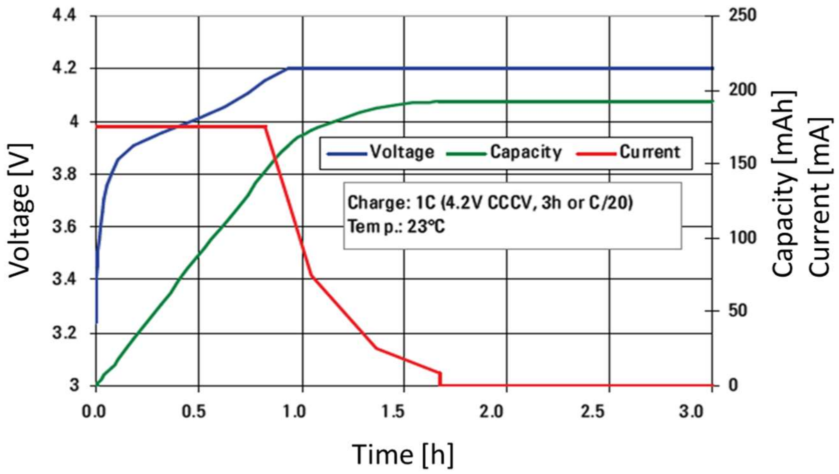
Rechargeable lithium-ion polymer batteries guidelines

Charging scheme

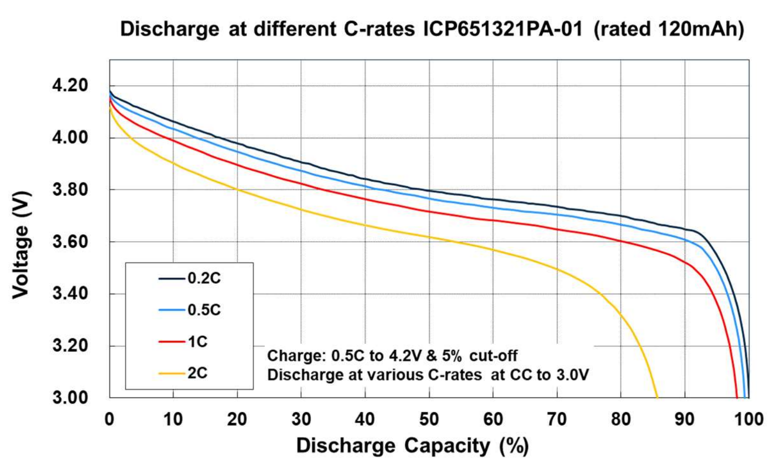
Lithium polymer batteries should be recharged at a constant current of 0.5 C (standard charge) up to a constant current of 1.0 C (fast charge), until a voltage of 4.2 V, followed by a constant voltage step at 4.2 V until the current falls to 0.05 C. The temperature range for a standard charge is between 0 °C and 45 °C, but 23 °C is recommended for optimal longevity of the cell. The characteristic of the battery during charge is shown below:



However, normal charging is not allowed if the battery is over-discharged. Over-discharging triggers the protection circuitry module (PCM) into protection mode and opens the switch to isolate the battery from the outside world. Therefore, it is important to measure the voltage of the battery before recharge. If no voltage can be measured, or if the voltage is below 3.0 V, do not charge the battery. For more details please see the section "Calendar Life" below.

Discharging scheme

Depending on the design, lithium-ion batteries can be discharged up to 2 C, but discharging at 0.5 C is recommended. Regardless of the discharge rate or the maximum charging voltage, discharge should be stopped at 3.0 V.
For applications where the battery will be discharged at high currents, the battery will heat up. If the temperature increases too much, above 60°C, the battery will likely to be damaged. Therefore, it is recommended, for these applications, that a PCM with temperature measurement capabilities is selected. The device should monitor the temperature of the battery to make sure that it is not overheated.
The discharge characteristics is shown in the chart below:



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Life of the battery

Cycle life and testing

Typical cycle tests of lithium batteries are done using C/2 currents for both charge and discharge at room temperature, with a rest period inserted between the charge and discharge process. The standard acceptance criterion is that a battery must provide >80% of the original capacity after 300 cycles.

Note: RENATA sells rechargeable lithium polymer batteries with cobalt oxide, and in some cases other oxides, as the main cathode active material. There are other type of lithium batteries that can be cycled for thousands of cycles. However, these batteries typically have lower operating voltage, thus lower energy density, than RENATA products.

The cycle life of lithium batteries is affected by these factors:

- Charge and discharge conditions
  Lithium batteries will have longer cycle life when the current is lower. Also, the life will be longer if the extent of the cycles are narrower. In other words, when the battery is not charged or discharged fully it can be operated for more cycles.
- Temperature: The best temperature range to operate the battery is between 0 and 45 °C.

Calendar life (Self-Discharge)

Lithium battery loses its capacity during storage, caused by the electrolyte decomposition, lithium ion re-insertion into the cathode, or contamination from impurities.

The self-discharge rate depends on several factors:

- Temperature: at higher temperature the reaction rate is higher, and the battery will lose its capacity faster.
- PCM: The PCM is used to protect the battery from going into dangerous territories if being charged or discharged inappropriately. The PCM monitors the voltage and current (and optionally the temperature) of a battery continuously. For this reason, it consumes current continuously, typically between 2 to 5 uA. This is higher than the self-discharge rate of the battery by itself. Therefore, if a battery is installed with a PCM, it is very important to recharge the battery within 6 months of receiving the battery. For smaller batteries with capacities less than 60mAh, this recharge period shall even be reduced.
- Charge level: A lithium battery by itself, i,e, without a PCM, has the lowest self-discharge rate at about 30% state of charge (SOC). At this state the open circuit voltage (OCV) is between 3.7 and 3.8 V and the self-discharge current is about 1 uA or less. On the other hand, when the SOC is higher, at 100%, or fully charged state, the discharge current can be about 4 uA. In general, the self-discharge rate for a battery alone is lower than the current consumption of the PCM. Therefore, when calculating how long the battery can be stored, the current consumption of the PCM must be considered.

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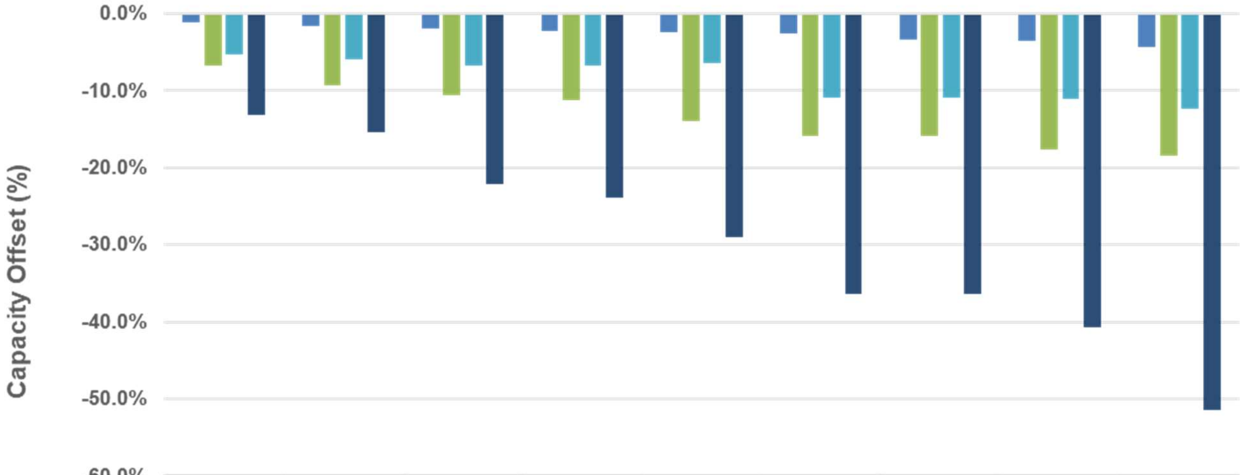
Due to self-discharge, the energy content of a battery decreases continuously, and it is important to make sure that the voltage does not fall below 3.0 V. If the battery is allowed to discharge past 2.5 V (or whatever the over-discharge protection voltage is), it would trigger the PCM to open the safety switch and isolate the battery from the outside. When this happens, please do not recharge and stop using the battery.

The effect of self-discharge can be seen in the chart below:



	1 Month	2 Months	3 Months	4 Months	5 Months	6 Months	9 Months	12 Months	18 Months
25C - 50% SOC	-1.2%	-1.6%	-1.9%	-2.2%	-2.4%	-2.5%	-3.4%	-3.5%	-4.4%
25C - 100% SOC	-6.7%	-9.3%	-10.6%	-11.3%	-14.0%	-15.8%	-15.8%	-17.6%	-18.4%
40C - 50% SOC	-5.3%	-5.9%	-6.7%	-6.7%	-6.4%	-10.9%	-10.9%	-11.1%	-12.4%
40C - 100% SOC	-13.2%	-15.4%	-22.2%	-23.9%	-29.0%	-36.4%	-36.4%	-40.7%	-51.5%

Housing considerations

Lithium-ion batteries can be charged and discharged repeatedly for hundreds, if not thousands of cycles. It is important to recognize that the thickness of the battery will increase during charge, and reduce during discharge. Furthermore, as the battery ages, it gradually grows thicker compared to the fresh state. In general, the thickness increases about 3% – 5% between charge and discharge. Throughout its life, the thickness may increase up to 7% after 300 cycles.

Because the thickness is not a constant, it should be noted that, when designing the battery chamber in the application, extra room should be provided to avoid any compression on the battery through its life. Furthermore, there must not be any sharp points pressing on the surface of the battery. These sharp points may create heavy pressure on the battery when it swells and damage the packaging material, leading to unsafe conditions such as leakage of the electrolyte, short-circuiting, or even fire.

Uneven pressure on the battery surface, however small it is, will disturb the uniformity of reactions and reduce the service life of the battery.

Rechargeable Lithium-ion polymer batteries guidelines

Internal resistance

Lithium batteries generate energy by the electrochemical reactions of their active materials. The process involves electron movement in conductive materials, ionic transfer through a liquid medium, and reactions of the two active materials.
Therefore, the internal resistance is not a constant, but changes as the internal state of the battery changes.

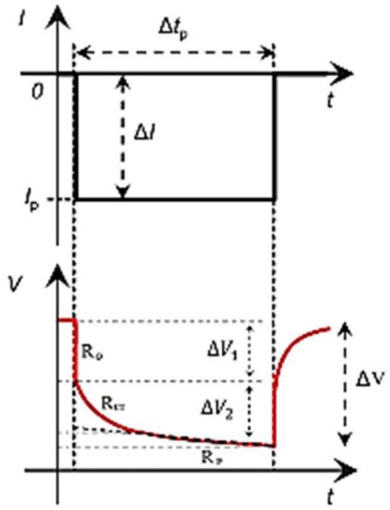
Measurement methods

There are two general methods to measure the internal resistance of a battery: AC method and DC method.

- AC Method: A small AC current is applied to the battery and the voltage of the battery is measured. The resistance is calculated by dividing the voltage change by the current change. Because the current is not a constant, the rate it changes, or the frequency of the AC signal, also affects the measurement results. Scientists use this method to analyze different components of the internal resistance of the battery. For example, the resistances generated by the current collectors, by the movement of lithium ions, and that for the electrochemical reactions.

  Because the input current is small and include both positive and negative values (discharge and charge of the battery), it does not change the SOC of the battery during the measurement. Furthermore, the measurement is quick if the frequency is fixed at a high value, such as 1 kHz. Therefore, it is popular for battery manufacturers to use this method to report the internal resistance of a battery.

- DC Method: The battery is discharged by a DC current for a short period of time and the OCV and the CCV is measured. The resistance is calculated from the differences in voltage and current, before and during the current pulse.
  The DC method is more practical for the user of the battery because the measurement can be done using the same condition in the application. The measured resistance represents the actual behavior of the battery under the application. It should be noted that, because the CCV of the battery decreases during the measurement, changing the measurement time will change the value of the resistance.



$$R = \frac{\Delta V}{\Delta I} = \frac{(OCV - CCV)}{Ip}$$

Cited from “Nature” – Scientific Reports, (2018) 8:21

Rechargeable Lithium-ion polymer batteries guidelines

Functions of safety circuit

Rechargeable lithium-ion polymer batteries usually come with an integrated safety circuit, or protective circuitry module (PCM). This safety circuit provide the following functions:

- Operating input voltage: 1.5 – 12V
- Current consumption (during operation): 2 – 5 µA
- Current consumption (when powered down): 0.05 – 0.1µA
- Over-charge threshold voltage: 3.5 to 4.6 V selectable, typical 4.3 V
- Over-charge release voltage: 4.0 to 4.3 V selectable, typical 4.225 V
- Over-discharge voltage protection: 2.0 to 3.4 V selectable, typical 2.5 V
- Over-discharge release voltage: 2.3 to 3.0 V selectable, typical 2.9 V
- Temperature measurement: typically done by NTC
- Sleep mode (optional)
- 0 V battery charge function

For more detailed information, please refer to the product specification sheet of the battery.

Nomenclature

- OCV – The static voltage when the circuit is open and the battery is not being charged or discharged.
- CCV – The voltage when the circuit is closed and the battery is being discharged or charged.
- SoC – State of Charge, a percentage value representing the amount of capacity left in the battery. 100% SoC stands for fully charged state, and 0% fully discharged state.
- R_i – Internal resistance.
- PCM – Protection Circuitry Module