



WORLD
PRECISION
INSTRUMENTS

INSTRUCTION MANUAL

EVOM2

Epithelial Voltohmmeter

Serial No. _____

www.wpiinc.com

031919



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ABOUT THIS MANUAL

The following symbols are used in this guide:



This symbol indicates a CAUTION. Cautions warn against actions that can cause damage to equipment. Please read these carefully.



This symbol indicates a WARNING. Warnings alert you to actions that can cause personal injury or pose a physical threat. Please read these carefully.

NOTES and TIPS contain helpful information.



Fig. 1—The EVOM2 measures resistance or voltage across a tissue membrane.

INTRODUCTION

EVOM was the first instrument designed to perform routine Trans Epithelial Electrical Resistance (TEER) measurement in tissue culture research. **EVOM2** is the next generation. The confluence of the cellular monolayer is determined by an increase in TEER detected using the unique electronic circuit of the **EVOM2** and **STX2** electrode (included with the instrument). The **EVOM2** qualitatively measures cell monolayer health and quantitatively measures cell confluence. When combined with WPI's **Endohm** chamber, the **EVOM2** can also be used to perform trans *endothelial* electrical resistance measurement.

The **EVOM2** produces an AC current that avoids electrode metal deposits and adverse effects on tissues, which can otherwise be caused by a DC current. In addition, resistance readings are unaffected by membrane capacitance and membrane voltage.

EVOM2 is designed with an internal rechargeable 6V NiMH 2700mAH battery pack. The unit is supplied with an external battery charger. A fully-charged battery pack will provide about eight hours of running time. When the battery power falls below the nominal threshold, the meter automatically powers off. While the meter operates safely when it is plugged into an AC power source, WPI recommends disconnecting the meter from the charger when it is in use. Doing so provides for the maximum electrical isolation and reduces the noise to ensure readings of the highest accuracy.

For automation of TEER measurement, consider WPI's **REMS AutoSampler** (WPI # **REMS**), which includes the robotic sampler, data acquisition board, base plate, Windows® based software and an electrode for either the 24- or 96-well plate.

QUICK REFERENCE

For complete instructions on performing measurements with the **EVOM2**, see "OPERATING INSTRUCTIONS" on page 5

For Resistance Measurements:

1. Disconnect the **EVOM2** from the charge and turn the **Power** on (I).
2. Sterilize the electrode.
3. Connect the electrode to the meter.
4. Precondition the electrode in growth media.
5. Set the **Function** switch to **Ohms**.
6. Measure the blank resistance and record the value.
7. Perform the measurements. To obtain the actual tissue reading, subtract the blank resistance value.
8. Clean, dry and store the electrode.

For Voltage Measurements:

1. Sterilize the electrode.
2. Connect the electrodes to the **EVOM2** and leave the power off.
3. Equilibrate the electrode in growth media with the **EVOM2** power off and the **Function** switch set to **Ohms**.
NOTE: Electrode tips must be immersed in solution to equilibrate.
4. Disconnect the **EVOM2** from the charger and set the **Function** switch to **Millivolts**.
5. Turn the **Power** on (I).
6. Measure the blank voltage and record the value.
7. Make your voltage measurements across the membranes you are testing. To obtain the actual tissue reading, subtract the blank voltage value.
8. Clean, dry and store the electrode.

INSTRUMENT DESCRIPTION

Parts List

- (1) **EVOM2** meter
- (1) **STX2** electrode set
- (1) **91750** 1000 Ω test resistor
- (1) 600-grade ultra-fine sandpaper
- (1) A/C power cord and charger
- (1) Instruction Manual

Unpacking

Upon receipt of this instrument, make a thorough inspection of the contents and check for possible damage. Missing cartons or obvious damage to cartons should be noted on the delivery receipt before signing. Concealed loss or damage should be reported at once to the carrier and an inspection requested. Please read the section entitled "Claims and Returns" on page 23 of this manual. Please call WPI Customer Service if any parts are missing.

Returns: Do not return any goods to WPI without obtaining prior approval (RMA # required) and instructions from WPI's Returns Department. Goods returned (unauthorized) by collect freight may be refused. If a return shipment is necessary, use the original container. If the original container is not available, use a suitable substitute that is rigid and of adequate size. Wrap the instrument in paper or plastic surrounded with at least 100mm (four inches) of shock absorbing material. Please read the section entitled "Claims and Returns" on page 23 of this manual.

Set-up

Test Resistor

The 1000 Ω test resistor (WPI #91750) is shown in **Fig. 2**. See "Testing the EVOM2 Meter" on page 5 for instructions on using the test resistor.



Fig. 2–1000 Ω Test resistor

STX2 Electrode

For resistance measurements only, the **STX2** electrode can be used directly from dry storage without preconditioning. The **STX2** electrode (Fig. 3) incorporates a fixed pair of probes, 4mm wide and 1mm thick. Each probe has an outer and an inner electrode. (See Fig. 4 on page 4) The outside electrodes are small silver (Ag) pads that pass current through the membrane sample. They are referred to as current electrodes. The inner electrodes are small Ag/AgCl pellet voltage sensors. They are referred to as voltage electrodes.

Fig. 3–(Right) STX2 electrode



Meter

The **EVOM2** is ready to use, but you will need a slot-head screwdriver (not included) to calibrate the **R ADJ** screw.

! CAUTION: Do not leave the meter in direct sunlight for extended periods of time. The LCD display will become dark and unreadable.

Labeled items on **Fig. 3** are described below.

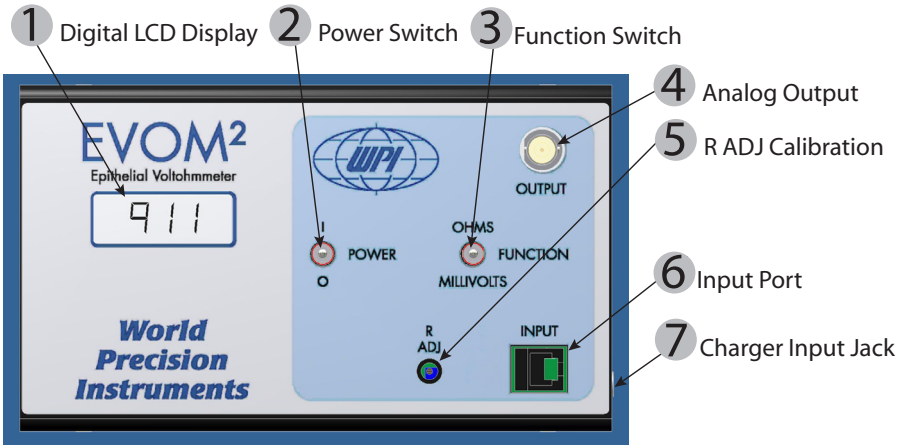


Fig. 4–EVOM2 meter

- ① **Digital LCD Display:** The Digital LCD Display registers readings of four and a half digits. When the meter is measuring voltage, it displays the potential difference between the two electrodes in millivolts (mV) up to 199.9mV. When the meter is measuring resistance, it displays the resistance between the two electrode probes in ohms (Ω). Although the meter will provide readings up to 13,000 Ω , the accuracy specification is only guaranteed up to 10,000 Ω .
- ② **Power Switch I/O:** The toggle switch turns the meter on (I) and off (O).
- ③ **Function Switch (Ohms/Millivolts):** When in the Ohms position, the meter is in the resistance measuring mode. When in the Millivolts position, the meter is in the voltage measuring mode.
- ④ **Analog Output:** This standard BNC connection allows for output of analog data to a recording device.
- ⑤ **R ADJ Calibration Screw:** When the 1000 Ω test resistor is inserted into the input port, this screw is used to calibrate the meter display to 1000 Ω while in the **Ohms** mode.
- ⑥ **Input Port:** Insert the RJ-11 plug of the test resistor, **STX2**, **STX3** or **Endohm** into this port to connect it to the meter.
- ⑦ **Charger Input Jack:** Insert the charger connector into the Charger Jack and plug the other end into a standard wall outlet to charge the **EVOM2** battery pack. Do NOT take resistance or voltage measurement with the charger connected.

Instrument Diagnostics

It is recommended that **EVOM2** be put through the diagnostics described below before using it for the first time and then periodically thereafter. If there is a concern that the meter or the electrode is not functioning properly, the following protocols may be used to confirm **EVOM2**'s operating status.

Testing the EVOM2 Meter

1. Insert the RJ-11 plug at the end of the test resistor (Fig. 2) into the **Input** port on the meter.
2. Set the **Function** Switch to **Ohms**.
3. Disconnect the **EVOM2** from the charger and turn the **Power** on (**I**). The meter should display 1000 Ω . If not, adjust the **R ADJ** screw with a small slot-head screwdriver until the meter shows a reading of 1000 Ω .

OPERATING INSTRUCTIONS

Before making any measurements, charge the **EVOM2** overnight. Allow the unit to warm up for 20 minutes before making any measurements.

Positioning Electrode in a Culture Cup

Proper placement of the electrode in the cell is critical to making accurate measurements. The **STX2** electrode is designed to facilitate measurements of membrane voltage and resistance of cultured epithelia in tissue culture wells. The lengths of the electrodes are unequal allowing the longer (external) electrode to touch the bottom of the dish containing the external culture media while preventing the shorter (internal electrode) from reaching the bottom of the tissue culture cup or insert (see Fig. 5). This feature ensures proper positioning between the electrode and the cell layer in the cup during the trans membrane measurement. In addition, by positioning the longer tip so that it touches the bottom of the dish each time, the reproducibility of the measurements is significantly improved.

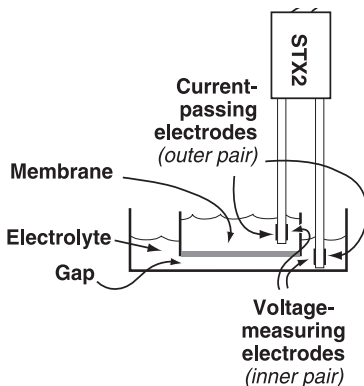


Fig. 5—Electrodes in solution

Place the electrode into the well so the tips just touch the bottom of the wells *without flexing* the electrode. See Fig. 6. *Variance of the angle* (Fig. 7) or *depth of immersion* (Fig. 8) of the electrode will affect resistance measurements.

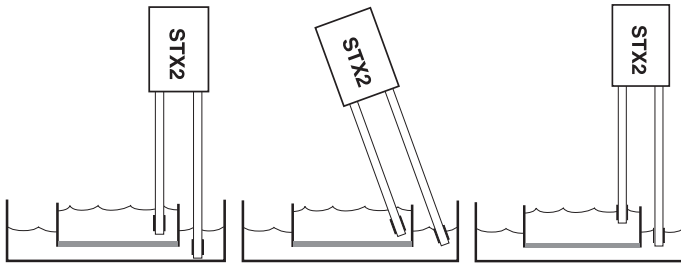


Fig. 6–(Left) Correct placement

Fig. 7–(Center) Angle variance

Fig. 8–(Right) Depth variance

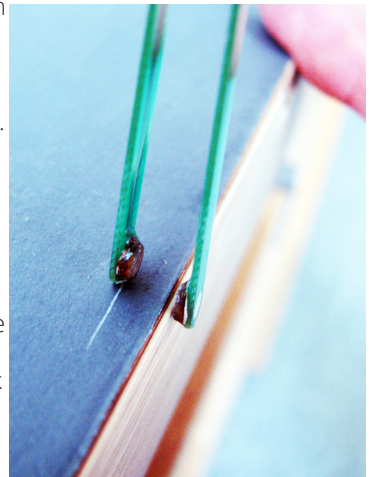
NOTE: To obtain reproducible results in the same cup, the position of the electrodes must remain constant. To improve the reproducibility and stability of the measurement, it is important to steady the electrode while measuring. You may either touch or hover, but for consistent results, you must use the same methodology each time.



CAUTION: When moving the electrodes from one sample cup to another, it is best **not** to rinse the electrodes with distilled water. Silver/silver chloride electrodes may take several minutes to recover from exposure to distilled water, during which time the potential may drift by a few millivolts. If it is necessary to wash the electrodes between measurements to avoid carryover of one sample into the next, the electrodes should be rinsed with the experimental culture media.

TIP: Transwell inserts made by Corning Costar, in general, have a greater distance between the bottom of the filter cup and the bottom of the plate (Fig. 5). This gap also varies from one lot to the other. It may be large enough to cause the shorter internal electrode to hit the cell layer when the longer electrode touches the bottom of the dish. In this case, the Transwell user can use the optional **STX3** electrodes instead of the **STX2**. They are adjustable. Or, Transwell users can sand 0.5mm off the shorter probe. See the image at the right. Place the 600-grade sand paper on the edge of a table, and holding the electrodes vertically with the tip of the shorter electrode against the sandpaper and the longer electrode hanging over the edge of the table, drag the electrode lightly over the sandpaper. Check the tip of the electrode, and repeat this procedure until the electrode is the proper length.

Fig. 9–(Right) Sanding STX2 electrode





CAUTION: Only the green body of the **STX2** electrode should be sanded. **DO NOT SAND ANY METAL PART** of the electrode or damage to the electrode will result.

Making Resistance Measurements

When the **EVOM2** is used for resistance measurements only, the electrode does not need to be equilibrated or preconditioned before use. Any galvanic voltage asymmetry present on the measurement electrode is cancelled by the EVOM2 circuitry.

1. Disconnect the **EVOM2** from the charger.
2. Connect the electrode to the meter. Insert the RJ plug at the end of the flexible electrode cable into the **Input** port on the meter.
3. Place the electrode in your culture medium for a few minutes.
4. To make resistance measurements, set the **Function** switch to **Ohms**. Disconnect the **EVOM2** from the charger and turn the **Power** on (**I**).
5. To measure the blank resistance, place the electrode in a blank culture cup filled with electrolyte (for example, the cell culture insert without cells). See "Positioning Electrode in a Culture Cup" on page 5. Insert the electrode into the blank cup. A steady ohms reading of the solution resistance should result. The value of the blank always adds to the total resistance measured across a tissue culture membrane. See "APPENDIX A: RESISTANCE CALCULATIONS" on page 18 for a more detailed discussion of the source of the blank resistance and information on calculating true tissue resistance and unit area resistance (the value that is normally reported).

NOTE: The blank resistance must be measured and then subtracted from the resistance reading across tissue in order to obtain the true tissue resistance.

6. Make your experimental resistance measurements. Subtract the blank resistance to obtain the true resistance value of your cultured cell monolayers.
7. When you finish making measurements, clean and store your electrodes dry. See "Cleaning the STX2 Electrode" on page 8.

Making Voltage Measurements

1. Disconnect the **EVOM2** from the charger.
2. Connect the electrode to the meter. Insert the RJ plug at the end of the flexible electrode cable into the **Input** port on the meter.
3. For **voltage** measurements, the electrodes should be equilibrated to eliminate any galvanic offset before use. To assure voltage stability and a low inter-electrode potential difference, turn the **Power** off (**O**) on the **EVOM2** and immerse the electrode in electrolyte solution (for example, 0.1 – 0.15M KCl) with the electrodes

connected to the **EVOM2**. The **STX2** voltage electrode pairs are shorted together when they are connected to the instrument and the **Power** is off (**O**). With the voltage electrode connector pins short-circuited for several hours, the asymmetrical potential difference across the two voltage electrodes is reduced. The inter-electrode DC potential will be a few millivolts or less and quite stable.

4. First, measure the voltage of the electrodes in growth media (or electrolyte) by following this sequence:
 - A. Set the **Function** switch to **Millivolts**. This prevents current from being applied as it does in the Ohms mode.
 - B. Then, disconnect the **EVOM2** from the charger. Ensure the galvanic charge on the voltage electrode has been minimized. Then, turn the **Power** on (**I**).
 - C. Insert an equilibrated electrode into the cell culture insert. A steady voltage reading of the trans membrane potential should result.

NOTE: The shorter (internal) electrode is connected to instrument ground and acts as the reference electrode. If the meter reading is positive in the Millivolts mode, the basal side of the cellular tissue (the side adhering to the filter of the insert) is positive with respect to apical side (exposed). Conversely, if the meter is reading negative, it means that the basal side is negative with respect to the apical side.

5. If the voltage value is of your growth media greater than a 20mV, equilibrate your electrode again by soaking it in 100mM KCl for 12–24 hours while the electrode is connected to the **EVOM2**. Set the **Function** switch to **Ohms**, and power off the meter. After equilibration, set the **Function** switch to **Millivolts**. Then, turn the meter on again and repeat step 5.
6. Make your experimental voltage measurements. Add or subtract the voltage of your growth media measured in step 5 to obtain the true voltage value of your cultured cell monolayers.

MAINTENANCE

Electrodes must be properly cleaned, sterilized and stored.



CAUTION: Do not flame electrodes. Doing so will cause them to melt.

Cleaning the STX2 Electrode

With use, the electrode surface can become coated with protein or other foreign materials. This build-up, or contamination, can degrade the performance of the system. After every use, rinse the STX electrodes with distilled water and store them dry. Periodically clean your STX electrodes with Tergazyme, a proteolytic detergent manufactured by Alconox.

1. Rinse with the electrodes with distilled water and dry them.

2. Make a 1% solution of Tergazyme according to the manufacturer's instructions.
3. Suspend the tips of the electrodes in the Tergazyme solution, with the exposed electrode surfaces fully immersed. During soaking, the surfaces of the electrodes may be brushed with a soft brush (like a tooth brush), if desired. The soaking time varies according to your maintenance schedule and the frequency of your cleaning.
 - Soak overnight when electrodes have not been on a routine maintenance cleaning schedule.
 - Soak 30–60 minutes if you are on a weekly cleaning schedule.
 - Soak 5 minutes if you clean your electrodes daily.
4. Rinse well with distilled or de-ionized water. Allow them to air dry and store the electrodes dry away from exposure to sunlight.

Disinfecting the STX Electrode

The STX electrodes are resistant to most methods of low temperature chemical disinfection. A solution of 5% sodium hypochlorite (undiluted household bleach) is a good choice. Ortho-phthalaldehyde (Cidex OPA or Rapicide OPA), ethanol or isopropyl alcohol are also acceptable.



CAUTION: NEVER leave the electrode in alcohol for more than 30 minutes at a time. Continuously soaking the electrode in alcohol will weaken the protective coating on the electrode and shorten its life.



CAUTION: Ammonia is NOT recommended, because the silver chloride electrodes dissolve in ammonia.

Sterilizing the STX2 Electrode

The STX2 electrodes are non-sterile as supplied. Acceptable low temperature sterilization methods for the electrodes include gamma irradiation, hydrogen peroxide plasma and ethylene oxide gas (ETO).



CAUTION: Do NOT autoclave the electrode.

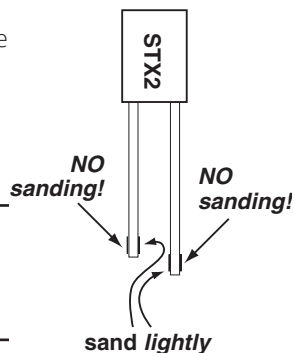


CAUTION: Do NOT expose the electrodes to ultra-violet light, because UV light decomposes silver/silver chloride electrodes.

Resurfacing the Electrode

To resurface the electrode, *lightly* sand the voltage electrode of the **STX2**, which is the silver pellet on the inner surface near the electrode tips. Use the 600-grade ultra fine sandpaper provided. (See **Fig. 9**, right.) Remove only a very thin surface layer of the pellet.

Fig. 10–(Right) Use caution when you are sanding electrodes.



CAUTION: Repeated sanding will eventually wear down the Ag/AgCl pellets. When sanding no longer improves the voltage readings, the electrode needs to be replaced.

TIP: In the absence of 600-grade sandpaper, an ink eraser may be substituted to clean the electrodes.

Storing of the Electrode

Short term storage (overnight): Immerse the electrode tip in electrolyte solution. Ensure the electrode cable plug is connected to the electrode port on the **EVOM2** meter and the meter is turned off, so that the system is short-circuited. This serves to maintain electrochemical symmetry.

Long term storage: When storing electrodes, rinse the electrode with distilled water and store it dry and in the dark.

EVOM2 Charger and Battery

Charge the batteries monthly. Charge the unit overnight with the power switch turned off.

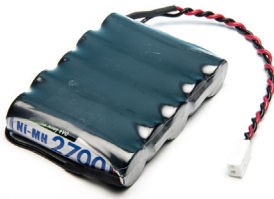


CAUTION: To avoid damage to the battery pack, make sure the **EVOM2** is powered off when charging the battery.

The **EVOM2** charger plugs into a standard AC wall outlet for recharging the battery pack. It incorporates a universal power supply allowing for use in many countries. The **EVOM2** contains a NIMH 6V 2700mAH rechargeable battery pack.

When the battery charge gets low, "BATT" appears in the digital display. To protect the battery, an automatic power down circuit is used when the battery charge gets too low. To avoid an automatic power down, recharge the battery when the BATT warning appears.

Changing the Battery Pack



The battery pack can be repeatedly charged and discharged for approximately 500 cycles. It may be charged at any time in the discharge cycle, and can be charged continuously without damage.



CAUTION: Use **ONLY** the **EVOM2** charger. Use of any other charger may damage the battery pack.

Fig. 11–NiMH replacement battery pack

The battery life is about 1 to 2 years, depending upon use. NiMH batteries discharge even if they are not being used. The rate of discharge is related to temperature. The cooler the temperature, the slower the discharge rate. If the battery pack is allowed to self discharge for too long, damage may result. To prevent battery damage, charge the battery pack at least once every two months. Should the battery pack fail in your **EVOM2**, replacements are available (WPI #91736). See "ACCESSORIES" on page 13. To change the battery pack:

1. Using a #1 Phillips screwdriver, remove the four screws from the **EVOM2** case.
2. The battery pack is mounted on the bottom chassis plate. Using a #1 Phillips screwdriver, remove the two screws securing the battery pack cover.

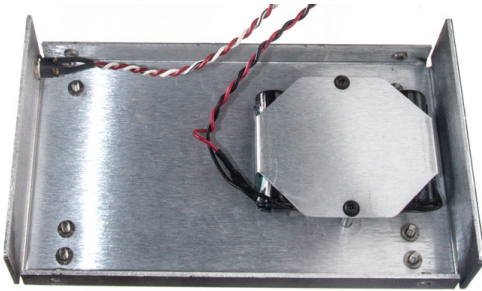


Fig. 12–Battery pack mounted to bottom chassis plate of **EVOM2**

3. Disconnect the small plastic connector by pulling it straight up at the circuit board (Fig. 13). Note the position of the connector and wire color code.
4. Properly dispose of the used battery pack.
5. The battery pack connector will only install on the circuit board one way. If it does not slide easily into place, do not force it. To install the battery pack, line up the locking guide on the circuit board with the tabs on the connector. The locking guide must face the latching ledge (Fig. 13). Slide the connector over the pins on the board and push the connector straight down.



WARNING: DO NOT REVERSE POLARITY WHEN CONNECTING THE BATTERY PACK. PERSONAL AND EQUIPMENT DAMAGE MAY RESULT.

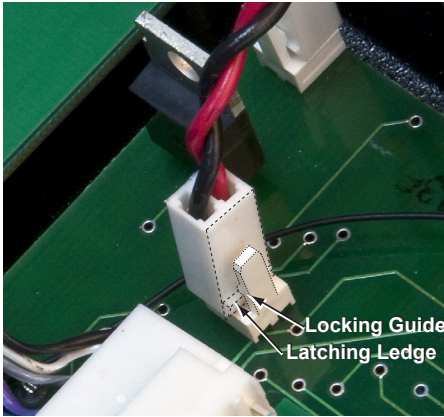


Fig. 13–Battery pack connector locked in place

6. Position the battery pack in the chassis so that the wires are routed under the aluminum clamp and towards the center of the chassis. Re-secure the battery pack cover with the two Phillips screws.



CAUTION: Before you reassemble the case, verify that no bare wires touch the metal chassis.

7. Reassemble the **EVOM2** case.
8. Charge the new battery pack for at least 24 hours.

ACCESSORIES

WPI Part #	Description
REPLACEMENT PARTS	
STX2	Replacement Electrode Set
METER ACCESSORIES	
3993	Electrode Adapter (for electrodes with 2mm pins)
2851	BNC cable, 6-ft
800496	Battery Charger
91736	NiMH Rechargeable Battery Pack
91750	1000 Ω Test Resistor
ELECTRODES FOR TEER (EPITHELIAL) MEASUREMENT	
STX2	Replacement Electrode Set
STX3	Adjustable Electrode Set
ELECTRODES FOR ENDOTHELIAL/EPITHELIAL MEASUREMENT	
ENDOHM-6	Endohm for 6 mm culture cup (24 wells per plate) and the 12 mm Millicell-CM
ENDOHM-12	Endohm for 12 mm culture cup (12 wells per plate)
ENDOHM-24SNAP	Endohm for 24 mm and Costar Snapwell cup (6 wells per plate)
ELECTRODES FOR HTS (High-Throughput) ENDOTHELIAL MEASUREMENT	
STX100C	STX100 for Corning Costar HTS Transwell-24
STX100M	STX100 for Millipore Multiscreen CaCo 96-Well Plate
STX100C96	STX100 for Corning HTS 96-Well Plate
OTHER	
7364-4	Cidex OPA
504611	Rapicide OPA/28
LAB-TRAX-4	4-Channel Data Acquisition System

Electrode Adapter (WPI# 3993) converts the four contacts in the RJ-11 into four independent 2-mm jack. It allows the user to utilize the **EVOM2** meter with another four-electrode system.

STX2 is the standard electrode for use with the **EVOM2** and is designed to facilitate measurements of membrane voltage and resistance (TEER) of cultured epithelia directly in tissue culture wells. The electrode incorporates a fixed pair of probes, 4mm wide and 1mm in thickness. Each probe has an outer (voltage) and an inner (current) electrode.

STX3 is an alternative electrode to the **STX2** that can be used with the **EVOM2**. It differs from the **STX2** in that the vertical distance between the probes of the **STX3** can be adjusted.

STX100C and **STX100F** are optional electrodes for use with the **EVOM2**. These electrodes have a smaller form factor specifically designed for high throughput screening (HTS) plates with higher well counts. The shape of the **STX100** electrode is keyed to the access ports of the well plate. This results in consistent spatial positioning leading to superior reproducibility from well to well.

Endohms are an optional electrode chambers for the **EVOM2** that may be used when working with well cups that are individually removable. It can also be used for studying the tight junction changes induced by chemicals and other factors. Concentric pairs of electrodes above and below the insert membrane results in excellent stability and reproducibility. (See "APPENDIX C: Improving the Accuracy and Repeatability of the System" on page 20.) Unlike the **STX2**, the inserts must be transferred from the culture plate to the **Endohm** chamber to make a measurement.

TROUBLESHOOTING

EVOM2 Meter

Most of the time, system problems are related to the electrode, not the meter itself. At least half of the meter failures result from a failed switch because of the presence of corrosion, and typically corrosion is caused by accidental spillage of saline solution or culture media on the meter. If the meter has been kept free of salt solution and functional testing of the meter demonstrates acceptable performance results, then the meter is working correctly. (See "Testing the EVOM2 Meter" on page 5.)

STX2 Electrode

Although the **STX2** electrode is warranted for 30 days, its normal life is 1 to 2 years, depending on its usage. Some issues you may encounter include:

- **UNSTABLE OR HIGH VOLTAGE READING:** If the electrode fails, the most common symptom is an unstable or unusually high reading.
- **LOW RESISTANCE:** When the meter displays a lower than expected resistance, but is stable and reproducible, the most likely cause is related to the cell culture, not the electrode or meter.

NOTE: Cleaning the electrode often corrects most of these issues. See "Cleaning the STX2 Electrode" on page 8.

While there is no quantitative method available to do an in situ or wet test on the electrode, this method helps you determine if the electrode is working and will respond to an increase in resistance. Test the resistance differences between a well filled with electrolyte and a blank culture insert filled with electrolyte. The resistance of electrolyte alone should be less than 50 Ω and stable, if the electrode is kept stationary. The resistance of the blank insert is normally in the 80 to 200 Ω range, depending on the brand and size.

TIP: During normal usage, it is helpful to write down the resistance range of each particular type of blank insert with the specific culture media used. If the electrode is subsequently suspected of having a problem, a comparison of current readings to past readings on the same blank insert and culture media could assist in determining if the electrode is functioning as expected.

Issue	Possible Cause	Solution
Unit runs briefly, and powers off	Unit is insufficiently charged	Recharge the unit for at least 12 hours. NOTE: Make sure the EVOM2 is powered off when charging the battery.
Unit does not charge	Insecure connection at power input jack on meter	Verify that the power connector is securely connected at the meter power input jack.
	Defective charger	Verify correct output voltage at the power supply connector with a volt meter. Replace the power supply if approximately +12V DC is not present at the center conductor on the connector. If the charger is working and the unit does not power up, contact WPI for service.
Meter will not power on with charger DISCONNECTED	Batteries are discharged	The meter powers down automatically when the batteries are depleted. Power off the meter and connect it to the battery charger. Charge it for at least 12 hours. A full charge may require up to 24 hours. For reliability, the meter should be charged each evening (with the power off) before use the next day.
	Batteries are defective	Replace the battery pack or contact WPI for service. See "Changing the Battery Pack" on page 11.
Voltage reading is unstable	Electrodes are heavily charged or dirty	Clean the electrodes. See "Cleaning the STX2 Electrode" on page 8.
	Electrode too close to strong electromagnetic radiation device	Move the system to a different area away from sources of electromagnetic fields. Electromagnetic field sources could include computers, MRI equipment, magnetic stirrers, etc. Cell phone signals can also interfere.
	Power line or output jack connected to a recording device causing noise	Remove the connection to the recording device to eliminate the possibility of a ground loop.

Issue	Possible Cause	Solution
Voltage reading is not zero in plain culture media or blank cell	Electrode not equilibrated	The Ag/AgCl disks (inner voltage measurement electrodes) on the probe may become polarized due to an uneven distribution of ions between the electrode pair. This ionic charge can be neutralized by immersing the probe into 0.1M KCL for 24 hours with the probe electrodes shorted electrically. The probe is shorted electrically when it is connected to the meter with the power OFF, and the FUNCTION switch in the OHMS position.
	Dirty electrode	Clean the electrode. (See "Resurfacing the Electrode" on page 10.)
	Conductive contamination between electrodes	Inspect the inter-electrode surface areas for material which could form a conductive bridge between the inner and outer electrodes. If the material cannot be removed, the electrode should be replaced.
	Corrosion has formed on conductive traces	An insulative transparent coating protects the copper conductors that connect each electrode to the main wiring in the handle. When the probe is very old, this coating can deteriorate, allowing the salts in the media solution to leech through to the copper conductors. This is observed as a black discoloration on the copper circuit traces underneath the conformal coating. If this is observed, replace the electrode.
Resistance reading unusually high	Contaminated electrode contacts	With use, the chopstick electrode probe contacts may acquire a buildup of protein or other foreign material that effectively increases the baseline resistance of the electrodes. The electrodes can be cleaned using various methods. See "Cleaning the STX2 Electrode" on page 8.
Resistance reading unusually low	Cell culture or media problem	If the cell culture has been given sufficient time to achieve confluence, and the reading is stable but significantly lower than expected, then the problem is probably related to the cell culture. Electrode failure will not generally cause a lower than expected yet stable reading. Use the test resistor to verify the meter is functioning correctly. The meter display should read 1000Ω. Refer to the appropriate electrode manual for instructions on testing the electrode.

Issue	Possible Cause	Solution
Resistance is a negative value	Conductive contamination on electrodes	Use the 1000 Ω test resistor to verify that the meter is working correctly. The meter display should show 1000 Ω . If a negative value exists only when using the STX electrode, inspect the electrode for the possible formation of a conductive bridge of foreign material that electrically joins the current and voltage electrodes. Remove the foreign material and retest.
Resistance reading drifts or is unstable	Electrodes are not immersed in culture media solution	Use the test resistor to verify that the meter is functioning correctly. The meter display should read 1000 Ω . The meter will not provide a stable reading if the electrodes are disconnected from the meter or if the electrodes are not immersed into culture media.
	Electrodes are not held still during measurement	Use the test resistor to verify the meter is functioning correctly. The meter display should read 1000 Ω . Hand-held electrodes must be kept as motionless as possible during a measurement. Excessive movement will cause the measurement to fluctuate.
	Charger is connected to the meter	The meter reading can become unstable due to the loss of electrical isolation when the charger is connected to the AC power. To ensure stability of readings, always disconnect the charger from the meter when making measurements.
	Meter needs set	Use the R ADJ calibration screw on the front panel to adjust the resistance value to 1000 Ω , using the test resistor. See "Testing the EVOM2 Meter" on page 5.
Resistance reading drifts or is unstable	Old electrode probe	Use the test resistor to verify the meter is functioning correctly. The meter display should read 1000 Ω . The lifetime of the chopstick electrodes is between 1- 2 years with normal use.

NOTE: If you have a problem/issue with your **EVOM2** that falls outside the definitions of this troubleshooting section, contact the WPI Technical Support team at 941.371.1003 or technicalsupport@wpiinc.com.

SPECIFICATIONS

Membrane Voltage Range.....	±200.0 mV
Resolution.....	0.1mV
Resistance Range.....	0 to 9999Ω
Resistance Resolution	1 Ω
AC Square Wave Current.....	±10μA nominal at 12.5Hz
Power.....	Internal rechargeable 6V NiMH 2700mAH battery with external 12VDC supply for recharging
Battery Charge Time	12 hours
Nominal Battery Run Time	8–10 hours*
Analog Output	Millivolt Mode: 1mV = 10mV
Ohm Mode: 1Ω = 1mV	
Dimensions	7.25"W x 4.25"H x 2.30"D (19cm x11cm x 6cm)
Weight	3 lb (1.4 kg)
Electrode Connection.....	RJ-11 connector (telephone style)
Test Resistor	External
Environmental Range	50-100°F (10-38°C)
.....	0-90% non-condensing relative humidity
Unit warmup time.....	20 minutes

* When the battery power level falls below a minimum threshold, the unit automatically powers off. A fully-charged battery will provide about eight hours of running time. **Make sure the EVOM2 is powered off when charging the battery.**

APPENDIX A: RESISTANCE CALCULATIONS

Resistance

The value of the blank always adds to the total resistance measured across a tissue culture membrane. (See below.) *The blank resistance must be measured and then subtracted from the resistance* reading across the tissue in order to obtain the true tissue resistance.

For example, suppose the resistance through a 0.15M KCl solution and across the membrane support (with no tissue present) of a 12-well cell culture insert measures 130Ω. This is the blank reading for that cell culture insert. (Resistance may vary for culture cups made by other manufacturers.) In this example, using 800 Ω as the sample measurement, the calculated resistance for the tissue itself (R_{tissue}) is:

$$\begin{aligned}
 R_{\text{Total}} &= 800 \\
 R_{\text{blank}} &= 130 \Omega \\
 R_{\text{blank}} + R_{\text{true tissue}} &= R_{\text{Total}} \\
 R_{\text{true tissue}} &= R_{\text{Total}} - R_{\text{blank}} \\
 R_{\text{true tissue}} &= 800\Omega - 130\Omega = 670\Omega
 \end{aligned}$$

Resistance Value of the “Blank” Insert

When using an **EVOM2** with an **STX2** to measure a blank insert, the resistance value is typically between 120 to 180 Ω , depending on the specific brand of the insert. This is not background resistance due to the resistance of the blank filter. Rather, if the filter membrane is removed from the insert, the resistance reading of the insert will remain the same, because the background resistance reading is due mainly to the small gap between the bottom of the cell culture insert and the bottom of the cell culture plate. See **Fig. 4**, page 4.

This gap is about 1 mm, with some insert brands having a slightly larger gap than others. The variation in this gap is the cause of the difference between blank readings of different brands. The smaller the gap, the higher the electric resistance. *The resistance of the filter membrane itself is actually negligible.*

If an **Endohm-24SNAP** or **Endohm-12** chamber is used, the blank resistance becomes near zero, because the external electrode is directly underneath the filter and the gap does not exist.

Unit Area Resistance

As the resistance is inversely proportional to the area of the tissue, instead of reporting resistance, typically the product of the resistance and the area is calculated and reported. The unit area resistance is independent of the area of the membrane used and may be used to compare data obtained from inserts of different sizes.

NOTE: Resistance readings for 24 mm or larger diameter inserts obtained by using the **EVOM2** with the **STX2** electrode should *not* be converted to unit area resistance. The **Endohm** is recommended for these larger inserts. (See "TROUBLESHOOTING" on page 14.)

The **unit area resistance** is obtained by **multiplying** the meter readings by the effective surface area of the filter membrane. The dimension is Ωcm^2 . The resistance is **inversely** proportional to the surface area. Thus, the larger the membrane, the lower the resistance.

Resistance of a unit area = Resistance (Ω) x Effective Membrane Area* (cm^2)

* See manufacturing specifications for the particular insert

Unit Area = 1 cm^2

The unit area resistance is independent of the area of the membrane used and may be used to compare data obtained from inserts of different sizes.

Continuing with the previous example, in which the $R_{\text{true tissue}} = 670\Omega$, if an effective membrane diameter (d) were 1.05 cm, the unit area resistance would be:

$$\begin{aligned} \text{Resistance} \times \text{Effective Membrane Area} &= 670\Omega \times \pi R^2 = 670\Omega \times \pi(d/2)^2 = 670\Omega \times \pi d^2/4 \\ &= 670\Omega \times (3.14) \times (1.05\text{cm})^2/4 \\ &= 580\Omega\text{cm}^2 \end{aligned}$$

580 Ω is the resistance of a unit area of 1 cm^2 .

The larger the membrane, the lower the resistance. The dimension is Ωcm^2 , not Ω/cm^2 . This may be confusing to a new user who might expect to divide to find the resistance of a unit area.

A further illustration may help to reinforce this concept:

Assuming a 1cm^2 membrane has a resistance of 500Ω , then a 5cm^2 membrane will have a resistance of 100Ω , not $2,500\Omega$, because the resistance is *inversely* proportional to the area. Accordingly, if a 5cm^2 membrane has a resistance of 100Ω , then the resistance of a 1cm^2 membrane will be $100\Omega \times 5\text{cm}^2 = 500\Omega\text{cm}^2$ because the smaller membrane is 1/5 the size and the resistance will therefore be five times greater.

APPENDIX B: 24 MM DIAMETER (6-WELL) INSERTS AND STX ELECTRODES

Note that the resistance readings from 24mm diameter tissue culture inserts (used in 6-well plates) obtained by using WPI's STX series of electrodes will be 1.8 to 2.2 times higher than that obtained using the **Endohm-24**, because the **STX** electrode cannot deliver a uniform current density over the relatively large membrane through the small gap between the membrane and the bottom of the well. *Therefore, the resistance reading of a 24 mm (6-well) diameter insert obtained by STX electrodes should not be used to calculate the unit area resistance.* **STX** electrodes are only intended for providing a qualitative measurement of cell monolayer health and quantitative measurement of cell confluence. This is not a problem with smaller inserts, such as the 12mm and 6mm diameter inserts, because of the relatively smaller size of the membrane compared to the electrode. When **EVOM2** is used with the **Endohm**, it gives a repeatable and accurate value of membrane resistance consistent with that obtained by using a well-designed Ussing chamber. It is also consistent with that obtained by the **STX2** electrode for the 12mm and 6mm diameter filter inserts.

NOTE: The unit area resistance is independent of the area of the membrane and may be used to compare data obtained from inserts of different sizes.

APPENDIX C: IMPROVING THE ACCURACY AND REPEATABILITY OF THE SYSTEM

Whenever possible, operate the **EVOM2** meter with the battery charger disconnected. This ensures maximum electrical isolation for the most accurate readings. When the charger remains connected to the meter during measurements, electrical noise can be introduced into the system. For the highest accuracy in measurement, WPI recommends disconnecting the unit from the AC power source.

For measuring low-resistance tissue culture or for more precise measurement, the user should consider using the **Endohm** chamber instead of **STX2** electrode. Although cells must be transferred from their culture wells to the **Endohm** chamber

for measurement, more accurate measurement of membrane resistance can be achieved. By introducing concentric pairs of electrodes above and beneath the membrane, the **Endohm** reduces background resistance (with a blank cup inserted) from 150Ω to less than 5Ω . (**Endohm-6** is higher.) The shape of the current electrodes allows a more uniform current density to flow across the membrane. See Fig. 14 and Fig. 15, below. Fig. 14 demonstrates how the **STX2** electrode measures TEER, and Fig. 15 shows how the **Endohm** chamber measures TEER. With fixed electrode geometry, the variation of readings on the same sample is $1-2\Omega$ as compared to 5-10% of the total reading using the **STX2** electrodes. The **Endohm**, together with the **EVOM2**, offers the most accurate, convenient and economical solution for trans membrane electrical resistance measurement.

For automation of TEER measurements, consider the **REMS AutoSampler** that integrates a robotic system and computer interface to automatically measure tissue resistance in 24- and 96-well plates. The ability of the **REMS AutoSampler** to precisely locate the electrode results in highly reproducible TEER measurement.

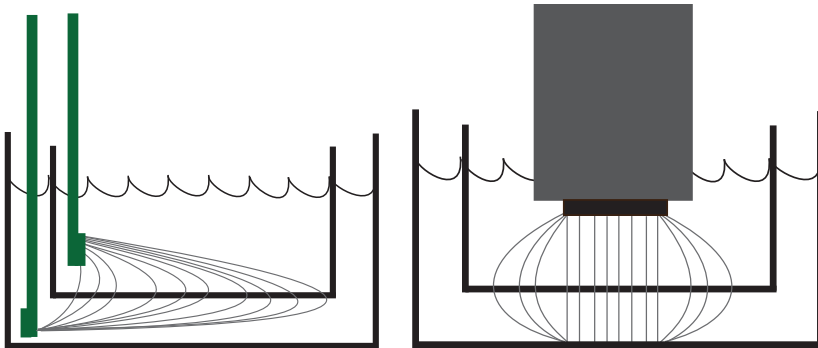


Fig. 14-(Left) The STX2 electrode measure TEER.

Fig. 15-(Right) The EndOhm electrode measure TEER.

DECLARATION OF CONFORMITY



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DECLARATION OF CONFORMITY CE

We: World Precision Instruments
175 Sarasota Center Boulevard
Sarasota, FL 34240-9258 USA


As the **manufacturer/distributor** of the apparatus listed, declare under sole responsibility that the product(s):
EVOM2

To which this declaration relates is/are in conformity with the following standards or other normative documents:

Safety:
EN 61010-1:2010
EMC:
EN 61326-2-3:2013, EN 61326-1:2013
EN 61000-3-2:2014, EN 61000-3-3:2013

And therefore conform(s) with the protection requirements of Council Directive 2014/30/EU relating to electromagnetic compatibility and Council Directive 2014/35/EU relating to safety requirements and Council Directive 2011/65/EU relating to hazardous substances:

Issued on: **Mar, 18, 2019**



President of WPI

WARRANTY

WPI (World Precision Instruments, Inc.) warrants to the original purchaser that this equipment, including its components and parts, shall be free from defects in material and workmanship for a period of one year* from the date of receipt. WPI's obligation under this warranty shall be limited to repair or replacement, at WPI's option, of the equipment or defective components or parts upon receipt thereof f.o.b. WPI, Sarasota, Florida U.S.A. Return of a repaired instrument shall be f.o.b. Sarasota.

The above warranty is contingent upon normal usage and does not cover products which have been modified without WPI's approval or which have been subjected to unusual physical or electrical stress or on which the original identification marks have been removed or altered. The above warranty will not apply if adjustment, repair or parts replacement is required because of accident, neglect, misuse, failure of electric power, air conditioning, humidity control, or causes other than normal and ordinary usage.

To the extent that any of its equipment is furnished by a manufacturer other than WPI, the foregoing warranty shall be applicable only to the extent of the warranty furnished by such other manufacturer. This warranty will not apply to appearance terms, such as knobs, handles, dials or the like.

WPI makes no warranty of any kind, express or implied or statutory, including without limitation any warranties of merchantability and/or fitness for a particular purpose. WPI shall not be liable for any damages, whether direct, indirect, special or consequential arising from a failure of this product to operate in the manner desired by the user. WPI shall not be liable for any damage to data or property that may be caused directly or indirectly by use of this product.

Claims and Returns

- Inspect all shipments upon receipt. Missing cartons or obvious damage to cartons should be noted on the delivery receipt before signing. Concealed loss or damage should be reported at once to the carrier and an inspection requested. All claims for shortage or damage must be made within 10 days after receipt of shipment. Claims for lost shipments must be made within 30 days of invoice or other notification of shipment. Please save damaged or pilfered cartons until claim settles. In some instances, photographic documentation may be required. Some items are time sensitive; WPI assumes no extended warranty or any liability for use beyond the date specified on the container.
- WPI cannot be held responsible for items damaged in shipment en route to us. Please enclose merchandise in its original shipping container to avoid damage from handling. We recommend that you insure merchandise when shipping. The customer is responsible for paying shipping expenses including adequate insurance on all items returned.
- Do not return any goods to WPI without obtaining prior approval and instructions (RMA#) from our returns department. Goods returned unauthorized or by collect freight may be refused. The RMA# must be clearly displayed on the outside of the box, or the package will not be accepted. Please contact the RMA department for a request form.
- Goods returned for repair must be reasonably clean and free of hazardous materials.
- A handling fee is charged for goods returned for exchange or credit. This fee may add up to 25% of the sale price depending on the condition of the item. Goods ordered in error are also subject to the handling fee.
- Equipment which was built as a special order cannot be returned.
- Always refer to the RMA# when contacting WPI to obtain a status of your returned item.
- For any other issues regarding a claim or return, please contact the RMA department.

Warning: This equipment is not designed or intended for use on humans.

* *Electrodes, batteries and other consumable parts are warranted for 30 days only from the date on which the customer receives these items.*

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