Consulting. If the internal sealed battery needs to be removed due to local safety requirements, the instructions for doing so are in Section V.

[29] Merrill generally recommends 3.5mA to 5 mA. The Wescor HR-33T Dew Point Microvoltmeter uses 8mA. The Burns Consulting BC-MPNV100 uses 8mA.

Care and feeding of Psychrometers

The number one rule for use of psychrometers is "Clean them immediately after use and always store the clean, ***never*** store them without cleaning."

Psychrometers are very susceptible to artifacts due to corrosion of the various metals used in their construction. Typical voltages generated by the clean thermocouples used in psychrometers is about 40μV/°C. For the chromel-constintan thermocouple used for the measurement of the water condensation, a typical voltage generated during a measurement is on the order of 10μV. For the copper-constintan thermocouple used for the measurement of the difference between the psychrometer temperature and the BI-APR100's internal temperature, a typical voltage generated is also on the order of 10μV.

III. Data Analysis

We present a method for analyzing data from psychrometers where the data was collected under isothermal conditions. Other methods of analysis, some of which use empirically derived relationships to do limited corrections for nonisothermal conditions can be found elsewhere.[30]

Raw data

For a given measurement, you should have 4 quantities measured using the BI-APR100 unit, namely the ***residual instrument zero reading (μV)***, the ***temperature reading (°C)***, ***psychrometer baseline reading (μV)*** and ***psychrometer reading (μV)***. To convert the ***psychrometer baseline reading (μV)*** and ***psychrometer reading (μV)*** to their true values, one must subtract off the ***residual instrument zero reading (μV)***.

actual psychrometer baseline reading (μV) = psychrometer baseline reading (μV) - residual instrument zero reading (μV)

actual psychrometer reading (μV) = psychrometer reading (μV) - residual instrument zero reading (μV)

The ***final psychrometer reading (μV)*** is related to the ***actual psychrometer baseline reading (μV)*** and ***actual psychrometer reading (μV)*** by

final psychrometer reading (μV) = actual psychrometer reading (μV) - actual psychrometer baseline reading (μV)

= psychrometer reading (μV) - psychrometer baseline reading (μV)

Converting the calibration solution reading to humidity

[30] One of the common methods is found in "A Calibration Model for Screen-caged Peltier Thermocouple Psychrometers" by Ray W. Brown and Dale L. Bartos, Research paper INT-293, July 1982, Intermountain Forest and Range Experiment Station, Ogden UT, 84401.

The relationship between humidity and water potential, for water in air, is:

$$\Psi = \frac{RT}{V_w}\, ln\left(\frac{h}{h_o}\right)$$

where

Ψ is the water potential (Pa)

R is the universal gas constant ($8.3143 \frac{\text{Joules}}{\text{mole °K}}$)

$\frac{h}{h_o}$ is the relative humidity expressed as a fraction

T is the absolute temperature (°K)

V_W is the molar volume of water ($1.8 \times 10^{-5} \frac{m^3}{\text{mole}}$)

Which means the equation above can be expressed as

$$\Psi = \kappa\, T\, ln\left(\frac{h}{h_o}\right) \qquad \text{eq (III.1)}$$

where $\kappa = 461905.6 \frac{\text{Pa}}{\text{°K}}$

Inverting this equation gives us

$$\left(\frac{h}{h_o}\right) = e^{\frac{\Psi}{\kappa\, T}} \qquad \text{eq (III.2)}$$

An approximate equation for the osmotic potential (Ψ) of a sucrose solution of molality (m) can be found in the excellent book, "Measuring the Water Status of Plants and Soils, 2nd Edition", John S. Boyer, (Academic Press, New York, 1995) page 99:

$$\Psi = -1000*(0.89\, m^2 + 0.998m)DRT$$

where the units of Ψ are in Pa, and D is the density of water[31] at temperature T in g/m^3. This makes the relative humidity of a given calibration solution

[31] Tables of the density of water as a function of temperature may be found in the *CRC Handbook of Chemistry and Physics*. (CRC Press, Cleveland Ohio)

$$\left(\frac{h}{h_o}\right) = e^{\frac{-1000(0.89\,m^2 + 0.998m)DRT}{\kappa\,T}}$$

$$\left(\frac{h}{h_o}\right) = e^{-(890\,m^2 + 998m)D\,V_W}$$

$$\boxed{\left(\frac{h}{h_o}\right) = e^{-1.8 \times 10^{-5}(890\,m^2 + 998m)D}}$$

Using the calibration solution humidity data

Using the above formula, calculate for each of the calibration solution measurements the value of $\left(\frac{h}{h_o}\right)_{caln}$, for the nth calibration solution. Then pair up the numbers for the ***final psychrometer reading (µV)*** for that nth calibration solution reading, called ***final psychrometer reading (µV)$_{caln}$***, so that you have a set of ($\left(\frac{h}{h_o}\right)_{caln}$, ***final psychrometer reading (µV)$_{caln}$***,) pairs. Plot the pairs as illustrated below:

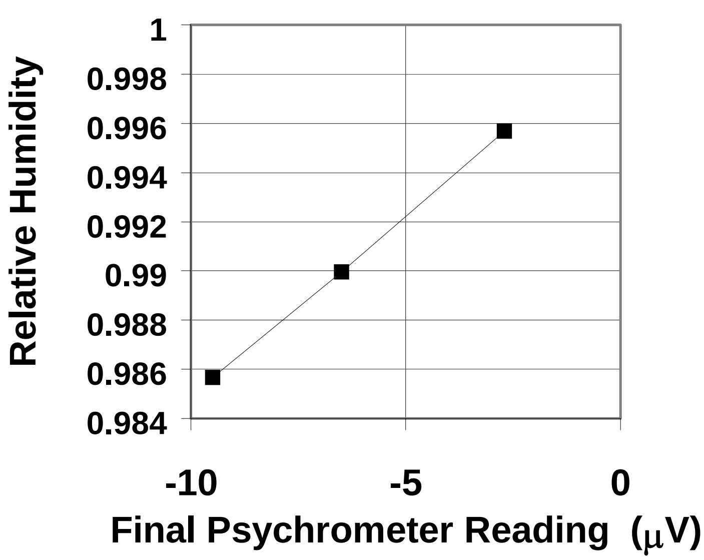

Figure III.1 - Calibration solution relative humidity versus ***final psychrometer reading (µV)$_{caln}$***.

Calculating the sample's water potential

Next, take the ***residual instrument zero reading (μV)***, the ***temperature reading (°C)***, ***psychrometer baseline reading (μV)*** and ***psychrometer reading (μV)*** for the sample and convert it to ***final psychrometer reading (μV)_{sample}***. Using your calibration solution chart, take the ***final psychrometer reading (μV)_{sample}*** and convert it to a relative humidity value, $\left(\frac{h}{h_o}\right)_{sample}$. Now take the ***temperature reading (°C)*** (T) and $\left(\frac{h}{h_o}\right)_{sample}$ pair, and using equation III.1, calculate the water potential (Ψ) for the sample.

IV. Troubleshooting and Getting Help

The BI-APR100 has been designed to be a trouble-free, easy to operate system for the field measurement of psychrometers. It is, however, a complex instrument incorporating ultra-low noise operational amplifier chips. The unit has been designed with two goals in mind: durability and precision. These goals are not necessarily complementary. It is possible that the chips, especially the ones at the front of the amplifier, may fail as they see the brunt of the influences from the outside world such as static discharges. In this case, Burns consulting will repair or replace, at our discretion, a defective BI-APR100 for a period of 1 year from the purchase of the BI-APR100.

It is possible that the troubles you are encountering are of a less catastrophic nature and can be remedied by corrective actions outlined in this section. In the following table, we outline some common difficulties along with recommendations. The suggested actions are listed in order of most common occurrence. Where appropriate, please refer to Figure II.1 for the location of the various controls and switches.

Symptom:	Action:
Unit drifts over the course of the day.[32]	1. Check to see if unit is on a place warmed by sun. Move it into the shade and give it time to cool down. 2. Check to see if psychrometers are being hit with draft from wind or ventilation system. Thermally isolate psychrometers.

Continued …

[32] An additional piece of information to bear in mind when troubleshooting the unit is the sizes of the thermal emf's generated by the electrical connections in the psychrometers are, at 25°C, 39.6μV/°C for copper-constintan, 59.8 μV/°C for chromel-constintan, and about 20μV/°C for copper-chromel.

Continued from previous page

Symptom:	Action:
Display reading is frozen, HOLD indicator is on.	1. Press the reset button for 1 second, then release. Repeat if need be. 2. Alternatively, the HOLD indicator may be cleared by momentarily turning the **POWER** switch (14) to **OFF**, and then back to **ON** again.
Analog output is ±1.2 volts all of the time and the display is showing ±1___ . Seems to be ignoring input signals.	1. The no psychrometer is connected (or there is a wire break). Connect psychrometer. 2. Adjust the "Zero Adjust" knob to bring the signal back within range. Referring to Figure II.1, remember to place the **ZERO ADJUST** switch (15) to **ADJUST** while turning the **ZERO ADJUST** knob (16). 3. Check that the **MANUAL** rotary switch (18) is set to **READ**.
Zero adjust knob has no effect on the output. Analog output is ±1.2 volts all of the time and the display is showing ±1___ . Seems to be ignoring input signals.	1. Check that psychrometer's signal wires are not grounded. 2. The input protection diodes are latched. Turn off the unit for 10 seconds and then back on. 3. Check that the **MANUAL** rotary switch (18) is set to **READ**.

Continued …

Continued from previous page

Symptom:	Action:
Analog output or display shows excessive noise. Other psychrometers seem OK.	1. Check that there are no loose wires associated with the psychrometer. 2. Check that there are no loose connectors associated with the psychrometer. 3. Check that the **MANUAL** rotary switch (18) is set to **READ**.
Strip chart tracing looks correct, except there is no plateau, or in automatic mode, cooling current peak appears but reading ends up pretty much back at baseline.	1. Check that the **ZERO ADJUST** switch (15) is in the **OPERATE** position. 2. Check to make sure the polarity of the psychrometer connections is correct.
Temperature reads roughly 20°C -15°C ***below*** the internal temperature. (Assuming of course, the psychrometers are not actually roughly 20°C -15°C ***below*** the internal temperature.)	1. Check to make sure the **CHANNEL SELECTOR** switch (22) is set to the correct psychrometer channel. 2. Check to make sure the psychrometer connections are correct. 3. Check the psychrometer for a broken thermocouple for the connections that would go to the **blue** and **black TERMINALS** (23), or pins 1 & 6 on the SUREFAST™ or Viking Connectors.

Continued …

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Symptom:	Action:
Temperature reads roughly 20°C -15°C ***above*** the internal temperature. (Assuming of course, the psychrometers are not actually roughly 20°C -15°C ***above*** the internal temperature.)	1. Check that the **COOLING** LED (3) is not on. In other words, that you do not have cooling current applied from hitting the AUTO START button (21) with the **MANUAL** rotary switch (18) is set to **TEMP**.
Psychrometer readings look odd.	1. Check to make sure the psychrometer connections are correct. 2. Check to make sure the **CHANNEL SELECTOR** switch (22) is set to the correct psychrometer channel. 3. Check the psychrometer for a broken thermocouple. 4. Check the wire assignments against those in Section VII.
Temperature readings look odd.	1. Make sure the **MODE** switch (20) is set to **MANUAL**, and the **MANUAL** rotary switch (18) is set to **TEMP**. 2. Check to make sure the psychrometer connections are correct. 3. Check to make sure the **CHANNEL SELECTOR** switch (22) is set to the correct psychrometer channel. 4. Check the wire assignments against those in Section VII.

Continued …

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Symptom:	Action:
Unit appears dead when powered on battery. **BAT CHK** indicates dead battery. Unit appears to work on external power sources.	1. Try charging battery overnight.
Reading jumps around a lot and does not make sense. Appears to correlate with the operator touching the unit.	1. Check to make sure the **CHANNEL SELECTOR** switch (22) is set to the correct psychrometer channel. 2. Check to make sure the psychrometer connections are correct. See Section VII. 3. Check the psychrometer for a broken thermocouple for the connections that would go to the **blue**, **red**, and **black TERMINALS** (23), or pins 1, 5 & 6 on the SUREFAST™ or Viking Connectors. See Section VII.
Unit appears dead when powered on battery. **BAT CHK** indicates dead battery. Unit appears to work on external power sources. Battery does not seem to charge. **BATTERY CHARGED** indicator fails to light when battery charging procedure is followed.	1. Check/replace internal 1 ampere internal battery fuse as described in Section VI. 2. Check/replace internal battery as described in Section VI.

Continued …

What if it never looks right?

Your BI-APR100 has been tested before shipping and demonstrated acceptable characteristics within the designed specifications. It is possible that something may have gone wrong with the unit subsequent to its departure for our test bench. If all else fails, fax or email us and describe your problem.

Email:

We are anxious to help you make the most out of your BI-APR100 Psychrometer Reader. You can best talk to us by email. You can send questions regarding your BI-APR100 Psychrometer Reader to us at:

mjburns@ix.netcom.com.

When you do contact us, please send a description of the problem and what steps you have already taken to try to rectify the problem. Please allow at least 24 hours for a reply to your question.

Fax:

You can also reach us by fax at (626) 398-7607. When you do contact us, please send a description of the problem and what steps you have already taken to try to rectify the problem. Please allow at least 24 hours for a reply to your question.

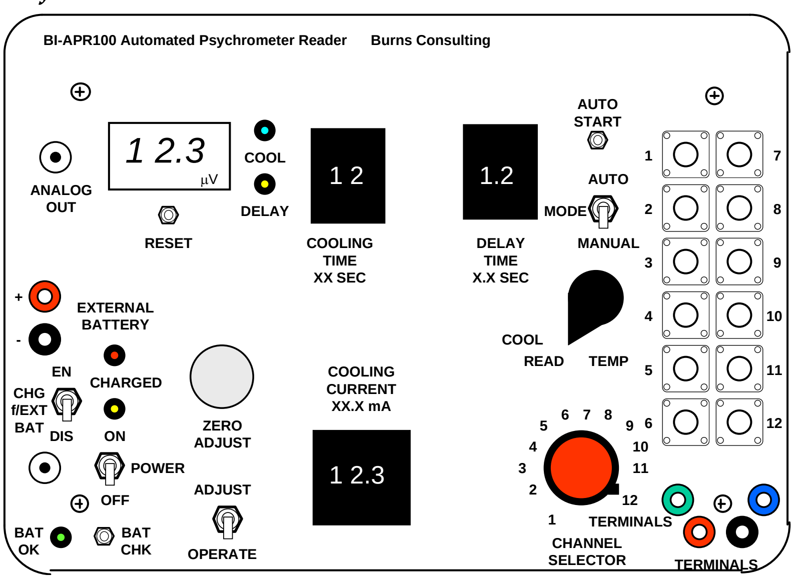
V. General Service and Technical Specifications

General Service

To extend the life of the batteries, the unit should be turned off when not in use unless connected to the 120 VAC adapter. Avoid exposing the unit to extreme temperature or conditions. While the unit is water resistant while the cover is closed and latched, getting the unit wet while the cover is open will damage the unit. ***No items of any kind should be stored inside the BI-APR100's cover as their motion may damage the unit or turn on its power.***

Try to keep the inside clean. If the units panel requires cleaning, use a damp cloth. Do not use solvents other than water, and do not use any household or commercial cleaning products.

Technical Specifications



General:

- Digital display
- selectable inputs with VIKING/SUREFAST(TM) connectors
- binding post input
- Analog output
- Internal sealed Yuasa-Exide lead acid battery (Meets Code of Federal Regulations and International Air Transport Association (IATA)

requirements) with charging and charge maintenance circuitry capable of operating the unit for 100 hours between charges.

- Battery check
- 120 VAC adapter-charger
- 1 binding post power connector for connection of an external 12-30 VDC power (e.g. automobile cigarette lighter)
- Zero Adjust capability
- User's Guide
- Fully manual mode psychrometric readings with:
    - input selection
    - amplifier zero adjust
    - user adjustable cooling current amplitude 0-59.9mA
    - continuous analog output
- Semiautomated mode psychrometric readings with:
    - input selection
    - amplifier zero adjust
    - user adjustable cooling current amplitude 0-59.9mA
    - user selection of cooling interval 0-99 seconds
    - continuous analog output
- Automated mode psychrometric readings with:
    - input selection
    - amplifier zero adjust
    - user adjustable cooling current amplitude 0-59.9mA
    - user selection of cooling interval 0-99 seconds
    - user selection of digital display reading delay 0-9.9 seconds
    - continuous analog output

Low-noise low-drift differential chopper amplifier

Input:	Type:	True differential.
	Differential input impedance:	250kΩ
	Impedance to ground:	10kΩ

Signal Readouts and Display

Analog Output:

READ setting:

1mV/1µV (±700mV maximum corresponding to ±700µV)

TEMP setting (psychrometer):

1 mV/1°C (±~20°C of internal reference)

TEMP setting (internal): 1 mV/1°C (0-70°C)

Digital Display:

READ setting: ±200µV

TEMP setting (psychrometer):

±~20°C of internal reference

TEMP setting (internal): 0-70°C

Current Source:

Output: Adjustable, 0-59.9mA

Repeatability: better than 0.5%

Absolute Accuracy: 6%

Power Supply:

Internal 12 volt 4.0 amp-hour sealed YUASA/EXIDE NP4-12 lead-acid battery @ 40 mA total with cooling current inactive. With cooling current active, 40mA + cooling current (60mA maximum cooling current). Internal power subsystem outputs 12 VDC (unregulated), ±10VDC (unregulated), 6 VDC (regulated) and 5 VDC (regulated) for internal use by BI-APR100 subsystems.

External 120 VAC to 18 VDC adapter for operation and charging of internal battery.

Box:

Extruded 064 gauge aluminum construction with latching hinged cover with gasket seal. 19 cm x 27 cm x 19 cm.

120 VAC Adapter:

Input: 120 VAC 60Hz 35W

Output: 18VDC 800mA (14.4VA) unregulated

Plug: ϕ2.1x5.5mm center positive

UL listed 20J8 E82323

SAC Listed LR60353 SAC

Made in Taiwan

Automobile cigarette lighter adapter

Input connector: Standard male automobile cigarette lighter plug.
Output connector: Color coded banana plugs on unequal length wires.

Polarity: **Red** +, black –
Output fuse: 0.75 amp GGS 5 x 20mm type fuse[33]

[33] Equivalent to Radio Shack part number 270-1048.

VI. Internal Battery and Power Management

Internal Battery Charge Circuitry and Power Management

Your BI-APR100 contains sophisticated circuitry to charge condition the internal lead acid battery for maximum charge retention and maximum battery life. The portion of the BI-APR100 power management circuitry concerned with battery charging and conditioning is based on the UC3906 manufactured by Unitrode.[34,35,36] The voltages mentioned below are approximate, as the power management circuitry in your BI-APR100 unit is temperature compensated in order to adjust its voltages appropriately to match the temperature characteristics of the lead-acid battery.

On application of an enabling external power source such as the 120 VAC adapter, the power management circuitry will assess the battery's charge state and start a controlled charge cycle. The voltages and currents applied to the battery are illustrated in Figure VI.1. Depending on which part of the cycle the power management circuitry is on, either the applied current is the controlled quantity, or the applied voltage.

This involves trickle charging the battery with approximately 40mA if the battery voltage is too low to fast charge without damaging the battery (less than 10.2 volts). If implemented by the power management circuitry, this trickle charge will continue until the battery voltage has been raised to 10.2 volts.

Once the battery voltage has been raised to 10.2 volts, or if the battery is already above this when the cycle is started, then the power management circuitry applies approximately 600mA to the battery. It continues to apply this current until the battery voltage is raised to approximately 14.3 volts.

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[34] Unitrode Data Sheet UC2906/UC3906 "Sealed Lead-Acid Battery Charger"
[35] Unitrode Application Note U-104, "Improved Charging Methods for Lead-Acid Batteries Using the UC3906"
[36] Unitrode, Inc. 7 Continental Blvd., Merrimack, NH 03054, phone (603) 424-2410, fax (603) 424-3460, http://www.unitrode.com

After 14.3 volts, the power management circuitry institutes an overcharge state which tapers down the charging current. The overcharge state lasts until the current reaches approximately 50mA at which point the battery voltage may be as high as 15 volts. At this point, the power management circuitry institutes a float state for the battery by applying a constant voltage of 14 volts. The **red** **CHARGED** LED (7) lights up, and the power management circuitry will maintain the battery at this voltage indefinitely. If the external power supply is removed and then reconnected, the power management circuitry repeats this cycle.

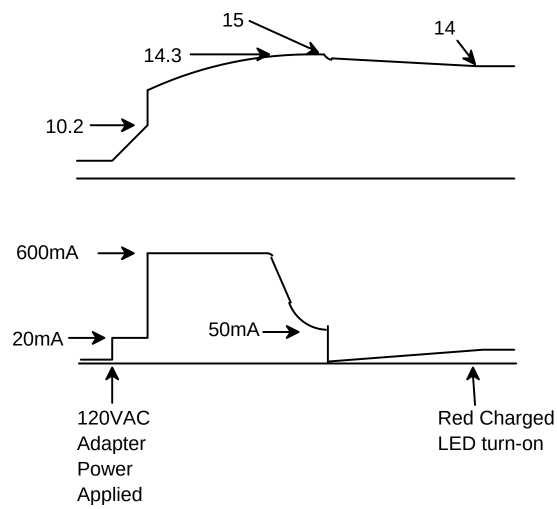

Figure VI.1 - Voltage and current history of a charge cycle. The top trace is the battery voltage, the bottom is the charging current into the battery.

While not illustrated in Figure VI.1, if the current drawn by operating the unit is larger than the float voltage current compliance for over an extended period of time, then when the battery voltage drops to approximately 12.6 volts the full charging cycle will be repeated.

Removing the internal battery from the BI-APR100

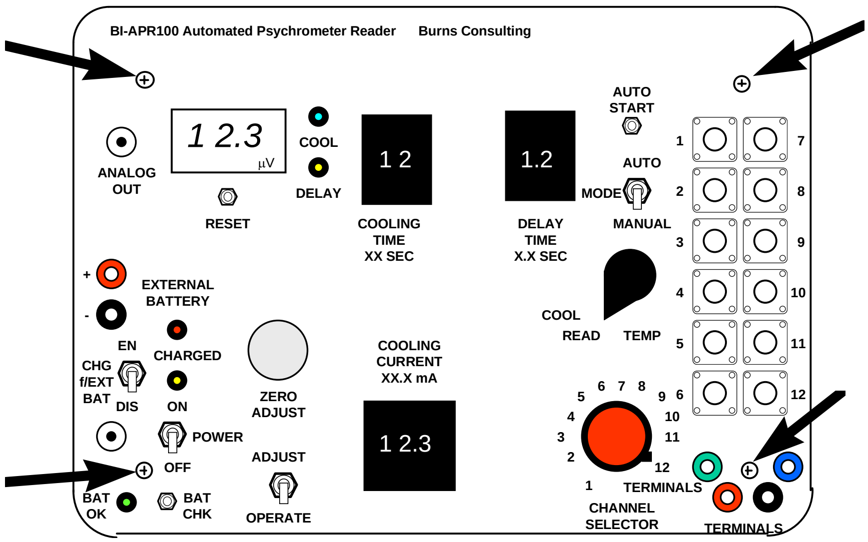

Figure VI.2 - Screws to be removed to access internal battery.

Remove the four 6-32 screws indicated by the arrows in Figure VI.2. Gently lift the panel from the box by holding on the **EXTERNAL BATTERY** terminals (8) and external channel **TERMINALS** (23).

The internal battery is held in place by a restraining bar held on by two wing nuts on two ¼-20 shafts. Unscrew the wing nuts and remove the restraining bar. Disconnect the two wires (one **red**, the other **black**) from the battery. Lift battery out and remove. Replace restraining bar and wing nuts. Place panel back on box and replace the four 6-32 screws indicated by the arrows in Figure VI.2. Be careful not to pinch any wires between the panel and the box edges nor between the panel and the mounting posts. Doing so may cause shorts and damage the unit.

Code of Federal Regulations and International Air Transport Association (IATA) Approval Certificate

It is the responsibility of the user to make sure that the user is in compliance with all laws and regulation concerning the storage and transport of batteries of all types. We have provided a copy of the Code of Federal Regulations and International Air Transport Association (IATA) Approval Certificate supplied by the manufacturer of the YUASA/EXIDE NP4-12 used in your BI-APR100 unit. YUASA EXIDE Inc. in the United States may be contacted by fax at (610) 208-1960.

07/22/97 14:11 ☎617 496 5854 Harvard Biolabs 001
06/12/97 THU 11:11 FAX 610 208 1960 YEI CORP PURCHASING 002

YELLOW LOGISTICS SERVICES, INC.

Approval Certificate

Packaging Shipper or Manufacturer: YUASA EXIDE, INC.
Address: One Yuasa Road
City, State, Zip Code: Hays, Kansas 67601

DOT/IATA Battery Product Performance Tests

Package Description: Batteries identified as NP24-12B, NP4-12, NP7-12, NP7-12FR, NP26-12B, NP38-12B, NPG18-12FR, NP24-12FR, NPG18-12, NP24-12FR, NPG18-12, NP10-6, NPH5-12, NP7-6, NPH5-12FR, NPH-6 subjected to *vibration testing and pressure differential tests.*

Batteries identified as NP7-12, NPG18-12, and NP38-12B with side ruptures subjected to *high temperature leakage tests.*

TEST	TEST LEVEL
VIBRATION TEST	95 Minutes in each of Three (3) Orientations
PRESSURE DIFFERENTIAL TEST	Six (6) Hours @ 13 PSI
HIGH TEMPERATURE TEST	130°F for 24 Hours

Test Results

The above described products meet the performance test requirements under the provisions of Title 49, *Code of Federal Regulations*, sections 173.159 d (3) (i) and (ii) and the *International Air Transport Association (IATA)* Dangerous Goods Regulations, Section 4.4, A67. The submitted test samples described above were tested in the applicable manner and exhibited no failure or leakage during or immediately after testing.

Yellow Logistics Services, Inc.

Date: May 31,1994

By Gary W. Lietzke
Gary W. Lietzke

Figure VI.3 - YUASA/EXIDE NP4-12 lead-acid battery Code of Federal Regulations and International Air Transport Association (IATA) Approval Certificate.

Checking/Replacing the internal battery fuse of the BI-APR100

Remove the four 6-32 screws indicated by the arrows in Figure VI.2. Gently lift the panel from the box by holding on the **EXTERNAL BATTERY** terminals (8) and external channel terminals (23).

The battery fuse is located in the in-line fuse holder on the red wire connected to the battery. Open the fuse holder and replace the blown fuse with a 1 ampere fast blow fuse. Check the unit visually for any burned or damaged parts. Fuses rarely blow due to age. ***If the fuse blew while manipulating an external power source, remember to only do such manipulations while the unit is turned off.***

Place panel back on box and replace the four 6-32 screws indicated by the arrows in Figure VI.2. Be careful not to pinch any wires between the panel and the box edges nor between the panel and the mounting posts. Doing so may cause shorts and damage the unit.

VII. Electrical connections for psychrometer sensors

Psychrometers from Wescor including models C-52, C-30, L-51, L-51A, PCT-55 and PST-55:

The wire color assignments in the table below are those supplied by Wescor in their SUREFAST™ connector instructions. However other (older) Wescor literature gives a different wire assignment.[37,38] We recommend that if in doubt that you test the psychrometer using the **TERMINALS** (23 in Figure II.1) to verify the color coding before attaching a SUREFAST™ connector:

BI-APR100 Terminals	SUREFAST™ or Viking Connector Pins	Cooling Current	Psychrometer Wire Color
red	5	+	red (copper)
black	6	-	black (copper)
blue	1		blue (constantan)
green	7		bare (copper)

Psychrometers from J.R.D. Merrill Specialty Equipment including model 75-2C:

BI-APR100 Terminals	SUREFAST™ or Viking Connector Pins	Cooling Current	Psychrometer Wire Color
red	5	+	white (copper)
black	6	-	blue (copper)
blue	1		red (constantan)
green	7		bare (copper)

---

[37] In "Thermocouple Psychrometers for Water Potential Measurements", by Ralph D. Briscoe, from the *Proceedings of the NATO Advanced Study Institute on "Advanced Agricultural Instrumentation"*, II Ciocco (Pisa), Italy, May 27-June 9, 1984 (reprints available from Westcor, Logan Utah,) , figure 1 assigns COPPER(+) as black, COPPER(-) as blue, CONSTANTAN as red, and the shield as bare.

[38] The thermal emf's generated by the electrical connections in the psychrometers are, at 25°C, 39.6µV/°C for copper-constintan, 59.8 µV/°C for chromel-constintan, and about 20µV/°C for copper-chromel.

VIII. Sources for Psychrometer Sensors

Pychrometric mode[39] sensors available from:

Wescor
459 South Main Street
Logan, UT 84321
(801) 752-6011
http://www.wescor.com

J.R.D. Merrill Specialty Equipment
R.F.D. Box 104A
Logan, Utah 84321
(801) 752-8403

Isopiestic mode psychrometer sensors are available from:

Isopiestics Company[40]
2 Harborview Road
Lewes, DE 19958
(302) 645-4014

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[39] Psychrometric mode is also know as the "Wet Bulb" or "Peltier" mode.
[40] These psychrometers can be operated in Psychrometeric mode provided the user can independently measure the psychrometer's temperature.

IX. Suggested Reading on Psychrometer Sensors and Methods

For further information on measuring water potential (psychrometry), please see:

- "Measuring the Water Status of Plants and Soils, 2nd Edition", John S. Boyer, (Academic Press, NewYork, 1995)

- "Thermocouple Psychrometers for Water Potential Measurements", Ralph D. Briscoe, From the *Proceedings of the NATO Advanced Study Institute on "Advanced Agricultural Instrumentation"*, II Ciocco (Pisa), Italy, May 27-June 9, 1984 (reprints available from Westcor, Logan Utah,)

- "Plant Physiological Ecology, Field Methods and Instrumentation" Edited by R.W. Pearcy, J. Ehleringer, H.A. Mooney, and P.W. Rundel (Chapman and Hall, London, 1989)

- "A Calibration Model for Screen-caged Peltier Thermocouple Psychrometers" by Ray W. Brown and Dale L. Bartos, Research Paper INT-293, July 1982, Intermountain Forest and Range Experiment Station, Ogden UT, 84401

The first three books may be ordered through your local bookstore, or may be ordered over the World Wide Web from virtual bookstores such as Amazon.com Inc.[41] at http://www.amazon.com/

The Brown and Bartos paper may be ordered from Publications,
Rocky Mountain Research Station-Ogden, 324 25th Street, Ogden UT 84401,
Phone: (801) 625-5437, Fax: (801) 625-5129, email: int@xmission.com,
http://www.xmission.com/~int/

[41] Burns Consulting is not affiliated with Amazon.com, Inc.

X. Customer Service and Guarantee Information

Customer Service

Email:

We are anxious to help you make the most out of your BI-APR100 Psychrometer Reader. You can best talk to us by email. You can send questions regarding your BI-APR100 Psychrometer Reader to us at:

mjburns@ix.netcom.com.

When you do contact us, please send a description of the problem and what steps you have already taken to try to rectify the problem. Please allow at least 24 hours for a reply to your question.

Fax:

You can also reach us by fax at (626) 398-7607. When you do contact us, please send a description of the problem and what steps you have already taken to try to rectify the problem. Please allow at least 24 hours for a reply to your question.

Guarantee

Your BI-APR100 is warranted free from defects for a period of one year from the date of purchase. Burns Consulting will repair or replace at its option any piece of defective equipment returned during this period. This service does not apply to apparatus subjected to excessive physical abuse or products that have been modified in any way. This amplifier is not to be used in any system for use with human subjects and the manufacturer will not be responsible for the results of such misuse. To return equipment for repair or replacement, email us at mjburns@ix.netcom.com, fax us at (626) 398-7607, or contact us through our Web page (http://ourworld.compuserve.com/homepages/mjburns/) to receive a return authorization number.

Prices

Prices are effective January 1, 1997 and supersede any previously published prices. Prices do not include any federal, state or local taxes and are subject to change without notice.

Shipping

Goods are shipped F.O.B. Altadena, California. Shipping charges are prepaid and billed with the goods. If special shipping instructions are required by the purchaser, they must be specified in writing on the customer's purchase order or letterhead.

Minimum Order

A minimum order of $50.00 is required. Orders less than $50.00 are subject to a $10.00 service charge.

Specifications

Specifications on all products are subject to change without notice. Burns Consulting reserves the right to make improvements to the products without incurring any obligation to incorporate these changes in products previously sold.

Return of Materials

To return equipment for repair or replacement, email us at mjburns@ix.netcom.com or fax us at (626) 398-7607 to receive a return authorization number.