Redefining Electrochemical Measurement

PWR800™
Electrochemical Energy Software

Gamry Instruments' PWR800 Electrochemical Energy Software is a tool for testing advanced electrochemical devices. It works with a Gamry Instruments Potentiostat to automate electrochemical testing in energy research. The PWR800 includes both simple, easy-to-use standard techniques and powerful sequencing tools for complicated tests.

Electrochemical cells used in energy technology include:

- fuel cells
- batteries
- solar cells
- super-capacitors

The PWR800 runs a wide range of techniques on all these cells. It can test: a half-cell in a 3-electrode setup, small test cells, packaged cells, and series-connected cell stacks.

Techniques in the PWR800 include:

- Cyclic Voltammety (CV)
- Cyclic Charge Discharge (CCD)
- Discharge in three modes: constant current, constant power and constant load resistance
- Constant current charge
- Polarization Curve
- Simple Potentiostatic and Galvanostatic tests
- CCD with EIS spectra in each charge state

The PWR800 includes a flexible system for limit testing that terminates an experiment step when a limit condition is true.

Possible limit tests parameters include:

- voltage
- current
- temperature
- power
- capacity
- energy
- step time

Limit tests include under- and over- conditions and may allow for rate-of-change or absolute value calculations before the test. All common recharge protocols for commercial batteries are possible using these limit tests.

Full PWR800 capability requires a Gamry Instruments' Reference 3000 Potentiostat. The Reference 3000 has:

- a stack mode allowing operation at up to 30 volts
- up to 3 amp output current
- EIS capability from 10 µHz to 1 MHz
- an AE (Auxiliary Electrometer) option

The AE option can measure the voltage of up to eight cells in a stack – even simultaneously recording eight EIS spectra.

The PWR800 uses the Gamry Framework™ for data acquisition and the Echem Analyst™ for data analysis. They are described in "An Overview of Gamry Software".

PWR800 Techniques

Cyclic Voltammetry (CV)

Electrochemical testing on a new chemical system begins with Cyclic Voltammetry. The PWR800 CV technique is a simplified version of CV in Gamry's PHE200 Physical Electrochemistry Software.

In CV, a cyclic linear voltage ramp is applied to an electrochemical cell and the cell current is plotted versus cell potential. The user has control of the ramp's Initial Potential, Final Potential and two Vertex Potentials. Potentials can be specified as relative to a measured open-circuit voltage or relative to a reference electrode voltage.

CV scan rates can vary from a few microvolts per second to more than 1000 volts per second. Current range selection may be specified as auto-ranging or fixed.

CV analysis includes peak location, base line correction, and integration.

Discharge Curve

The Discharge Curve technique implements the most common test for fuel cells and primary batteries. An electrochemical device is discharged in one of three discharge modes (see highlight text below). The device's voltage and current are plotted versus time.

You can also use a Discharge Curve for a one-time discharge of a secondary battery or super-capacitor.

A typical Discharge Curve Setup is shown below. Note the two Stop At tests that can terminate the discharge process.

A Discharge Curve is analyzed on an XY plot; normally plotted as voltage versus time. Other quantities that can be plotted on either axis include: voltage, power, current, time, energy, capacity and percent capacity.

Control Modes

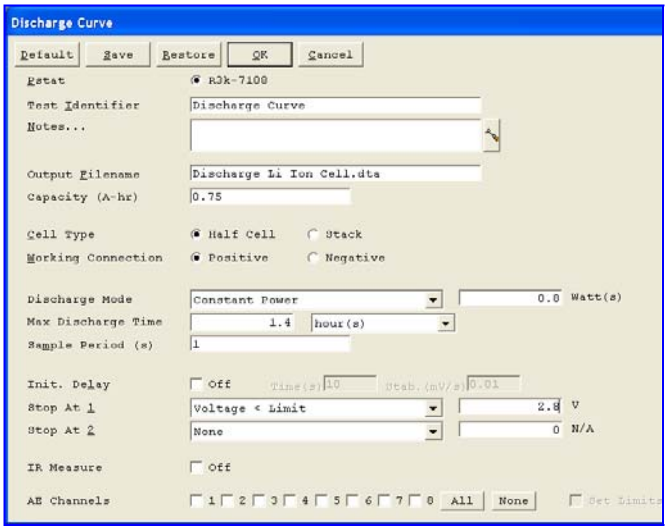
Battery tests in the PWR800 use four different control modes:

- Constant Current,
- Constant Resistance,
- Constant Power,
- Constant Potential

In all these modes the potentiostat functions as a galvanostat. In the latter three modes, a secondary software control loop adjusts the current to achieve the desired value for the constant parameter. The current can never overload, so charge is never lost.

Cyclic Voltammetry is an exception. It uses the instrument's normal potentiostat mode.

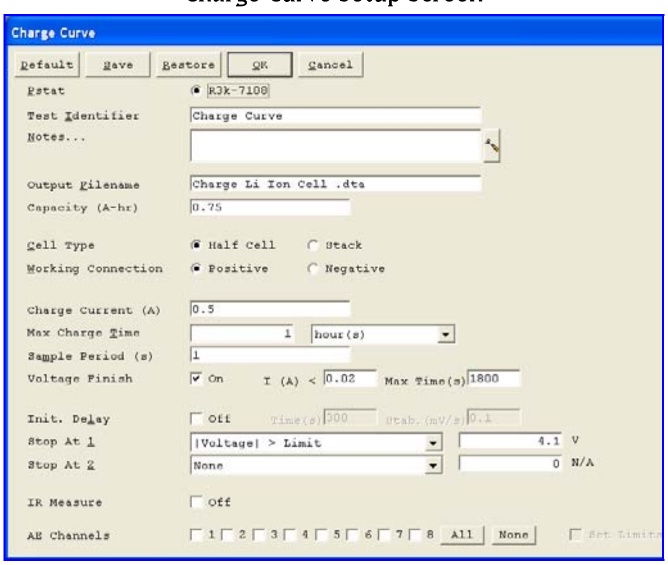
Discharge Curve Setup Screen



Charge Curve

The Charge Curve technique is used to charge a device by applying a constant current. Charge always includes an optional voltage finish. As the device charges, voltage and current are plotted versus time.

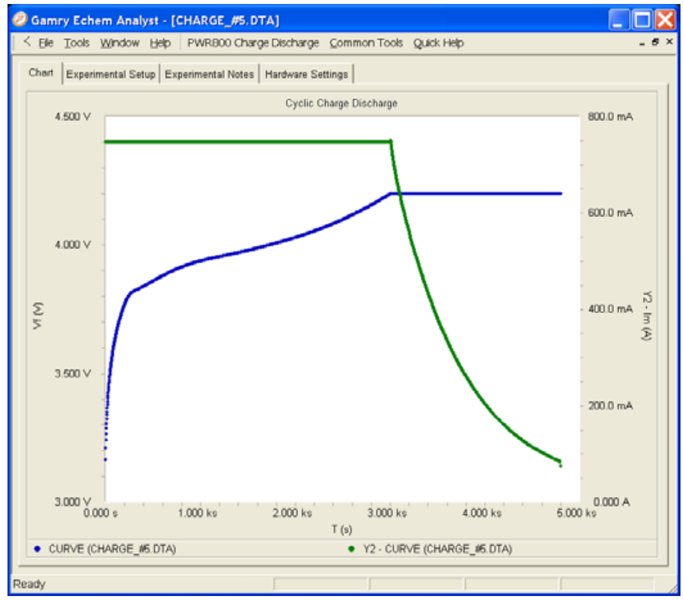
Charge Curve Setup Screen



Limit tests (described above) can be used to implement most of the DC charging schemes used for commercial batteries.

Charge curves are analyzed graphically on an XY plot - normally as voltage versus time. Other quantities that can be plotted on either axis include: voltage, power, current, time, energy, capacity and percent capacity.

CCCV Charge Curve on AA Li Ion Battery



Charge with Optional Voltage Finish

The PWR800 always charges devices using constant current. When the user requests a Voltage Finish, the constant current charge is followed by a constant voltage charge. The voltage is applied for either a set time or until the current falls to a limit value. The capacities from the two portions of the charge are summed.

This two part charge is also known as Constant Current Constant Voltage (CCCV) charge.

Stop At tests in the charge step always end the constant current portion of the charge process.

Cyclic Charge-Discharge (CCD)

The Cyclic Charge-Discharge is used in the study of secondary batteries and capacitors as they store and then release energy.

A CCD test starts with a charge or discharge step and repeats the charge-discharge process through a number of cycles. The test can end early if a Loop End test becomes true.

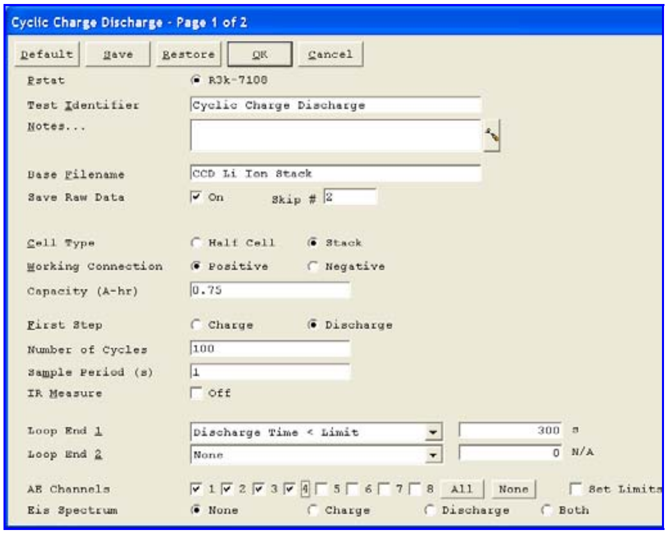
CCD can measure:

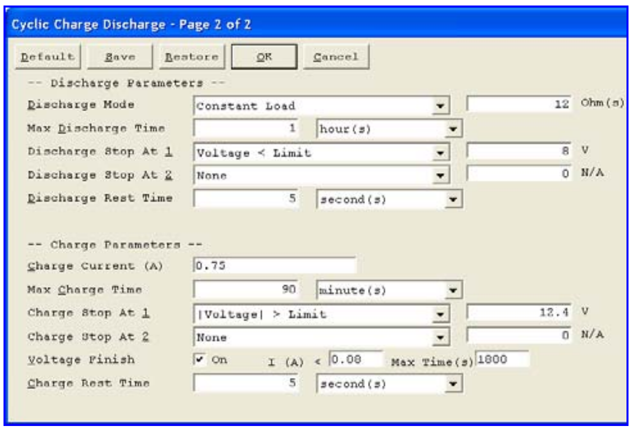
- capacity fade
- energy efficiency
- coulombic efficiency
- imbalance in cell stacks

CCD uses constant current charging with optional voltage finish. See the highlighted section above.

CCD discharge is done at constant current, constant power or constant resistance. The discharge step ends after a set time or after a Stop At test becomes true.

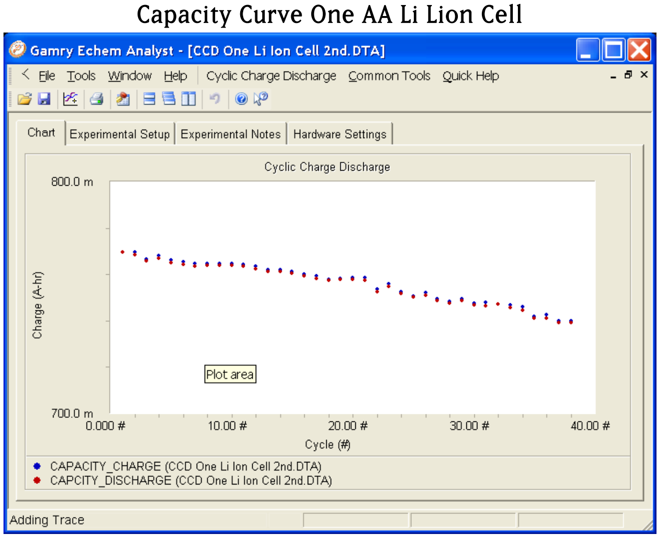
CCD Setup Screens





The data curve for a CCD test is a plot of capacity (in A-hrs) versus cycle number. Each charge and discharge curve is reduced to one data point in the plot. The user can change the Y axis on the Framework plot to be energy, duration, initial voltage or final voltage.

Capacity Curve One AA Li Lion Cell



The most recent charge or discharge curve can be plotted as voltage versus time. In systems with an AE option, the user can choose to plot the AE potential at the beginning or the end of a step (versus cycle number). The potentials will drift if the stack is unbalanced.

In CCD users can save selected "raw" charge and discharge curves. If the test uses the AE option, the raw data file will include AE voltages.

CCD data is analyzed with Gamry's Echem Analyst. By default, a CCD file plots with Cycle Number, Discharge Capacity and Charge Capacity on the X, Y and Y2 axes.

Axis transforms in the Echem Analyst allow the data to be plotted in the format you need. The X axis can be transformed from cycle number to time. Y axis transforms include:

- Charge Capacity
- % Capacity
- Energy
- Step Duration
- Capacitance
- Coulombic Efficiency
- Energy Efficiency

AE data from a CCD test is plotted using the Echem Analyst's **CCD, View AE data...** command with initial potential, final potential or energy on the Y or Y2 axis.

Raw charge or discharge curves associated with a CCD data file can be accessed easily during analysis of that file using the **CCD, View Raw Data...** menu command.

StopAt versus Loop End

A Loop End test terminates an experiment when a conditional test becomes true. In a CCD test, a Loop End test is used to stop an experiment when the device has lost most of its capacity or fails to charge.

A StopAt test is different. When its condition becomes true, the current step in a multi-step experiment terminates and the script proceeds to the next step in the experiment. In a one step experiment the StopAt test terminates the experiment.

CCD with EIS

The PWR800 combines Cyclic Charge-Discharge with EIS (Electrochemical Impedance Spectroscopy). EIS spectra can be recorded after charge, after discharge, or after both.

EIS can be useful in determining capacity fade mechanisms. Comparison of EIS spectra at different points in a battery's lifetime can detect increases in electrolyte resistance, loss of active electrode area, and changes in reaction kinetics (to name only a few). See the Gamry Instruments Website www.Gamry.com for additional EIS information.

CCD with EIS will not operate unless the system includes an EIS300 software license. Galvanostatic spectra are recorded with zero DC current and selectable AC current.

With the AE option the PWR800 can simultaneous measure the EIS spectra of cells in a series-connected stack. The same AC current is applied to all cells, so an AC voltage measurement is sufficient for calculation of the complex impedance of the cells.

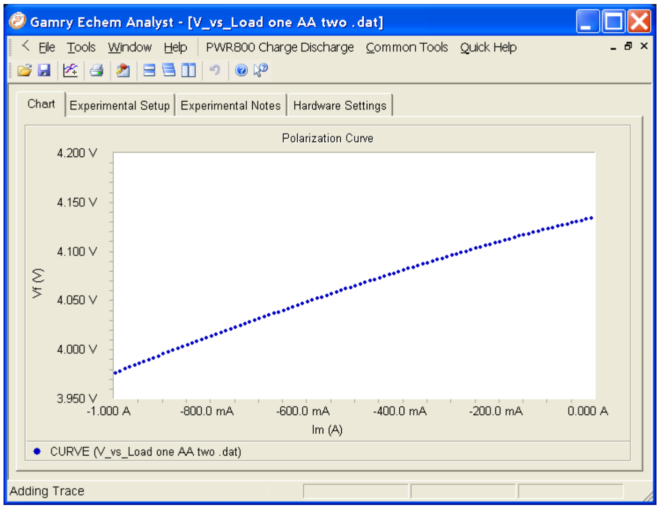
Polarization Curve

The voltage of electrochemical devices varies with changes in the load across the device. The PWR800 Polarization Curve technique automates collection of a voltage versus load curve.

All three discharge modes (constant current, constant load and constant power) are supported. A linear ramp is applied to the load and the voltage is measured.

Polarization Curves can be recorded on primary and secondary batteries, fuel cells, and super-capacitors. In AE systems, the voltage of individual cells in a series-connected stack can be measured as the stack's load changes.

Polarization Curve of AA Li Ion Battery



Galvanostatic

The PWR800 Galvanostatic technique can be used to manually charge and/or discharge an electrochemical device. An AE option can read the potential of cells within a stack.

Potentiostatic

The PWR800 Potentiostatic technique controls the voltage of an electrochemical device. It uses a software control loop to maintain the desired potential. Voltage measurement of individual cells in a stack is possible using an AE option.

Analysis of PWR800 Data

Data files recorded with the PWR800 are plotted using Gamry's Echem Analyst™.

The PWR800 stores secondary data (raw charge and discharge curves in CCD tests, and EIS spectra) in a sub-folder of the **My Gamry Data** folder. All the secondary data generated by the PWR800 can be accessed and plotted from the analysis window for the main data file.

Attention to Details

The PWR800 is the first laboratory system designed for electrochemical energy research. A lot of attention went into the details of how researchers measure and analyze data.

Examples include:

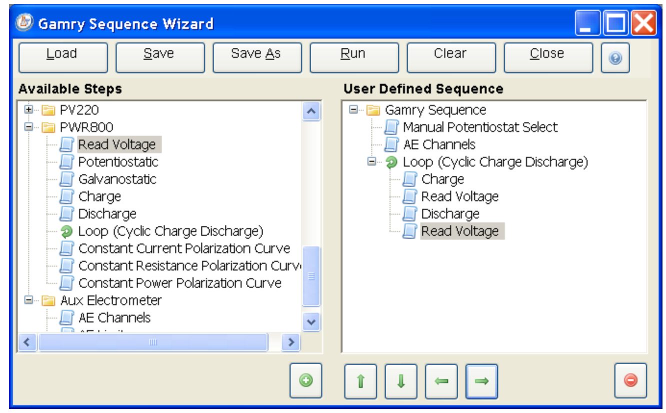
- No more wondering which sign to use; both discharge and charge current are positive numbers.
- Test the anode or the cathode of a 3-electrode cell.
- Multiple stop tests allow test termination on both normal and failsafe criteria.
- In super-capacitor research using CCD the PWR800 calculates the effective capacitance in every cycle.

Sequences for Even More Flexibility

Gamry's Framework includes a versatile Sequence Wizard™ which can run a number of experiment steps in order and allows for looping though steps.

All of the PWR800 tests have Sequence Wizard versions. For example, CCD in the Sequence Wizard repetitively loops between charge and discharge steps.

CCD Sequence in the Wizard



Because all the PWR800 tests can be run in a sequence, they can be easily modified. Possible sequences include:

- EIS at various states-of-charge in a discharge curve
- Periodic polarization curves during fuel cell discharge
- Multi-step formation processes for secondary batteries
- A CCD curve with variable charge and discharge limits

Gamry Instruments can engineer special scripts and sequences for specific customer needs.

System Information

The PWR800 Electrochemical Energy Software currently requires a Gamry Instruments' Reference 3000 Potentiostat. Its AE option is required for simultaneous tests on multiple cells.

The PWR800 requires Microsoft Windows® XP or Vista.

Later software releases may operate with other Gamry Potentiostats. Contact Gamry for current information.

Gamry Instruments can supply complete systems including the Potentiostat and software installed on a computer. Custom computer configurations, software, training, and installation are also available.

Specifications

See Potentiostat specifications for additional information. All Gamry Potentiostats are electrically floating allowing tests on cells with an earth ground connection.

GAMRY INSTRUMENTS

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