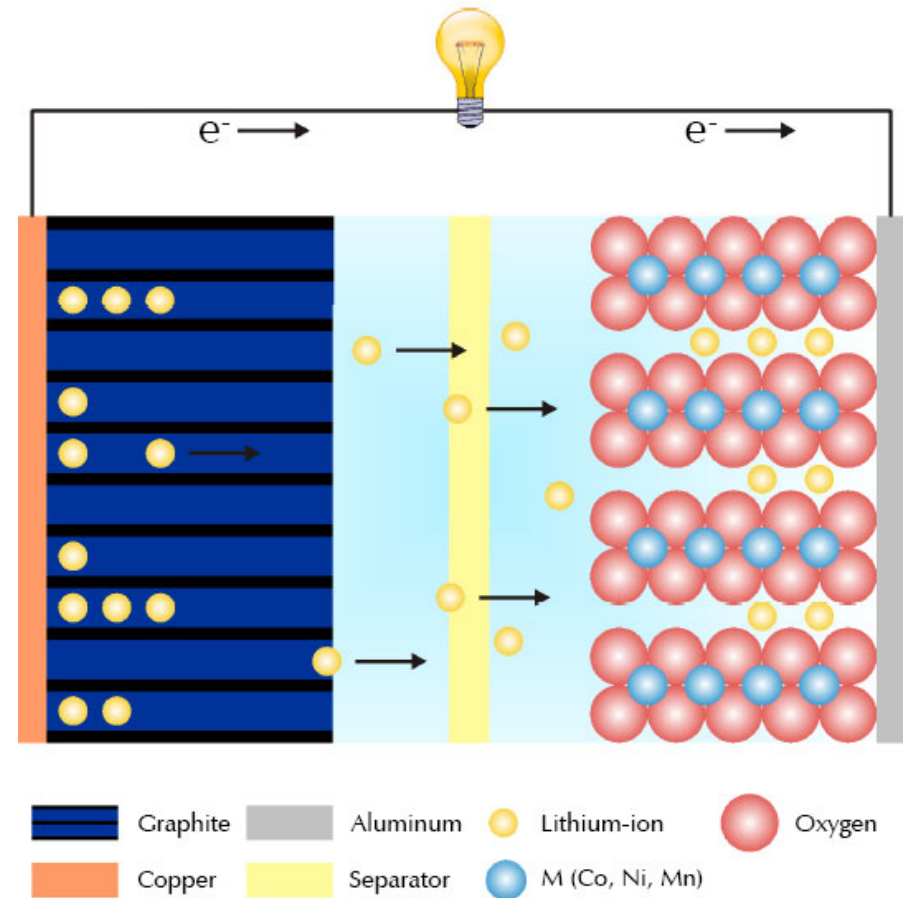


Battery Testing Techniques

Types of Cell

- Primary Cells
 - Alkaline
 - Lithium coin cells
- Secondary Cells
 - Lithium ion
 - NiMH
 - Lead-Acid



Cell Construction

Lithium Ion

- Highly porous materials used for high/power densities
- Anode (negative)
 - Graphite attached to copper current collector
- Cathode (positive)
 - Mostly Lithium transition metal oxides attached to aluminum foil
- Separator
 - Ion permeable membrane placed between the electrodes to prevent shorts

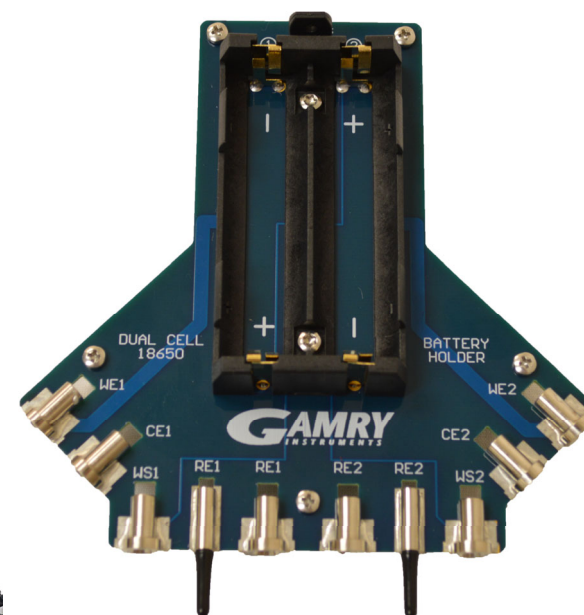
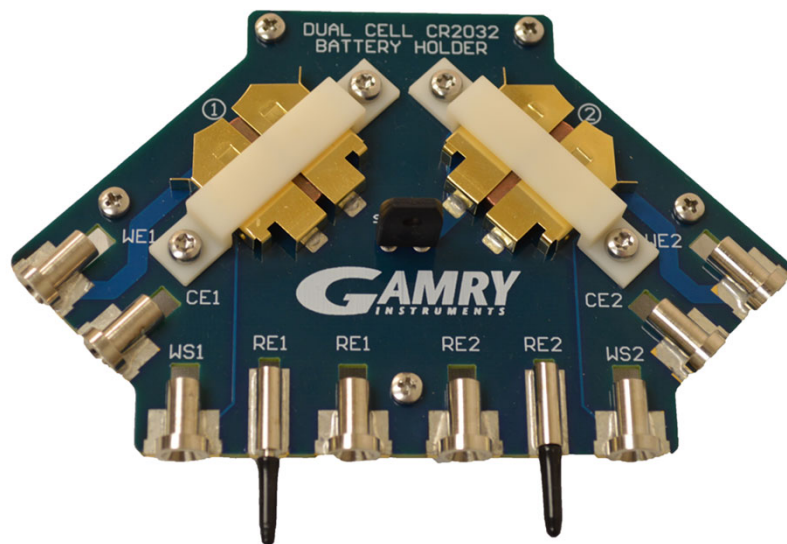
Battery Reactions

- Charging
 - Lithium ions migrate from the Lithium-rich cathode to the anode and intercalate into the multi-layered structure
- Discharging
 - The process is reversed
- Anode: $x\text{Li}_+ + xe^- + \text{C}_6 \rightleftharpoons \text{Li}_x\text{C}_6$
- Cathode: $\text{Li}_{x+y}\text{MO}_2 \rightleftharpoons x\text{Li}_+ + xe^- + \text{Li}_y\text{MO}_2$

Factors Affecting Performance

- Extreme temperatures
- Exceeding battery specifications with regard to Potential and current
 - Irreversible reactions
 - overheating

Cell Holders



Cell Holders

- Cell holders constructed with separate current and voltage sensing
- Precise and accurate measurements need Kelvin sensing

Read Voltage

- Measure the voltage of the battery in its resting state.
- No current passed

PWR Read Voltage - Page 1

Default Save Restore OK Cancel

Pstat IFC5000-03505

Test Identifier

Output Filename

Notes...

Capacity (A-hr)

Cell Type Half Cell Full Cell Both

Working Lead Positive Negative

Expected Max V (V)

Cable Check On

PWR Read Voltage - Page 2

Default Save Restore OK Cancel

Max Time hour(s)

Sample Period (s)

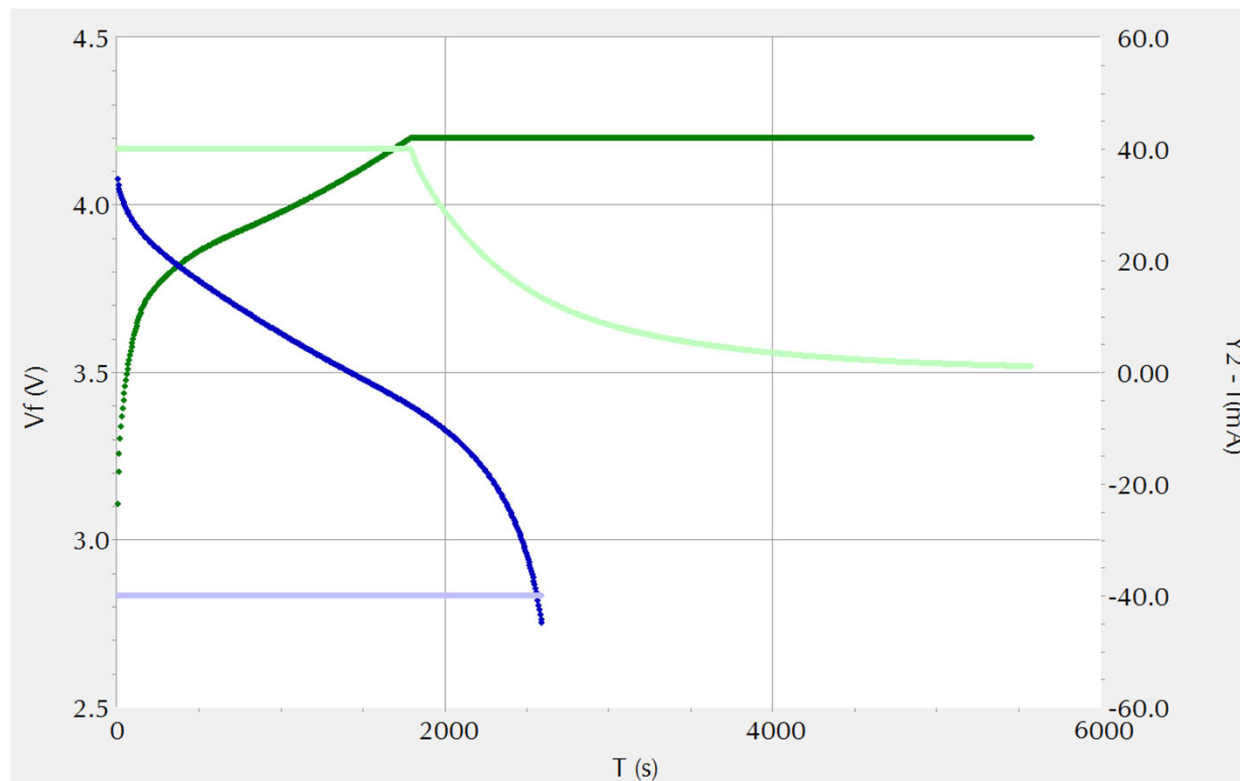
Stop At 1 N/A

Stop At 2 N/A

Charge and Discharge

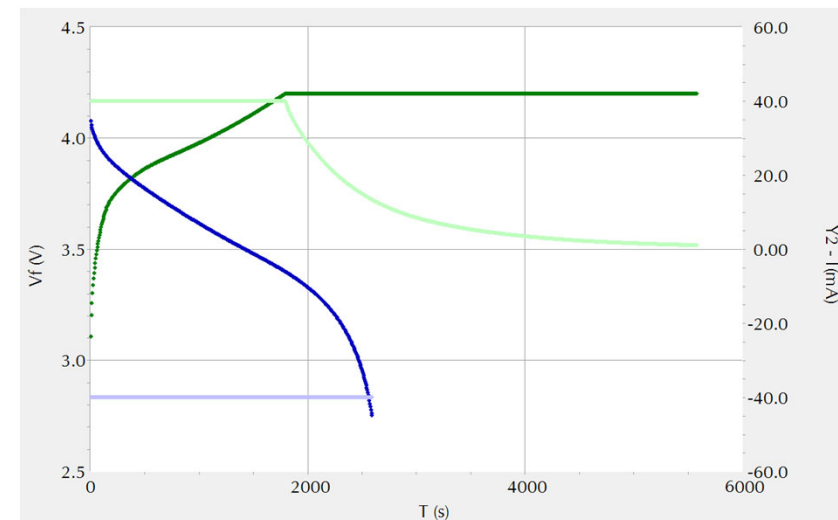
- Terminology
 - C – capacity of battery (usually in Ah)
 - C-rate – A charge rate of 1 C is the current required to charge the battery in 1 hour
 - SOC – State of Charge
 - DOD – Depth of Discharge
 - Voltage Finish – Constant voltage hold at the end of a charge step

Charge and Discharge



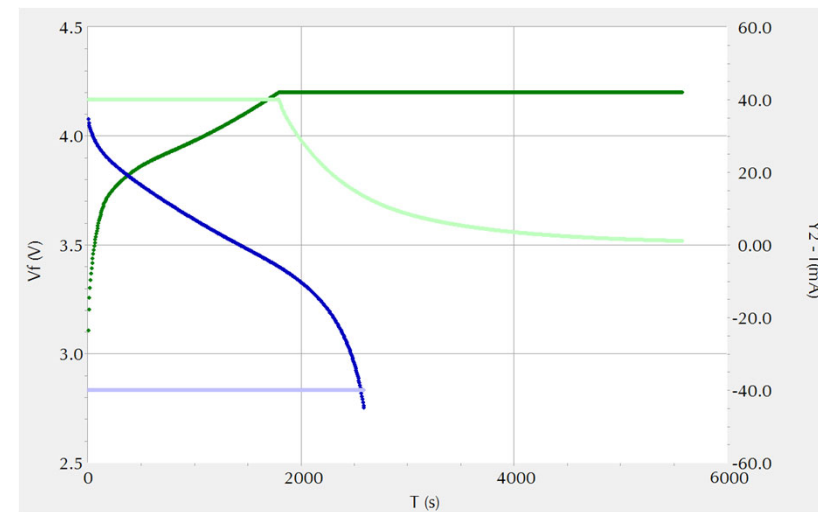
Charge and Discharge

- Charging
 - Voltage increases steadily
 - Lithium ions are extracted from the cathode and intercalate in the anode
 - Cell is held at constant voltage at 4.2V until current drops below specified current limit.
 - SOC of battery is 100%



Charge and Discharge

- Discharging
 - Voltage drops initially
 - Voltage drop proportional to Equivalent Series Resistance
 - Equivalent Series Resistance is equal to the sum of all the resistances in the battery due to the electrodes, electrolyte, separator and electrical contacts
 - This voltage drop affects the maximum output energy of the battery



Charge and Discharge

$$\Delta X = I \cdot HV \cdot t$$

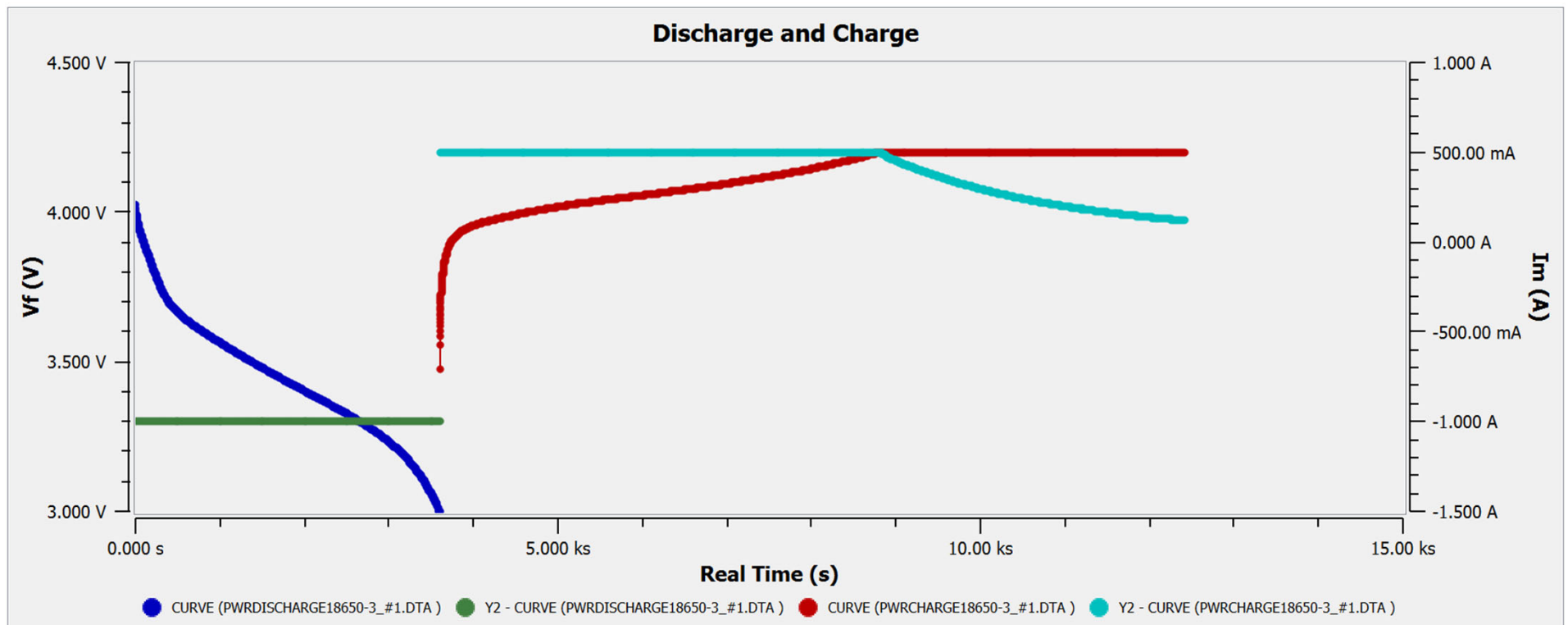
ESR from the voltage drop

$$H = \frac{X_3 - \Delta X}{I}$$

Available Energy of the battery

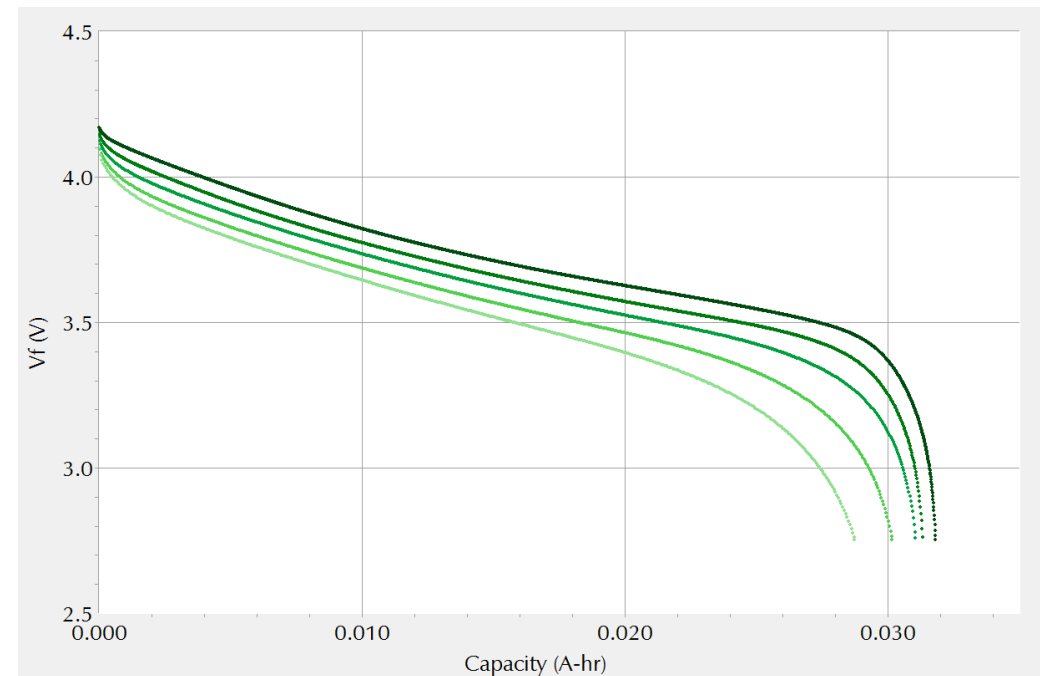
Demo

Charge and Discharge



Discharge – C-Rate

- Discharge rates of
 - 0.2 C
 - 0.4 C
 - 0.6 C
 - 0.8 C
 - 1 C



Voltage vs. Capacity

Discharge – C-Rate

- Discharge time decreases for increased C-rate
- Initial voltage drop increases with increased C-rate
- However, ESR drops, possibly due to higher temp. in battery
- Could lead to material degradation
- Lower capacity and energy for increased C-rate

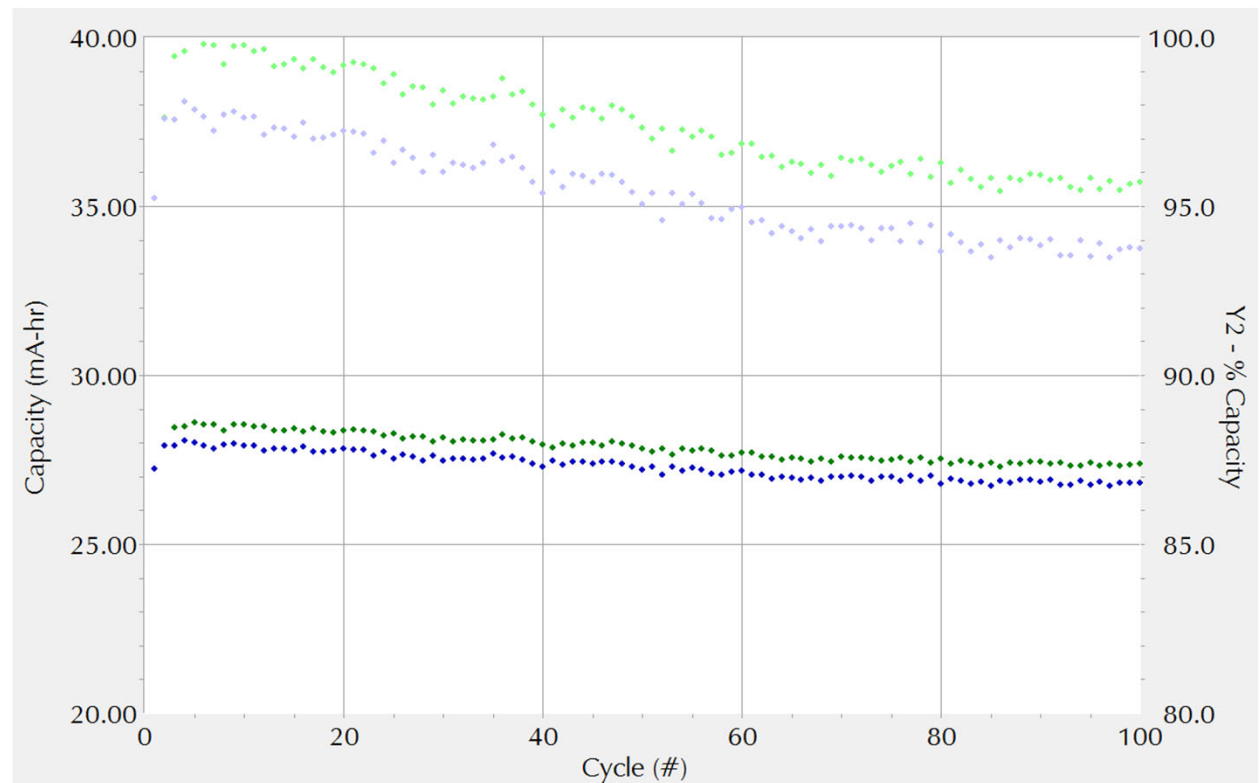
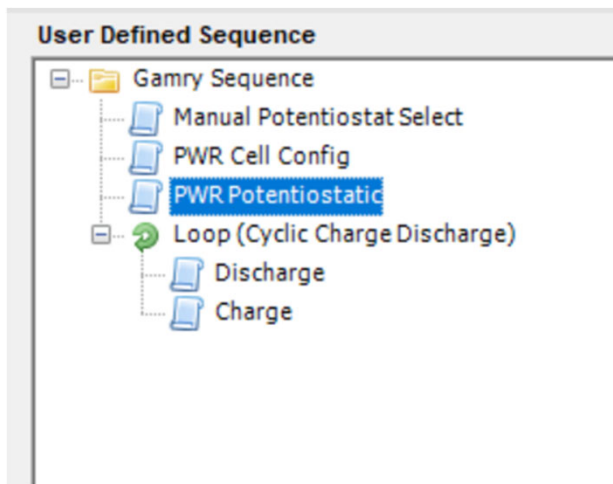
C-rate	0.2	0.4	0.6	0.8	1.0
I [mA]	8	16	24	32	40
t [h]	4.0	2.0	1.3	1.0	0.7
ΔU [mV]	-4.8	-8.8	-13.1	-17.3	-20.8
ESR [m Ω]	605	555	548	542	522
Q [mAh]	31.8	31.3	31.1	30.1	28.7
E [mWh]	118	115	112	107	101

Battery Cycling

Cyclic Charge Discharge

- Test Battery's long-term stability
- Battery is charged and discharged several hundred times and the capacity is measured.

Cyclic Charge Discharge



Cyclic Charge Discharge

- Good cycling behavior shown
- Capacity only decreased slightly over the 100 cycles
- Capacity loss of 4.5% after 100 cycles
- Capacity loss due to electrolyte impurities and electrode imperfections
- Coulombic efficiency also calculated
- Coulombic efficiency of 98%

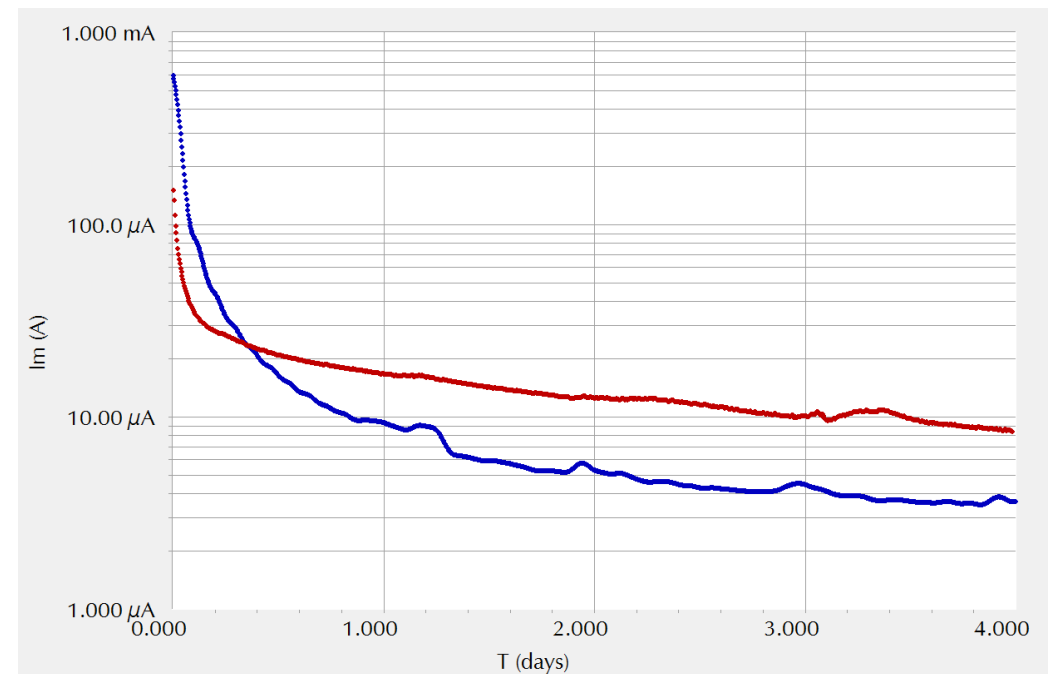
$$\eta_F = \frac{Q_{\text{discharge}}}{Q_{\text{charge}}} \cdot 100\%$$

Leakage Current

- Current that flows due to internal current flow in the battery.
- Measured by applying constant potential and measuring the current for a specified period of time
- Most battery specification rate the leakage current after 72 hours

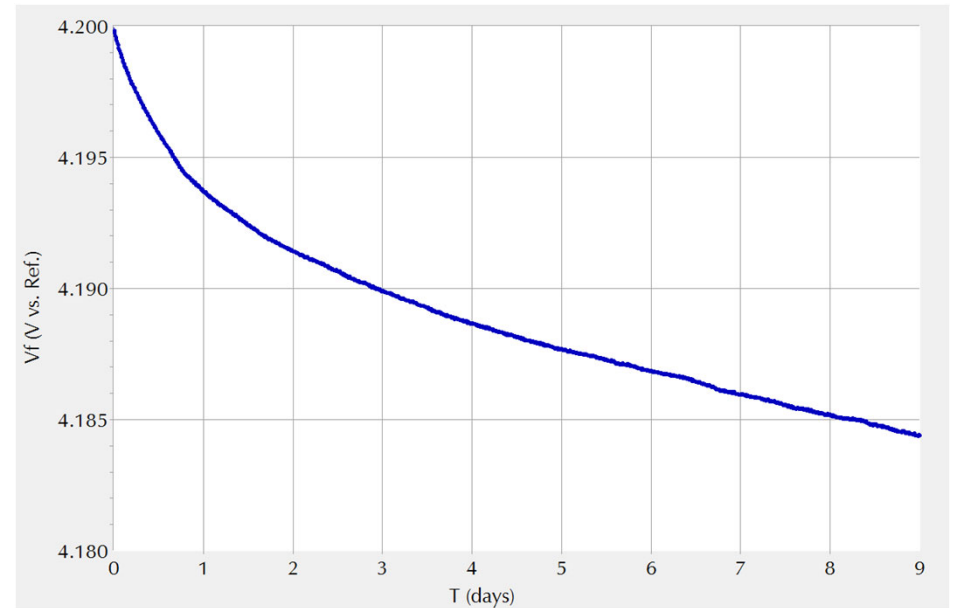
Leakage Current

- Two batteries
 - One new (blue)
 - One aged by heating (red)
- Current measured for 4 days
- Leakage current
 - 4.7 microamps (blue)
 - 10 microamps (red)



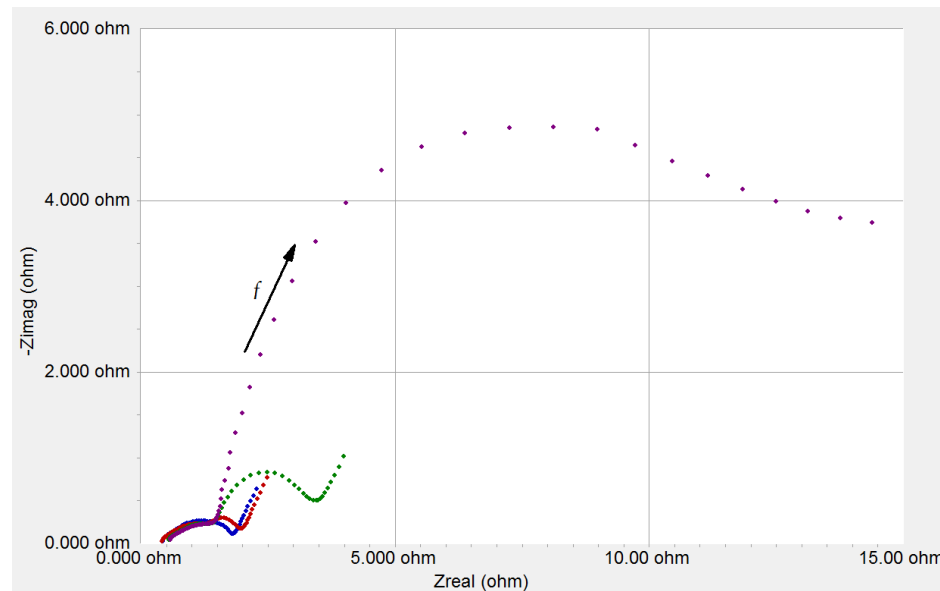
Self Discharge

- Voltage loss of battery at open circuit
- Due to internal current flow
- Potential drop 15.6 mV after 9 days
- Rate influenced by age and usage



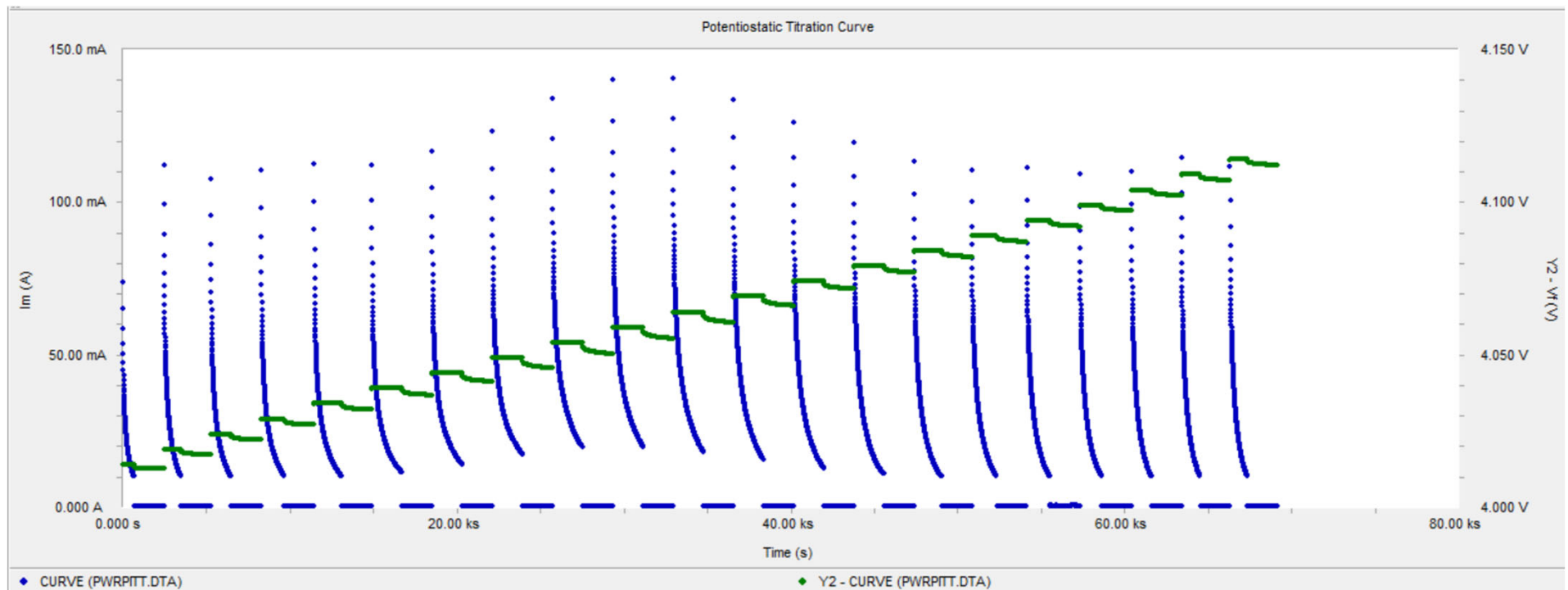
Other techniques

- Impedance Spectroscopy (EIS)



Other techniques

Potentiostatic Intermittent Titration Technique (PITT)



Other Techniques

Galvanostatic Intermittent Titration Technique (GITT)

