WaveDriver 20 Bipotentiostat/Galvanostat
WaveDriver 10 Potentiostat/Galvanostat
System User Guide

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1. Preface

1.1 Scope

This User Guide describes the WaveDriver 10 Potentiostat/Galvanostat and WaveDriver 20 Bipotentiostat/Galvanostat systems. This guide is written for the professional scientist or engineer (or student of science and engineering) and assumes a basic knowledge of scientific measurement and data presentation. Portions of this manual devoted to electrochemical concepts assume some familiarity with the subject of electrochemistry.

A small portion of this guide is dedicated to the subject of using the AfterMath Data Organizer software package to control the WaveDriver 10 and WaveDriver 20 instruments, primarily in the context of installing the instrument and verifying that it is working correctly. More extensive descriptions of how to use the AfterMath software are provided in the additional documents listed below:

- *AfterMath User Guide* (describes plotting and analysis functions)
- *AfterMath Electrochemistry Guide* (describes electrochemical techniques)

Both of the documents listed above are available at Pine Research Instrumentation's online site at the following URL:

https://www.pineresearch.com/shop/knowledgebase/aftermath/

1.2 Copyright

1.3 Trademarks

All trademarks are the property of their respective owners. *Windows* is a registered trademark of Microsoft Corporation (Redmond, WA). *WaveDriver 10*®, *WaveDriver 20*® and *AfterMath*® are registered trademarks of Pine Research Instrumentation (Durham, NC).

1.4 Use Limitation

The WaveDriver 10 or WaveDriver 20 instrument is not designed for use in experiments involving human subjects and/or the use of electrodes inside or on the surface of the human body.

Any use of this instrument other than its intended purpose is prohibited.

1.5 Service and Warranty Information

For questions about proper operation of the WaveDriver 10 or WaveDriver 20 systems or other technical issues, please use the information below to contact Pine Research.

TECHNICAL SERVICE CONTACT
Pine Research Instrumentation, Inc. **http://www.pineresearch.com** **Phone: +1 (919) 782-8320** **Fax: +1 (919) 782-8323**

If the WaveDriver 10 or WaveDriver 20 system or one of its components or accessories must be returned to the factory for service, please communicate with the Technical Service Contact (above) to obtain a Return Material Authorization (RMA) form. Include a copy of this RMA form in each shipping carton and ship the cartons to the Factory Return Service Address (below).

FACTORY RETURN SERVICE ADDRESS
Pine Instrument Company **ATTN: RMA # <RMA number>** **104 Industrial Drive** **Grove City, PA 16127** **USA**

RETURN MATERIAL AUTHORIZATION REQUIRED!

Do not ship equipment to the factory without first obtaining a Return Material Authorization (RMA) from Pine Research Instrumentation.

LIMITED WARRANTY

The WaveDriver 10 Potentiostat/Galvanostat or WaveDriver 20 Bipotentiostat/Galvanostat instrument (hereafter referred to as the "INSTRUMENT") offered by Pine Research Instrumentation (hereafter referred to as "PINE") is warranted to be free from defects in material and workmanship for a one (1) year period from the date of shipment to the original purchaser (hereafter referred to as the "CUSTOMER") and used under normal conditions. The obligation under this warranty is limited to replacing or repairing parts which shall upon examination by PINE personnel disclose to PINE's satisfaction to have been defective. The customer may be obligated to assist PINE personnel in servicing the INSTRUMENT. PINE will provide telephone support to guide the CUSTOMER to diagnose and effect any needed repairs. In the event that telephone support is unsuccessful in resolving the defect, PINE may recommend that the INSTRUMENT be returned to PINE for repair. This warranty being expressly in lieu of all other warranties, expressed or implied and all other liabilities. All specifications are subject to change without notice.

The CUSTOMER is responsible for charges associated with non-warranted repairs. This obligation includes but is not limited to travel expenses, labor, parts and freight charges.

1.6 Icons (*Icônes*)

Special icons are used to call attention to safety warnings and other useful information found in this document (see: Table 1-1). *Des icônes spéciales (voir: tableau 1-1) sont utilisées pour attirer l'attention sur des avertissements de sécurité et autres renseignements utiles disponibles dans ce document.*

	**STOP:** **For a procedure involving user action or activity, this icon indicates a point in the procedure where the user must stop the procedure.** ***ARRÊT:*** ***Dans une opération impliquant l'action ou l'activité d'un utilisateur, cette icône indique la partie de l'opération où l'utilisateur doit arrêter l'opération.***
	**NOTE:** **Important or supplemental information.** ***REMARQUE:*** ***Renseignements importants ou complémentaires.***
	**TIP:** **Useful hint or advice.** ***CONSEIL:*** ***Astuce ou conseil utile.***
	**CAUTION:** **Indicates information needed to prevent damage to equipment.** ***ATTENTION:*** ***Indique les informations nécessaires à la prévention des dommages aux équipements.***
	**RISK OF ELECTROSTATIC DAMAGE:** **Indicates information needed to prevent damage to equipment due to electrostatic discharge.** ***RISQUE DE DOMMAGES ÉLECTROSTATIQUES:*** ***Indique les informations nécessaires à la prévention des dommages à l'équipement à cause d'une décharge électrostatique.***
	**WARNING:** **Indicates information needed to prevent injury or death to a person or to prevent damage to equipment.** ***AVERTISSEMENT:*** ***Indique les informations nécessaires à la prévention de blessures corporelles ou de mort d'un individu ou à la prévention des dommages aux équipements.***

Table 1-1. Special Icons used in this Document.

(Tableau 1-1. Icônes spéciales utilisées dans ce document)

1.7 Back Panel Markings

The lower portion of the back panel of the WaveDriver 10 and WaveDriver 20 bears information to identify the instrument and to indicate any certifications or independent testing agency marks which pertain to the instrument (see: Figure 1-1).

1.7.1 Certifications and Listings

CE MARK:

The WaveDriver complies with one or more EU directives and bears the CE marking. See the "CE Declaration of Conformity" attached to the end of this manual for more details.

ETL LISTING:

The WaveDriver is listed by ETL to UL 61010-1 (issued 11-MAY-2012; Ed. 3), CSA C22.2 #61010-1 (issued 11-MAY-2012; Ed. 3), and IEC 61010-1 (issued 10-JUN-2010; Corrigendum 1: 11-MAY-2011). ETL is a Nationally Recognized Testing Laboratory (NRTL) recognized by the United States Occupational Safety and Health Administration (OSHA).

1.7.2 Serial Number

For purposes of uniquely identifying a particular instrument, there is a label on the bottom panel of each WaveDriver 10 or WaveDriver 20 that indicates the model number and the serial number. The serial number is also encoded with a machine readable barcode on the back panel of the instrument (see: Figure 1-1).

1.7.3 Model Numbers

The relationship between the model name and model number for the WaveDriver 10 or WaveDriver 20 system is described below (see: Table 1-2). The model numbers have the format "AFP**X**" where **X** is a single alphanumeric character used to indicate the particular model name. Part numbers for power cords and other accessories are provided later (see: Section 2.5, Section 5 and Section 7).

	A	**F**	**P**	**X**	**Y**	**Z**	**Model Name**
Model Number:	A	F	P	1			WaveDriver 10
	A	F	P	2			WaveDriver 20

Table 1-2. WaveDriver 10 or WaveDriver 20 Model Numbers

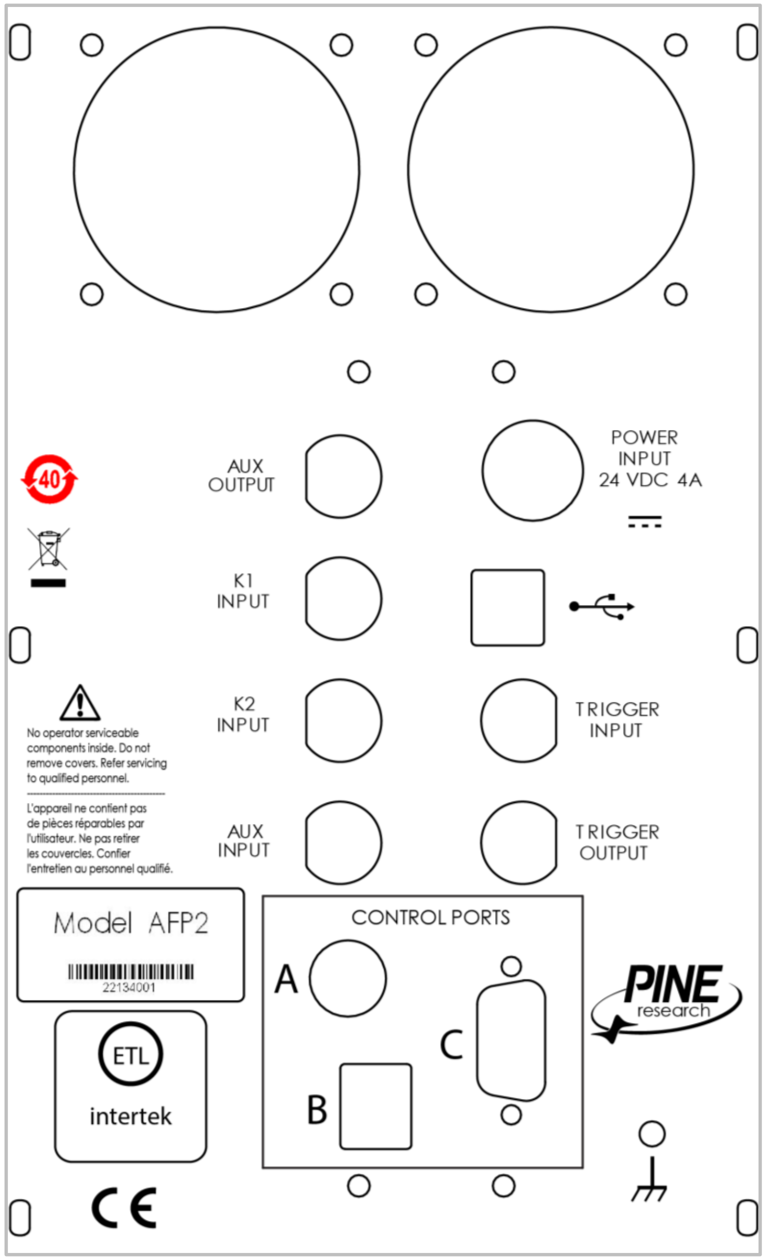

Figure 1-1. WaveDriver Back Panel Markings

1.8 Safety Warnings *(Avertissements de sécurité)*

CAUTION:

There are no user serviceable components inside the WaveDriver 10 or WaveDriver 20 chassis. Do not remove the chassis covers. Refer any service issue to qualified personnel.

ATTENTION:

Le châssis de l'appareil WaveDriver 10 ou WaveDriver 20 ne comporte aucune pièce pouvant être remplacée par l'utilisateur. Ne retirez pas les protections du châssis. Signalez tout problème d'entretien au personnel qualifié.

CAUTION:

Connect the Power Supply to the AC mains using the Power Cord supplied with the WaveDriver 10 or WaveDriver 20 and certified for the country of use. (see: Section 7 of this User Guide for more details).

ATTENTION:

Connectez le bloc d'alimentation au secteur à l'aide du cordon d'alimentation fourni avec l'appareil WaveDriver 10 ou WaveDriver 20 et conforme aux réglementations du pays d'utilisation (pour plus de détails, consultez la partie 7 du présent mode d'emploi).

CAUTION:

Do not block access to the Power Supply or the Power Cord. The user must have access to disconnect the Power Supply or the Power Cord from the AC mains at all times.

ATTENTION:

Ne bloquez pas l'accès au bloc d'alimentation ou au cordon d'alimentation. L'utilisateur doit être en mesure de déconnecter le bloc d'alimentation ou le cordon d'alimentation du secteur à tout moment.

CAUTION:

Connect the Power Supply to the AC mains using the Power Cord and appropriate plug style adapter supplied with the WaveDriver 10 or WaveDriver 20.

ATTENTION:

Branchez l'alimentation au secteur à l'aide du cordon d'alimentation et de l'adaptateur de type de prise fourni avec WaveDriver 10 ou WaveDriver 20.

CAUTION:

The switch on the front of the WaveDriver 10 or WaveDriver 20 turns the power to the potentiostat on and off. Do not block access to the switch. The user must have access to the switch at all times.

ATTENTION:

L'interrupteur sur le devant du WaveDriver 10 or WaveDriver 20 permet la mise en marche et l'arrêt du potentiostat. Ne pas bloquer l'accès à l'interrupteur. L'utilisateur doit avoir accès à l'interrupteur en tout temps.

CAUTION:

Provide proper ventilation for the WaveDriver 10 or WaveDriver 20. Maintain at least two inches ($50\ mm$) of clearance around the sides (left, right, and back) and above (top) the instrument.

ATTENTION:

Assurez-vous que l'appareil WaveDriver 10 ou WaveDriver 20 soit correctement ventilé. Laissez au moins $50\ mm$ (2 po) autour de l'appareil (à gauche, à droite et derrière), ainsi qu'au-dessus.

WARNING:

Do not operate the WaveDriver 10 or WaveDriver 20 in an explosive atmosphere.

AVERTISSEMENT:

N'utilisez pas l'appareil WaveDriver 10 ou WaveDriver 20 dans une atmosphère explosive.

CAUTION:

Do not operate the WaveDriver 10 or WaveDriver 20 in wet or damp conditions. Keep all instrument surfaces clean and dry.

ATTENTION:

N'utilisez pas l'appareil WaveDriver 10 ou WaveDriver 20 dans un environnement humide. Veillez à ce que toutes les surfaces de l'appareil soient toujours propres et sèches.

CAUTION:

Do not operate the WaveDriver 10 or WaveDriver 20 if it has suffered damage or is suspected of having failed. Refer the instrument to qualified service personnel for inspection.

ATTENTION:

N'utilisez pas l'appareil WaveDriver 10 ou WaveDriver 20 s'il a été endommagé ou si vous pensez qu'il est tombé en panne. Signalez l'appareil au personnel d'entretien qualifié pour qu'il soit examiné.

CAUTION:

When connecting a WaveDriver 10 or WaveDriver 20 system to an electrode rotator other than the Pine Research MSR rotator, carefully consider the magnitude of the WaveDriver 10 or WaveDriver 20 rate control signal ratio ($1\ RPM/mV$) and take steps to ensure that the rotator is configured to use the same ratio.

ATTENTION:

Lorsque vous connectez un appareil WaveDriver 10 ou WaveDriver 20 à un rotateur à électrodes autre que le rotateur Pine Research MSR, faites très attention à la valeur du rapport du signal de contrôle de vitesse de l'appareil WaveDriver 10 ou WaveDriver 20 ($1\ tr/min/mV$) et assurez-vous que le rotateur soit configuré avec le même rapport.

1.9 Electrostatic Discharge Information

Electrostatic discharge (ESD) is the rapid discharge of static electricity to ground. An ESD event occurs when two bodies of different potential approach each other closely enough such that static charge rapidly passes from one object to the next. Sensitive electronics in the path of the discharge may suffer damage. Damaging ESD events most often arise between a statically charged human body and a sensitive electronic circuit. The human body can easily accumulate static charge from simple movement from one place to another (*i.e.*, walking across a laboratory).

Potentiostat users must always be aware of the possibility of an ESD event and should employ good practices to minimize the chance of damaging the instrument. Some examples of good ESD prevention practices include the following:

- Self-ground your body before touching sensitive electronics or the electrodes. Self-grounding may be done by touching a grounded metal surface such as a water pipe.
- Wear a conductive wrist-strap connected to a good earth ground to prevent a charge from building up on your body.
- Wear a conductive foot/heel strap or conductive foot wear in conjunction with standing on a grounded conductive floor mat.
- Increase the relative humidity in the air to minimize static generation.

The WaveDriver 10 or WaveDriver 20 Potentiostat/Galvanostat Systems have been tested and found to be compliant with the European EMC product specific Standard EN 61326-1:2013 for immunity and emissions. The immunity standard includes testing for ESD to IEC 61000-4-2:2008.

RISK OF ELECTROSTATIC DAMAGE:

The WaveDriver 10 and WaveDriver 20 instruments may be susceptible to ESD events that occur on or near the electrode cable assembly. Such an ESD event can result in data loss, corruption of data, loss of communication with PC, and instrument unresponsiveness. Addition of a metallic shield to the electrode cable will improve the immunity of the system to an ESD event.

RISQUE DE DOMMAGES ÉLECTROSTATIQUES:

Les appareils WaveDriver 10 et WaveDriver 20 peuvent être sensibles à des épisodes de décharges électrostatiques qui surviennent sur ou près du câble de l'ensemble des électrodes. Un tel épisode peut résulter en une perte de données, une corruption de données, une perte de communication avec l'ordinateur et une absence de réponse de l'appareil. L'addition d'une enveloppe métallique au câble des électrodes améliorera l'immunité du système à l'épisode de décharge électrostatique.

1.10 Hazardous Material Information

Hazardous Material Disclosure Table						
AFP1, AFP2						
Part Name	Hazardous Substances					
	Lead (Pb)	Mercury (Hg)	Cadmium (Cd)	Hexavalent Chromium (Cr (VI))	Polybrominated biphenyls (PBB)	Polybrominated diphenyl ethers (PBDE)
Analog PCB Assembly	X	O	O	O	O	O
Digital PCB Assembly	X	O	O	O	O	O
Dummy Cell Assembly	X	O	O	O	O	O

This table is prepared in accordance with the provisions of SJ/T 11364.

O: indicates that said hazardous substance contained in all of the homogeneous materials for this part is below the limit requirements of GB/T 26572.

X: indicates that said hazardous substance contained in at least one of the homogeneous materials for this part is above the limit requirements of GB/T 26572.

Note: the date of manufacture for this item may be coded in the serial number as follows:
wwyy4nn: ww indicates week; yy indicates year; and nn is the number of the item, starting with 01 each week.

Table 1-3. Hazardous Materials Disclosure (English).

有害物质披露表						
AFP1, AFP2						
部件名称	有害物质					
	铅 (Pb)	汞 (Hg)	镉 (Cd)	六价铬 (Cr (VI))	多溴联苯 (PBB)	多溴二苯醚 (PBDE)
模拟电路板	X	O	O	O	O	O
数字电路板	X	O	O	O	O	O
虚拟电解池	X	O	O	O	O	O

本表格依据 SJ/T 11364 的规定编制。

O： 表示该有害物质在该部件所有均质材料中的含量均在 GB/T 26572 规定的限量要求以下。

X： 表示该有害物质至少在该部件的某一均质材料中的含量超出 GB/T 26572 规定的限量要求。

注： 该部件的制造日期可能会按照以下格式出现在序列号码中：
wwyy4nn：ww 表示周数； yy 表示年的最后两位数； nn 是该周序列号、每周都从01开始。

Table 1-4. Hazardous Materials Disclosure (Mandarin)

1.11 Software License

Purchase of a WaveDriver 10 or WaveDriver 20 instrument includes a license to use the AfterMath software package to control the instrument and analyze data collected using the instrument. Pine Research Instrumentation understands that the instrument is typically used in a laboratory environment where multiple computers are present and where data acquired using one computer might be analyzed using a different computer. The following software license describes how AfterMath may be used with the WaveDriver 10 or WaveDriver 20 in a laboratory with multiple computers.

PINE RESEARCH INSTRUMENTATION

AFTERMATH DATA ORGANIZER SOFTWARE LICENSE

Pine Research Instrumentation, Inc. (hereafter "PINE") licenses purchasers (hereafter "LICENSEES") of Pine electrochemical potentiostats (hereafter "INSTRUMENTS") to use the AfterMath Data Organizer software (hereafter "SOFTWARE") in conjunction with these INSTRUMENTS. This License contains the terms and conditions of use of the SOFTWARE.

1. **Scope of License**: This License covers the software, user documentation and any related computer programs provided by PINE for use with one or more specific INSTRUMENTS. This License does not grant any proprietary or ownership rights in the SOFTWARE or related technology. The scope of this License is limited to an exclusive group of one or more specific INSTRUMENTS, where the members of this exclusive group are specifically enumerated and identified by make, model, and serial number at the time this License is purchased. The one or more specific INSTRUMENTS belonging to this exclusive group are hereafter referred to as the "DESIGNATED INSTRUMENTS".
2. **License**: PINE grants to LICENSEE a nonexclusive, nontransferable license to use the SOFTWARE in object code form on any computer which is connected to the DESIGNATED INSTRUMENTS for purposes of controlling the operation of the DESIGNATED INSTRUMENTS. The LICENSEE is not authorized to use the SOFTWARE to control the operation of any instruments other than the DESIGNATED INSTRUMENTS. PINE further grants to LICENSEE a nonexclusive, nontransferable license to use the SOFTWARE in object code form on up to five (5) other computers which are not connected to the DESIGNATED INSTRUMENTS for the sole purpose of analyzing data previously generated by the DESIGNATED INSTRUMENTS. PINE further grants permission to LICENSEE to make one (1) archival copy of the SOFTWARE for back-up purposes if required. Except as expressly authorized above, LICENSEE shall not: copy, in whole or in part, any of the SOFTWARE or documentation, modify the SOFTWARE, reverse engineer, reverse compile (de-compile), or reverse assemble all or any portion of the SOFTWARE, or rent, lease, distribute, sell or create derivative works of the SOFTWARE.
3. **Term and Termination**: The License hereby granted will continue in force until terminated, as set forth herein. If LICENSEE fails to pay any monies owed to PINE or its agents in connection with LICENSEE's purchase of the DESIGNATED INSTRUMENTS or this SOFTWARE, or violates any term of condition of this License, PINE or its agents may terminate this License immediately by giving notice of termination to LICENSEE.
4. **Limited Warranty**: PINE warrants the SOFTWARE to conform to the description of its function and performance. In the event that the SOFTWARE does not perform in accordance with this warranty, PINE agrees to repair or fix any non-conformity free of charge, or to refund any amount paid by LICENSEE for the SOFTWARE. Any modifications made to the SOFTWARE by LICENSEE shall void this warranty entirely.
5. **DISCLAIMER OF WARRANTY FOR SOFTWARE**. EXCEPT FOR THE EXPRESS WARRANTIES SET FORTH IN THIS AGREEMENT, PINE DISCLAIMS ALL IMPLIED WARRANTIES FOR THE SOFTWARE, INCLUDING

WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. PINE MAKES NO REPRESENTATIONS CONCERNING THE QUALITY OF THE SOFTWARE AND DOES NOT PROMISE THAT THE SOFTWARE WILL BE ERROR FREE OR WILL OPERATE WITHOUT INTERRUPTION.

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7. **Ownership of SOFTWARE**: PINE has and will retain all ownership rights in the SOFTWARE, including all patent rights, copyrights, trade secrets, trademarks, service marks, related goodwill and confidential and proprietary information. LICENSEE will have no rights in the SOFTWARE except as explicitly stated in this Agreement. Title to the SOFTWARE and documentation remains solely with PINE. LICENSEE may not assign this Agreement or any rights under it and may not delegate any duties under this Agreement without PINE's prior written consent. Any attempt to assign or delegate without such consent will be void.
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2. Product Specifications

2.1 Instrument Description

The WaveDriver 10 and WaveDriver 20 are benchtop instruments designed to connect to a personal computer via a USB cable and are controlled by Pine Research AfterMath software. The WaveDriver 10 potentiostat/galvanostat system is capable of controlling an electrochemical cell comprised of one working electrode, a reference electrode, and a counter electrode. The WaveDriver 20 system is capable of controlling an electrochemical cell comprised of one or two working electrodes, a reference electrode, and a counter electrode. Both systems feature two potential ranges ($\pm 2.5\,V, \pm 10.0\,V$) and eight current ranges (from $\pm 1.0\,A$ down to $\pm 100\,nA$), making them suitable for a variety of electroanalytical techniques. Because the WaveDriver 20 can control two independent working electrodes (*i.e.*, two channels) in the same electrochemical cell, it is called a bipotentiostat. A bipotentiostat is required when operating a rotating ring-disk electrode (RRDE), where for example, differing waveforms are independently applied to the disk and ring electrodes while the currents at the disk and ring electrodes are simultaneously and independently measured.

2.2 Software Description

The AfterMath scientific data analysis software is able to create high quality graphs and reports from experimental results. A licensed copy of AfterMath is included with each potentiostat purchased from Pine Research Instrumentation. AfterMath offers several important benefits:

Instrument Control. When started, AfterMath automatically detects all compatible instrumentation attached to the computer and provides complete control over each instrument. AfterMath can simultaneously control multiple instruments, and multiple experiments may be queued on each individual instrument. Even as new experiments are queued or running in the background, data acquired in previous experiments may be manipulated by the user.

Flexible Plotting. AfterMath has a powerful "drag-n-drop" feature that allows traces from one plot to be quickly and easily copied and moved to other plots. Preparing an overlay plot from several voltammograms is straightforward. AfterMath provides precise control over line sizes, point markers, colors, axis limits, axis labels, and tick marks. One or more text boxes may be placed anywhere on a plot, and the text may be formatted with any combination of fonts, font sizes, or colors as desired.

Scientific Units. Unlike graphing software designed for business and marketing applications, AfterMath is designed with scientific data in mind. Proper management of scientific units, metric prefixes, scientific notation, and significant figures is built into Aftermath. For example, if an operation divides a potential measured in millivolts by a current measured in nanoamps, then Aftermath properly provides the result as a resistance measured in megaohms.

Data Archiving. A unique and open XML-based file format allows data from several related experiments to be kept together in one single archive file. The archive file avoids the user having to search the hard drive for a set of related voltammograms. The internal archive hierarchy can contain as many subfolders, reports, plots, notes, experimental parameters, and data sets as desired.

Tools and Transforms. Flexible tools can be placed on any graph to precisely measure quantities like peak height and peak area. Multiple tools can be placed on a plot, and all such tools remain exactly where they are placed, even if the data archive is saved to a disk and reloaded at a later time. Fundamental mathematical operations (addition, multiplication, integration, logarithm, etc.) can be applied to any trace on any plot.

2.3 Instrument Specifications

The WaveDriver 10 and WaveDriver 20 benchtop potentiostat systems offer the following electrode control modes: potentiostat (POT), galvanostat (GAL), open circuit potential (OCP), and zero resistance ammeter (ZRA). These instruments offer an iR compensation mode.

INFO:

All specifications provided in this section are subject to change without notice.

The following specifications are common to the WaveDriver 10 or WaveDriver 20.

ELECTRODE CONNECTIONS	
Reference Electrode	Sense line with driven shield
Counter Electrode	Drive line with grounded shield
First Working Electrode (K1)	Separate sense and drive lines, each with driven shield (current measurement via passive shunt)
Second Working Electrode (K2)‡	Separate sense and drive lines, each with driven shield (current measurement via passive shunt)

GROUNDING	
DC Common (signal ground)	The signal ground (DC Common) is isolated from the USB port and floats with respect to the instrument chassis and earth ground. The signal ground is accessible via the black banana plug on the cell cable
Chassis Terminal	The metal case (chassis) terminal is a banana binding post (back panel) which may optionally be used to connect the chassis to earth ground or signal ground to improve noise screening (shielding).
Earth Ground	No direct connection to earth ground is provided. The chassis may (either intentionally or unknowingly) be connected to earth ground via a USB cable connected to a remote computer.

MEASURED CURRENT	
Ranges	± 1 A, ± 100 mA, ± 10 mA, ± 10 mA, ± 100 µA, ± 10 µA, ± 1 µA, ± 100 nA
Resolution (at each range)	$31.3\ \mu A, 3.13\ \mu A, 313\ nA, 31.3\ nA, 3.13\ nA, 313\ pA, 31.3\ pA, 3.13\ pA$
Autoranging	yes
Practical Range§	100 pA to 1.0 A
Accuracy	$\pm$ 0.2% setting; $\pm$0.05% of range
Leakage Current	$10\ pA\ at\ 25^{\circ}C$
ADC Input	16 bits
Filters	$10\ Hz, 30\ Hz, 100\ Hz, 1\ kHz, 10\ kHz$ (2-pole, low pass Bessel filters)

APPLIED CURRENT (GALVANOSTATIC MODE)	
Ranges	± 1 A, ± 100 mA, ± 10 mA, ± 10 mA, ± 100 µA, ± 10 µA, ± 1 µA, ± 100 nA
Resolution (at each range)	$31.3\ \mu A, 3.13\ \mu A, 313\ nA, 31.3\ nA, 3.13\ nA, 313\ pA, 31.3\ pA, 3.13\ pA$
Accuracy	$\pm$ 0.2% setting; $\pm$0.05% of range
DAC Output	16 bits

POWER AMPLIFIER (COUNTER ELECTRODE AMPLIFIER)	
Output Current	$\pm 1.0\ A$ (maximum)
Compliance Voltage	$> \pm 16.5\ V$
Speed	9
Bandwidth	$> 200\ kHz$ (on fastest speed setting)
Rise Time	$10\ V/\mu sec$ (on fastest speed setting)

ELECTROMETER (REFERENCE ELECTRODE AMPLIFIER)	
Input Impedance	$> 10^{13}\ \Omega$ in parallel with $< 10\ pF$
Input Current	$< 10\ pA$ leakage/bias current at $25^{\circ}C$
CMRR	$> 84\ dB\ at\ 0-1\ kHz; > 74\ dB\ at\ 10$ kHz
Bandwidth	> 11 MHz $(3\ dB)$

APPLIED POTENTIAL (POTENTIOSTAT MODE)	
Ranges	± 10.0 V, ± 2.5 V
Resolution (at each range)	$313\ \mu V$, $78\ \mu V$ per DAC bit
Accuracy	$\pm$0.2% of setting, $\pm 1.0\ mV$
DAC Output	16 bits
CV Scan Rate (min)	$10\ \mu V/s$ ($313\ \mu V$ step per $31.3\ s$ or $78\ \mu V$ per $7.8\ s$)
CV Scan Rate (max)	$125\ V/s$ ($10\ mV$ step per $1.0\ ms$)

MEASURED POTENTIAL

Ranges	± 10.0 V, ± 2.5 V
Resolution (at each range)	$313\ \mu V$, $78\ \mu V$ per DAC bit
Accuracy	$\pm 0.2\%$ of setting, $\pm 1.0\ mV$
ADC Input	16 bits
Filters	$10\ Hz, 30\ Hz, 100\ Hz, 1\ kHz, 10\ kHz$ (2-pole, low pass Bessel filters)

ROTATOR CONTROL CONNECTIONS (BACK PANEL)

Connector A	7-pin mini circular DIN includes analog and digital signal grounds, digital rotator enable signal, auxiliary digital output signal, and analog rotation rate control signal
Connector B	3-pin connector includes analog signal ground, digital rotator enable signal, and analog rotation rate control signal
Rate Control Signal	± 10.0 V, ± 2.5 V
Digital Enable Signal	open drain (TTL compatible)

DATA ACQUISITION

Clock Resolution	$10\ ns$ (minimum time base)
Point Interval*	$80\ \mu s$ (minimum)
Synchronization	Simultaneous sampling of all analog input signals
Raw Point Total	$< 10\ million$ per experiment

ACCESSORIES

Dummy Cell	external dummy cell (included)
Cell Cable	Combination D-SUB connector to multiple banana plugs via shielded coaxial cables (included)

AUXILIARY CONNECTIONS (BACK PANEL)

Connector C	9-pin DSUB connector includes digital signal ground, two digital output signals, and three digital input signals
Trigger Input	BNC female, TTL compatible
Trigger Output	BNC female, TTL compatible
K1 input, K2 input‡	BNC female, $\pm 10\ V$ differential input, $20\ k\Omega$ impedance, $\pm 0.5\%$ accuracy; allows external waveform to be summed directly to the working electrode excitation signal. K2 Input available only on WaveDriver 20 bipotentiostat.
Auxiliary Analog Output	BNC female, $\pm 10\ V$ bipolar output, $313\ \mu V$ resolution, 0.2% accuracy (available only when second working electrode not in use)

GENERAL SPECIFICATIONS

Power Required	$24.0\ VDC\ (\pm 5\%), 4.0\ A$ (low voltage DC device)
Power Supply	input: $100\ to\ 240\ VAC, 2.3\ A, 50\ to\ 60\ Hz$; C13 type connector output: $24.0\ VDC, 4.2\ A$
Power Cord	various international cables available separately (C13 type)
LED Indicators	power, USB, and status
Instrument Dimensions	$140 \times 305 \times 248\ mm\ (5.5 \times 12.0 \times 9.75\ in)$
Instrument Weight	$3.6\ kg\ (8\ lbs)$
Shipping Dimensions	$254 \times 356 \times 457\ mm\ (10 \times 14 \times 18\ in)$
Shipping Weight	$7.7\ kg\ (17\ lbs)$
Temperature Range	$10℃\ to\ 40℃$
Humidity Range	80% RH maximum, non-condensing

*Data acquisition using the minimum point interval is possible for short duration bursts. The burst duration depends upon the available host PC USB bandwidth and is typically at least $3\ s$.

§The "practical range" of measurable currents goes from the maximum current output of the amplifier down to the current level at which noise begins to interfere with the signal. Using proper grounding, a cell shielded by a Faraday cage, and coaxial cell cables, it is possible to routinely measure signals as low as $100\ pA$.

‡The WaveDriver 10 is a single channel potentiostat and thus has only one working electrode, K1. The WaveDriver 20 is a dual channel bipotentiostat and thus has two working electrodes, K1 and K2.

2.4 Standard Electrochemical Methods

The WaveDriver 10 or WaveDriver 20, together with the AfterMath software package, can perform many electrochemical techniques (see: Table 2-1). Further descriptions about how to configure and execute these techniques can be found in the documentation for the AfterMath software.

Simple Methods

- Open Circuit Potential (OCP)
- Constant Potential Electrolysis (BE)
- Constant Current Electrolysis (BE)
- Zero Resistance Ammeter (ZRA)

Voltammetric Methods

- Cyclic Voltammetry (CV)
- Linear Sweep Voltammetry (LSV)
- Staircase Voltammetry (SCV)
- Chronoamperometry (CA)
- Normal Pulse Voltammetry (NPV)
- Cyclic Step Chronoamperometry (CSCA)
- Differential Pulse Voltammetry (DPV)
- Square-Wave Voltammetry (SWV)
- Double Potential Step Chronoamperometry (DPSCA)

Galvanostatic Methods

- Chronopotentiometry (CP)
- Current Ramp Chronopotentiometry (CRP)
- Staircase Potentiometry (SCP)
- Cyclic Step Chronopotentiometry (CSCP)

Stripping Voltammetry

- Anodic & Cathodic Stripping Voltammetry (ASV)
- Differential Pulse Stripping Voltammetry (DPSV)
- Square-Wave Stripping Voltammetry (SWSV)

Uncompensated Resistance Methods

- Current Interrupt (RUCI)
- Positive Feedback (RUPF)

Rotating Ring-Disk Methods*‡

- Rotating Ring-Disk Voltammetry (RRDE)
- Rotating Ring-Disk Koutecky-Levich (KL-RRDE)
- Rotating Ring-Disk Electrolysis (BE-RRDE)

Rotating Disk & Cylinder Methods*

- Rotating Disk Electrode (RDE)
- Koutecky-Levich Series (KL-RDE)
- Rotating Disk Electrolysis (BE-RDE)
- Rotating Disk Chronopotentiometry (CP-RDE)
- Rotating Disk Ramp Chronopotentiometry (RCP-RDE)

Corrosion Methods*

- Linear Polarization Resistance (LPR)
- Rotating Cylinder Voltammetry (RCE)
- Rotating Cylinder Electrolysis (BE-RCE)
- Rotating Cylinder Eisenberg Study (EZB-RCE)
- Rotating Cylinder Polarization Resistance (LPR-RCE)
- Rotating Cylinder Open Circuit Potential (OCP-RCE)
- Rotating Cylinder Chronopotentiometry (CP-RCE)
- Rotating Cylinder Ramp Chronopotentiometry (RCP-RCE)

Spectroscopic Methods*

- Spectroscopy (SPEC)
- Spectroelectrochemistry (SPECE)

Table 2-1. Electrochemical Techniques in AfterMath

*Access to these electrode methods requires a different software license; by default, the WaveDriver 10 or WaveDriver 20 instruments are sold without these experiments. If you have a Pine Research electrode rotator or Avantes spectrometer and would like to access these experiments, please contact Pine Research Instrumentation for assistance.

‡The WaveDriver 10 is a single channel potentiostat and thus has only one working electrode, K1. The WaveDriver 20 is a dual channel bipotentiostat and thus has two working electrodes, K1 and K2. Therefore, the WaveDriver 10 cannot perform Dual Electrode or Rotating Ring-Disk Methods.

TIP:

More information about configuring electrochemical techniques using AfterMath may be found by searching our knowledgebase.

https://www.pineresearch.com/shop/knowledgebase/

2.5 System Components

The WaveDriver 10 or WaveDriver 20 systems, as shipped from the production facility, include all parts, cables, and software necessary for use (see: Table 2-2 and Table 2-3).

1

2

3

4

1	**Instrument**	A WaveDriver 10 or WaveDriver 20 potentiostat/galvanostat
2	**USB Flash Drive**	Contains AfterMath software, drivers, and license files
3	**Power Cord**	Power cord ($10\ A$) with a standard C13 connector. Use power cord supplied with instrument and certified for the country of use (see: Section 7 of this User Guide for details)
4	**Power Supply**	A $24\ VDC$ ($4.2\ A$) power supply. This power supply is compatible with any power source capable of providing 100 to $240\ VAC$ (50 or $60\ Hz$) to the standard C13 input connector on the power supply.

Table 2-2. Primary Components Included with WaveDriver Potentiostat

1

2

3

4

1	**USB Cable**	Communication cable between computer and WaveDriver (USB type A male to type B male)
2	**Universal Dummy Cell**	A network of known resistors and capacitors that can be used to test the WaveDriver to ensure that the instrument is working properly.
3	**WaveDriver 20 Cell Cable***	A general purpose 7-lead cell cable kit. All electrode lines are shielded coaxial cables from the cell port connector out to the banana plug at each end of the cable. A set of alligator clips which can slide on to the banana plugs is also included.
4	**WaveDriver 10 Cell Cable***	A general purpose 5-lead cell cable kit. All electrode lines are shielded coaxial cables from the cell port connector out to the banana plug at each end of the cable. A set of alligator clips which can slide on to the banana plugs is also included.

Table 2-3. Cables Included with WaveDriver Series Potentiostat

*Depending on whether the WaveDriver 20 or the WaveDriver 10 is purchased, either the 7-lead (WaveDriver 20) or the 5-lead (WaveDriver 10) cell cable will be shipped accordingly.

2.6 WaveDriver Front Panel

The front panel contains three important LEDs, the power switch, and the cell cable connector (see: Figure 2-1 and Figure 2-2). The three LEDs are used to indicate power, USB activity, and instrument status. Each LED corresponds to one of these indicators, and the various colors that one LED can assume are described in more detail below (see: Table 2-4).

Figure 2-1. Front Panel of the WaveDriver 10

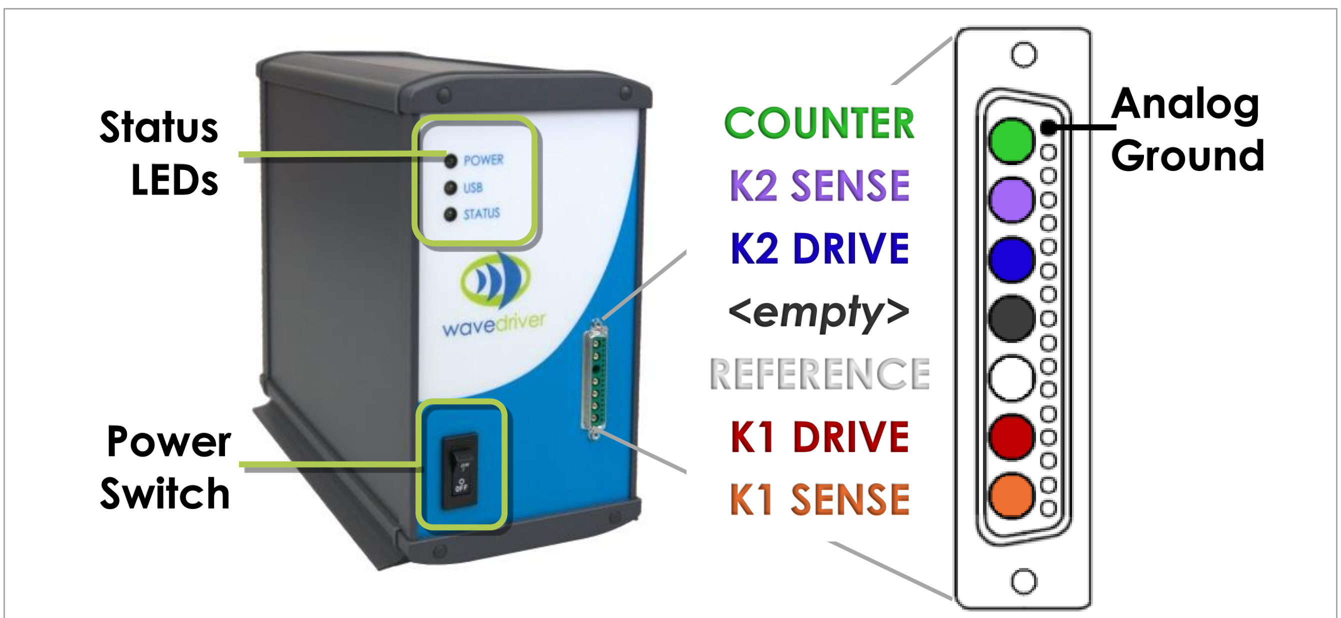


Figure 2-2. Front Panel of the WaveDriver 20

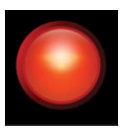
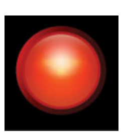
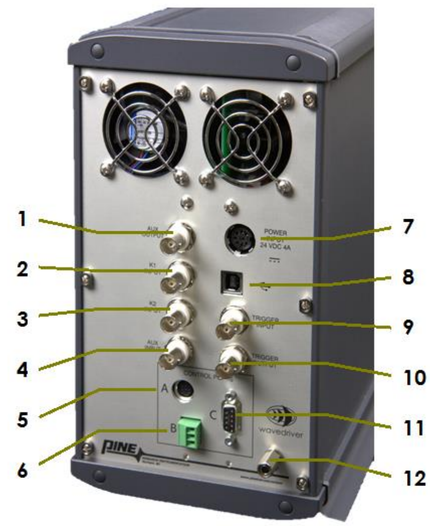
LED	LED Color/State	Indication
Power	 not illuminated	When the power LED is off, the instrument power switch is in the "off" position (or the power supply is not providing power).
	 solid yellow	When the power LED is solid yellow, the power supply is providing power to the instrument and the power switch is in the "on" position.
USB	 blinking green	The USB indicator will blink (or flicker) whenever data transfer occurs between the instrument and the computer.
	 not illuminated	No data is being transferred between the instrument and computer.
Status	 solid red	When the instrument is initially powered on, the instrument performs a self-test. The status light is red during the self-test. After the self-test completes, the status light changes to green.
	 solid green	When the instrument is idle and ready for use, the status light is green.
	 blinking green	When the instrument is performing an experiment, the status light is green and blinks on and off.
	 blinking red	If the status light is read and blinking on and off, then there is a problem with the instrument.

Table 2-4. Overview of the LED Indicator Lights

2.7 WaveDriver Back Panel

The back panel features several input and output connections (see: Figure 2-3) to facilitate connection to other instruments.



1	**AUX Output**	BNC female, $\pm 10\ V$ bipolar output, $313\ \mu V$ resolution, 0.2% accuracy
2	**K1 Input**	BNC female, $\pm 10\ V$ differential input, $20\ k\Omega$ impedance, $\pm 0.5\%$ accuracy; sums an external waveform to first working electrode (K1)
3	**K2 Input***	BNC female, $\pm 10\ V$ differential input, $20\ k\Omega$ impedance, $\pm 0.5\%$ accuracy; sums an external waveform to the second working electrode (K2)
4	**AUX Input***	BNC female, $\pm 10\ V$ differential input, $313\ \mu V$ resolution, $20\ k\Omega$ impedance, 0.2% accuracy; available only when K2 electrode not in use
5	**Rotator Control Port A**	7-pin mini-DIN input for rotator control – includes analog and digital signal grounds, digital rotator enable signal, auxiliary digital output signal, and analog rotation rate control signal
6	**Rotator Control Port B**	3-pin terminal block connector for rotator control – includes analog signal ground, digital rotator enable signal (open drain – TTL compatible), and analog rotation rate control signal ($\pm 10\ V$, $\pm 2.5\ V$)
7	**Power Input**	A low voltage ($24.0\ VDC\ \pm 5\%$, $4.0\ A$) power input connector
8	**USB Input**	USB jack (type B) for computer communication
9	**Trigger Input**	BNC female, TTL compatible
10	**Trigger Output**	BNC female, TTL compatible
11	**Digital Port**	9-pin DSUB connector includes digital signal ground, two digital output signals, and three digital input signals
12	**Chassis Terminal**	Banana binding post which provides a secure connection to the chassis of the instrument

Figure 2-3. The Back Panel of the WaveDriver 10 or WaveDriver 20

*The WaveDriver 10 is a single channel potentiostat and thus has only one working electrode (K1). The WaveDriver 20 is a dual channel bipotentiostat and thus has two working electrodes (K1 and K2).

2.8 Universal Dummy Cell Description

A "dummy cell" is a network of known resistors and capacitors that can be used to test a potentiostat to ensure that the instrument is working properly. The Universal Dummy Cell (part number AFDUM3) included with the WaveDriver offers four separate networks which represent the extremes encountered during routine aqueous voltammetry experiments (see: Figure 2-4).

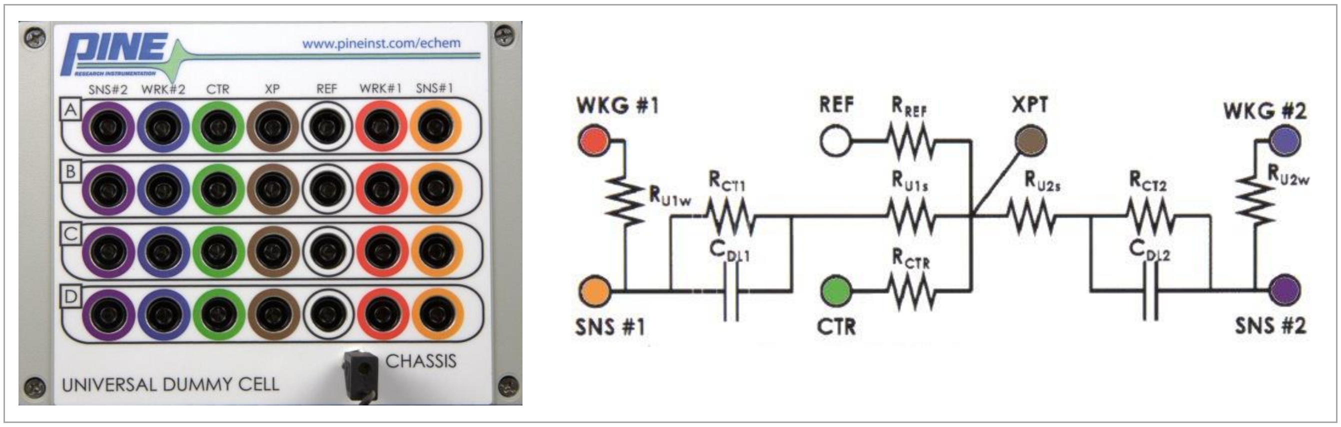


Figure 2-4. Universal Dummy Cell (with Schematic Diagram)

There are four rows of connections on the dummy cell (labeled "A" through "D") which correspond to four different dummy cell circuits. Each circuit has the same schematic (see: Figure 2-4), but the values of the resistors and capacitors in each circuit are different (see: Table 2-5).

To connect the WaveDriver to a particular row on the Universal Dummy Cell, connect each of the colored banana plugs on the Cell Cable to the corresponding colored banana jack on the dummy cell. The black banana plug (DC Common) should be plugged into the Universal Dummy Cell "CHASSIS" connection (see: Figure 2-5 and Figure 2-6).

Component	CELL A	CELL B	CELL C	CELL D
R_{U1w}	0.1 Ω	10 Ω	1 kΩ	5 kΩ
R_{CT1}	10 Ω	5 kΩ	1 MΩ	1 $G\Omega$
C_{DL1}	500 µF	20 µF	1 μF	500 pF
R_{U1s}	2 Ω	100 Ω	2 kΩ	1 $M\Omega$
R_{REF}	100 kΩ	100 kΩ	100 $k\Omega$	2 $M\Omega$
R_{CTR}	10 Ω	1 kΩ	5 kΩ	5 $M\Omega$
R_{U2w}	0.1 Ω	10 Ω	1 $k\Omega$	5 $k\Omega$
R_{CT2}	50 Ω	20 $k\Omega$	5 $M\Omega$	5 $G\Omega$
C_{DL2}	100 μF	5 μF	200 nF	100 pF
R_{U2s}	5 Ω	200 Ω	5 $k\Omega$	2 $M\Omega$

Table 2-5. Universal Dummy Cell Resistance and Capacitance Values

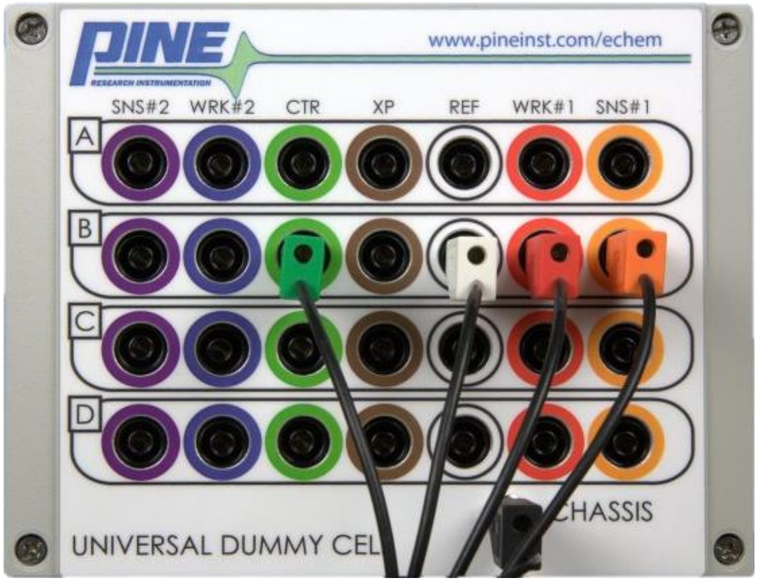


Figure 2-5. Universal Dummy Cell Connected to the WaveDriver 10

NOTE:

The WaveDriver10 Cell Cable has no K2 electrode connections, and the K2 jacks on the dummy cell (blue and violet) are unused.

Figure 2-6. Universal Dummy Cell Connected to the WaveDriver 20

3. System Installation

Setting up the WaveDriver 10 or WaveDriver 20 system in a laboratory consists of three basic steps: (1) physical installation; (2) software installation; and (3) system testing. The entire process usually requires about 60 minutes. The physical and software installation steps are described in this section (below), and the system testing procedure is described in the next section (see: Section 4).

3.1 Physical Installation

The WaveDriver 10 and WaveDriver 20 are benchtop instruments designed for use in a typical laboratory environment. Physical installation involves positioning the instrument and the computer which controls the instrument in a suitable location and connecting the instrument to a source of electrical power (*i.e.*, the AC Mains) and to the computer via a USB cable.

3.1.1 Location

The instrument should be placed on a sturdy lab bench or table in such a way that there is unobstructed access to the instrument's front panel; this will ensure space for the cell cable connection and allow the user to easily operate the power switch and see LED lights. There should also be at least two inches ($50\ mm$) of clearance around the sides (left, right, and back) and above (top) the instrument. Particular care should be given to selecting a clean and dry location. The vent fans on the back panel must not be blocked so that adequate ventilation is available for cooling the circuitry inside the instrument.

During normal use, the instrument is connected to an electrochemical cell via a cell cable plugged into the front panel of the instrument. Thus, it is important to ensure that the lab bench or table also has sufficient work space for securely mounting the electrochemical cell and for routing the cell cable between the instrument and the electrochemical cell.

3.1.2 Glovebox Installation

There are two practical ways to perform electrochemical experiments inside of a glovebox. Both require that electrical power be present inside the glovebox to power the instrument, and the glovebox must also be equipped with special feedthroughs for the cell cables, or preferably for the USB cable. These two approaches are discussed in more detail below.

Potentiostat and Electrochemical Cell in Glovebox

Placing the instrument and the electrochemical cell inside the glovebox is by far the easiest and preferred approach. By keeping the instrument close to the cell, the cell cables are shorter, minimizing interference from environmental noise sources. This approach requires that the glovebox be equipped with a special USB feedthrough port. This allows the computer controlling the instrument to be placed outside the glovebox, and the only signals passing through the wall of the glovebox are those in the USB communications cables. Inexpensive third-party USB cable feedthroughs are available (see: Figure 3-1) which fit into the standard KF style flanges found on most gloveboxes. Many Pine Research customers have successfully used feedthroughs offered by the Kurt J. Lesker Company (www.lesker.com).

The instrument may be safely passed into the glovebox through the antechamber. Any cables, power cords, or instrument accessories are also safe to bring into the glovebox through the antechamber. The exact time needed to fully remove any residual air from the potentiostat and accessories varies by antechamber size and vacuum strength; in addition to following established glovebox user protocols, it is recommended to place everything under vacuum overnight. Once inside the glovebox, operation of the potentiostat is identical to outside the glovebox, though some signal noise may be introduced by the glovebox environment (vacuum pumps, purging gases, vibrations, etc.). Once inside the glovebox, it is a good idea to leave it there; repeated cycling through the antechamber is not recommended.

Figure 3-1. USB Cable Glovebox Feedthrough

Figure 3-2. Cell Cable Glovebox Feedthrough

Electrochemical Cell Only in Glovebox

If the potentiostat must remain outside the glovebox, then it is possible to feed a special longer version of the cell cable through a port in the wall of the glovebox. A port with a KF-40 flange is ideal, and epoxy can be used to seal around the individual cell cable lines as they pass through the flange (see: Figure 3-2). To mitigate any signal noise picked up by the longer cell cable, an electrically conductive and earth grounded mesh may need to be installed around the cell cable bundle. Contact Pine Research Instrumentation for further details.

3.1.3 Electrical Power

The power supply provides the DC power required by the instrument ($24\ VDC, 4.0\ Amps$) via a low voltage cable. One end of the low voltage cable is permanently connected to the power supply, and the other end is connected to the DC power port (located on the back panel of the instrument and marked "POWER INPUT" (see: Figure 3-3).

The WaveDriver Power Supply is connected to the AC Mains via a Power Cord. The Power Cord must be rated to carry at least $10\ amps$. One end of the Power Cord is connected to the standard C13 connector on the Power Supply, and the other end is connected to the AC Mains (wall outlet). Pine Research Instrumentation offers power cords suitable for use in a variety of different countries and regions (see: Section 7).

The local source of electrical power (*i.e.*, the AC Mains) must be a branch circuit protected by a circuit breaker rated between 10 and $15\ amps$. The AC voltage supplied by the AC Mains must be between 100 and $240\ VAC$, and the AC frequency must be between 50 and $60\ Hz$. The Power Supply and cord must be positioned in such a way that the instrument user has free and unobstructed access to these items. The user must be able to disconnect the instrument from the Power Supply and disconnect the power supply from the AC mains (wall outlet) without any obstructions.

Figure 3-3. Power Supply with Low Voltage ($24\ VDC$) Cable Connection to the Back Panel

CAUTION:

Connect the Power Supply to the AC mains using the Power Cord supplied with the WaveDriver and certified for the country of use (see: Section 7 of this User Guide for more details.)

ATTENTION:

Connectez le bloc d'alimentation au secteur à l'aide du cordon d'alimentation fourni avec l'appareil WaveDriver et conforme aux réglementations du pays d'utilisation (pour plus de détails, consultez la partie 7 du présent mode d'emploi)

CAUTION:

Do not block access to the Power Supply or its cord. The user must have access to disconnect the Power Supply or the Power Cord from the AC mains at all times.

ATTENTION:

Ne bloquez pas l'accès au bloc d'alimentation ou son cordon. L'utilisateur doit être en mesure de déconnecter le bloc d'alimentation ou le cordon d'alimentation du secteur à tout moment.

CAUTION:

The Power Switch located on the front panel of the instrument disconnects the instrument from the power source. Do not block access to the Power Switch. The user must have access to the Power Switch at all times.

ATTENTION:

L'interrupteur situé sur le devant de l'appareil permet de couper l'alimentation. Ne bloquez pas l'accès à l'interrupteur. L'utilisateur doit avoir accès à l'interrupteur à tout moment.

3.1.4 USB Cable Connection

The WaveDriver 10 or WaveDriver 20 is connected to a computer using the USB cable supplied with the instrument (Type A male to Type B female USB cable, see: Figure 3-4). The USB port on the computer must be capable of USB 2.0 (or better) data transfer rates.

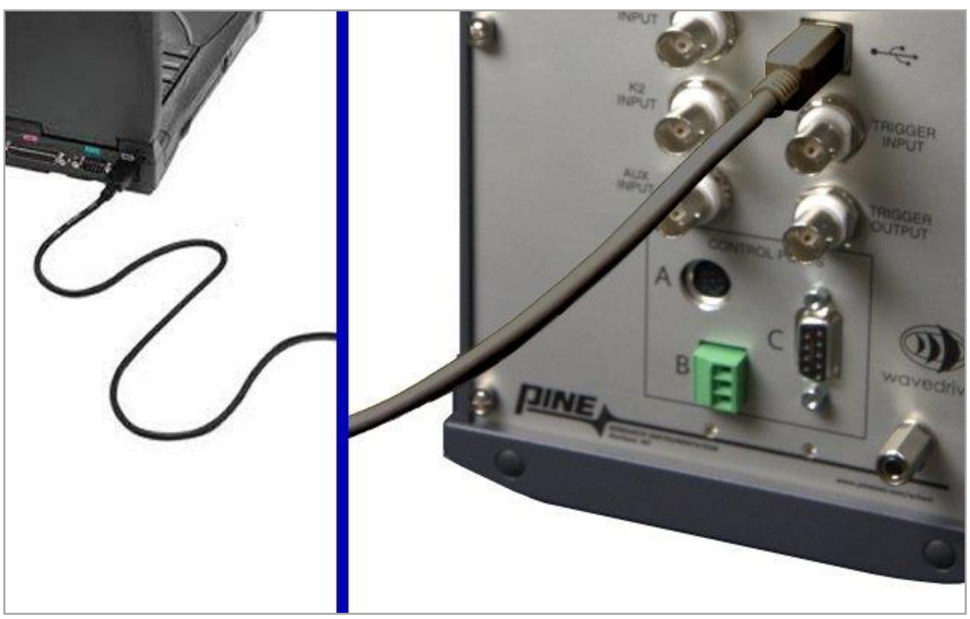


Figure 3-4. USB Cable Connection between WaveDriver Potentiostat and Computer

3.2 AfterMath Software Installation

AfterMath is a software package designed to run on a personal computer using the Windows operating system. The minimum system requirements for the personal computer and operating system are listed below (see: Table 3-1).

Processor Class	Intel Pentium IV or equivalent/compatible
Processor Speed	1 GHz minimum recommended
Physical Memory	1 GB minimum recommended for 32 bit operating systems 2 GB minimum recommended for 64 bit operating systems
Screen Resolution	1024 x 768 pixels or greater required
Operating System	Windows XP (32-bit only), Windows Vista (32 or 64 bit), Windows 7 (32 or 64 bit), Windows 8 (32 or 64 bit), Windows 10 (32 or 64 bit)
USB Port	USB 2.0 must be available
Prerequisite Software	.NET Framework version 2.5.50727 Visual C++ 8.0 Runtime

Table 3-1. Computer System Requirements for AfterMath Software

Note that the prerequisite software (Visual C++ runtime and .NET Framework) are often already present on modern personal computers. In the event that they are missing from the computer, these components are available for free download from the website of Microsoft Corporation. Pine Research Instrumentation maintains updated links to recent AfterMath and Microsoft downloads at the following web address: https://www.pineresearch.com/shop/knowledgebase/software-downloads.

TIP:

If any problem is encountered during software installation, please search "AfterMath" on the knowledgebase:

https://www.pineresearch.com/shop/knowledgebase/

3.2.1 Step-by-Step Software Installation Instructions

AfterMath is shipped with the WaveDriver 10 or WaveDriver 20 on removable media such as a CD-ROM or a USB data stick. The media contains the latest release of AfterMath available at the time of purchase, device drivers for communicating with the instrument, and the permissions file which implements the software license.

The installation media contains a file called "**setup.exe**". Launch this executable file and follow the instructions on the screen. Screenshots of a typical installation are provided below (see: Figure 3-5 through Figure 3-14).

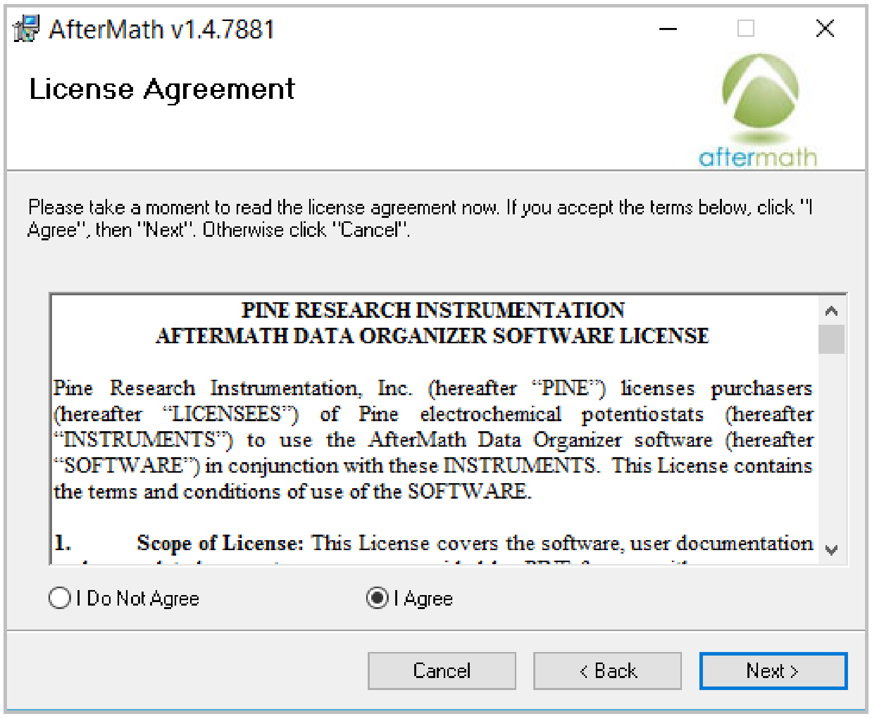


Figure 3-5. License Agreement Window during the Installation of AfterMath

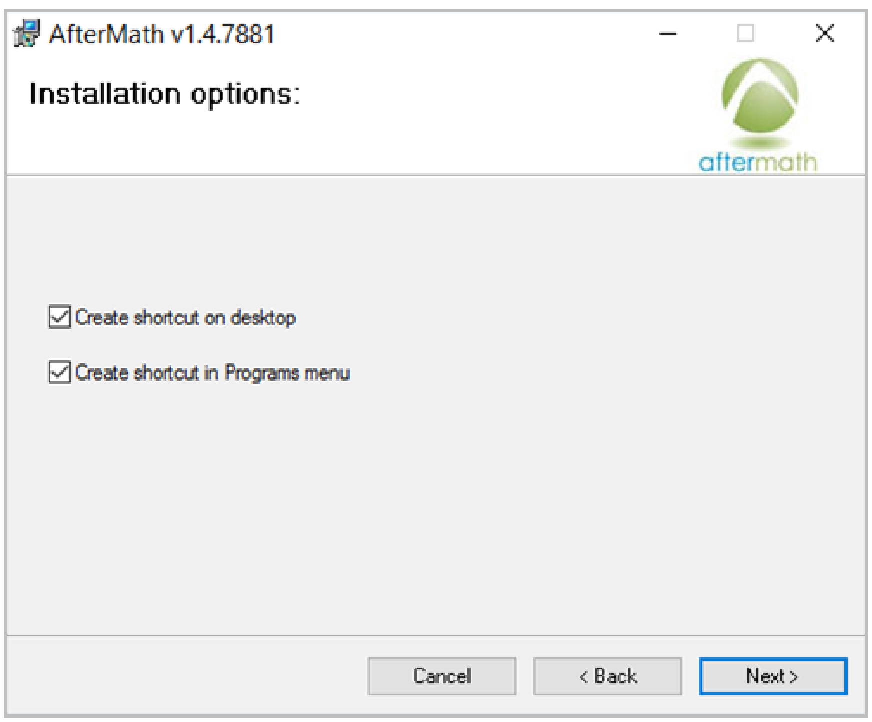


Figure 3-6. Installation Options Dialog during AfterMath Installation

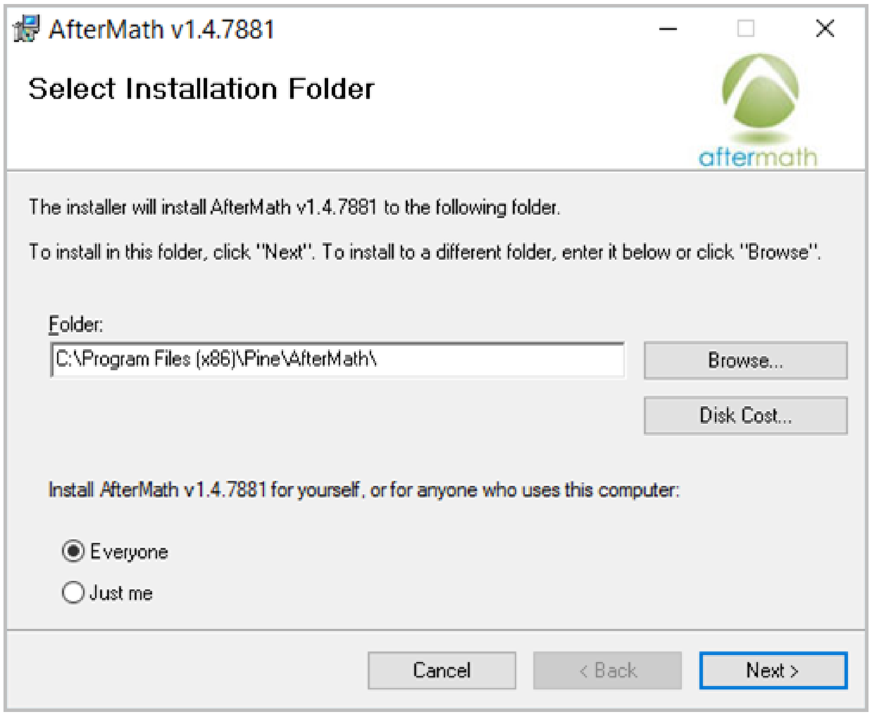


Figure 3-7. Select Installation Location and User Access (choose "Everyone")

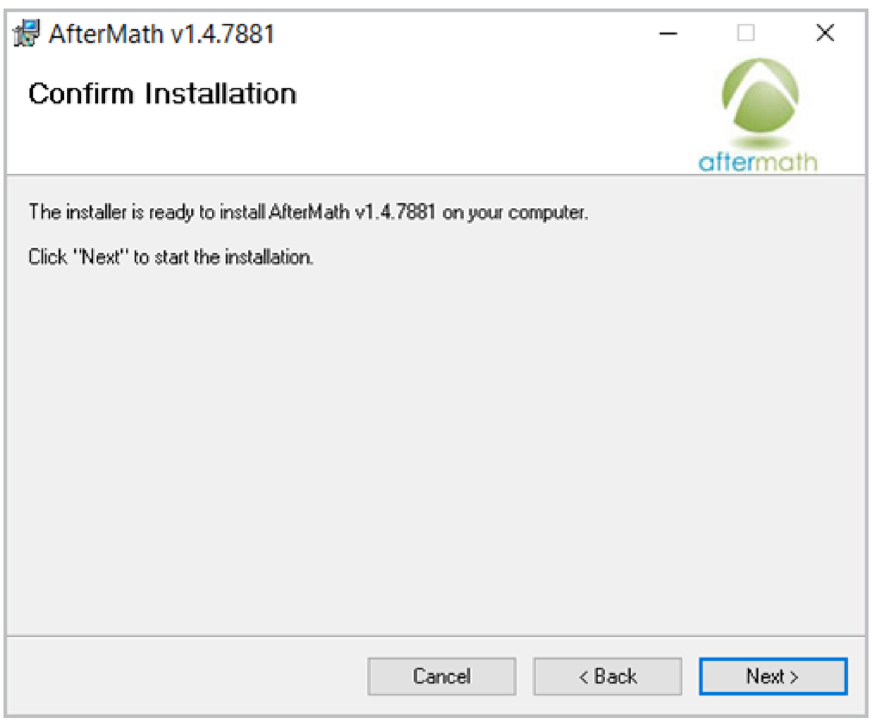


Figure 3-8. Confirmation of Installation Settings during the Installation of AfterMath

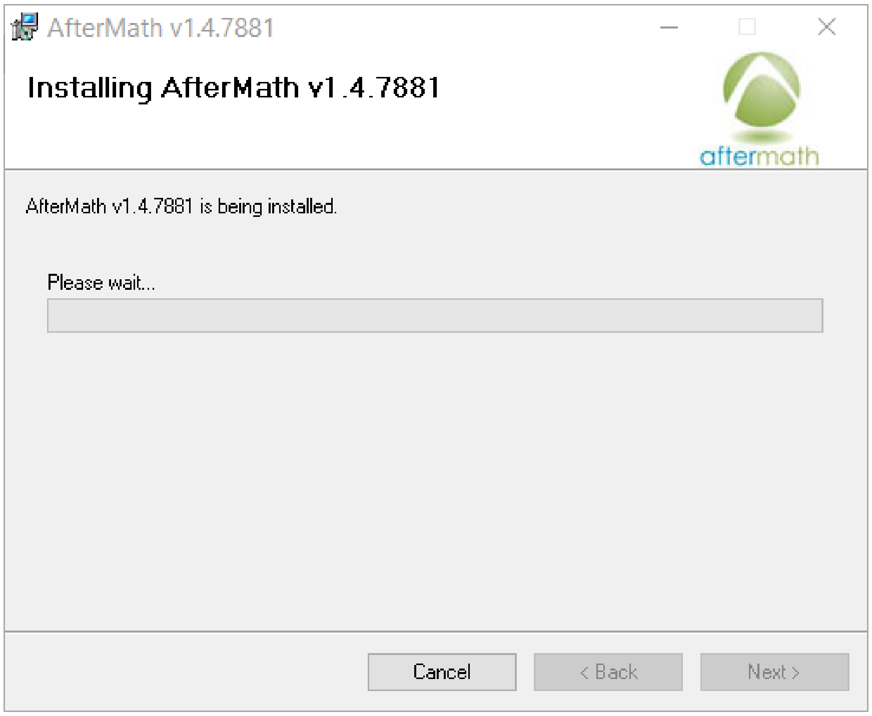


Figure 3-9. Dialog Box Showing Progress during AfterMath Installation

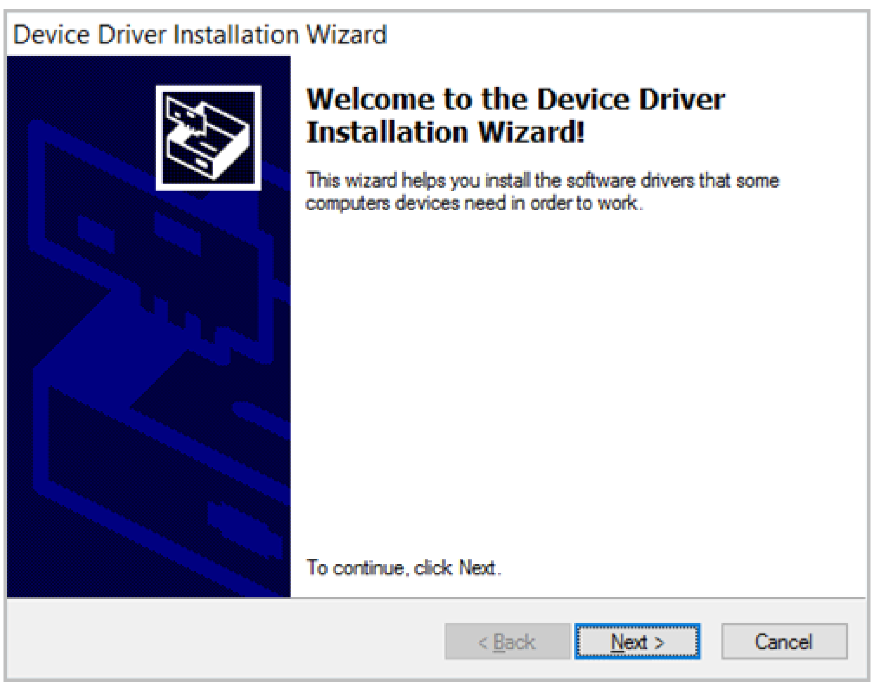


Figure 3-10. Automatic Device Driver Installation Wizard during AfterMath Installation

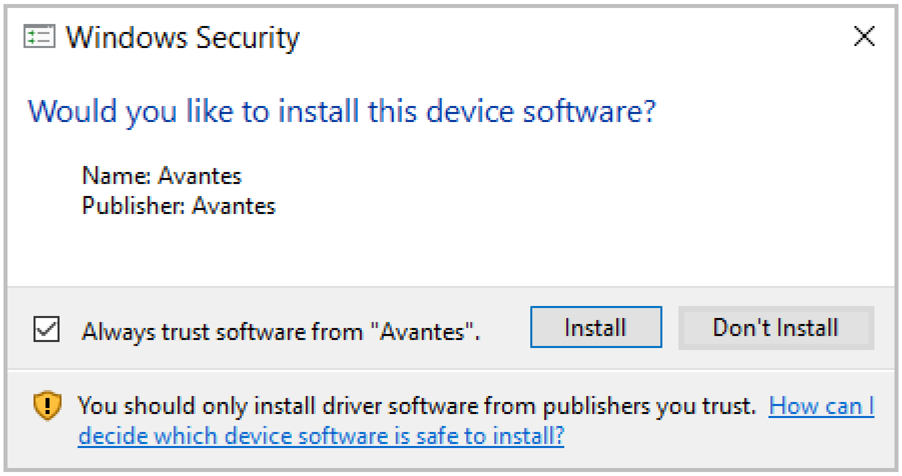


Figure 3-11. Windows Security Prompt to Install Device Software

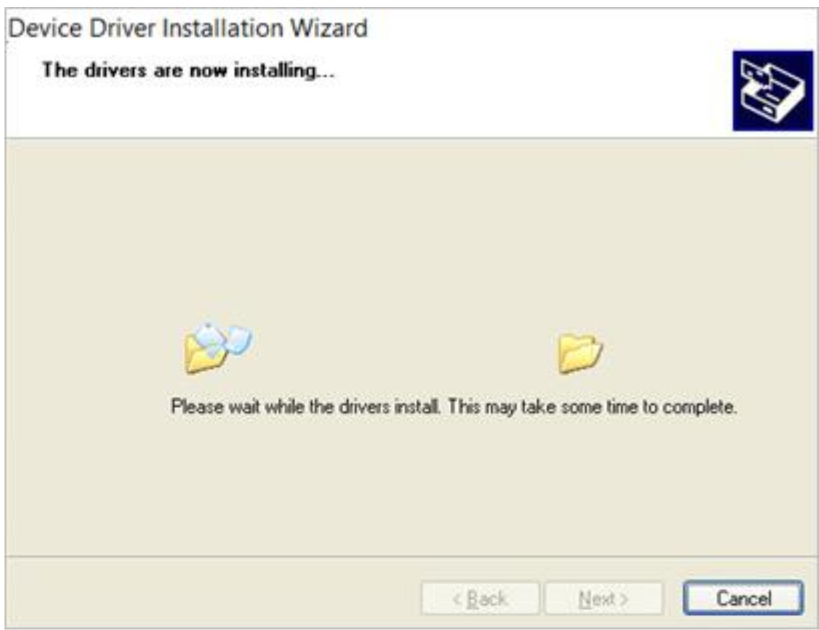


Figure 3-12. Device (USB) Driver Progress Window during AfterMath Installation

Figure 3-13. USB/Device Driver Installation Complete during AfterMath Installation

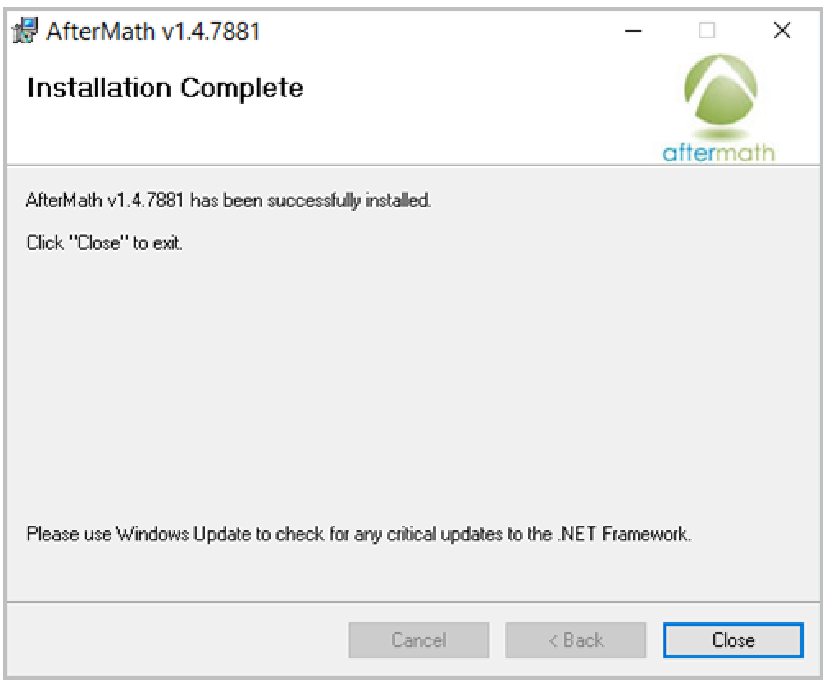


Figure 3-14. Windows Prompt to Indicate Successful Installation of AfterMath

3.2.2 Permission File Verification

On the installation media, there are licenses or "permission files" that authorize a computer running AfterMath to control specific instruments (see: Figure 3-15). If Aftermath is installed on the computer using the installation media shipped with a particular instrument, then these permission files are automatically copied to the computer.

If AfterMath is downloaded directly from the internet and installed on a computer, the permission files may not be present on the computer. This is most often noticed by the user when the AfterMath "Perform" button is disabled (gray shading, see: Figure 3-16). To ensure the proper permissions files are on the computer, open the installation media and launch the AfterMath software. Create a new archive in AfterMath (this can be accomplished by selecting **Cyclic Voltammetry** from the **Experiments** menu). Next, simply drag and drop the permission files (all file names ending in "*.papx") from the installation folder directly into the archive (see: Figure 3-17). The AfterMath program will remember the permission files even after the program is closed (*i.e.*, this step only needs to be performed once). You may be prompted to accept changes by the AfterMath program.

NOTE:

Contact Pine Research Instrumentation if you encounter any issues with software licensing or permissions files.

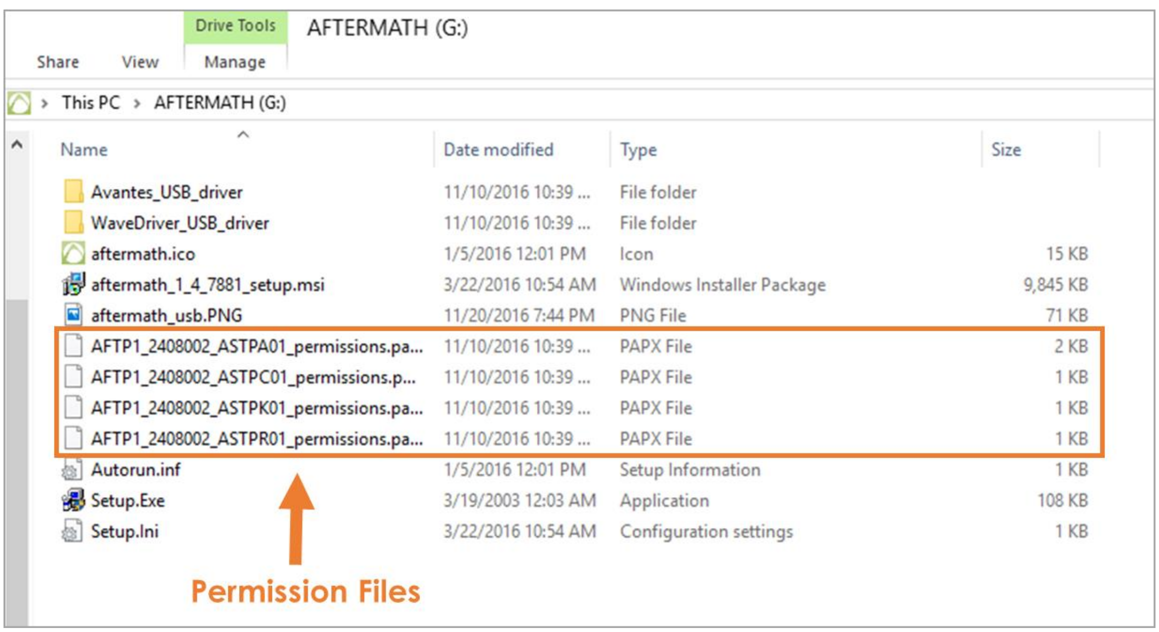


Figure 3-15. Permission Files on Installation Media

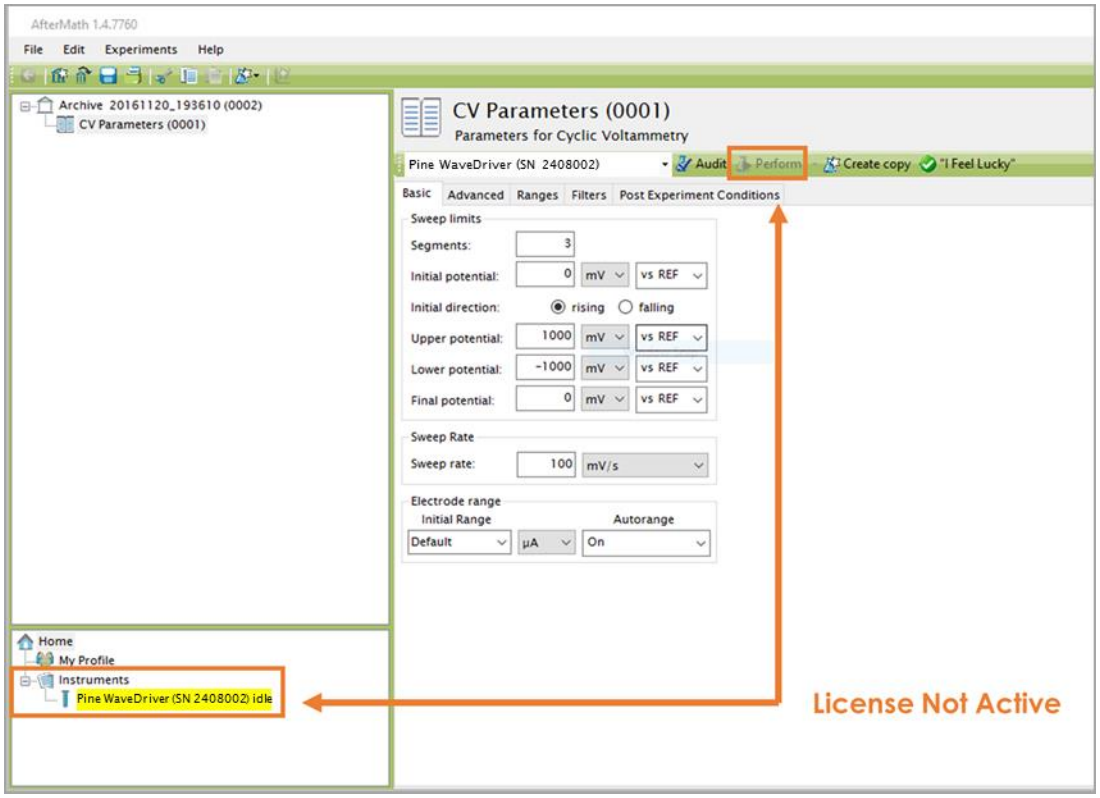


Figure 3-16. Indications that the AfterMath License is not Active

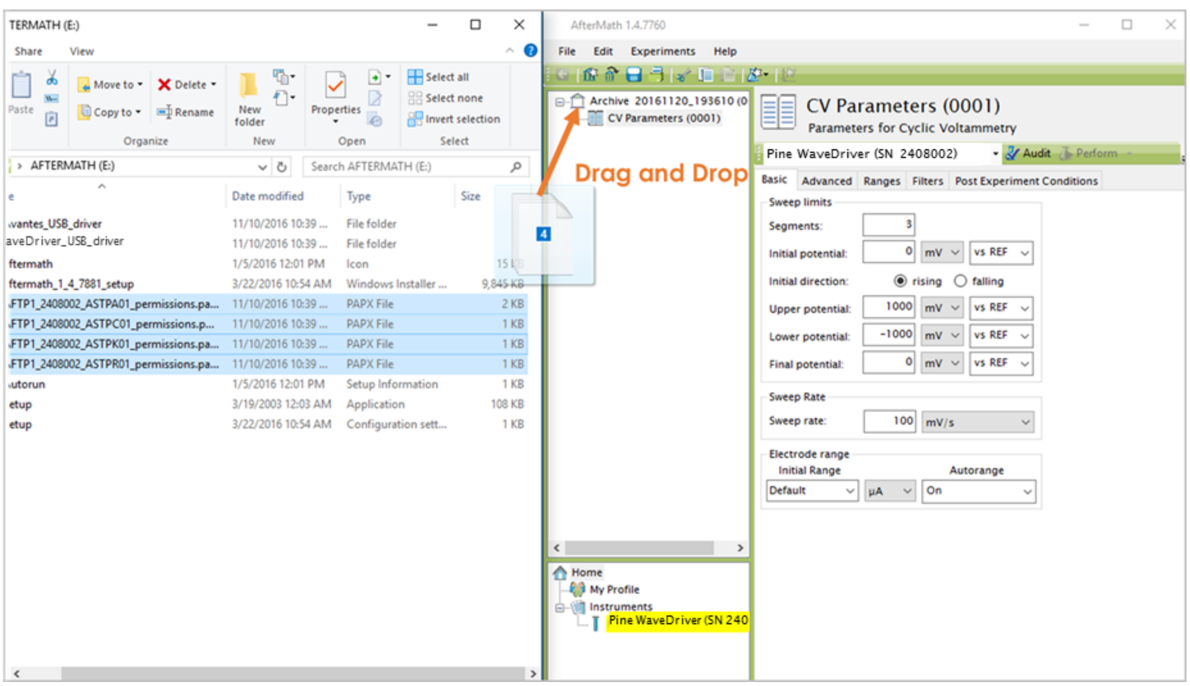


Figure 3-17. Copying Permission Files to AfterMath

3.3 Installation Checklist

The next section of this guide will describe testing a fully-installed WaveDriver 10 or WaveDriver 20. Before proceeding, ensure the following installation steps have been completed:

- ✓ The WaveDriver 10 or WaveDriver 20 instrument is located in a secure, dry location with adequate space
- ✓ Electrical Power is connected to the WaveDriver 10 or WaveDriver 20
- ✓ The WaveDriver 10 or WaveDriver 20 instrument is connected to a computer via the USB cable
- ✓ AfterMath software is installed on the computer

4. System Testing

This section describes a fast way to test the WaveDriver 10 or WaveDriver 20 potentiostat system. By connecting the potentiostat to a well-behaved network of resistors and capacitors (using the Universal Dummy Cell), the potentiostat circuitry can be tested to ensure that it is working properly.

TIP:

To verify the instrument is operating correctly, perform the system test described here. This test is one of the first actions that will be suggested if you contact Pine Research for technical support.

The system test is presented here in three distinct sections: §4.1 describes the basic test setup, §4.2 describes a single channel (K1 only) test, and §4.3 describes a dual channel (K1 and K2 together) test. The dual channel test is only applicable to the WaveDriver 20 Bipotentiostat/Galvanostat system. For the WaveDriver 10, only the steps described in §4.1 and §4.2 need to be performed.

4.1 Test Setup

4.1.1 Launch the AfterMath Software

Launch AfterMath (which should already be installed – see: Section 3) and log into AfterMath (see: Figure 4-1). Click "OK" on the AfterMath Login dialog window to start the program.

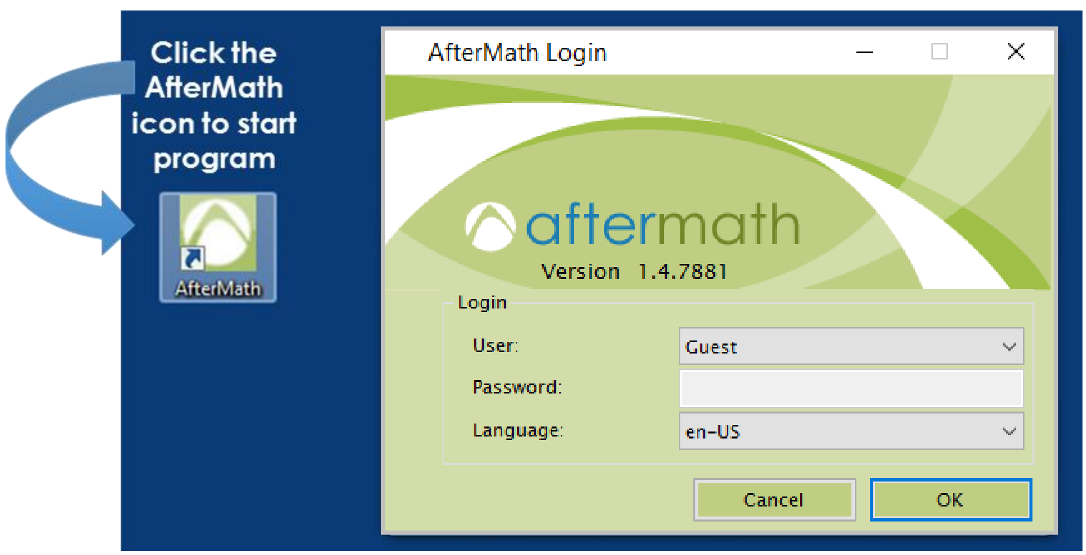


Figure 4-1. Initial Login Screen when Starting AfterMath

4.1.2 Verify Instrument Status

Turn on the instrument using the side panel power switch and wait for the WaveDriver 10 or WaveDriver 20 to appear in the AfterMath Instrument List. The instrument should appear along with its serial number under the "Instruments" node (see: Figure 4-2).

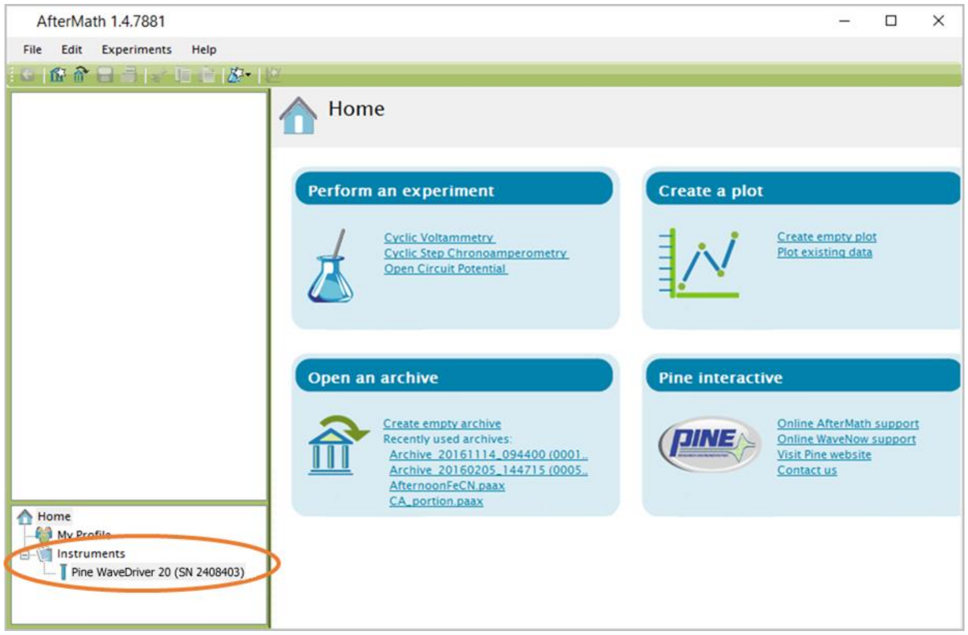


Figure 4-2. AfterMath Screenshot with the Instrument Status Circled

4.1.3 Confirm Connections

Check the status LED on the WaveDriver 10 or WaveDriver 20. It should be green, indicating that the potentiostat is idle (see: Figure 4-3). The USB indicator light should flicker occasionally (see: Table 2-4 for more information about LED indicators).

Figure 4-3. LED Status Light on the Front Panel of the WaveDriver 10 or WaveDriver 20

4.1.4 Review Instrument Status

Examine the instrument status display (see: Figure 4-2). Initially, the status may indicate that the cell is disconnected. If desired, the idle controls on the Instrument Status screen can be used to apply a known idle condition to the cell. In the example shown (see: Figure 4-4), both working electrodes have been set to idle under potentiostatic control while applying +1.2 *volts* to the first working electrode (K1) and zero volts to the second working electrode (K2).

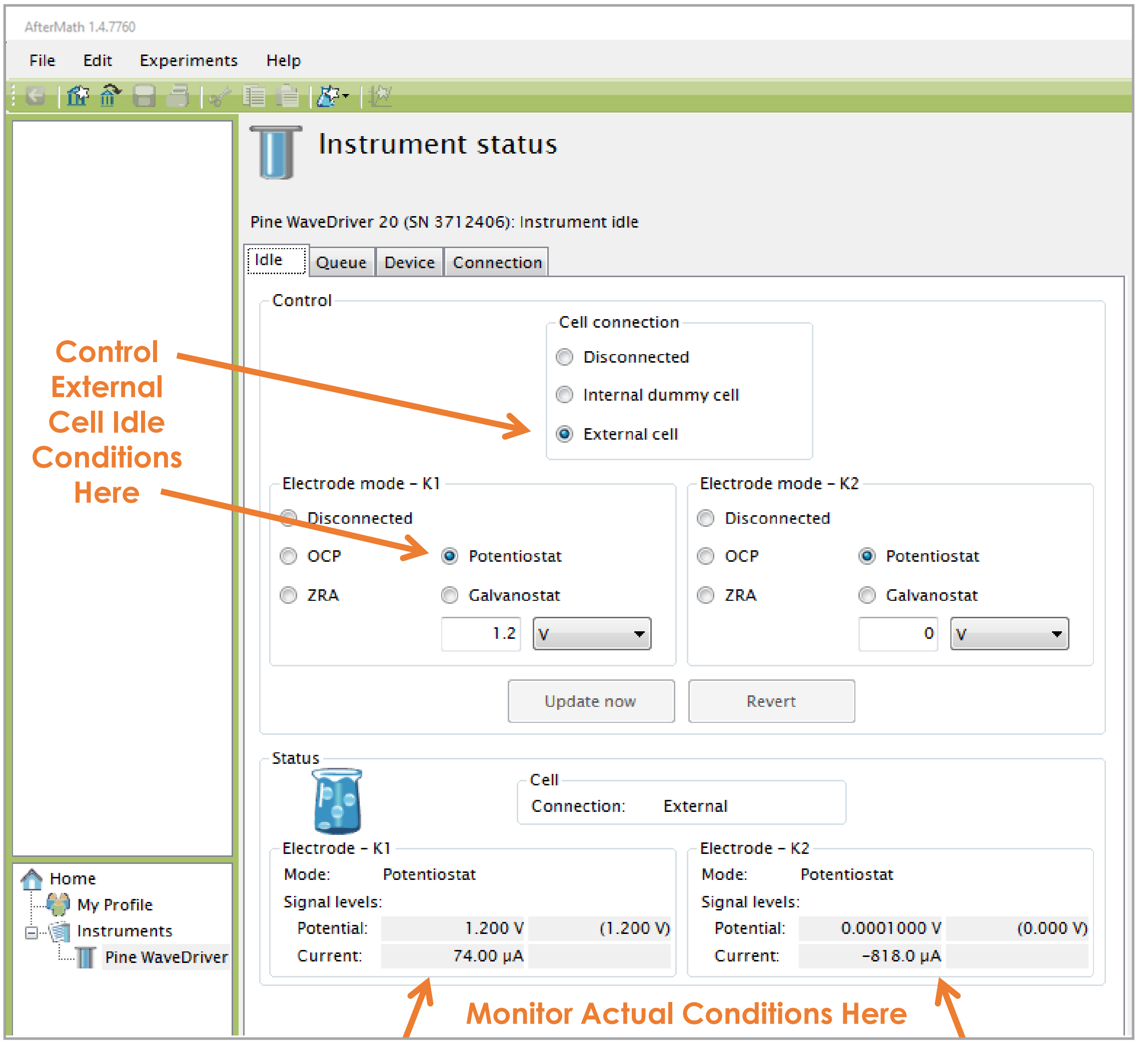


Figure 4-4. AfterMath Instrument Status Window showing External Cell Idle Conditions

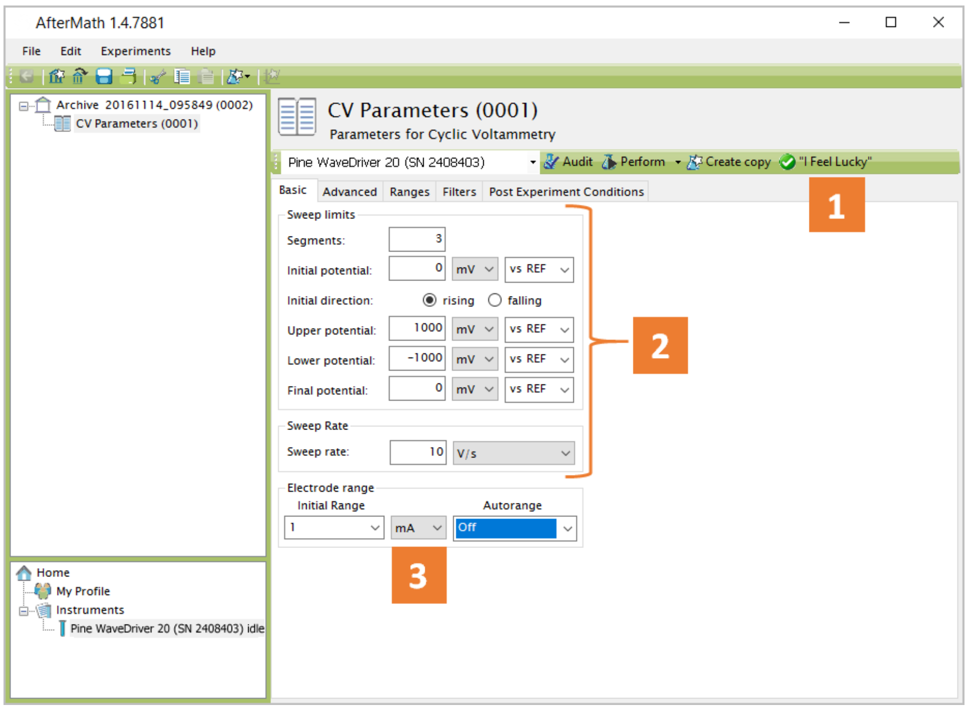
4.2 Single Channel (K1) Test

4.2.1 Connect to the Universal Dummy Cell

Connect one end of the Cell Cable to the front panel of the WaveDriver. Connect the other end to row "B" of the Universal Dummy Cell (see: Figure 2-5). Connect the black banana plug on the Cell Cable to the chassis connector on the Universal Dummy Cell. Connect all of the other banana plugs to the banana jacks with corresponding colors on the dummy cell (see: Section 5.1 for more information).

4.2.2 Create a Cyclic Voltammetry (CV) Experiment

From the AfterMath Experiments menu, choose the Cyclic Voltammetry (CV) option from the list of available electrochemical techniques. A new CV specification is created and placed in a new archive. Configure the parameters as detailed below (see: Figure 4-5).



1 Click on the "I Feel Lucky" button

2 Note that the number of segments, sweep limits, and scan rate automatically fill.

3 Set the Electrode Range to "$1\,mA$", Autorange "Off." (This causes the $1\,mA$ range to be used throughout the test, without any current autoranging)

Figure 4-5. Cyclic Voltammetry (CV) Parameters Dialog Window

4.2.3 Audit Experimental Parameters

Choose the WaveDriver 10 or WaveDriver 20 potentiostat in the drop-down menu (see: Figure 4-6, to the left of the "Audit" button). Then, press the "Audit" button to check the parameters. AfterMath will perform a quick audit of the parameter values to ensure that all required parameters have been specified and are within allowed ranges.

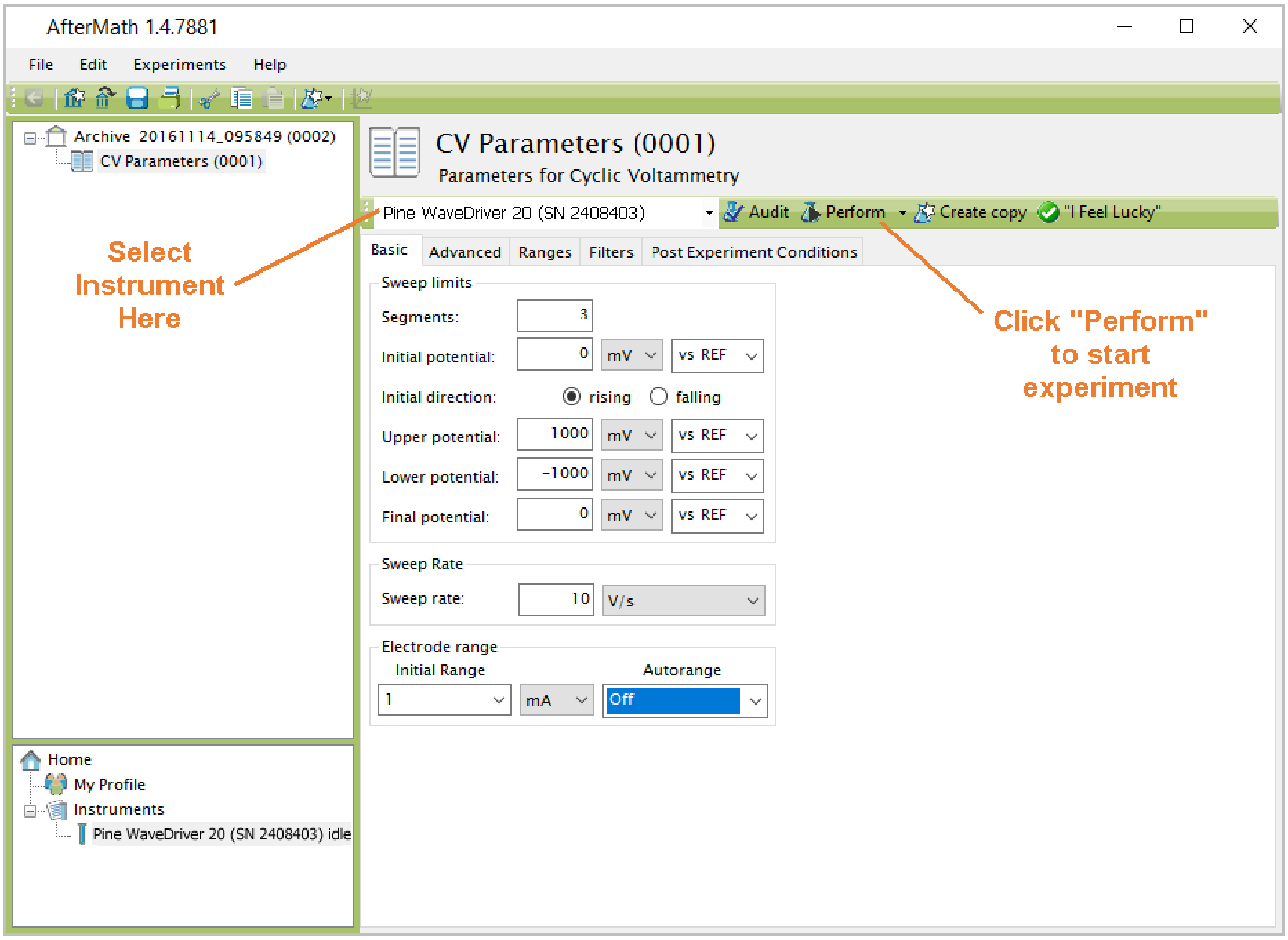


Figure 4-6. Location of Instrument Selection Menu and Perform Button (CV)

4.2.4 Initiate the Experiment

Next, click on the "Perform" button to initiate the cyclic voltammetry experiment. The "Perform" button is located just to the right of the "Audit" button (see: Figure 4-6).

NOTE:

If the "Perform" button is disabled (shaded gray), this is an indication that the AfterMath software on the computer is not licensed to control the instrument. The remedy for this issue is to obtain and install the appropriate permissions files (see: Section 3.2.2).

4.2.5 Monitor Experimental Progress

Monitor the progress of the experiment by observing the real time plot, the numeric percent complete indicator, or the progress bar (see: Figure 4-7).

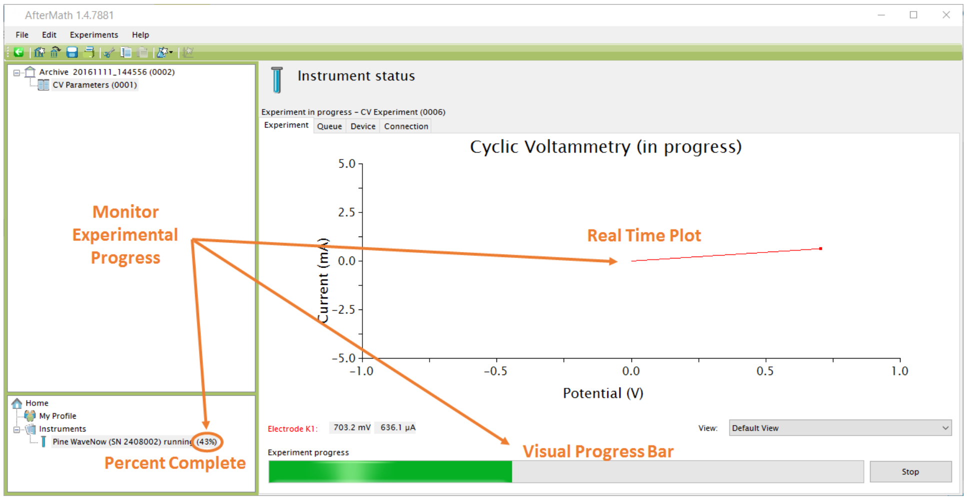


Figure 4-7. Monitoring the Progress of the Experiment

4.2.6 Review the Results

When the experiment is finished, the results of the experiment are placed in a study folder in the archive (see: Figure 4-8). In addition to the main voltammogram plot in the study folder, additional graphs are available in the "Other Plots" folder. The results can also be viewed in tabular form under the "experiment" node.

EXPECTED UNIVERSAL DUMMY CELL RESULT:

The anticipated test result is a diagonal trace (see: Figure 4-8) which is obviously not an actual voltammogram. The slope of this trace is inversely related to the total resistance in "Cell B" of the dummy cell (~5 $k\Omega$).

EXPLORE EXPERIMENTAL NODES:

Click on the "+" sign next to a node to open it. Additional data can be found in the "experiment" node. Nodes may be renamed and organized in folders as desired.

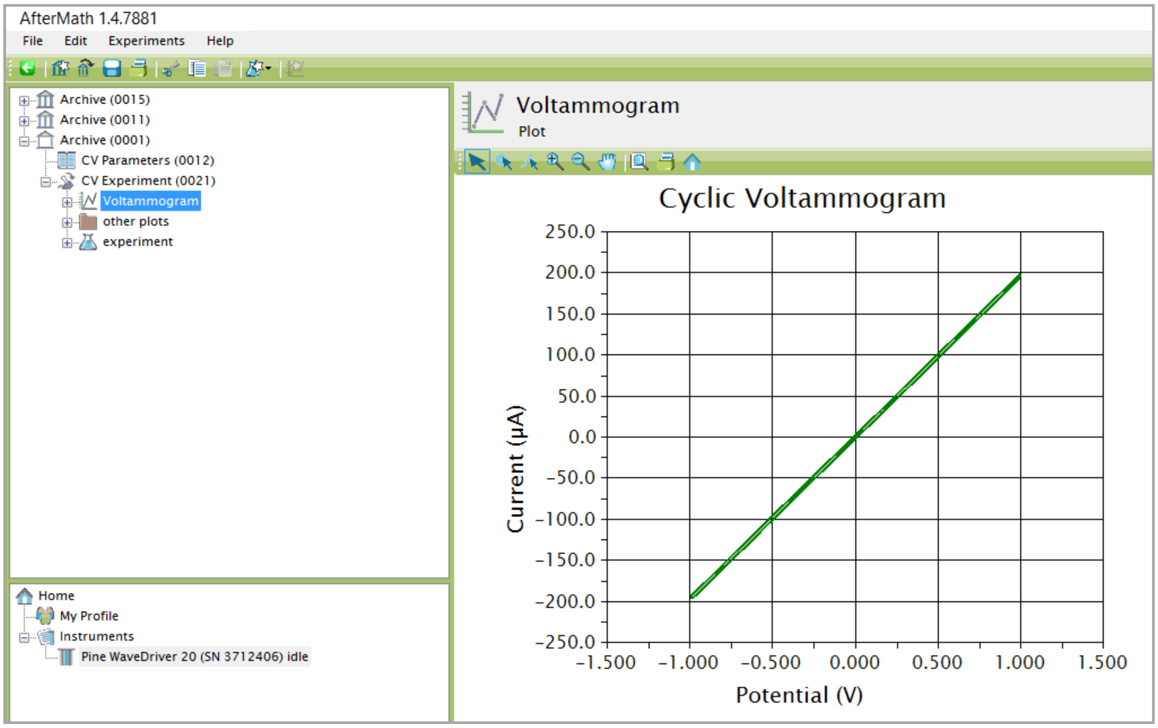


Figure 4-8. Anticipated Results for Cyclic Voltammetry (using Dummy Cell "B")

For a more thorough discussion of how to use the AfterMath software, please consult the *AfterMath User Guide* on our knowledgebase:

https://www.pineresearch.com/shop/knowledgebase/

End of Single Channel Test!

If testing a WaveDriver 10 Potentiostat/Galvanostat system, stop here. If testing a WaveDriver 20 Bipotentiostat/Galvanostat system, continue to the next test (see: Section 4.3) to test both working electrode channels.

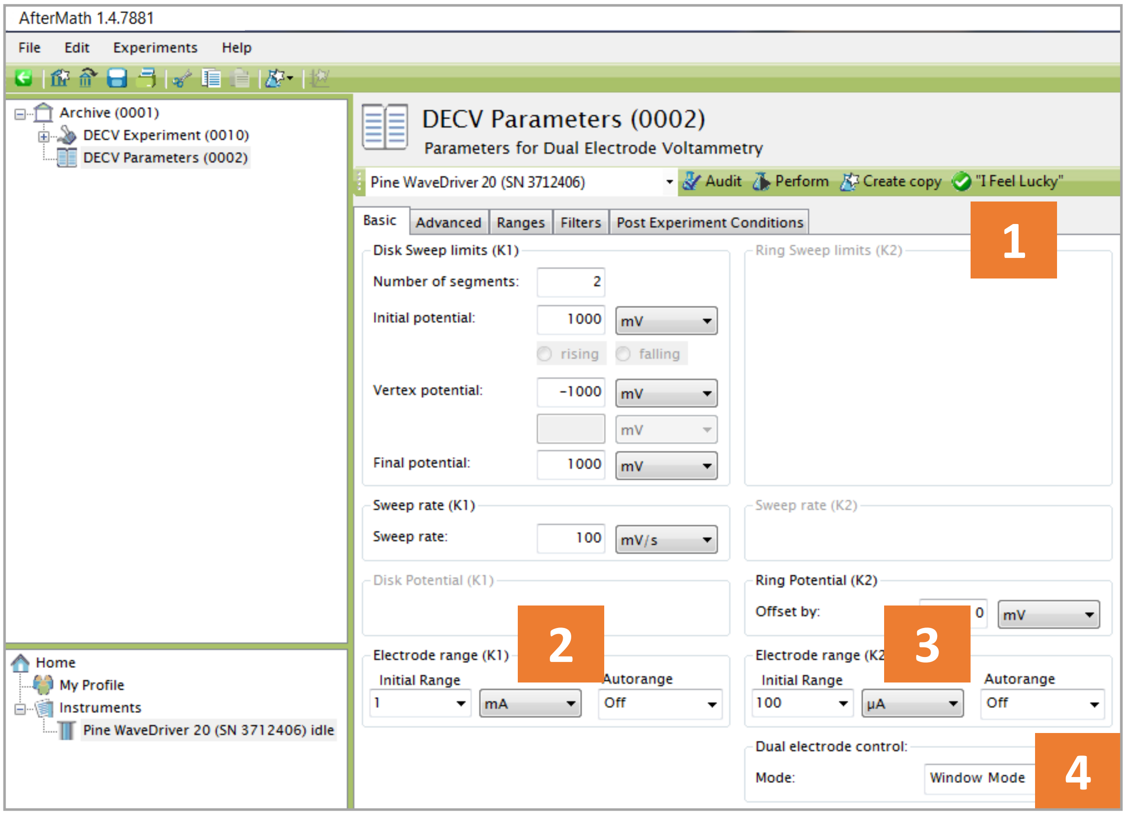
4.3 Dual Channel (K1 and K2) Test

4.3.1 Connect to the Universal Dummy Cell

Connect one end of the Cell Cable to the front panel of the WaveDriver. Connect the other end to row "B" of the Universal Dummy Cell (see: Figure 2-6). Connect the black banana plug on the Cell Cable to the chassis connector on the Universal Dummy Cell. Connect all of the other banana plugs to the banana jacks with corresponding colors on the dummy cell (see: Section 5.1 for more information).

4.3.2 Create a Dual Electrode Cyclic Voltammetry (DECV) Experiment

From the AfterMath Experiments menu, choose the Dual Electrode Cyclic Voltammetry (DECV) option from the dual electrode sub-menu. A new DECV specification is created and placed in a new archive. Configure the parameters as detailed below (see: Figure 4-9).



1	Click on the "I Feel Lucky" button. Note that the number of segments, sweep limits, and scan rate automatically fill.
2	Set the K1 Electrode Range to "$1\ mA$" with Autorange "Off"
3	Set the K2 Electrode Range to "$100\ \mu A$" with Autorange "Off"
4	Change the Dual electrode control mode to "Window"

Figure 4-9. Dual Electrode Cyclic Voltammetry (DECV) Parameters

4.3.3 Modify the Potential Range Setting

Select the ten volt ($10\ V$) range for both working electrodes (K1 and K2) as follows:

1. Click the "Ranges" tab (see: Figure 4-10).
2. Change the Electrode Range to "$10V$" and Autorange to "On". Do this for both the K1 and K2 potential ranges.

4.3.4 Audit Experimental Parameters

Choose the WaveDriver potentiostat in the drop-down menu (see: Figure 4-11, to the left of the "Audit" button). Then, press the "Audit" button to check the parameters. AfterMath will perform a quick audit of the parameter values to ensure that all required parameters have been specified and are within allowed ranges.

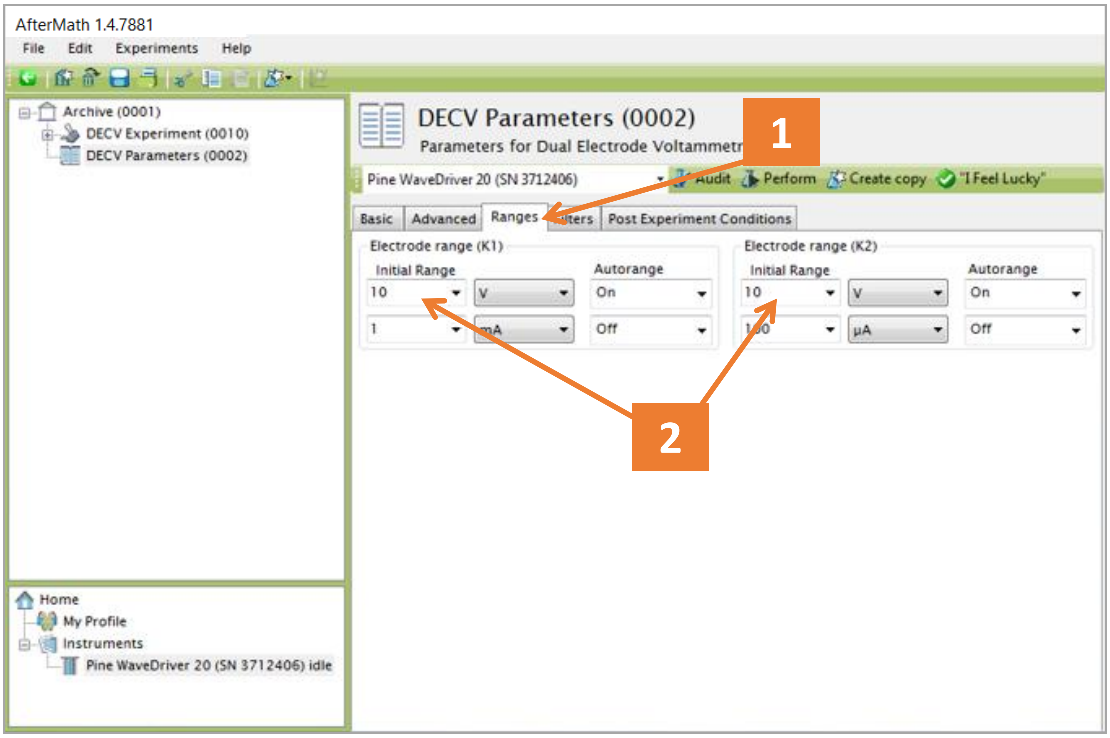


Figure 4-10. Adjusting the Potential Range on the "Ranges" Tab

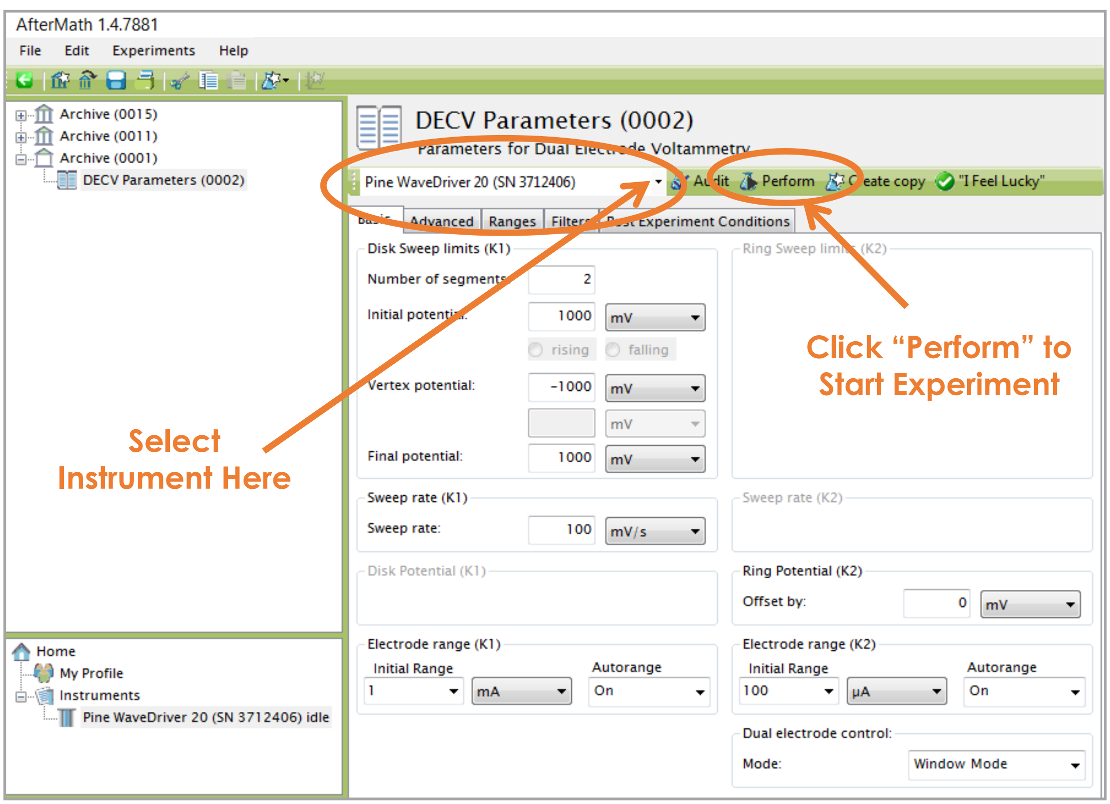


Figure 4-11. Location of Instrument Selection menu and Perform button (DECV)

4.3.5 Initiate the Experiment

Next, click on the "Perform" button to initiate the cyclic voltammetry experiment. The "Perform" button is located just to the right of the "Audit" button (see: Figure 4-11).

4.3.6 Monitor Experimental Progress

Monitor the progress of the experiment by observing the real time plot, the percentage complete value, and the progress bar (see: Figure 4-12).

4.3.7 Review the Results

When the experiment is finished, the results of the experiment are placed in a study folder in the archive (see: Figure 4-13). In addition to the main voltammogram plot in the study folder, additional graphs are available in the "Other Plots" folder. The results can also be viewed in tabular form under the "experiment" node.

NOTE:

The anticipated test results are two diagonal traces (see: Figure 4-13) with different slopes based on the resistances in "Cell B" of the Universal Dummy Cell. The slope of red trace (K1) is a measure of the total resistance associated with the K1 portion of the dummy cell ($\sim 5\ k\Omega$). The slope of the blue trace (K1) is a measure of the total resistance associated with the K2 portion of the dummy cell ($\sim 20\ k\Omega$.)

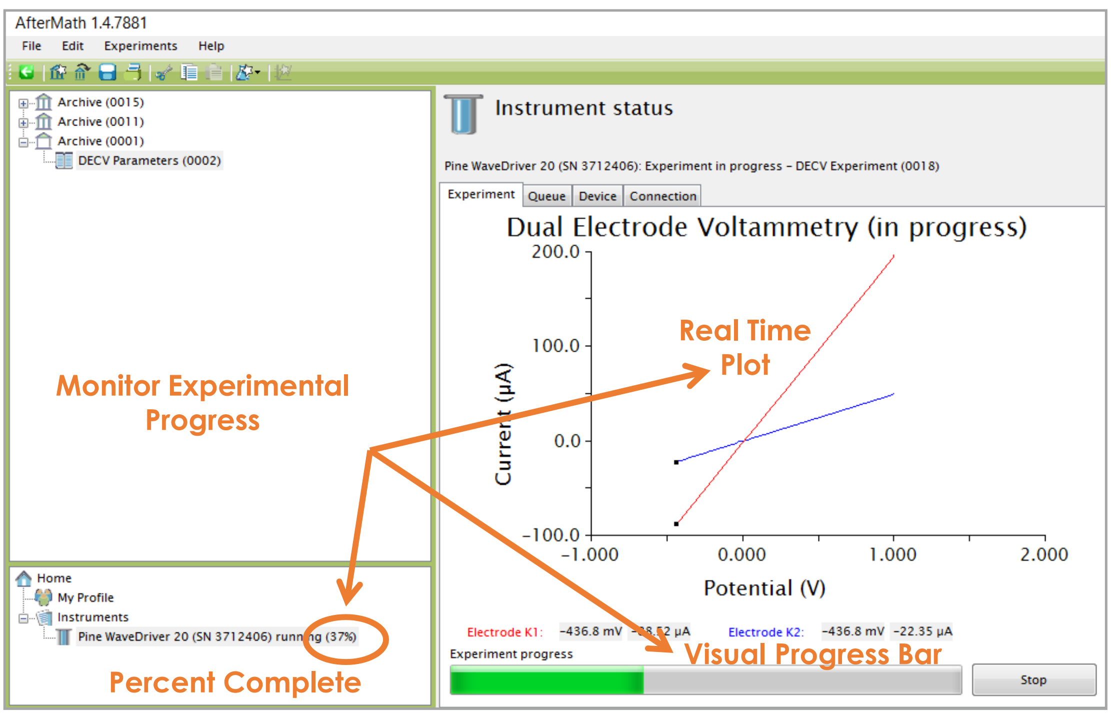


Figure 4-12. Monitoring the Progress of the Dual Channel Test (K1 and K2)

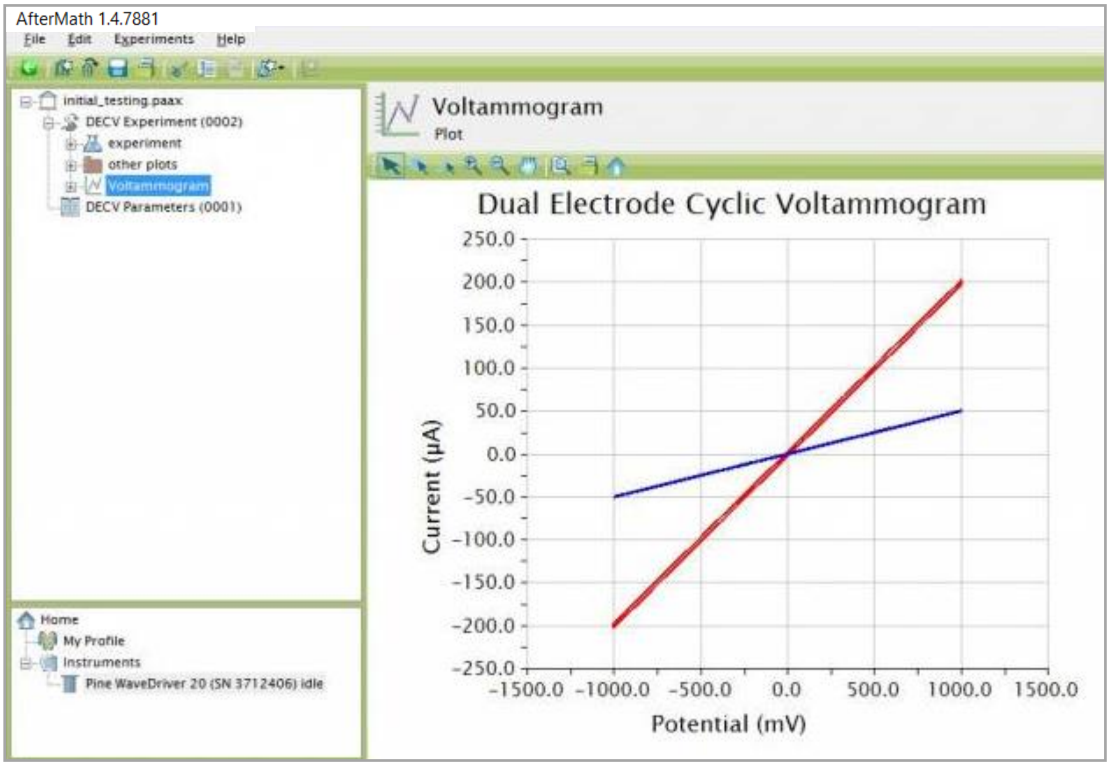


Figure 4-13. Anticipated DECV Results (using Dummy Cell B)

5. Cell Cable Connections

This section describes how to connect several different kinds of electrochemical cells to the WaveDriver. Before proceeding, the user should be familiar with general concepts associated with electrochemical cells. There are a variety of cell cable options for the WaveDriver that utilize the same color code for signal lines but serve a different purpose. Depending on the cable, connections to simple two-electrode cells, traditional three-electrode voltammetry cells (including rotating disk and rotating cylinder electrode cells), compact voltammetry cells, and to more complex dual working electrode cells (including rotating ring-disk electrode cells) are permitted.

5.1 Cell Cable Color Code

The front panel of the WaveDriver has a large cell connection port. This port presents several signal, shield, and grounding lines for the working, counter, and reference electrode connections. It is important to understand that some of the signal lines are low impedance DRIVE lines while others are high impedance SENSE lines. In general, the DRIVE lines are used to drive current through the electrochemical cell while the SENSE lines are used to measure potential at various electrodes. Very little charge flows through the high impedance SENSE lines.

NOTE:

DRIVE lines are low impedance lines used to drive current.

SENSE lines are high impedance lines used to measure potential.

The cell cable breaks out the various cell port connections to shielded coaxial cables which terminate at stackable banana plugs. Alligator clips that slide on to the banana plugs are included. The banana plugs are color coded to indicate how they should be connected to the electrodes in the electrochemical cell (see: Table 5-1 and Table 5-2).

Color		Description	ID	Type
	WHITE	Reference Electrode	RE	Sense
	GREEN	Counter Electrode	CE	Drive
	BLACK	DC Common (signal ground)		Ground
	RED	Primary Working Electrode	K1	Drive
	ORANGE	Primary Working Electrode		Sense
	BLUE	Secondary Working Electrode	K2	Drive
	VIOLET	Secondary Working Electrode		Sense

Table 5-1. WaveDriver 20 Cell Cable Color Description

Color		Description	ID	Type
	WHITE	Reference Electrode	RE	Sense
	GREEN	Counter Electrode	CE	Drive
	BLACK	DC Common (signal ground)		Ground
	RED	Primary Working Electrode	K1	Drive
	ORANGE	Primary Working Electrode		Sense

Table 5-2. WaveDriver 10 Cell Cable Color Description

5.2 Cell Cable Options

With the proper cell cable connections, several kinds of electrochemical cells can be connected to the WaveDriver 10 and WaveDriver 20, including two-electrode cells, traditional three-electrode cells, rotating disk electrodes, rotating cylinder electrodes, rotating ring-disk electrodes and screen-printed electrodes. In addition to the universal five- or seven-lead cell cable included with the WaveDriver 10 or WaveDriver 20, respectively, other cable designs are available for specific purposes (see: Figure 5-1). The discussion of cell cable connections in this section assumes the reader is already familiar with general concepts associated with electrochemical cells and also understands the cell cable color coding scheme (see: Table 5-1 and Table 5-2).

Five-Lead Universal Cell Cable

7-Lead Universal Cell Cable

Compact Voltammetry Cell Cable

Compact Voltammetry Cell Cable with Reference Electrode Breakout

Figure 5-1. Cell Cables for use with the WaveDriver

5.3 Universal Five- and Seven-Lead Cell Cables

The five- or seven-lead universal cell cables are included with each WaveDriver 10 or WaveDriver 20 instrument, respectively. These cables (part #: ACP2E05 and ACP2E01, respectively) may be used with a variety of two-electrode, three-electrode, rotating cylinder, rotating disk, and rotating ring-disk electrochemical cell configurations. The cables have a D-Shell connector which fits the cell port on the instrument. There are two drive screws on the D-Shell connector which tighten into the cell port to provide a secure connection (see: Figure 5-2).

Figure 5-2. Securely Tighten the D-Shell Connector to the Cell Port

As the cable emerges from the D-Shell connector, a conductive mesh shield protects runs along most of the length of the cable. This mesh shield is electrically connected to the chassis of the instrument and provides some additional protection from environmental noise and ESD events.

At the cell end of the cable, multiple signal cables emerge from the mesh sleeve and terminate at banana plugs. All of these signal cables (except for the black DC Common cable) are coaxial cables. The outer (shield) portion of each coaxial cable further protects sensitive signals from environmental noise. Optional alligator clips may be installed on the banana plugs as needed.

5.3.1 Simple Two-Electrode Configurations

Solid-state experiments that probe the electrochemical behavior across a single interface and experiments that involve ion-selective electrodes (where the open circuit potential is measured between an ion-selective electrode and a reference electrode) are typical electrochemical experiments that require a two-electrode cell configuration. Simple experiments with common resistors or capacitors also use the two-electrode arrangement (see: Figure 5-3).

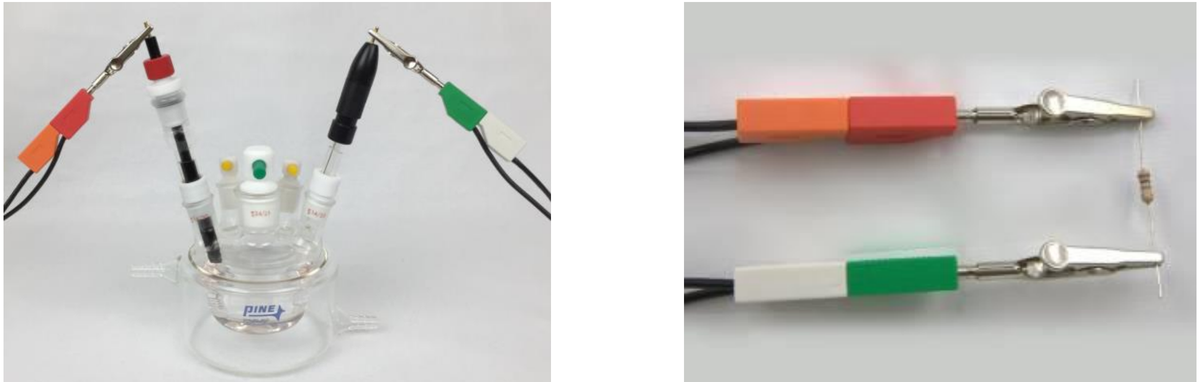


Figure 5-3. Examples of Two-Electrode Cells

The WaveDriver 10 and WaveDriver 20 cell cables can be configured for such two-electrode experiments by carefully stacking together the banana plugs. The green (counter electrode) and white (reference electrode) plugs are shorted together, and the red and orange (working electrode drive and sense) are also shorted together (see: Figure 5-3). One pair of shorted banana connectors is connected to one of the electrodes in the cell, and the other pair is connected to the other electrode.

Using the recommended two-electrode polarity convention, the GREEN/WHITE pair should be connected to whichever electrode is considered to be the reference electrode. This convention ensures that when the software applies a positive potential to the working electrode, the RED/ORANGE cell connection is more positive than the GREEN/WHITE "reference" cell connection.

TIP:

When connecting a WaveDriver 20 to a simple two electrode cell, the K2 electrode connections (BLUE and VIOLET) are not used. These may simply be shorted together and set aside (see: Figure 5-4).

Figure 5-4. Short Unused Secondary Electrode (K2) Connections and Set Them Aside

5.3.2 Three-Electrode Cells

In a traditional three-electrode cell, three different electrodes (counter, reference, and working) are placed in the same electrolyte solution. During three-electrode voltammetry experiments, charge flow (current) primarily occurs between the working electrode and the counter electrode while the potential of the working electrode is measured with respect to the reference electrode. The WaveDriver 10 and WaveDriver 20 cell cables can be used for such three-electrode experiments by appropriate connection of the drive and sense lines (see: Figure 5-5).

To drive current between the working and counter electrodes, the RED line (working electrode drive) is connected to the working electrode, and the GREEN line (counter electrode drive) is connected to the counter electrode. To measure potential between the working and reference electrodes, the ORANGE line (working electrode sense) is connected to the working electrode, and the WHITE line (reference electrode sense) is connected to the reference electrode (see: Figure 5-5).

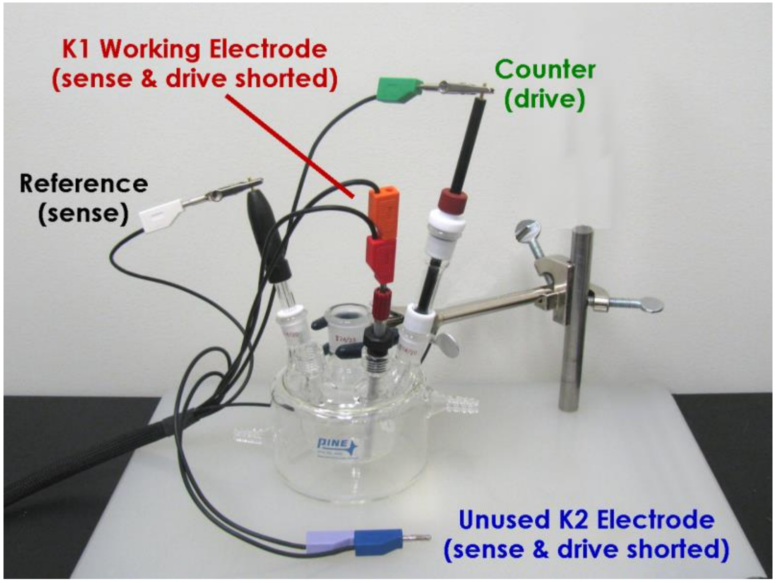


Figure 5-5. Traditional Three-Electrode Cell Connections

Note that the three-electrode cell configuration requires both the RED and ORANGE lines (working electrode drive and sense) to be connected at a point very near the working electrode. An easy way to make this connection is to stack the RED and ORANGE banana plugs together prior to connecting to the working electrode (see: Figure 5-6). Both of these cables must be connected to the working electrode in order for the potentiostat to properly control the electrochemical cell.

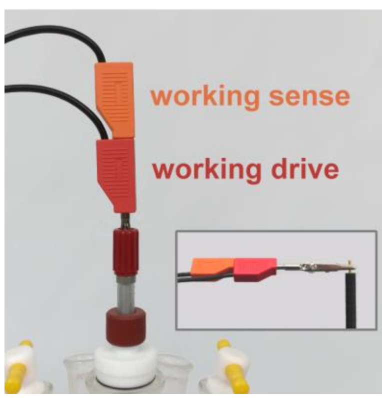


Figure 5-6. Connect Working Electrode Sense and Drive Lines Together Near the Cell

The cell cable for the WaveDriver 20 provides two pairs of working electrode connections, one pair for the primary working electrode (K1) and another pair for the secondary working electrode (K2). When using the WaveDriver 20 with a three-electrode cell use the primary working electrode connections (ORANGE and RED) to connect to the working electrode. The (unused) secondary working electrode connections (VIOLET and BLUE) should be shorted and set aside (see: Figure 5-4).

5.3.3 Rotating Disk & Rotating Cylinder Electrodes (RDE & RCE)

The WaveDriver 10 or WaveDriver 20 may be used in conjunction with an electrode rotator to perform Rotating Disk Electrode (RDE) or Rotating Cylinder Electrode (RCE) experiments. These experiments are hydrodynamic variations of traditional three-electrode voltammetry. Rotating the working electrode (which may have a disk or cylinder geometry) at a controlled rate sets up a well-defined flow of electrolyte solution (and dissolved electroactive species) toward the electrode surface. Connecting the potentiostat to a hydrodynamic experiment involves not only making connections to the electrodes (working, reference, and counter) but also providing a rotation rate control signal to the electrode rotator.

The WaveDriver 10 and WaveDriver 20 cell cables can be used for such hydrodynamic experiments by making similar connections as those used in a traditional three-electrode electrochemical cell. The GREEN line (counter electrode drive) is connected to the counter electrode, and the WHITE line (reference electrode sense) is connected to the reference electrode. Connections of the RED and ORANGE lines (working electrode drive and sense) to the rotating working electrode are typically made via spring-loaded brush contacts which push against the shaft of the rotating electrode.

As an example of how connections are made to the rotating working electrode, consider the brush contacts on the popular Pine Research MSR Rotator system (see: Figure 5-7). This rotator system features two pairs of opposing brushes on either side of the rotating shaft. The upper pair of brush contacts (RED) are used to make electrical contact with a rotating disk or cylinder electrode mounted in the rotator. To make good contact on opposite sides of the rotating shaft, both of the red brushes (left and right sides) are used. A short banana jumper cable connects the opposing brushes together, and then the working electrode drive and sense lines (RED and ORANGE) are connected the jumper cable (see: Figure 5-7).

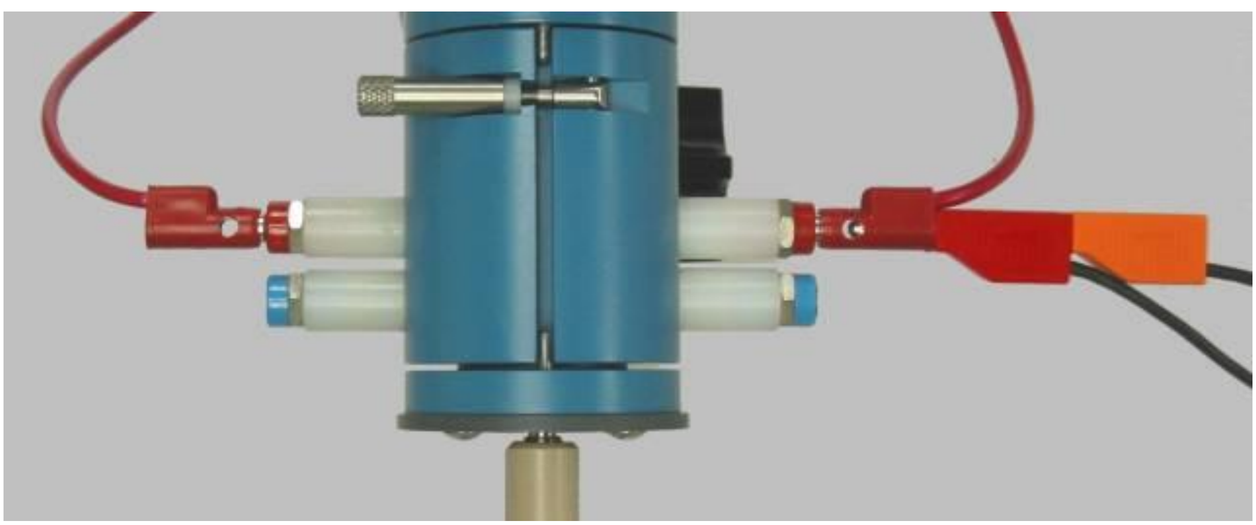


Figure 5-7. Working Electrode Connections for Rotating Disk or Cylinder Electrodes

5.3.4 Rotating Ring-Disk Electrode (RRDE) Cell

In a rotating ring-disk electrode (RRDE) experiment, the counter and reference electrode connections are made in the manner described for traditional three-electrode voltammetry (see: Section 5.3.2), and the connection to the disk electrode is the same as that described for the RDE cell (see: Section 5.3.3). The rotator usually has one or more brushes which contact the disk electrode and additional brushes which contact the ring electrode.

As an example, the Pine Research Instrumentation MSR Rotator system has two pairs of opposing brushes on either side of the rotating shaft (see: Figure 5-8). The upper pair of brush contacts (RED) is used to make electrical contact with the disk electrode while the lower pair of brushes (BLUE) makes contact with the ring electrode. To make good contact on opposite sides of the rotating shaft, both of the red brushes (left and right sides) should be used to contact the disk, and both of the blue brushes should be used to contact the ring. Use short banana jumper cables to connect the opposing brushes together (see: Figure 5-8). Connect the primary working electrode (K1) cables to the disk electrode (RED and ORANGE cables). Connect the secondary working electrode (K2) cables to the ring electrode (BLUE and VIOLET cables).

TIP:

More information about rotating electrodes may be found by searching the knowledgebase:

https://www.pineresearch.com/shop/knowledgebase/

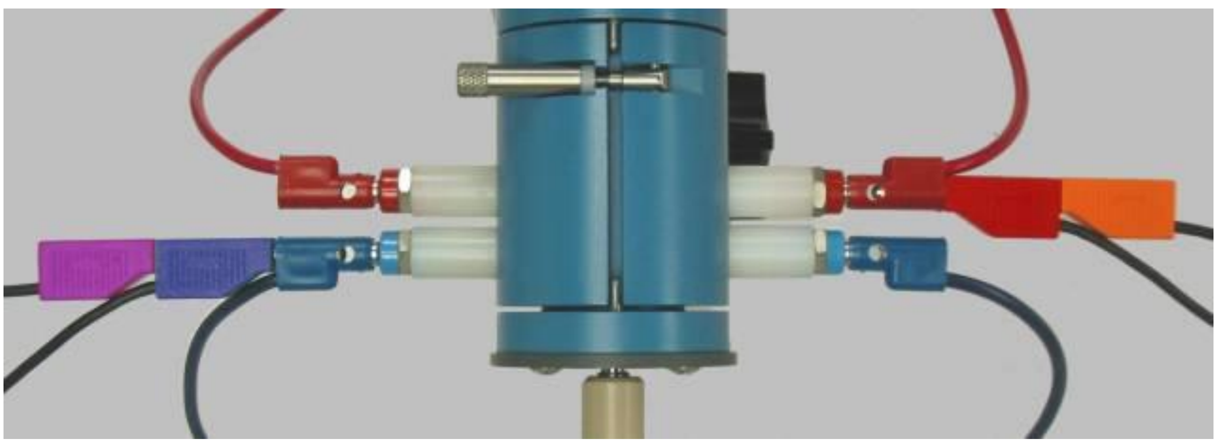


Figure 5-8. Electrode Connections (K1 and K2) for a Rotating Ring-Disk Electrode

NOTE:

The lower pair of brushes (blue) contacts on the MSR rotator system are not compatible with the WaveDriver 10. More information about rotating electrodes may be found in our knowledgebase:

www.pineresearch.com/shop/knowledgebase/

5.3.5 Rotation Rate Control

Many electrode rotators are able to accept rotation rate control signals from a potentiostat. The WaveDriver 10 or WaveDriver 20 instruments provide both a digital "on/off" signal and an analog rotation rate signal that can be used to control the motor on an electrode rotator. These signals are presented at the rotator control port on the back panel of the instrument (see: Figure 2-3). Special cables are available from Pine Research which may be used to connect these signals to various electrode rotator models.

Connecting a WaveDriver 10 or WaveDriver 20 to a Pine Research MSR rotator system requires a special cable (part #: AKCABLE4, sold separately). One end of the cable has a small green connector which mates with the rotator control port (see: Figure 5-9). The other end of the cable is connected to two locations on the Pine MSR control unit. The first connection is made between the coaxial cable (terminated with a dual banana plug adapter) and the rotation rate INPUT jacks on the front panel of the control unit. The second connection is made between the single banana plug and the (blue) MOTOR STOP jack on the back panel of the control unit.

Figure 5-9. Rotation Rate Control Between WaveDriver and MSR Rotator

CAUTION:

When connecting a WaveDriver 10 or WaveDriver 20 system to an electrode rotator other than the Pine Research MSR rotator, carefully consider the magnitude of the WaveDriver 10 or WaveDriver 20 rate control signal ratio ($1\ RPM/mV$) and take steps to ensure that the rotator is configured to use the same ratio.

ATTENTION:

Lorsque vous connectez un appareil WaveDriver 10 ou WaveDriver 20 à un rotateur à électrodes autre que le rotateur Pine Research MSR, faites très attention à la valeur du rapport du signal de contrôle de vitesse de l'appareil WaveDriver 10 ou WaveDriver 20 ($1\ tr/min/mV$) et assurez-vous que le rotateur soit configuré avec le même rapport.

5.4 Compact Voltammetry Cell Cable Connection

The following information details how to use the Compact Voltammetry Cell Cable (part #: ACP2E08) with the WaveDriver 10 or WaveDriver 20 potentiostats, and also how to use it with the Pine Research Compact Voltammetry Cell Kit (available separately). One end of this cable connects directly to the cell port and the other end terminates with a mini-USB style plug. Within this shielded cable are four signal lines as follows: working electrode (drive and sense), counter electrode (drive), and reference electrode (sense).

The Compact Voltammetry Cell Kit consists of a grip, a cell cap, a glass vial, and various screen-printed electrodes. Built into the grip are mini-USB jacks which may be connected to the cell cable. Circuitry within the grip makes electrical connection to the screen-printed electrode mounted to the bottom of the grip (see: Figure 5-10). This simple cable configuration makes the compact voltammetry kit ideal for use in educational settings and in confined spaces such as glove boxes.

Figure 5-10. Cable Connections for the Compact Voltammetry Cell Kit

TIP:

More information about the compact voltammetry cell kit can be found by searching the knowledgebase:

www.pineresearch.com/shop/knowledgebase

5.5 Compact Voltammetry Cell Cable with Reference Breakout

A version of the compact voltammetry cell cable with a special reference electrode breakout connection is available (part #: ACP2E09). This cable may be used with certain compact voltammetry cells and spectroelectrochemical cells offered by Pine Research. One end of this cable connects directly to the cell port and the other end terminates with a mini-USB style plug and a separate (white) reference electrode pin connector. Within this shielded cable are four signal lines as follows: working electrode (drive and sense), counter electrode (drive), and reference electrode (sense).

The separate reference electrode lead allows use of an external reference electrode rather than a screen-printed reference electrode. Examples of an external reference electrode in use with a Honeycomb Spectroelectrochemical cell (see: Figure 5-11, left) and a Compact Voltammetry Cell (see: Figure 5-11, right) are shown below (see region outlined in blue square).

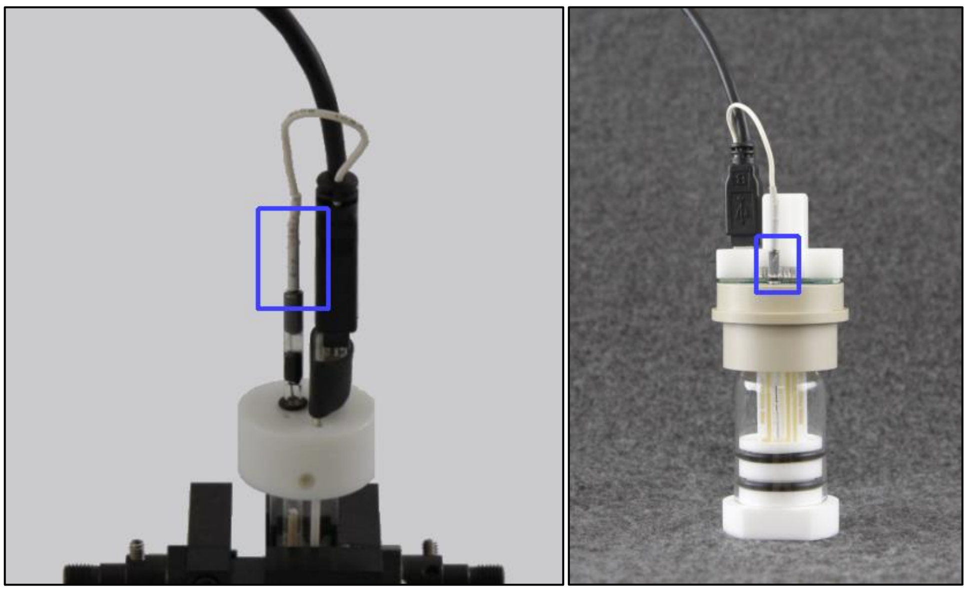


Figure 5-11. Compact Voltammetry and Spectroelectrochemical Cells with Separate Reference Electrode Connections

6. Grounding Information

The general goal of a grounding strategy is to reduce the level of signal noise in the electrochemical measurement caused by noise sources in the laboratory environment. To avoid issues with laboratory noise sources, it is important to properly ground all metal objects near an electrochemical cell and to make proper grounding connections between the potentiostat and any other electronic equipment being used as part of the experiment.

6.1 Common Environmental Noise Sources

A modern laboratory is often full of noise sources that can interfere with the measurement of small amplitude electrochemical signals. Computers, LCD displays, video cables, network routers, network cables, ovens, hotplates, stirrers, and fluorescent lighting are all examples of common laboratory equipment that may electromagnetically interfere with a delicate electrochemical measurement.

In general, the electrochemical cell, the cell cable, and the potentiostat should be located as far away from such noise sources as possible. It is especially important that the cell cable be located well away from any digital noise sources such as mouse or keyboard cables, network cables, video cables, USB cables, cell phones, etc. The reference electrode cable is particularly sensitive to picking up noise from the environment.

A piece of laboratory equipment which intermittently draws a lot of current, such as an oven or hotplate under thermostatic control, should not be powered using the same branch circuit as the potentiostat. When such a piece of equipment goes through a power cycle, it may induce noise or a glitch in the electrochemical measurement.

6.2 Grounding Terminology

When using a potentiostat in conjunction with other electronic instruments, it is often necessary to make various grounding connections between the potentiostat and the other instrumentation. A proper approach to making such connections begins with a good understanding of the terminology associated with grounding. A potentiostat or other piece of electronic equipment generally has three types of grounding connections which are often confused with one another: the earth ground, the chassis terminal, and the DC Common. These are discussed in more detail below.

6.2.1 Earth Ground

EARTH GROUND:

An earth ground connection is a direct physical and electrical connection to the Earth.

An earth ground connection is available in most modern laboratories via the third prong on the power receptacle for the local power system. The power system infrastructure for a laboratory building usually has a long metal probe buried in the earth, and the third prong in the building wiring is connected to this earth connection. Many electronic devices have a three prong power cord which brings the earth ground connection to the power supply for the device. Whether or not the earth ground connection passes through the power supply and to the internal circuitry of the device depends upon the design of the power supply.

In general, a connection to earth ground need only be made if it helps to reduce (or, at least, has no effect on) the amount of noise in the electrochemical signals being measured. In some laboratory environments, a connection to earth ground may actually increase the amount of signal noise. Some trial and error may be necessary to decide whether or not to make use of the earth ground.

The power supplies for the WaveDriver 10 or WaveDriver 20 potentiostats do not allow the earth ground connection to pass through to the instrument circuitry. This means that there is no permanent, direct connection to the earth ground when the instrument is connected to the AC Mains (*i.e.*, there is no connection to earth ground via the power cable plugged into a receptacle). Nevertheless, an indirect, whether deliberate or inadvertent, connection to earth ground may occur when the potentiostat is connected to other electronic equipment. Such indirect connections are discussed in more detail below.

6.2.2 Chassis

CHASSIS:

A metal case which surrounds and protects the electronic circuitry is called the chassis.

The metal case that contains the WaveDriver 10 or WaveDriver 20 circuitry is the instrument chassis. The chassis helps to protect the circuitry from environmental noise sources and from ESD events. The universal cell cable included with the WaveDriver has a mesh shield which is directly connected to the instrument chassis via the shield on the Cell Port (see: Figure 5-1 and Section 0). This mesh shield has the effect of extending the instrument chassis for some distance along the cell cable.

When a USB cable is connected to the instrument, the shield within the USB cable is directly connected to the instrument chassis. When the other end of the USB cable is connected to a computer, it is almost certain that a direct electrical connection between the instrument chassis and the computer chassis will be made. If the computer chassis happens to be connected to earth ground, then the USB cable becomes an indirect means by which the instrument chassis is connected to the earth ground.

When a personal computer is connected to a second device using a USB cable, the computer usually attempts to supply power ($+5\ VDC$) to the second device. So, when the WaveDriver is connected to a USB port on a computer, a pair of power lines (and a pair of data transfer lines) from the computer are brought into the instrument. Special circuitry within the WaveDriver isolates these USB lines from the remaining instrument circuitry. Depending upon the exact configuration of the USB ports and USB cable, the USB cable shield (i.e., the chassis) may or may not be connected to the negative side of the USB power supplied by the computer.

While not a requirement for normal operation of the instrument, in some circumstances it may be desirable for the chassis to be connected to earth ground. A USB connection to a desktop (or tower) computer usually creates such an earth ground connection in an indirect fashion. If not, or if a battery-powered laptop is being used, a deliberate connection to earth ground may be made via the chassis terminal on the back panel of the WaveDriver (see: Figure 2-3).

6.2.3 DC Common

DC COMMON:

In an analog circuit, such as a potentiostat, the DC Common is the zero reference point against which voltages are measured. This point is also known as the analog ground, signal ground, or signal common.

The DC Common for the WaveDriver 10 and WaveDriver 20 instruments is the zero volt reference point used by the waveform generation and signal measurement circuits. External connections to the DC Common may be made at the center pin of the Rotator Control Port or via the black banana plug on the universal cell cable.

The WaveDriver may send or receive analog signals to and from other electronic instruments such as a waveform generator, an $x - y$ recorder, a digital oscilloscope, a rotator control unit, a spectrometer, a quartz crystal microbalance, etc. All of these other instruments also have a DC Common line which represents the common "zero" analog signal level. In general, the act of connecting the WaveDriver to any of these other instruments causes the DC Common lines for each of the instruments to be connected together.

The distinction between the DC Common and the instrument chassis is important to maintain and preserve whenever possible. The WaveDriver offers separate connection points for the chassis terminal and the DC Common, and as long as these connection points are not purposefully shorted together, then the DC Common line is able to "float" with respect to the chassis.

A floating ground configuration is required when the WaveDriver is used in conjunction with certain other instruments, such as a scanning electrochemical microscope or a quartz crystal microbalance. When interconnecting these types of instruments with the WaveDriver, care must be taken to maintain electrical separation between the chassis and the DC Common.

In other cases where electrical separation of the DC Common and instrument chassis is not a requirement, the act of deliberately shorting the DC common signal to the chassis may reduce the amount of noise in the signals recorded by the WaveDriver. For example, when the WaveDriver is connected to a rotator, it may be helpful to try connecting the DC Common to the rotator chassis to see if this action improves the appearance of electrochemical data. Some trial and error may be necessary to decide whether or not to this connection is helpful.

It is also important for WaveDriver users to be aware of cases where the floating ground feature is indirectly compromised by a hidden connection. These cases can occur when multiple instruments and/or computers are interconnected with the WaveDriver as part of a larger experimental configuration. One of the other instruments may make an internal connection between the DC Common and the chassis or earth ground. Again, it is important to understand the chassis and earth ground connections for all of the instruments involved in a given experimental configuration.

6.3 Faraday Cages and Metal Hardware

When making sensitive electrochemical measurements (*i.e.*, current below one microampere), it is common practice to place the entire electrochemical cell inside of a Faraday cage to shield the cell from environmental noise. A connection should be made from the metal (or metal mesh) framework of the Faraday cage to the instrument chassis and/or earth ground.

Electrochemical cells are often mounted using metal items such as a ring stand with a clamp. These mounts and any other metal objects located near the electrochemical cell should be connected to the instrument chassis and/or earth ground (see: Figure 6-1).

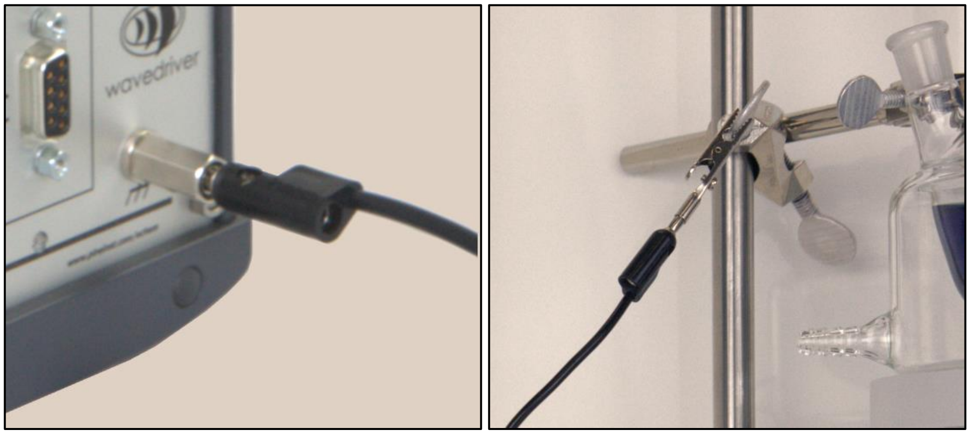


Figure 6-1. Connect Clamps and Other Metal Objects to Instrument Chassis and/or Earth Ground

6.4 Grounding Multiple Instruments

When a potentiostat is connected to one or more additional pieces of electronic equipment (*i.e.*, a computer, an electrode rotator, a spectrometer, etc.), it is important to understand how or if each piece of equipment is connected to earth ground, how or if the chassis of each piece of equipment is connected to neighboring equipment, and how or if the DC Common lines of each piece of equipment are connected together.

While the details of proper grounding for any given experimental configuration may differ, a very common strategy is to bring all of the chassis connections for all of the instruments together to one single point. In addition, any other metal objects near the electrochemical cell, such as a cell clamp or support rod, should be connected to the same point. The reason that all connections are brought together to a single point is to prevent the creation of a grounding loop. A grounding loop is often accidently created when connections are made in series from one instrument to the next, and the resulting loop can act as antenna which injects more noise into sensitive measurements.

Once all of the connections have been brought together to a single point, it may also be desirable to connect this point to earth ground. In the example shown (see: Figure 6-2), the cell clamp and the chassis of the WaveDriver have been connected to the earth ground connection point on the front panel of a Pine Research MSR Rotating Electrode control unit. This avoids a grounding loop and assures that the chassis of both the instruments involved in the experiment (potentiostat and rotator) and the metal objects near the cell are all at earth ground.

Just like a potentiostat, other types of scientific instrumentation also have a DC Common line which represents the common zero analog signal level. When a potentiostat is connected to an electrode rotator control unit, a spectrometer, a quartz crystal microbalance, or other kind of instrument, it is very likely that the DC Common lines for each of the instruments will be connected together. The researcher should be aware of whether or not the DC Common of one of the other instruments happens to be held at earth ground or connected to its instrument chassis. This is especially important in those scenarios where the researcher intends for the DC Common of the potentiostat to float with respect to earth ground.

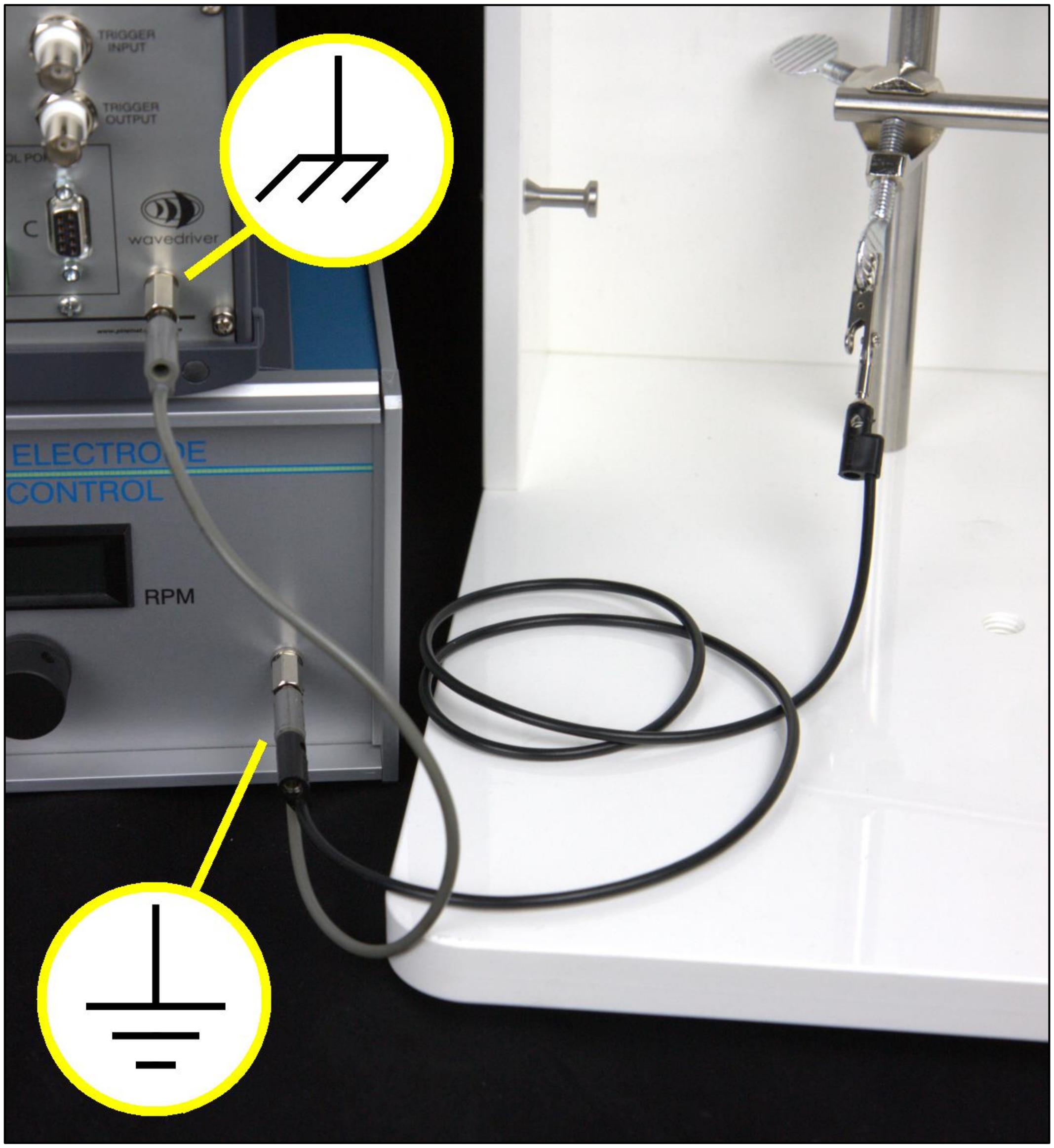


Figure 6-2. Ground Multiple Instruments and Objects to a Common Point

7. Power Cords

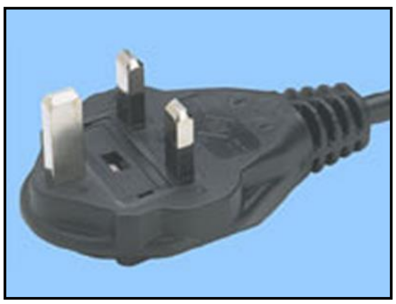
The standard C18 connector on the WaveDriver 10 or WaveDriver 20 power supply is compatible with a wide range of power cords available from Pine Research Instrumentation (see: Table 7-1 and Table 7-2). Each of the available power cords is rated at $10\ Amps$ (minimum), and each cord is designed for use in a specific country or region of the world. Pine Research part numbers are provided.

This cord is for use in the USA, Canada, Mexico, Brazil, Columbia, Korea, Mexico, Saudi Arabia, and Taiwan.

Power Cord (USA), part #:EWM18B7

This cord is for use in continental Europe, Russia, and Indonesia.

Power Cord (Europe), part #: EWM18B8EU



This cord is for use in the United Kingdom, Ireland, Oman, Hong Kong, and Singapore.

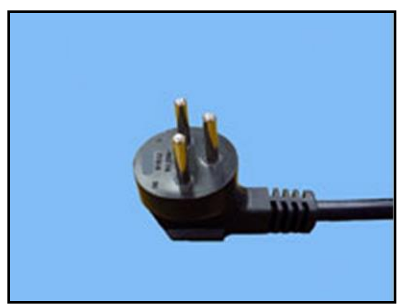
Power Cord (UK), part #: EWM18B8UK

This cord is for use exclusively in China.

Power Cord (China), part #: EWM18B8CN

This cord is for use in India and South Africa.

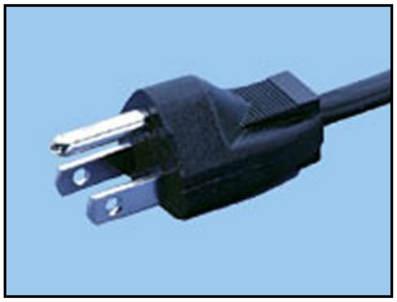
Power Cord (India), part #: EWM18B8IN



This cord is for use exclusively in Israel.

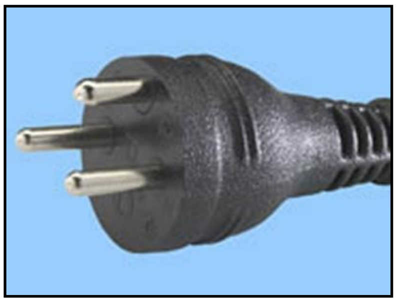
Power Cord (Israel), part #: EWM18B8IL

Table 7-1. Select Power Cords Available from Pine Research Instrumentation (Part I)



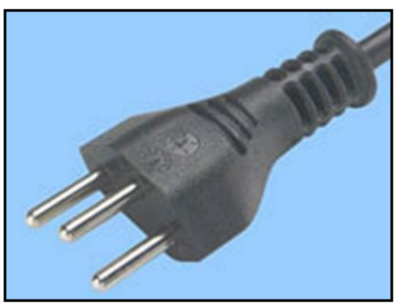
This cord is for use exclusively in Japan.
Power Cord (Japan), part #: EWM18B8JP

This cord is for use exclusively in Argentina.
Power Cord (Argentina), part #: EWM18B8AR



This cord is for use exclusively in Denmark.
Power Cord (Denmark), part #: EWM18B8DK

This cord is for use in Australia & New Zealand.
Power Cord (Australia), part #: EWM18B8NZ



This cord is for use exclusively in Switzerland.
Power Cord (Switzerland), part #: EWM18B8CH

This cord is for use exclusively in Italy.
Power Cord (Italy), part #: EWM18B8IT

Table 7-2. Select Power Cords Available from Pine Research Instrumentation (Part II)

8. Glossary

8.1 Important Terms used in this Guide

Anodic Current	Flow of charge at an electrode as a result of an oxidation reaction occurring at the electrode surface. For a working electrode immersed in a test solution, an anodic current corresponds to flow of electrons out of the solution and into the electrode.
Auxiliary Electrode	(see: Counter Electrode)
Banana Cable	A banana cable is a single-wire (one conductor) signal cable often to make connections between various electronic instruments. Each end of the cable has a banana plug. The plug consists of a cylindrical metal pin about $25\ mm$ (one inch) long, with an outer diameter of about $4\ mm$, which can be inserted into a matching banana jack.
Banana Jack	Female banana connector
Banana Plug	Male banana connector
BNC Connector	The BNC (Bayonet Neill-Concelman) connector is a very common type of used for terminating coaxial cables.
Cathodic Current	Flow of charge at an electrode as a result of a reduction reaction occurring at the electrode surface. For a working electrode immersed in a test solution, a cathodic current corresponds to flow of electrons out of the electrode and into the solution.
Coaxial Cable	Coaxial cable, or coax, is an electrical cable with an inner conductor surrounded by a flexible, tubular insulating layer, surrounded by a tubular conducting shield. The term coaxial comes from the inner conductor and the outer shield sharing the same geometric axis. Coaxial cable is often used to carry signals from one instrument to another in situations where it is important to shield the signal from environmental noise sources.
Counter Electrode	The counter electrode, also called the auxiliary electrode, is one of three electrodes found in a typical three-electrode voltammetry experiment. The purpose of the counter electrode is to carry the current across the solution by completing the circuit back to the potentiostat.
Cyclic Voltammetry	An electroanalytical method where the working electrode potential is repeatedly swept back and forth between two extremes while the working electrode current is measured.
Dummy Cell	A known network of resistors and capacitors used to test a potentiostat. The dummy cell is used in place of an actual electrochemical cell when troubleshooting a potentiostat because the dummy cell provides a known response whereas the response from an actual cell is complicated by chemical phenomena.
Electroactive	An adjective used to describe a molecule or ion capable of being oxidized or reduced at an electrode surface.

Electrode	An electrode is an electrical conductor used to make contact with a nonmetallic part of a circuit.
Electrostatic Discharge (ESD)	The rapid discharge of static electricity to ground. Sensitive electronics in the path of an ESD event may suffer damage.
Faradaic Current	The portion of the current observed in an electroanalytical experiment that can be attributed to one or more redox processes occurring at an electrode surface.
Half-Reaction	A balanced chemical equation showing how various molecules or ions are reduced (or oxidized) at an electrode surface.
Linear Sweep Voltammetry	Experiment in which the working electrode potential is swept from initial value to final value at a constant rate while the current is measured.
K1	A symbol referring to the primary working electrode. Two connections (drive and sense) are required between the working electrode and the potentiostat.
K2	Refers to the secondary working electrode found on a bipotentiostat. Two connections (drive and sense) are required between the working electrode and the bipotentiostat.
Non-Faradaic Current	The portion of the current observed in an electroanalytical experiment that cannot be attributed to any redox processes occurring at an electrode surface.
Overpotential	The overpotential is the difference between the formal potential of a half-reaction and the potential actually being applied to the working electrode.
Oxidation	Removal of electrons from an ion or molecule.
Redox	An adjective used to describe a molecule, ion, or process associated with an electrochemical reaction.
Reduction	Addition of electrons to an ion or molecule.
Reference Electrode	A reference electrode has a stable and well-known thermodynamic potential. The high stability of the electrode potential is usually achieved by employing a redox system with constant (buffered or saturated) concentrations of the ions or molecules involved in the redox half-reaction.
Standard Electrode Potential	A thermodynamic quantity expressing the free energy of a redox half-reaction in terms of electric potential.
Sweep Rate	The rate at which the electrode potential is changed when performing a sweep voltammetry technique such as cyclic voltammetry.
Three-Electrode Cell	A common electrochemical cell arrangement consisting of a working electrode, a reference electrode, and a counter electrode.
Two-Electrode Cell	A common electrochemical cell arrangement when using a micro- or ultramicroelectrode consisting of a working and reference electrode

Voltammogram	A plot of current vs. potential from an electroanalytical experiment in which the potential is swept back and forth between two limits.
Working Electrode	The electrode at which the redox process of interest occurs. While there may be many electrodes in an electrochemical cell, the focus of an experiment is typically only on a particular half-reaction occurring at the working electrode.
Working Electrode Drive	The connection on a potentiostat or galvanostat through which charge flows to or from a working electrode. Drive lines have low impedance to allow significant charge flow (current) through the working electrode.
Working Electrode Sense	The connection on a potentiostat or galvanostat which measures the potential of a working electrode. Sense lines have a high input impedance so that the potential can be measured without significant charge flow (current) through the sense line.

9. References

The WaveDriver 10 and WaveDriver 20 have been actively used for many different types of electrochemical experiments in industry as well as academia. A short list of peer-reviewed research where the WaveDriver has been used is provided here. It is not an exhaustive list, merely a snapshot of some modern research.

1. Alkan, A.; Klein, R.; Shylin, S. I.; Kemmer-Jonas, U.; Frey, H.; Wurm, F. R. Water-Soluble and Redox-Responsive Hyperbranched Polyether Copolymers Based on Ferrocenyl Glycidyl Ether. *Polym. Chem.* **2015**, *6*, 7112–7118.
2. Alkan, A.; Steinmetz, C.; Landfester, K.; Wurm, F. R. Triple-Stimuli-Responsive Ferrocene-Containing PEGs in Water and on the Surface. *ACS Appl. Mater. Interfaces* **2015**, *7*, 26137–26144.
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10. Support

After reviewing the content of this user guide, please contact Pine Research Instrumentation should you have any issues or questions with regard to the use of the instrument, accessories, or software. Contact us anytime by the methods provided below:

10.1 Online

Our website has a contact form which allows technical support requests to be sent directly to Pine Research. Visit www.pineresearch.com/contact.

10.2 E-mail

Send an email to pinewire@pineresearch.com. This is the general sales email, and our team will ensure your email is routed to the most appropriate technical support staff available. Our goal is to respond to emails within 24 hours of receipt.

10.3 Phone

Our offices are located in Durham, NC in the eastern US time zone. We are available by phone Monday through Friday from 9 AM EST to 5 PM EST. You can reach a live person by calling +1 (919) 782-8320.

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EU Declaration of Conformity

In accordance with EN ISO 17050-1:2010

Object of the Declaration:

Product:	WaveDriver 10/ WaveDriver 20 Potentiostats
Models:	AFPnxy (where n is an integer 1 to 4; x & y may be blank or alpha characters)
Serial numbers:	251601 and higher (wwyynn: where ww is week of manufacture; yy is year; nn is a consecutive number, beginning with 01 each week)
Manufacturer:	Pine Electronics LLC
Address:	101 Industrial Drive, Grove City, PA, 16127, USA

This declaration is issued under the sole responsibility of the manufacturer.

The object of the declaration described above is in conformity with the relevant Union harmonization legislation:

2014/35/EU	The Low Voltage Directive
2014/30/EU	The Electromagnetic Compatibility Directive
2011/65/EU	The Restriction of Hazardous Substances Directive

Conformity is shown by compliance with the applicable requirements of the following documents:

Reference and Date	**Title**
EN 55011:2007	Industrial, scientific and medical RF Equipment; Electromagnetic disturbance characteristics
EN 61326-1:2013	EMC Requirements for Electrical equipment for measurement, control and laboratory use
IEC 61010-1-2010+ Corrigendum 1:2011	Safety Requirements for electrical equipment for measurement, control and laboratory use

Signed for and on behalf of:	Pine Electronics LLC
Place of Issue:	Grove City, PA, USA
Date of Issue:	6/7/2016
Name:	Edward T. Berti
Position:	Vice President of Engineering

Signature: Edward T. Berti

The technical documentation for the machinery is available from the above address.

The CE Mark was applied per the following reports:

Keystone Compliance: 1303-064E

Intertek: 101178673CLE-001