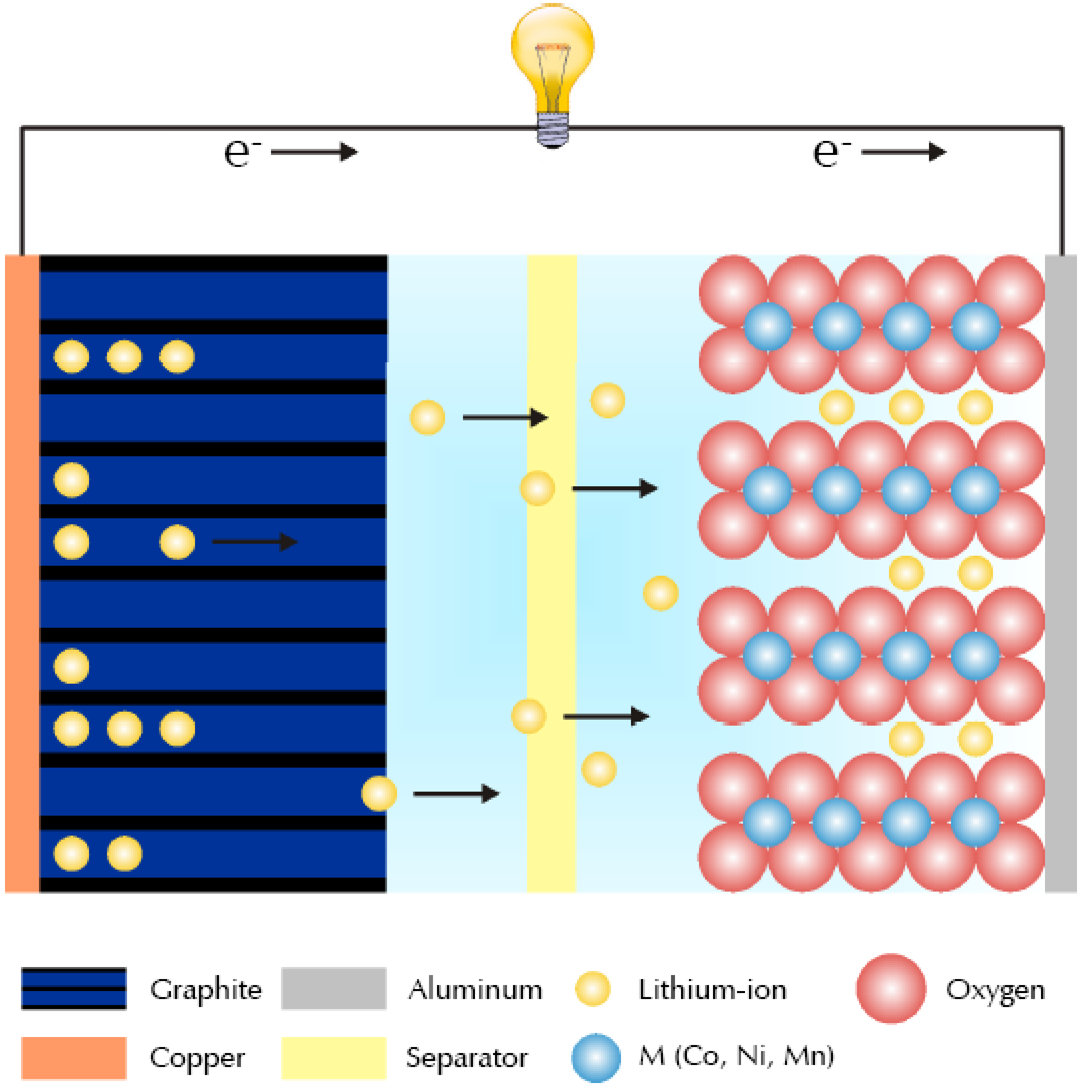
Battery Testing Techniques

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

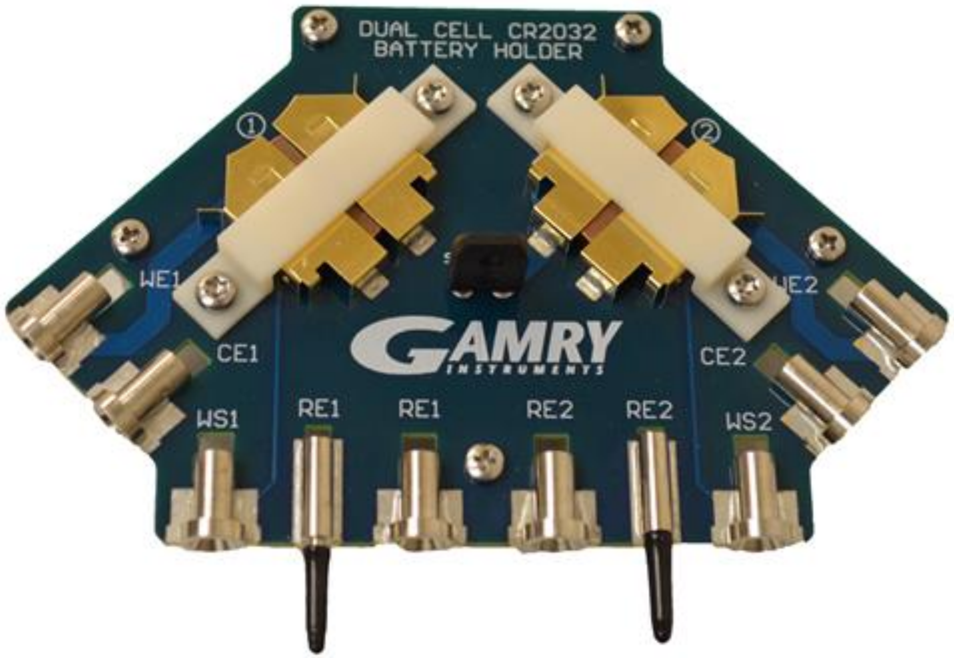
Battery Reactions

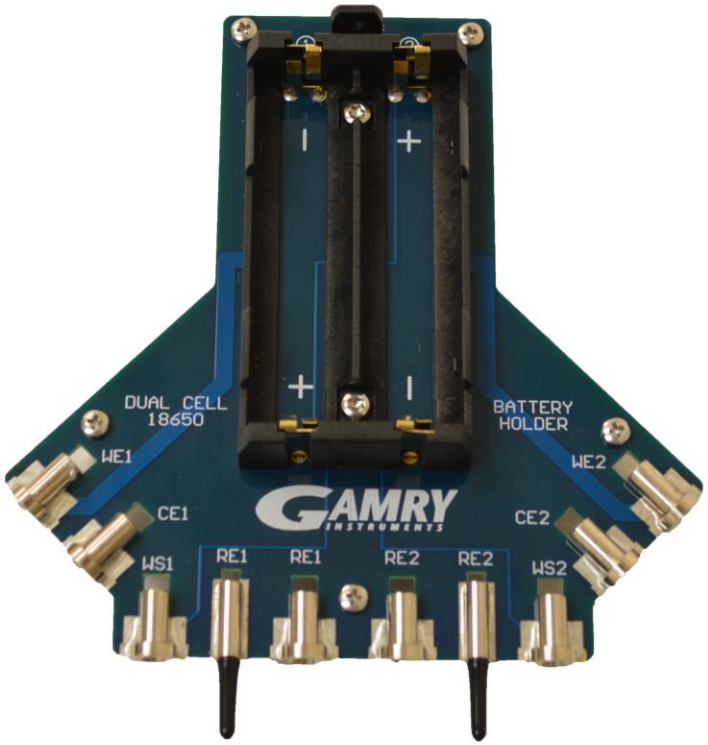
- Discharging
  - Lithium ions migrate from the Lithium-rich cathode to the anode and intercalate into the multi-layered structure
- Charging
  - The process is reversed
- Anode: $x\mathrm{Li}^{+} + x\mathrm{e}^{-} + \mathrm{C}_6 \leftrightarrows \mathrm{Li}_x\mathrm{C}_6$
- Cathode: $\mathrm{Li}_{x+y}\mathrm{MO}_2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

Factors Affecting Performance

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

Cell Holders



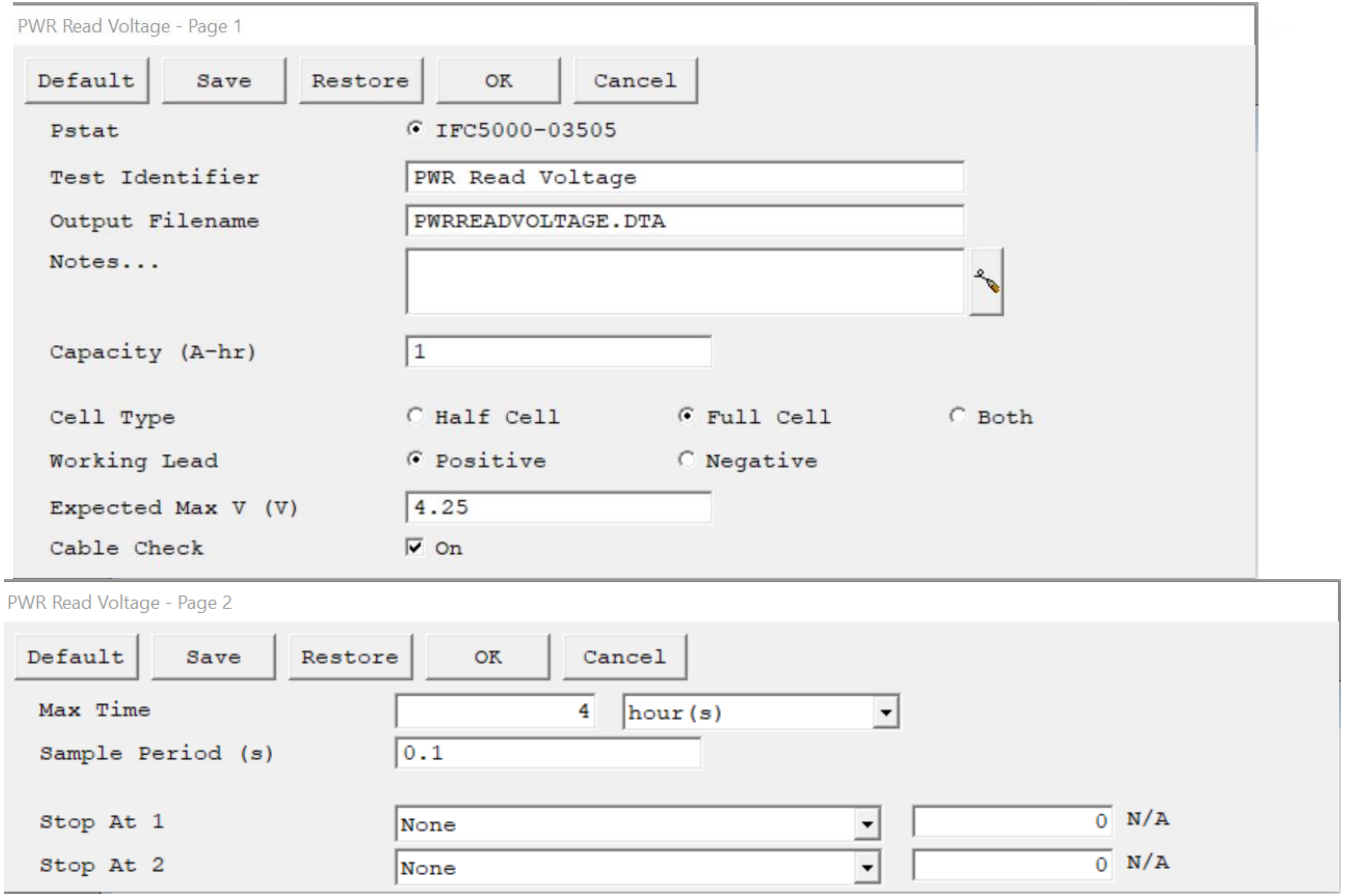


Cell Holders

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

Read Voltage

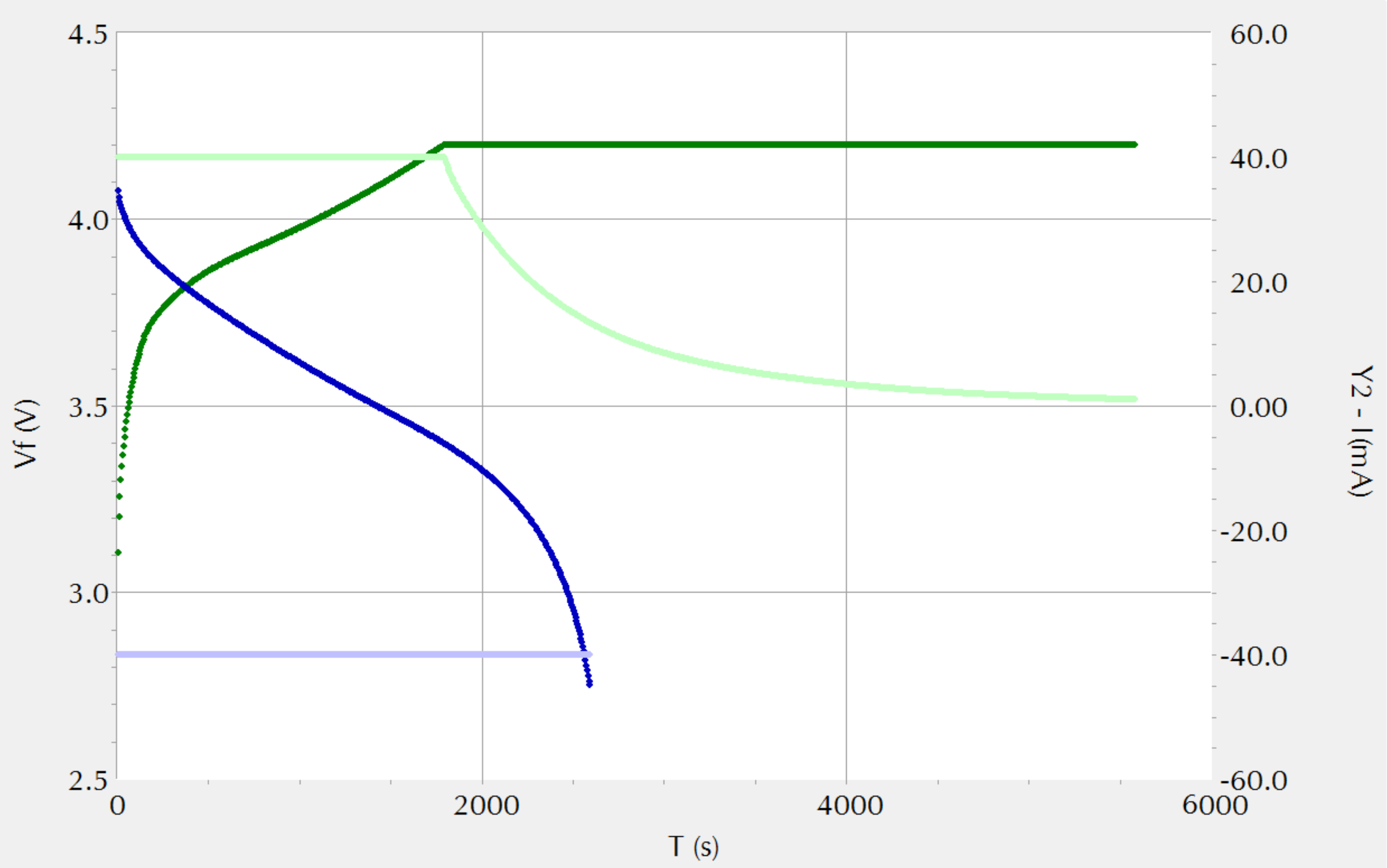
- Measure the voltage of the battery in its resting state.
- No current passed



Charge and Discharge

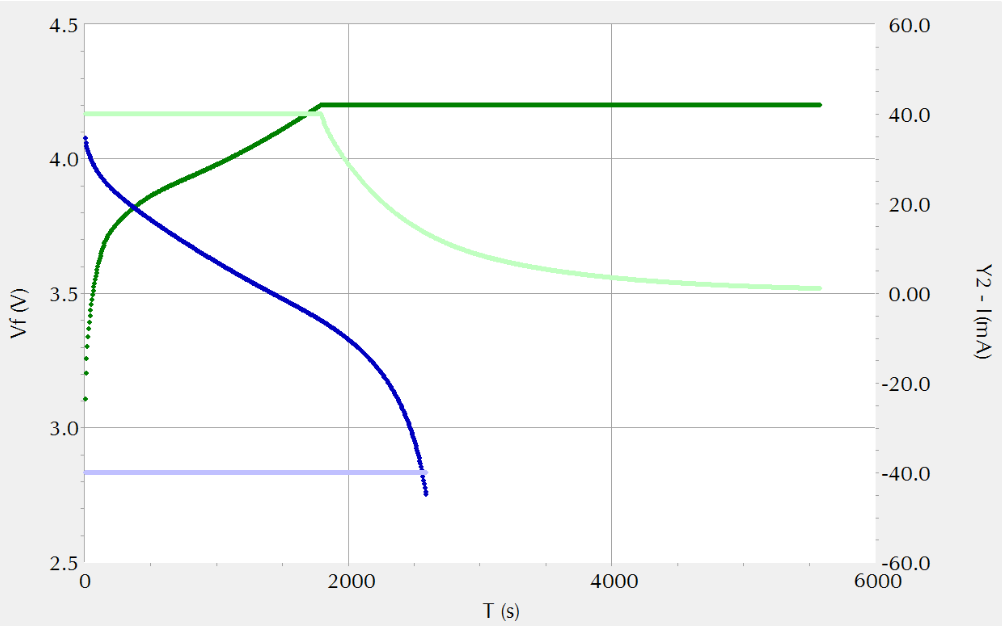
- Terminology
  - C – capacity of battery (usually in Ah)
  - C-rate – A charge rate of 1 C is the current required to charge the battery in 1 hour
  - SOC – State of Charge
  - DOD – Depth of Discharge
  - Voltage Finish – Constant voltage hold at the end of a charge step

Charge and Discharge



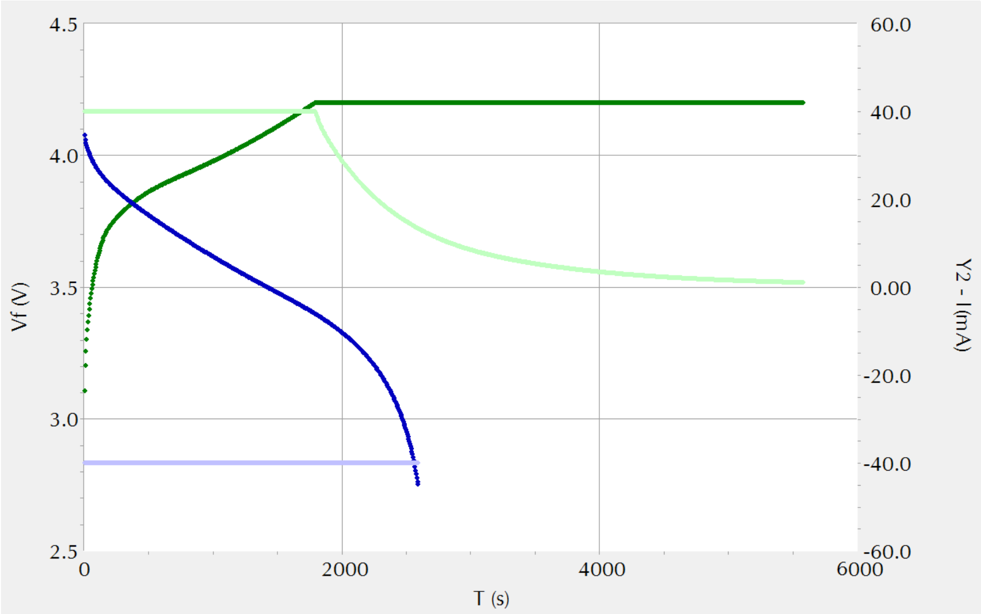
Charge and Discharge

- 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

$$\Delta U = I \cdot ESR$$

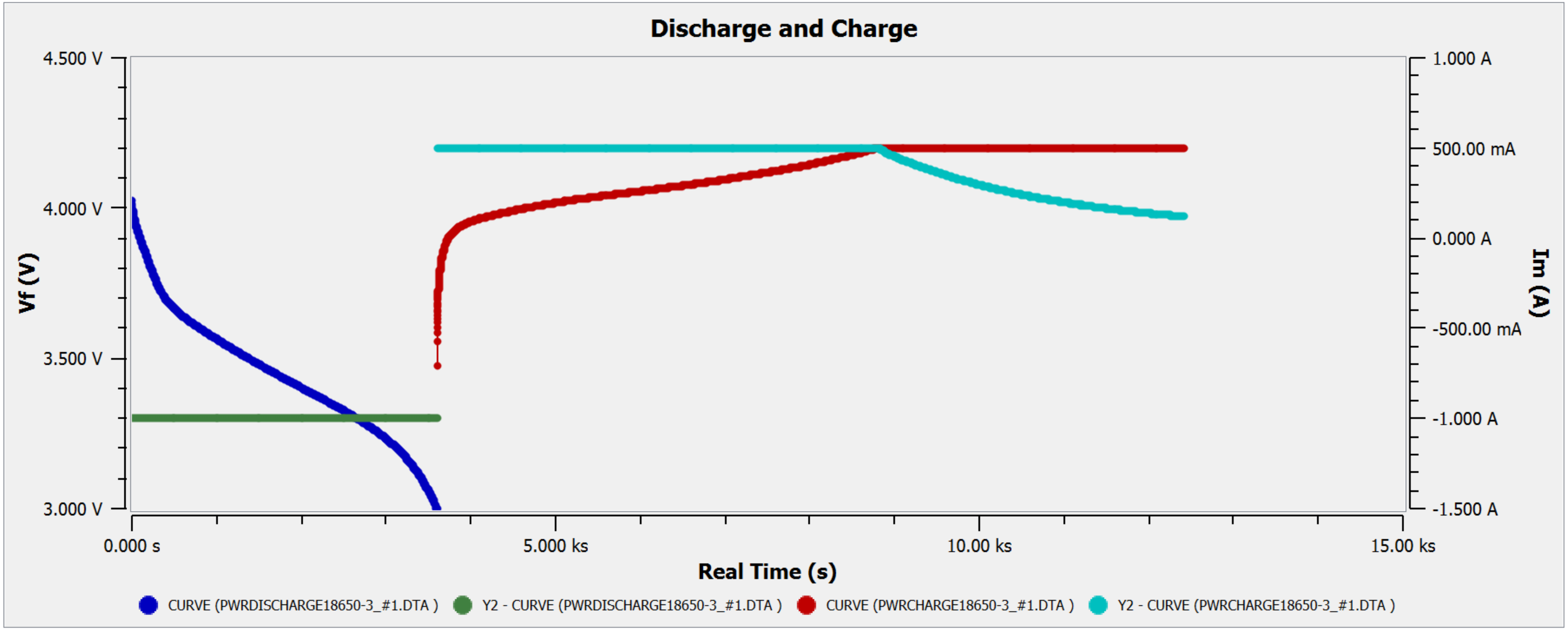
ESR from the voltage drop

$$E = (U_0 - \Delta U) \cdot It$$

Available Energy of the battery

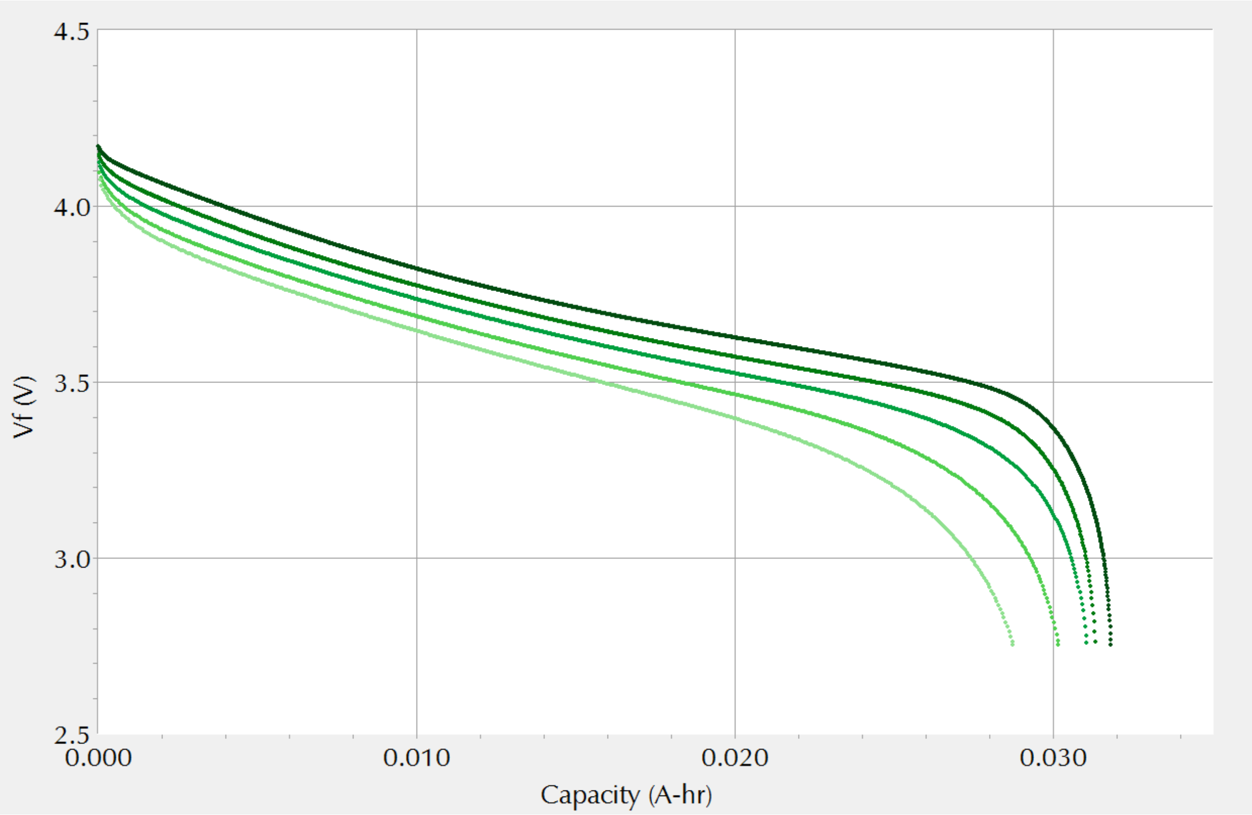
Demo

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

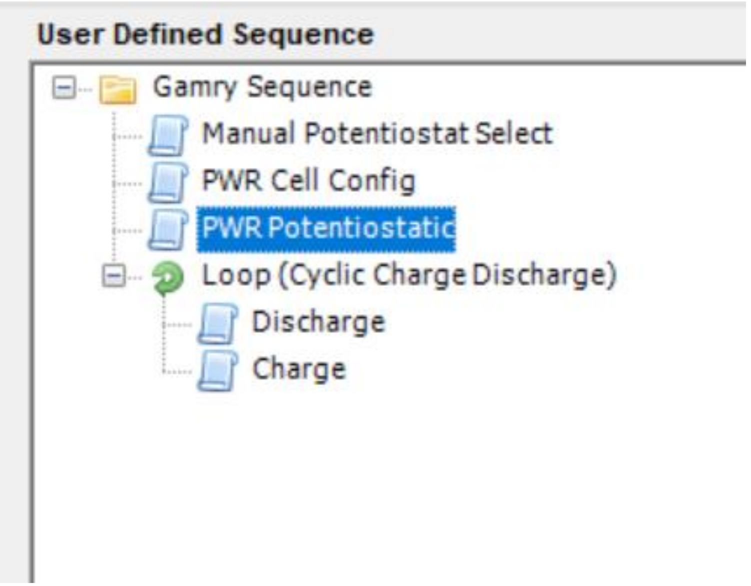
C-rate	0.2	0.4	0.6	0.8	1.0
I [mA]	8	16	24	32	**40**
t [h]	4.0	2.0	1.3	1.0	**0.7**
∆U [mV]	-4.8	-8.8	-13.1	-17.3	**-20.8**
ESR [mΩ]	605	555	548	542	**522**
Q [mAh]	31.8	31.3	31.1	30.1	**28.7**
E [mWh]	**118**	**115**	**112**	**107**	**101**

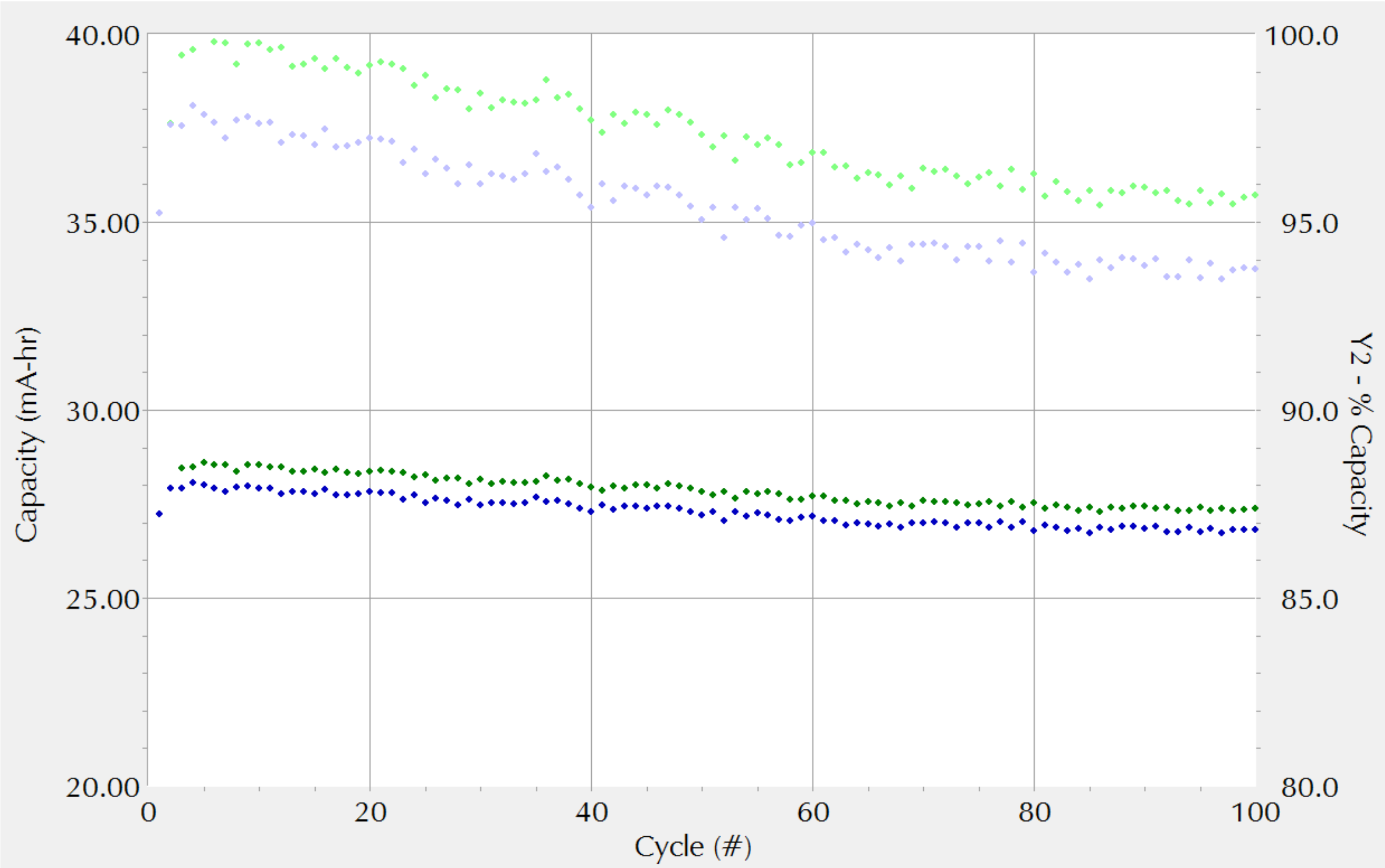
Battery Cycling

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%

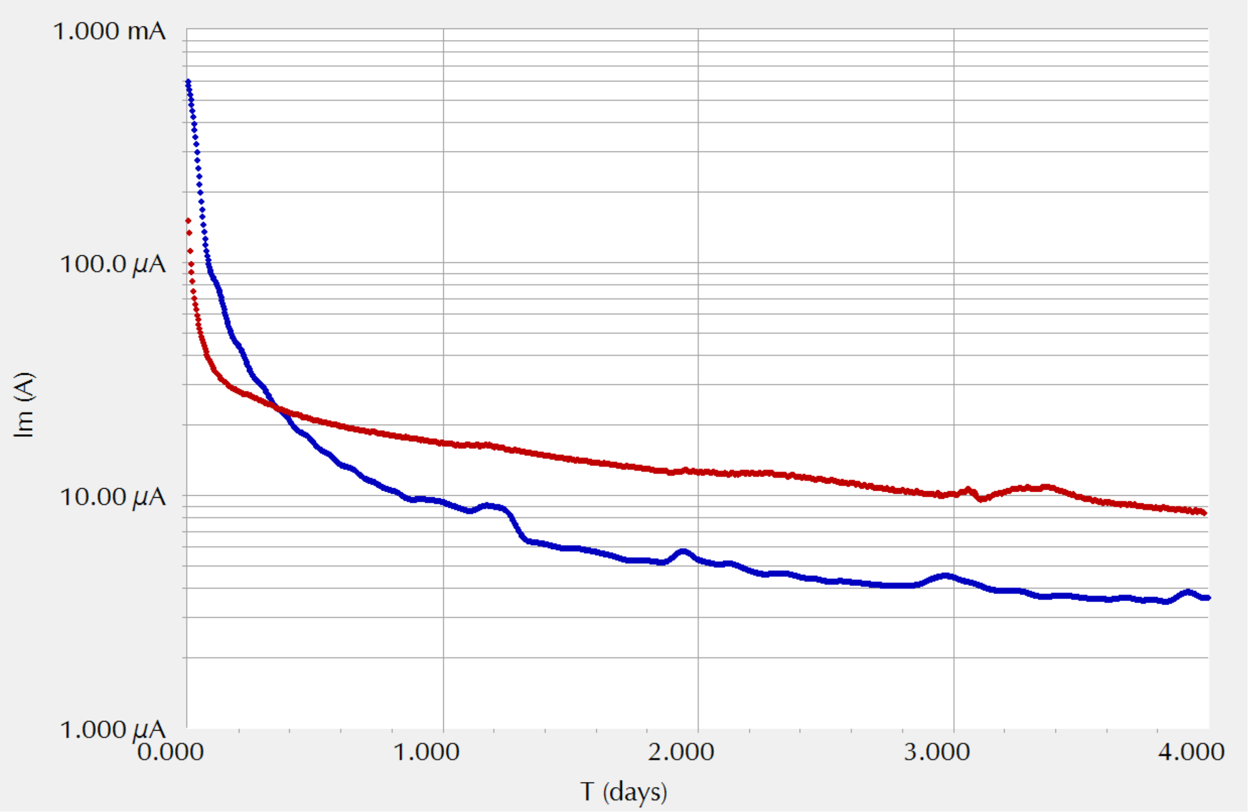
$$\eta_C = \frac{Q_{discharge}}{Q_{charge}} \cdot 100\%$$

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

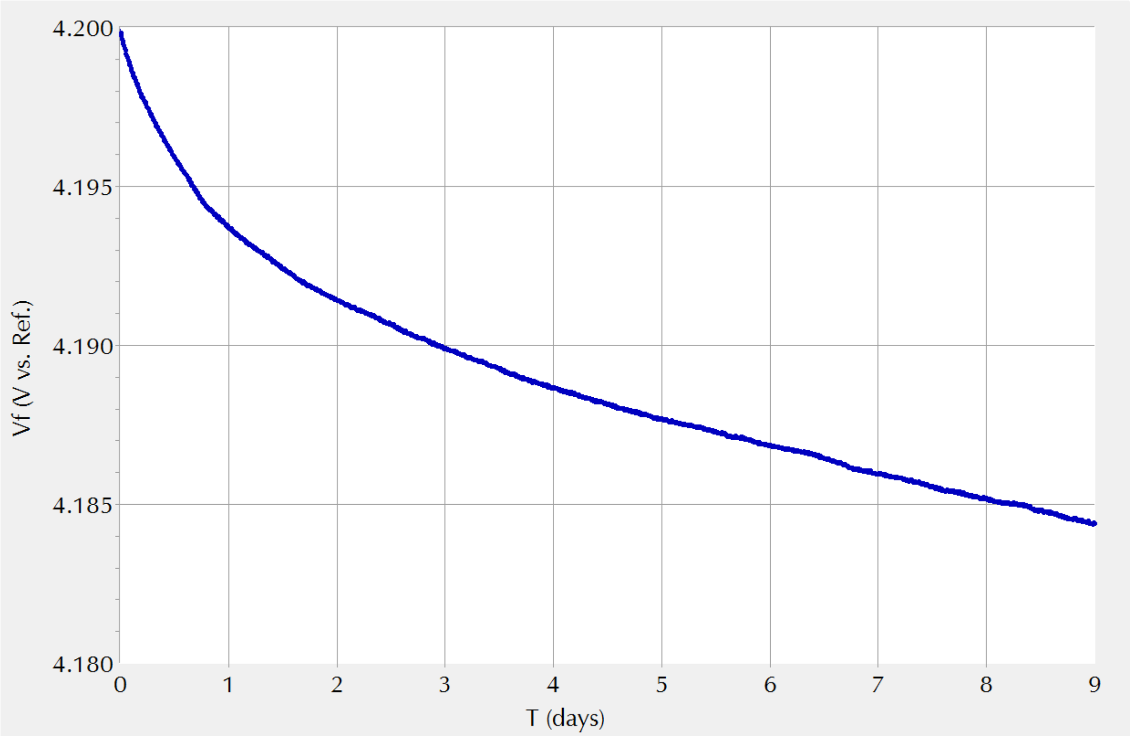
Leakage Current

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



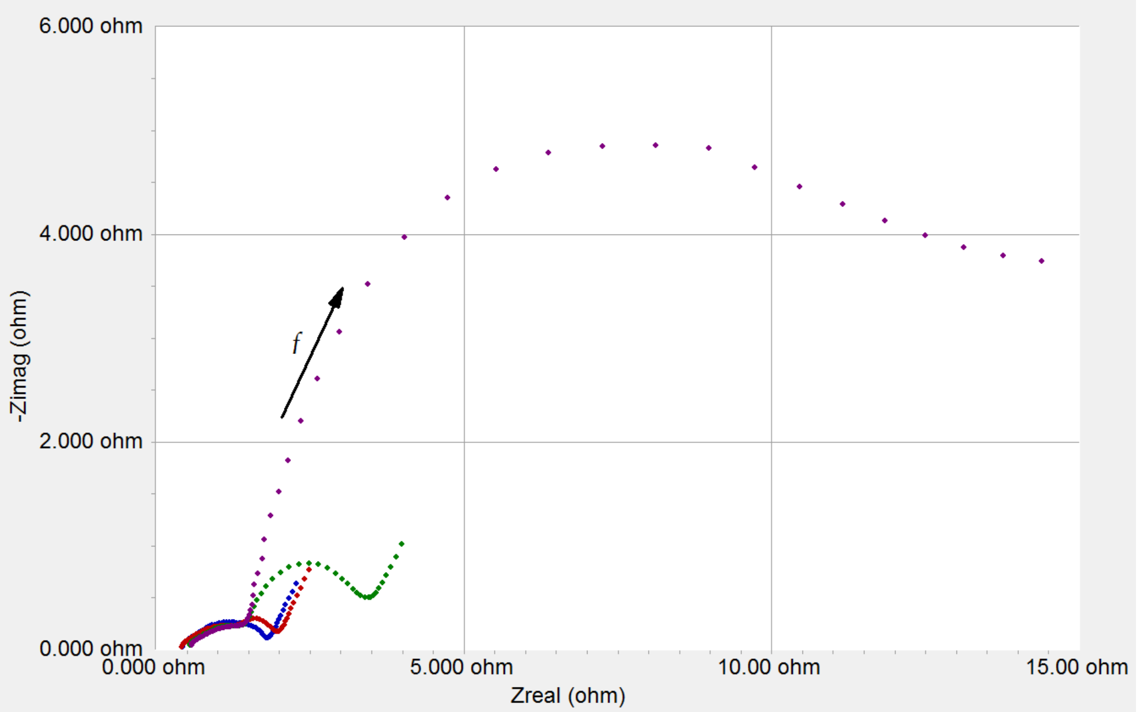
Self Discharge

- 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



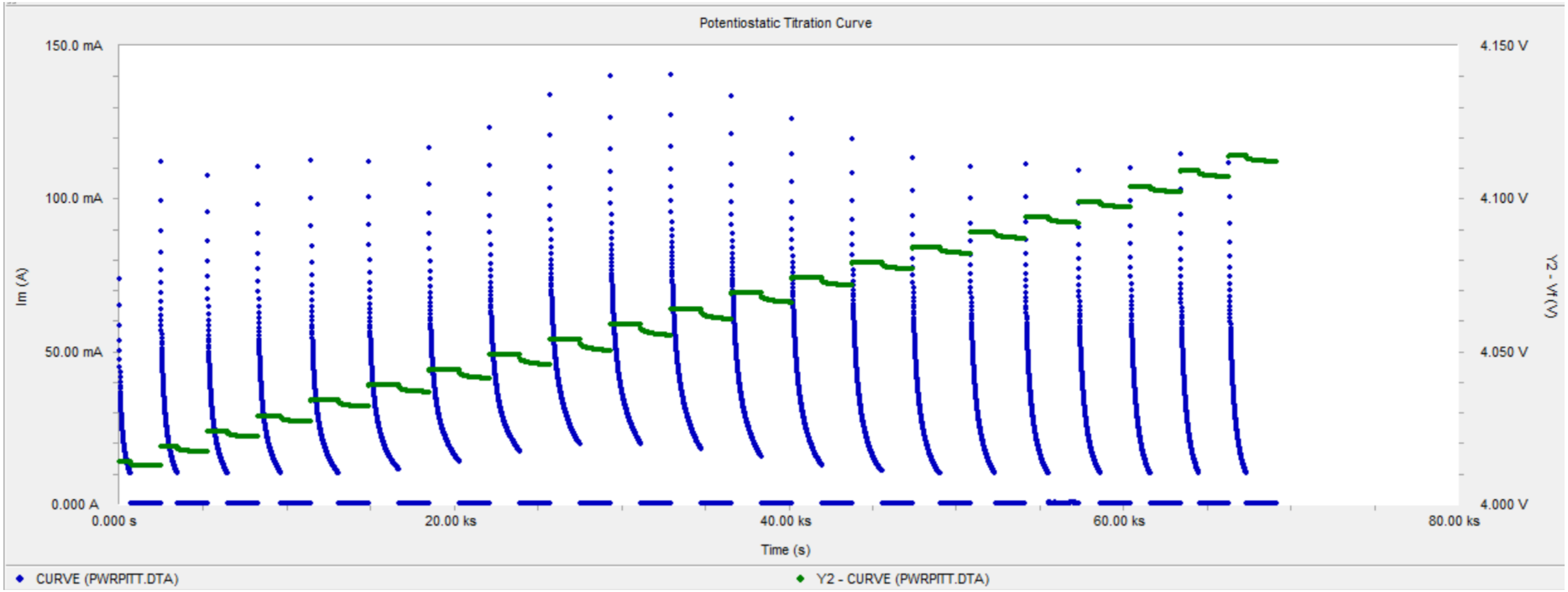
Other techniques

- Impedance Spectroscopy (EIS)



Other techniques

Potentiostatic Intermittent Titration Technique (PITT)



Other Techniques

Galvanostatic Intermittent Titration Technique (GITT)