

# Epithelial Physiology

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# Trans Epithelial Electric Resistance (TEER) Measurements

During the last two decades TEER measurements have become universally established as the most convenient, reliable and non-destructive method to evaluate and monitor the growth of epithelial tissue cultures *in vitro*. The confluence of the cellular monolayer is quickly determined by a sharp increase in TEER. Recently there has been a significant surge of interest in introducing a

combined electrode for resistance measurements in the Millipore 96-well PAMPA (parallel artificial membrane permeability assay) plate.

TEER measurement technology, which was first introduced by WPI in the mid-1980's, has since been perfected and expanded to include a range of TEER related manual and automatic instrumentation.

## EVOM<sup>2</sup>™

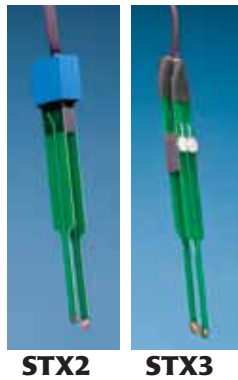
### Epithelial Voltohmmeter

- **Manual TEER measurements of epithelial cells in 6-, 12-, and 24-well plates**
- **Electrically isolated meter that plugs into a standard outlet for continual readout without push buttons**
- **Compatible with Endohm chambers**
- **STX2 manual electrodes and test electrode included with every meter**



The EVOM was the first instrument designed specifically to perform routine Trans Epithelial Electrical Resistance (TEER) measurement in tissue culture research. EVOM2 is the next generation, redesigned for ease of use. The EVOM2 not only qualitatively measures cell monolayer health, but also quantitatively measures cellular confluence. The unique electronic circuit of the EVOM2 and the included STX2 electrode detect the confluence of the cellular monolayer. When combined with WPI's Endohm chamber, the EVOM2 can also be used to perform more accurate quantitative measurements or lower resistance measurements like trans endothelial electrical resistance measurements.

The isolated power source of the EVOM2 was specifically designed to avoid adverse effects on tissue and the formation of electrode metal deposits, even when it is plugged into a standard wall outlet. Now, the EVOM2 is always on when you need it. In addition, its rechargeable battery allows up to 10 hours of mobile use. The four and a half digit readout provides a range of 1-9,999 Ω. The included test electrode lets you calibrate the resistance



measurements for an accurate reading every time, and the voltage meter never needs calibration. An analog BNC output is standard with the EVOM2, providing an output port for recording data or remote display of the EVOM2 output.

EVOM2 comes complete with the popular STX2 "chopstick" electrodes, 4 mm wide and 1 mm thick. Each stick of the electrode pair contains a silver/silver-chloride pellet for measuring voltage and a silver electrode for passing current. The small size of each electrode is designed to facilitate placement of the electrodes into a variety of standard cell culture wells.

#### EVOM2 SPECIFICATIONS

MEMBRANE VOLTAGE RANGE	±200 mV
RESOLUTION	0.1 mV
RESISTANCE RANGE	0 to 9999 Ω
RESISTANCE RESOLUTION	1 Ω
AC SQUARE WAVE CURRENT	±10 μA nominal at 12.5 Hz
POWER	Internal rechargeable 6V NiMH 2200 mA battery with external 12 VDC supply for recharging
NOMINAL BATTERY RUN TIME	10 hours
BNC OUTPUT	1-10 V (1 mV/ohm)
DIMENSIONS	19 x 11 x 6 cm (7.25" x 4.25" x 2.30")
WEIGHT	1.4 kg (3 lb)
ELECTRODE CONNECTION	RJ-11 connector (telephone style)
TEST RESISTOR	External
ENVIRONMENTAL RANGE	10-38°C (50-100°F) 0-90% non-condensing relative humidity

**EVOM2** Epithelial Tissue Voltohmmeter (includes STX2 electrode set)

#### REPLACEMENTS AND ACCESSORIES

- STX2** Replacement "Chopstick" Electrode Set  
**STX3** Adjustable Tip Spread "Chopstick" Electrode Set  
**3993** Electrode Adapter (for electrodes with 2 mm pins)  
**503540** 4-Way Switchbox & Interface Cable  
**91736** Replacement Battery, Rechargeable NiMH

Prices shown are in U.S. dollars. Actual charges will vary because of import duty, freight, and currency fluctuations. To obtain an exact quotation, contact your WPI office.

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# TEER measurements in High Throughput

## STX100

### Series Electrodes

- **Designed for 24-well HTS plate (Corning Costar and BD Falcon) and with 96-well plates (Millipore and BD Falcon)**
- **Improved accuracy down to 5 Ohm**
- **Sterilized with EtO, alcohol or bactericide**

With the development of a High Throughput Screening (HTS) protocol for faster drug discovery, a new line of cell culture filter plates have been introduced by several major cell culture insert manufacturers. These HTS plates normally have either 24 or 96 individual cell culture inserts "bonded" together as one plate so that it can be handled by a robot apparatus. In response to these developments, WPI has developed an automatic REMS system and a manual electrode, STX100, for TEER measurements using HTS plates.

STX100's design is based on the same reliable design principle as the universally used STX2 electrode, with several important modifications. The size of the electrode tip has been reduced to 1.5 mm to facilitate positioning through the narrower slit of the HTS plate. The STX100 electrode itself is constructed using a stronger material for higher durability and maximum usage applications. The bottom section of the electrode is shaped to fit neatly into the "keyhole" shaped filter well. This enables the STX100 electrode to produce increased accuracy and reproducibility of TEER readings ( $\pm 5\Omega$ ) compared to the standard STX2. Several versions of STX100 are available, designed to fit the Corning Costar 24-well HTS plate, the Falcon 24 well HTS plate, and the Millipore

Multiscreen CaCo 96-well plate. Measurement can be directly performed when the HTS plate is in either a common or divided tray, reducing the possibility of contamination as well as mechanical damage to the cultured cells.

<b>STX100C</b>	STX100 for Corning Costar HTS Transwell-24
<b>STX100F</b>	STX100 for Falcon HTS Multiwell Insert System
<b>STX100M</b>	STX100 for Millipore Multiscreen™ CaCo 96-Well Plate
<b>STX100C96</b>	STX100 for Corning HTS 96-Well Plate

#### OPTIONAL ACCESSORIES

<b>13685</b>	Modular Cable, 7 ft
<b>13347</b>	Chart Recorder Adapter
<b>2851</b>	Standard BNC Cable, 5'2"
<b>500184</b>	Standard BNC Cable, 10 ft (3m)

## CaliCell™

### Cell culture cups with synthetic membrane for testing STX electrodes, Endohm and Ussing chambers

It takes a long time and a lot of work to grow a batch of cells, so you will want to make certain that your test apparatus is functioning properly. The CaliCell™ provides a quick and positive way to test STX electrodes, EVOMs, Endohm, and Ussing chamber.

The CaliCell™ is a major improvement in TEER electrode calibration. Its membrane makes use of our unique electric current constriction technology to produce resistance readings comparable to those obtained with real cell cultures. The CaliCell™ does not have to be refrigerated, and can be cleaned and sterilized with alcohol. Readings will not drift over time as long as the unit is kept in good physical condition.

<b>CALICELL-12</b>	12 mm Calibration Cell for Endohm-6/Endohm-12
<b>CALICELL-24</b>	24 mm Calibration Cell for Endohm-24



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# Screening (HTS) cell culture filter plates



Also for use with Millicell ERS-2

## Endohm™

**For TEER measurement of endothelial cell cultures in individual cups**

- **Compatible with EVOM2**
- **Improved accuracy of 1-2 Ohm**
- **Accommodates 6mm, 12mm, 24mm cups and Costar Snapwell cup**
- **Sterilized with EtO, alcohol or a bactericide**

Using WPI's EVOM2 resistance meter, Endohm chambers provide reproducible resistance measurements of endothelial tissue in culture cups. Transfer cups from their culture wells to the Endohm chamber for measurement rather than using hand-held electrodes. The chamber and the cap each contain a pair of concentric electrodes: a voltage-sensing silver/silver chloride pellet in the center plus an annular current electrode. The height of the top electrode can be adjusted to fit cell culture cups of different manufacture. Endohm's symmetrically apposing circular disc electrodes, situated above and beneath the membrane, allow a more uniform current density to flow across the membrane than with STX2 electrodes. The background resistance of a blank insert is reduced from 150  $\Omega$  (when using WPI's hand-

held STX2 electrodes) to less than 5  $\Omega$ . With Endohm's fixed electrode geometry, variation of readings on a given sample is reduced from 10-30  $\Omega$  with STX2 electrodes (depending on the experience of the user) to 1-2. Compared with other resistance measurement methods, Endohm with EVOM2 offers a much more convenient and economic solution to "leaky tissue" measurement. Because of the uniform density of the AC square wave current from EVOM2, errors owing to electrode polarization or membrane capacitance are largely eliminated. Endohm together with EVOM2 offers the most accurate and economical endothelial ohmmeter now available. To date, cups from Costar, Millipore, ICN Biomedicals, and Falcon have been tested. Endohm chambers may be sterilized with EtO, alcohol or a bactericide (also see: Cidex, Microsurgery section); not autoclavable.

<b>ENDOHM-6</b>	Endohm for 6 mm culture cup (24 wells per plate)
<b>ENDOHM-12</b>	Endohm for 12 mm culture cup (12 wells per plate)
<b>ENDOHM-24SNAP</b>	Endohm for 24 mm & Costar Snapwell™ cup (6 wells per plate)
<i>Requires EVOM2, EVOM or EVOMX to operate</i>	
<b>53330-01</b>	Replacement Endohm Cable

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# Automated TEER Measuring System



The **REMS AutoSampler** automates measurements of electrical resistance of transepithelial, transendothelial or Caco-2 cell membranes being grown to confluence on microporous filters of high throughput screening (HTS) 24- and 96-well microplates. It is a PC-controlled, tissue resistance measurement system that offers reproducibility, accuracy, flexibility and ease-of-operation for this kind of measurement. Automated measurement of tissue resistance in cell culture microplates provides the important advantages of speed, precision, decreased opportunity for contamination and the instant availability of measured resistance data on a computer. These measurements are useful in applications such as drug bioavailability studies and studies on the mechanisms of drug transport.

The main components of the REMS AutoSampler include: the robotic sampler that moves the electrode over each well of the microplate, the electrode which is located on the robotic arm, a base plate for the 24- and 96-well tray, a Windows-based data acquisition card, the REMS interface unit and the REMS software to operate the system on a Windows-based computer.

The REMS AutoSampler automates TEER measurements previously made with WPI's **EVOM** Epithelial VoltOhmmeter. Automated tissue resistance measurements up to 20 k can

be performed on 24- or 96-well HTS microplates. Microplates presently supported include the Corning Costar HTS Transwell-24, Falcon HTS Multiwell insert systems, and Millipore Multiscreen™ CaCo 96-well plate.

The REMS AutoSampler is designed to facilitate integration with other robotic systems. Special locating bars are installed on the REMS base platform that allow other system robots to place an HTS tray into a precise location on the REMS base.

The REMS AutoSampler will automatically measure and record tissue resistance from a user-specified matrix of culture wells on the microplate. According to the specified sequence, the robotic arm moves over the identified wells taking TEER measurements. By means of a x-y-z locating system, the electrode-containing arm is positioned precisely and reproducibly over each well. The ability of the REMS AutoSampler to reproducibly and precisely locate the electrode results in highly reproducible TEER measurements. TEER measurements are stored in the computer as the electrode moves from one well to the next. The Windows-based software provides user-friendly features to acquire, display and store the tissue resistance measurements.

The REMS electrode is very compact and robust in design. Each of two rod-shaped probes, 1.5 mm in diameter, consists of a pair

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of electrodes: one electrode for injecting current and the other for measuring the voltage. The use of two pairs of electrodes eliminates the error caused by the electrode-liquid interface. To take a measurement, the robot inserts one probe into the center of the filter well and the other into the opening slot of the 24- or 96-well plate. The use of AC current to measure resistance provides several advantages over DC current, including:

- Absence of offset voltages on measurements;
- There is a zero net current being passed through the membrane and, therefore, it is not adversely affected by a current charge;
- No electrochemical deposition of electrode metal.

The REMS AutoSampler also features a rinse and calibration check station. If occasional rinsing of the REMS electrode is required it may be sent to a rinse station by pressing the rinse station button on the menu bar.

### REMS AUTOSAMPLER SPECIFICATIONS

MEMBRANE RESISTANCE RANGE	0 to 2000 $\Omega$ and 0 to 20 k $\Omega$
AC SQUARE WAVE CURRENT	+/- 20 $\mu$ A @ 12.5 Hz
ELECTRODE POSITIONING	Resolution in X, Y and Z: +/- 1 mm
ELECTRODE PERFORMANCE	Repeatability in X, Y and Z: +/- 0.25 mm
ELECTRODE ARM SPEED	X- and Y-axis: 250 mm/sec Z-axis: 247.3 mm/sec
TYPICAL MEASUREMENT TIME 24-WELL	1 min, 10 sec
SCAN PATTERN	Choice of any well pattern sampling
LINE VOLTAGE	User specified: 100/120 V or 220/240 V
DIMENSIONS	53.5 x 43.7 x 37.1 cm (21 $\frac{3}{8}$ x 17 $\frac{1}{8}$ x 14 $\frac{1}{8}$ in.)
WEIGHT	24 kg (52 lb)

#### REMS Automated Tissue Resistance Measuring System

**Includes robot sampler, base plate, data acquisition board; computer, display, keyboard, mouse; software for Windows XP or Vista; and electrode for either 24-well plate (Corning Costar HTS Transwell-24 or Falcon HTS Multiwell) or 96-well plate (Millipore Multiscreen CaCo) — SPECIFY WHEN ORDERING.**

#### ACCESSORIES

<b>REMS-24</b>	Replacement REMS STX Electrode for 24-well HTS Plate
<b>REMS-96</b>	Replacement REMS STX Electrode for MilliporeTM 96-well Plate

**Contact WPI for detailed information.**

**Give your HTS system the ability to perform REMS TEER measurements**



WPI's REMS TEER measurement system is also available in a fully customizable package that does not include the robot. The REMS-KIT is designed to enable manufacturers and users of robotic and HTS systems to incorporate TEER measurement capability into their own automated protocols. Essentially the REMS-KIT provides the same TEER measuring system as the REMS but without the robot positioner. Control over TEER measurement is accomplished using the DDE protocol. Virtually any Windows-compatible programming language that uses the DDE protocol (including LabView and Visual Basic) can be used. The REMS-KIT is designed for use with Corning Costar HTS Transwell-24, Falcon HTS Multiwell Insert System and Millipore Multiscreen™ CaCo 96-well plates. The system includes the following components:

- REMS TEER electrode with 5-ft cable
- Dummy TEER electrode for training robot
- REMS TEER measurement electrode interface unit
- Windows PCI A/D data acquisition card
- Interface software using the DDE protocol
- Instruction Manual

#### REMS KIT SPECIFICATIONS

Resistance range . . . . . 0 to 20 k Ohms  
 Time for each measurement. . . . . 1 to 2.5 seconds  
*REMS KIT includes one electrode which fits either the Corning Costar 24-well microplate, the Falcon 24-well microplate, or the Millipore Multiscreen CaCo 96-well microplate.*

#### REMS-KIT REMS Kit for Corning Costar HTS Transwell-24 or Falcon HTS Multiwell Insert System

# Multi-Channel Voltage / Current Clamp



**More channels and a wider range of voltage clamp commands than WPI's classic DVC-1000. The superior design of the cartridge electrodes makes 100-volt current excursion unnecessary, so this safe, low-voltage system is easier to adjust and use.**

EVC4000 employs the voltage clamp technique to monitor membrane permeability as a function of membrane voltage or applied chemicals. When combined with WPI's patented EKC and EKV cartridge electrodes, EVC4000 can efficiently voltage or current clamp up to four sample membranes simultaneously using safe moderate voltages on the current wire leads. The superior design of the cartridge electrodes makes 100-volt current excursion unnecessary, so this safe, low-voltage system is easier to adjust and use. Extremely stable and accurate, each module, with its companion preamplifier, can operate independently in one of three different modes: Voltage Clamp (VC), Current Clamp (CC), or Open Circuit Potential (PD) measurement. EVC4000 can be controlled from the front panel of the instrument or from computer generated commands applied at the rear panel of the instrument. A feature unique to EVC4000 is an electronic potentiostat in the preamplifier box that maintains the serosal electrode invariant potential at zero relative to system ground. The preamplifier apparatus actively maintains one surface of the test membrane close to ground potential under all operating conditions.

## References

W. K. MacNaughton (2000) "Role of constitutive cyclooxygenase-2 in prostaglandin-dependent secretion in mouse colon *in vitro*." *Journal of Pharmacology and experimental Therapeutics* 293, 2, 539-544

<b>EVC4000-4</b>	4-Channel Voltage Clamp & preamps (shown above)
<b>EVC4000-3</b>	3-Channel Voltage Clamp & preamps
<b>EVC4000-2</b>	2-Channel Voltage Clamp & preamps
<b>EVC4000-1</b>	1-Channel Voltage Clamp & preamp

**Specify line voltage**

## EVC4000 SPECIFICATIONS

<b>PREAMPLIFIER</b>	
Input Resistance	10 <sup>12</sup> Ohms
Input Leakage Current	100 pA, max.
Maximum Input Voltage	±15 volts
<b>VOLTAGE CLAMP</b>	
Panel Display	±200 mV ±0.1 mV
Clamp Voltage / External Input	100 mV per Volt
Range of Voltage Electrodes	±32 Volts
Max. Clamp Voltage	±100 mV
Fluid Resistance Compensation	0 to 1000 Ohms
<b>CURRENT CLAMP</b>	
Panel Display	±999 µA ±1 µA
Maximum Clamp Current	±1 milliampere
Current Clamp Output	1 µA / mV
<b>DISPLAY RESOLUTION</b>	
Voltage	0.1 mV
Current	1 µA
<b>DIMENSIONS</b>	
	18.25 x 7.2 x 9.6 in. (46 x 18 x 24 cm)
<b>SHIPPING WEIGHT (EVC4000-4)</b>	
	26 lb (12 kg)

## OPTIONAL ACCESSORIES

<b>SYS-EVC4000</b>	Replacement Voltage Clamp & EVC3 Preamplifier
<b>EVC3</b>	Replacement Preamplifier Module
<b>EK1</b>	Ussing Electrode Kit (2 voltage, 2 current)
<b>EKV</b>	Extra Ussing Voltage Electrode (each)
<b>EKC</b>	Extra Ussing Current Electrode (each)
<b>2851</b>	BNC Cable
<b>3845</b>	Post Mounting Kit for Preamp (see page 91)

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# Two-Channel Voltage / Current Clamp

## DVC-1000



**The FIRST — and still the most popular, with thousands of users around the world!**

WPI's DVC-1000 Two-Channel Voltage/Current Clamp is well-known and widely used for studying epithelial tissues. Each DVC-1000 consists of two separate clamp instruments, one for clamping a control tissue, another for clamping a test tissue. This dual clamp technique lets you monitor changes in membrane permeability as a function of voltage or applied chemical agents. Either clamp unit operates in five modes. **Voltage clamp:** Clamps the tissue voltage to a given level and displays the current required to maintain that level. **Amplify:** Shows the potential difference between the two voltage electrodes. **Current clamp:** Lets you deliver a constant current between the two current electrodes while simultaneously monitoring voltage changes at the tissue. **Timer:** Functions in either current clamp or voltage clamp experiments, letting you cycle automatically between zero clamp and a preset clamp level. **Remote:** Allows you to control clamp operation from a computer or other logic level source. Small preamplifiers (included) which mount close to the chamber let you connect to voltage and current electrodes without long cables or agar bridges. DVC-1000 also features a unique  $\pm 100$  V power supply capable of delivering up to 1 mA of clamp current. Each clamp lets you correct for input offset voltages and fluid resistance error.

**SYS-DVC1000** Voltage/Current Clamp  
Includes two DVC3 preamps and one DVC2 dummy membrane.  
*Specify line voltage*

### OPTIONAL ACCESSORIES

<b>DVC2</b>	Replacement Dummy Membrane
<b>DVC3</b>	Replacement Preamplifier
<b>2935</b>	Rack Mount Kit
<b>EK1</b>	Ussing Electrode Kit (2 voltage, 2 current)
<b>EKC</b>	Extra Ussing Current Electrode (red) (each)
<b>EKV</b>	Extra Ussing Voltage Electrode (blue) (each)
<b>3485</b>	Post Mounting Kit for Preamp (see page 91)

### DVC-1000 SPECIFICATIONS

<b>PROBES</b>	
INPUT IMPEDANCE	$10^{12} \Omega$
LEAKAGE CURRENT	100 pA max
MAXIMUM INPUT VOLTAGE	10 V
<b>VOLTAGE CLAMP</b>	
CLAMP VOLTAGE RANGE:	
SET CLAMP POT	$\pm 100$ mV
EXTERNAL COMMAND	$\pm 1$ V
COMMAND FACTOR	10 mV/mV
MAX. CLAMP CURRENT	$\pm 1$ mA
<b>CURRENT CLAMP</b>	
CLAMP CURRENT RANGE:	
SET CLAMP POT	$\pm 1$ mA
EXTERNAL COMMAND	$\pm 1$ mA
COMMAND FACTOR	1 mV/ $\mu$ A
COMPLIANCE	$\pm 100$ V
INPUT OFFSET RANGE	$\pm 130$ mV
<b>FLUID RESISTANCE</b>	
COMPENSATION RANGE	
	0-1000 $\Omega$
TEST CURRENT	10 $\mu$ A to 180 $\mu$ A adjustable
OUTPUT RESISTANCE	100 $\Omega$
TIMER RANGE	500 ms to 500 s each side
<b>LCD METER</b>	
TYPE	
	3 $\frac{1}{2}$ digits with NoiseLok™
MAX. READING	
	2000 $\mu$ A, 200 mV
<b>POWER REQUIREMENTS</b>	
	95-135 V or 220-240 V, 50/60 Hz
<b>DIMENSIONS</b>	
	17 x 8.75 x 9.5 in. (43 x 22 x 24 cm)
<b>SHIPPING WEIGHT</b>	
	21 lb (9.5 kg)

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# Ussing System

**For electrophysiological investigation of epithelial transport**

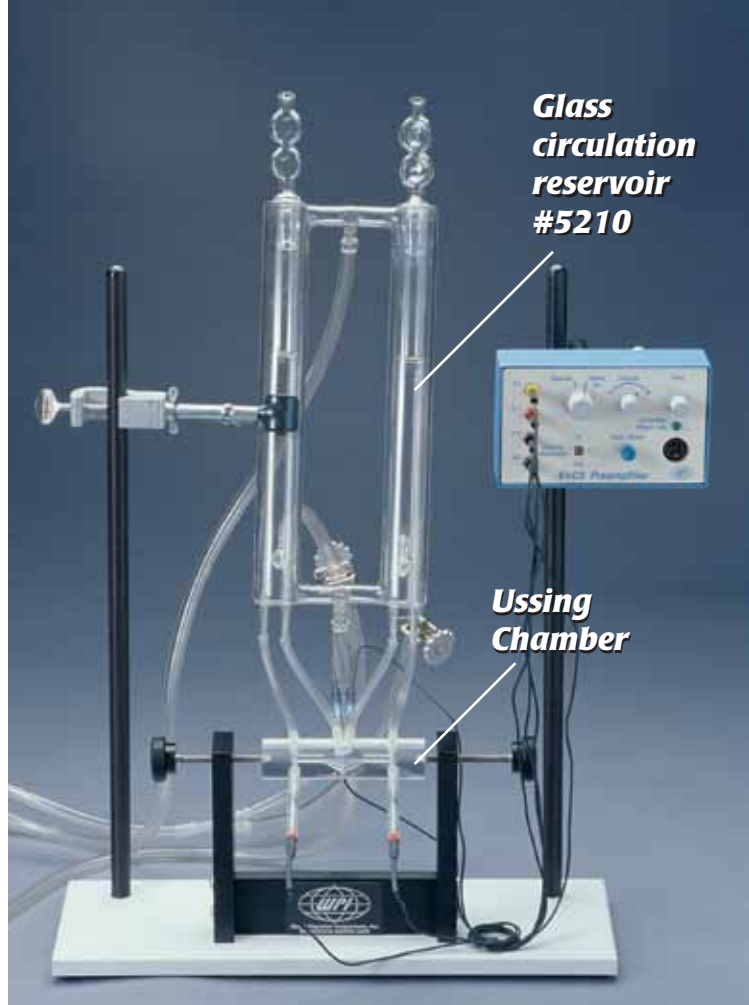
- **Direct connect low-resistance electrodes**
- **Simplified operation, easy to control temperature and clean after use**
- **Luer type leak-free attachment of tubing and electrodes**
- **Recessed electrode ports to avoid air bubble formation**
- **Secure membrane holding by sharp stainless steel pins or O-ring**
- **Specialized chamber adapts cell culture insert (Costar Snapwell) for monolayer cell culture**
- **Chambers with rectangular openings for tubular tissues from small animals**

WPI's Ussing System offers researchers a quick, effective means of making low-resistance electrical connections to the Ussing chamber without need of long agar bridges or Calomel half-cells. Ag/AgCl half-cells screw into short tubes which plug firmly into place in the chamber's luer ports. These direct-connect electrodes eliminate the inconvenience and expense of Calomel half-cells in open liquids. The System includes one Ussing Chamber (eight sizes available), Support Stand, Electrode Kit, Glass Circulation Reservoir (two sizes available), and a Tubing start-up kit (25 feet of 0.375-in. tubing, 10 feet of 0.156-in. tubing, plus four male luer fittings, two compressor clamps, one Y-connector, and one clip). Sixteen possible system configurations are listed at right. Components are also available separately. (Pre-amplifier in photo not included.)

## Ussing Chambers

WPI's classical Ussing Chambers are well established perfusion chambers that are easy to operate, easy to control temperature, and easy to clean after use. Hundreds of them are used daily by scientists in the field. Ussing Chambers are machined from solid acrylic with eight entry ports for fluid lines, electrodes, or agar bridges. For easy, leak-free attachment of tubing and electrodes, all eight ports are luer type. The four ports for voltage and current electrodes are recessed to prevent formation of air bubbles in the chamber. The fluid compartments in each side of the chamber are separated by the epithelial membrane being studied. Sharp stainless steel pins on one side of the chamber hold the membrane in position and mate with holes in the opposite chamber interface. (In the CHM4, tissue is held by an O-ring instead of pins.)

The CHM5 chamber adapts the Costar Snapwell, a cell culture insert for monolayer cell culture, into WPI's "classical" epithelial voltage clamp system. Until now, classical Ussing Chambers have not been widely used for monolayer cell culture inserts because most inserts have a very deep profile, limiting good fluid perfusion at the surface of the membrane — and limiting voltage electrodes from measuring the potential close to the surface of the membrane. CHM5 solves these problems: Perfusion fluid is introduced into the chamber at an angle so that it will flow directly to the surface of the membrane. The voltage electrode is also inserted into the chamber at an angle so as to reduce the distance between the surface of the membrane and the electrode.



**Complete Ussing System includes stand, glass reservoir, electrodes, Ussing chamber and tubing (EVC3 preamp and post mounting kit not included—see page 27).**

Two small chambers with rectangular openings are designed for tubular tissue from small animals such as the mouse intestinal tract membrane (CHM6) and rat intestinal tract membrane (CHM7). The rectangular opening more closely matches the shape of the tissue than would a circular opening, significantly increasing the membrane area available for testing. The larger membrane area increases the transport rate of low permeability chemicals; it also reduces the electrical resistance of the system for easier current clamping.

## Optional Drains

Drains may be added to Ussing chambers to allow quick and complete evacuation of radioactive or toxic substances. To have drains added at the time of order, add a "D" to the part number (such as "USS1LD"); \$100 will be added to the cost of the chamber or system you order.

## Cartridge Electrodes

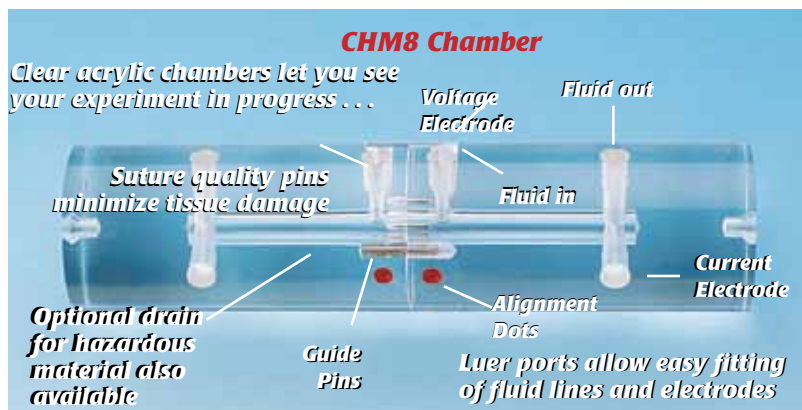
The Electrode Kit contains four voltage/current electrodes, plus four luer-tipped cartridges. Electrodes are threaded and screw securely into the end of each cartridge. The luer tip then plugs securely into the luer openings of the chamber. The cable from each electrode terminates with a 2 mm pin which may be plugged into voltage/current clamps such as WPI's DVC1000 or EVC-4000.



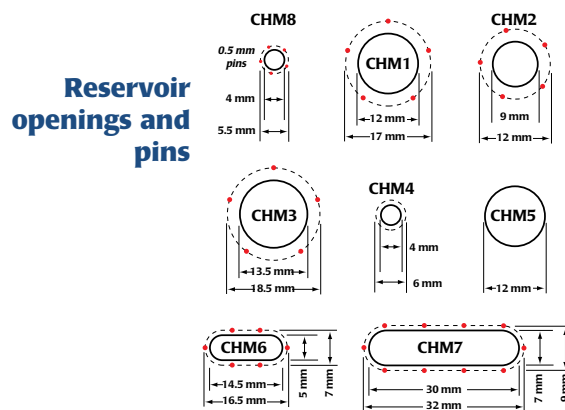
**EKV and EKC Cartridge Electrodes**

The miniature electrode-gel cartridge is a small plastic tube with a male luer tip identical to those at the tip of hypodermic syringes. The tube may be filled with different gel materials; agar is commonly used but other gel materials may also be satisfactory.

Prices shown are in U.S. dollars. Actual charges will vary because of import duty, freight, and currency fluctuations. To obtain an exact quotation, contact your WPI office.



Assembled chambers are 101.6 mm (4 in.) long.



	CHM1 (Medium)	CHM2 (Small)	CHM3 (Large)	CHM4 (Extra Small)	CHM5 (Snap)	CHM6 (Rect., Small)	CHM7 (Rect., Large)	CHM8 (Extra Small)
<b>Reservoir Opening</b>	12 mm	9 mm	13.5 mm	4 mm	12 mm	5 x 14.5 mm	7 x 30 mm	4 mm
<b>Half-Chamber Volume</b>	1.0 mL	0.75 mL	1.2 mL	0.5 mL	1.7 mL	0.8 mL	5.5 mL	0.5 mL
<b>Pin Circle Diameter</b>	17 mm	12 mm	18.5 mm	6 mm*	N/A	7 x 16.5 mm	9 x 32 mm	5.5 mm

\*O-ring diam.



### Circulation Reservoirs

Hand-blown borosilicate glass, with jacketed chambers for temperature control. Available in two sizes — #5210 holds 20 mL per side, and #5362 (at left) holds 10 mL per side (useful when expensive chemicals are involved). Reservoir condenser caps prevent air bubbles and turbulence in fluid reservoirs.

### Water Bath

The Julabo circulating bath (see inside back cover) is ideal for controlling temperatures of external systems. With a powerful 15L/min flow rate, the pump provides optimum heat exchange. The tap water cooling feature is standard with a range of 20-100°C. The bath opening is 15cm x 15cm and can hold 3-4.5L of liquid.



### USSING SYSTEMS, LARGE RESERVOIR

<b>USS1L</b>	Medium Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS2L</b>	Small Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS3L</b>	Large Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS4L</b>	Extra Small Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS5L</b>	Snap Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS6L</b>	Small Rectangular Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS7L</b>	Large Rectangular Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS8L</b>	Extra Small Chamber, Stand, Reservoir, Electrodes, Tubing

### USSING SYSTEMS, SMALL RESERVOIR

<b>USS1S</b>	Medium Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS2S</b>	Small Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS3S</b>	Large Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS4S</b>	Extra Small Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS5S</b>	Snap Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS6S</b>	Small Rectangular Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS7S</b>	Large Rectangular Chamber, Stand, Reservoir, Electrodes, Tubing
<b>USS8S</b>	Extra Small Chamber, Stand, Reservoir, Electrodes, Tubing

\* Add EVC4000 at reduced price when buying Ussing System with equivalent number of channels

<b>EVC4000-1</b>	1-Channel Voltage Clamp & Preamps
<b>EVC4000-2</b>	2-Channel Voltage Clamp & Preamps
<b>EVC4000-3</b>	3-Channel Voltage Clamp & Preamps
<b>EVC4000-4</b>	4-Channel Voltage Clamp & Preamps

### System components also available separately:

<b>xxxxD</b>	Drain option (add "D" to part number of chamber or system)
<b>CHM1</b>	Medium Chamber
<b>CHM2</b>	Small Chamber
<b>CHM3</b>	Large Chamber
<b>CHM4</b>	Extra Small Chamber with O-Ring Seal
<b>CHM5</b>	Snap Chamber (fits Costar Snapwell cups)
<b>CHM6</b>	Small Rectangular Chamber
<b>CHM7</b>	Large Rectangular Chamber
<b>CHM8</b>	Extra Small Chamber with Mounting Pins
<b>EK1</b>	Ussing Electrode Kit (2 voltage, 2 current)
<b>EKC</b>	Extra Ussing Current Electrode (red) (each)
<b>EKV</b>	Extra Ussing Voltage Electrode (blue) (each)
<b>5210</b>	Large Glass Circulation Reservoir, (20 mL per side)
<b>5233</b>	Replacement Condenser for 5210
<b>5362</b>	Small Glass Circulation Reservoir, (10 mL per side)
<b>5361</b>	Replacement Condenser for 5362
<b>3955</b>	EKV Cartridges, 35 mm (pkg of 12)
<b>3960</b>	EKC Cartridges, 58 mm (pkg of 12)
<b>3669</b>	Tubing Kit (flexible hose and luer fittings)
<b>3579-20</b>	Replacement luer fittings for tubing connections (pkg of 20)
<b>5153</b>	Support Stand
<b>3845</b>	Post Mounting Kit for Preamp (see page 91)

Prices shown are in U.S. dollars. Actual charges will vary because of import duty, freight, and currency fluctuations. To obtain an exact quotation, contact your WPI office.

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# Vibroslice™

**An economical, easy-to-use precision microtome for preparing live tissue sections for physiological, pharmacological and biochemical research**

EPITHELIAL PHYSIOLOGY

**Blade speed up to 4500 rpm**

**Sensitive parts sealed to avoid damage from spillage**

**Removable molded top cover for easy maintenance**

**Advance speed as low as 0.07 mm/sec**

**Blade angle variable through 90 degrees from horizontal to vertical**



Model NVSL offers a manual advance for positioning the specimen holder and bath chamber. Sample positioning on Model NVSLM1 is motorized. Other features include independent, removable specimen holder and bath chamber, variable advance speed and hands-free operation via a footswitch.



## NVSL & NVSLM1 SPECIFICATIONS

SECTION THICKNESS	
MINIMUM	20 µm (fixed tissue) 50 µm (fresh tissue)
MAXIMUM	700 µm
STEP SIZE	5 µm
CHAMBER	
DIMENSIONS	2 1/8 x 3 1/4 x 1 1/4 in. (55 x 82 x 31 mm)
VOLUME	8.5 cu. in. (140 mL)
BATH	
ADVANCE SPEED	0.07 to 1.6 mm/s (NVSLM1) (continuously variable)
REVERSE SPEED	4 mm/s (NVSLM1)
VIBRATION	
SPEED	60 to 4500 rpm
AMPLITUDE	1 mm (approx.)
POWER	95-135 V, 50/60 Hz, or 220-240 V, 50/60 Hz
SHIPPING WEIGHT	19 lb (8.6 kg)

Vibroslice uses a vibrating blade to slice tissues without the trauma produced by other methods. Live brain or other tissues can be cut into slices 50- to 700-microns thick. Fixed tissues can be cut down to 20-micron slices (these need not be embedded or frozen). Particularly useful for improving the access for certain histological reagents (e.g., during processing for horseradish peroxidase).

The blade has a lateral displacement of about 1 mm, and its oscillating frequency may be varied between 60 and 4500 rpm. This allows you to achieve clean cuts in tissues of different mechanical consistencies.

<b>SYS-NVSL</b>	Manual Vibroslice
<b>SYS-NVSLM1</b>	Motorized Vibroslice

*Specify line voltage*

### OPTIONAL ACCESSORIES

<b>VSLM1H</b>	Spare Specimen Holder
<b>VSLM1C</b>	Spare Bath Chamber
<b>5450</b>	Replacement Belts for NVSL (2)
<b>5451</b>	Replacement Belts for NVSLM1 (4)
<b>BLADES</b>	Blades, Single Edge (100)
<b>7600</b>	Temperature Controller, Standard Power
<b>7600S</b>	Temperature Controller, High Performance
<b>503566</b>	Footswitch for NVSLM1

**See adhesives, in Lab Supplies section. See Cidex, in Microsurgery section.**

Prices shown are in U.S. dollars. Actual charges will vary because of import duty, freight, and currency fluctuations. To obtain an exact quotation, contact your WPI office.



# Tissue Bath Coolers for Vibroslice



thermoelectric elements in the base of the tissue bath. These act as energy transfer units so that heat is drawn off through the heat exchanger and removed by tap water flow. The unit uses P.I.D. (proportional integral derivative) temperature control to take the bath temperature to within 0.5°C at the point of measurement. The temperature feedback thermistor is located in the bath floor and software calculates an offset automatically.

Immediate cooling of the tissue prevents anoxia by lowering the oxygen demand. Once removed from the animal tissue should be immediately placed in cooled saline or sucrose buffer before mounting in the tissue bath. (See adhesives, pages 132-134.)

Once removed from the animal, tissue must be immediately cooled to lower the oxygen demand and prevent anoxia. Holding the tissue close to 4°C must continue throughout the slicing procedure. This can be done with passive cooling where a known amount of ice is used to maintain the cooled a.c.s.f. or with an electronically controlled Tissue Bath Cooler.

The control unit supplies power to the Peltier

**MODEL 7600 SPECIFICATIONS**

DISPLAY RESOLUTION: 0.1 °C  
 TEMP. ACCURACY: +/- 1 °C  
 TEMPERATURE RANGE: +8°C to 0°C  
*(Note that the actual temperatures achievable will be dependent upon the solutions used and local temperature conditions)*

VOLTAGE REQUIREMENTS: 230V 50Hz or 115V 60Hz  
 POWER RATING: 60W  
 INLET FUSE RATING: 2A

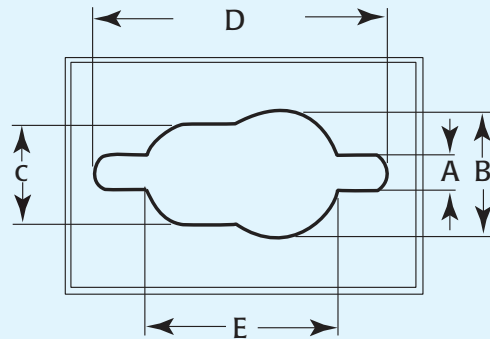
<b>7600</b>	Controller & Standard Tissue Bath Cooler (Ⓐ)
<b>7600S</b>	Controller & Autoclavable Tissue Bath Cooler (Ⓑ)

# Rodent Brain Matrices

WPI offers one of the largest selections of brain matrices available. Made of acrylic, or stainless steel, these matrices are sturdy and can be heated, chilled, autoclaved

(stainless steel only), scrubbed — and stand up to rigorous daily use. Coronal matrices have the additional feature of a mid-line sagittal cut to facilitate splitting

of the left and right hemispheres. Sections can be as fine as 1-mm. The olfactory/spinal/notch is cut into each matrix.



BRAIN MATRICES										
Order #	Subject	Material	Section	A	B	C	D	E	Cavity Depth	Weight
<b>RBMA-200C</b>	Adult Mouse, 40-75g	Acrylic	Coronal	3.18	11.1	8.73	19.1	12.2	7.4	0.5 lb
<b>RBMA-200S</b>	Adult Mouse, 40-75g	Acrylic	Sagittal	3.18	11.1	8.73	19.1	12.2	7.4	0.5 lb
<b>RBMA-300C</b>	Rat, 175-300g	Acrylic	Coronal	4.7	15.9	12.7	36.6	23.8	7.61	0.5 lb
<b>RBMA-300S</b>	Rat, 175-300g	Acrylic	Sagittal	4.76	15.9	12.7	36.6	23.8	10.91	0.5 lb
<b>RBMA-600C</b>	Rat, 300g-600g	Acrylic	Coronal	4.76	19.8	14.7	36.6	24.7	10.91	0.5 lb
<b>RBMA-600S</b>	Rat, 300g-600g	Acrylic	Sagittal	4.76	19.8	14.7	36.6	24.7	10.91	0.5 lb
<b>RBMS-200C</b>	Adult Mouse	Stainless Steel	Coronal	3.18	11.1	8.73	19.1	12.2	7.4	1.0 lb
<b>RBMS-200S</b>	Adult Mouse	Stainless Steel	Sagittal	3.18	11.1	8.73	19.1	12.2	7.4	1.0 lb
<b>RBMS-300C</b>	Rat, 175-300g	Stainless Steel	Coronal	4.76	15.9	12.7	36.6	23.8	7.61	1.0 lb.
<b>RBMS-300S</b>	Rat, 175-300g	Stainless Steel	Sagittal	4.76	15.9	12.7	36.6	23.8	7.61	1.0 lb
<b>RBMS-600C</b>	Rat, 300g-600g	Stainless Steel	Coronal	4.76	19.8	14.7	36.6	24.7	10.91	1.0 lb
<b>RBMS-600S</b>	Rat, 300g-600g	Stainless Steel	Sagittal	4.76	19.8	14.7	36.6	24.7	10.91	1.0 lb

Prices shown are in U.S. dollars. Actual charges will vary because of import duty, freight, and currency fluctuations. To obtain an exact quotation, contact your WPI office.

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