Application Area: Batteries

Galvanostatic charge-discharge of a Li-ion battery with Autolab

Keywords

Batteries, Charge and discharge, Galvanostatic, Capacity, C-rate

Introduction

Lithium-ion (Li-ion) batteries are one of the most important energy storage devices on the market. Li-ion batteries are used to power, for example, portable electronics, (hybrid) electric vehicles, and grid storage solutions.

A typical Li-ion battery is usually composed of one or more cells. Each cell is made of one positive electrode, one negative electrode and a separator between the electrodes, soaked with electrolyte.

Each electrode contains an active material which is the host material for lithium ions. On the negative electrode, the active material is usually graphite. On the positive electrode, the active material is normally a transition metal oxide, such as lithium cobalt oxide, $LiCoO_2$, or lithium manganese oxide $LiMn_2O_4$. The active materials are mixed with carbon black, to enhance the electronic conduction. The separator is usually a porous polymeric foil, while the electrolyte is a lithium salt dissolved in organic, water-free liquid solvents.

Li-ion batteries work through the intercalation (lithiation) and de-intercalation (delithiation) of lithium ions inside the active materials of the electrodes.

One way to characterize the performances of Li-ion batteries is to measure the amount to charge stored and delivered during charge and discharge, respectively. Characterization of Li-ion cells and batteries usually involves the galvanostatic charge and discharge during various cycles at different current rates.

This application note discusses the charging and discharging of a Li-ion battery at different current rates. Potential vs. time plots were recorded and potential vs. capacity plots were calculated.

Experimental setup

For the experiments, an Autolab PGSTAT302N was used, together with an Autolab BOOSTER20A. A 2.6 Ah Li-ion battery, with a nominal voltage of 3.7 V was the device under test (DUT). All measurements and calculations were performed with NOVA software.

During the galvanostatic cycling of batteries, the charge and discharge current are often expressed as a C-rate, calculated from the battery nominal capacity, i.e., the capacity value the battery has when completely charged. The C-rate is a measure of the rate at which a battery is completely charged or discharged, relative to its nominal capacity. For example, a C-rate of 1C means that the current necessary for complete charge or discharge in one hour is applied. C-rate multiples of 1C are also used. In battery research, it is common to use a C-rate of 0.1C, to charge and discharge a battery in ten hours. The current $i\ (A)$ necessary to charge or discharge a battery is calculated multiplying the C-rate by the ratio between the battery nominal capacity $C_{max}\ (Ah)$ and the one hour time (h).

$$i\ (A) = C\text{–}rate \cdot \frac{C_{max}\ (Ah)}{1(h)} \qquad 1$$

In this experiment, the 2.6 Ah nominal capacity of the battery was divided by one hour, giving 2.6 A of current. This value corresponds to a C-rate of 1C, the current needed to completely charge the battery in one hour, starting from a completely discharged state. Alternatively, a current of -2.6 A is needed to completely discharge the battery in one hour, starting from a completely charged state. In this experiment, the battery was cycled at 0.1C (or C/10, 260 mA, ten hours), 0.2C (or C/5, 520 mA, five hours), 1C (2.6 A, 1 hour) and 2C (5.2 A, 30 minutes).

The galvanostatic charge and discharge was performed with a potential range between 3.0 V and 4.2 V.

In order to calculate the capacity $C\ (Ah)$ during charge and discharge, the current $i\ (A)$ was multiplied by the duration $t\ (s)$ of a single charge or discharge step applied during that step, and divided by the conversion factor between seconds and hours, $3600\ (s/h)$.

$$C\ (Ah) = \frac{i\ (A) \cdot t(s)}{3600\ (s/h)} \qquad 2$$

Furthermore, the capacity values were reported in a percentage, as relative capacity $C_{rel}\ (\%)$. Each measured capacity value C_{meas} was normalized, by dividing it by the nominal capacity C_{max} of the battery, 2.6 Ah, and multiplied by 100.

$$C_{rel}\,(\%) = \frac{C_{meas}}{C_{max}} \cdot 100 \qquad 3$$

Results and discussion

In Figure 1, the potential vs. time plot at different C-rates is shown.

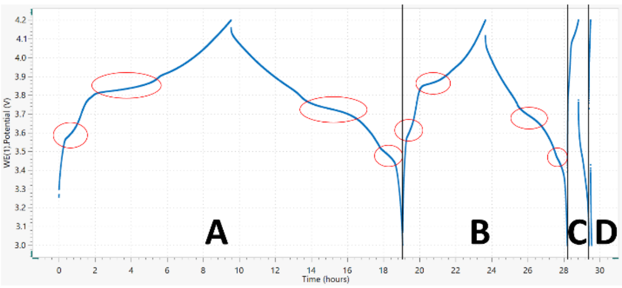

Figure 1 – Potential vs. time at different C-rates rates. Section A, 0.1C; Section B, 0.2C; Section C, 1C; Section D, 2C. The red circles highlight the plateaus at 0.1C and 0.2C.

At slow charge/discharge rates, i.e., at 0.1C and 0.2C, plateaus (red circles) along the potential plots are noticeable. These plateaus are responsible of the capacity value of the battery and occur at the redox potentials of the active materials. Such plateaus are due to Li-ions intercalation and de-intercalation of lithium ions inside the active materials of the electrodes.

At higher C-rates, i.e., at 0.5C and 1C, the time during a charge or discharge is not sufficient to completely intercalate and de-intercalate the lithium ions, resulting in a charge and discharge states mostly due to polarization of the battery, with only a partial lithiation and delithiation of active materials.

These results can be depicted more clearly in Figure 2, where the potential is plotted against the relative capacity (Equation 3).

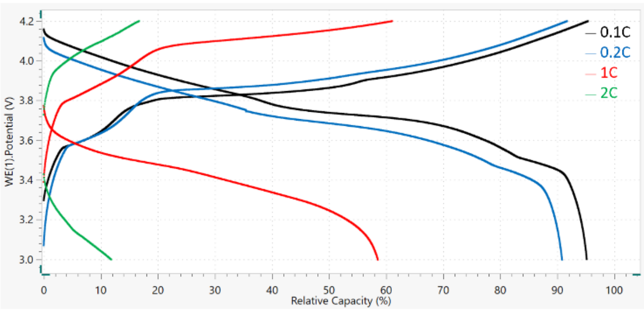

Figure 2 – Potential vs. relative capacity plot, at different C-rates

Here, it can be noticed that at 0.1C, the battery stores almost 100% of the nominal capacity, 2.6 Ah. At 0.5C, only 90% of the nominal capacity is reached. At higher C-rates, only a small percentage of the nominal capacity is stored. At 1C, the relative capacity is approx. 60% of the nominal value, while at 2C the relative capacity value is only the 12% of the nominal value.

Conclusions

This application note illustrates the possibility to perform charge/discharge tests on a Li-ion battery with the Autolab PGSTAT302N in combination with the BOOSTER20A. With the NOVA software, it was possible not only to plot the potential behavior vs. time, but also to calculate the battery capacity, to have a clearer picture of the state of the battery during different cycling procedures.

Date

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For more information

Additional information about this application note and the associated NOVA software procedure is available from your local **Metrohm distributor**. Additional instrument specification information can be found at **www.metrohm.com/electrochemistry**