How to prolong lithium-based batteries *(BU34)*

Battery research is focusing heavily on lithium chemistries, so much so that one could presume that all portable devices will be powered with lithium-ion batteries in the future. In many ways, lithium-ion is superior to nickel and lead-based chemistries and the applications for lithium-ion batteries are growing as a result.

Lithium-ion has not yet fully matured and is being improved continuously. New metal and chemical combinations are being tried every six months to increase energy density and prolong service life. The improvements in longevity after each change will not be known for a few years.

A lithium-ion battery provides 300-500 discharge/charge cycles. The battery prefers a partial rather than a full discharge. Frequent full discharges should be avoided when possible. Instead, charge the battery more often or use a larger battery. There is no concern of memory when applying unscheduled charges.

Although lithium-ion is memory-free in terms of performance deterioration, batteries with fuel gauges exhibit what engineers refer to as "digital memory". Here is the reason: Short discharges with subsequent recharges do not provide the periodic calibration needed to synchronize the fuel gauge with the battery's state-of-charge. A deliberate full discharge and recharge every 30 charges corrects this problem. Letting the battery run down to the cut-off point in the equipment will do this. If ignored, the fuel gauge will become increasingly less accurate. (Read more in 'Choosing the right battery for portable computing', Part Two.)

Aging of lithium-ion is an issue that is often ignored. A lithium-ion battery in use typically lasts between 2-3 years. The capacity loss manifests itself in increased internal resistance caused by oxidation. Eventually, the cell resistance reaches a point where the pack can no longer deliver the stored energy although the battery may still have ample charge. For this reason, an aged battery can be kept longer in applications that draw low current as opposed to a function that demands heavy loads. Increasing internal resistance with cycle life and age is typical for cobalt-based lithium-ion, a system that is used for cell phones, cameras and laptops because of high energy density. The lower energy dense manganese-based lithium-ion, also known as spinel, maintains the internal resistance through its life but loses capacity due to chemical decompositions. Spinel is primarily used for power tools.

The speed by which lithium-ion ages is governed by temperature and state-of-charge. Figure 1 illustrates the capacity loss as a function of these two parameters.

Temperature	40% charge level (recommended storage charge level)	100% charge level (typical user charge level)
0°C	98% after 1 year	94% after 1 year
25°C	96% after 1 year	80% after 1 year
40°C	85% after 1 year	65% after 1 year
60°C	75% after 1 year	60% after 3 monlhs

Figure 1: Permanent capacity loss of lithium-ion as a function of temperature and charge level.
High charge levels and elevated temperatures hasten permanent capacity loss. Improvements in chemistry have increased the storage performance of lithium-ion batteries.

The mentioning of limited service life on lithium-ion has caused concern in the battery industry and I will need to add some clarifications. Let me explain:

If someone asks how long we humans live, we would soon find out that the longevity varies according to life style and living conditions that exist in different countries. Similar conditions exist with the batteries, lithium-ion in particular. Since BatteryUniversity bases its information on the feedback from users as opposed to scientific information derived from a research lab, longevity results may differ from manufacturer' specifications. Let's briefly look at the various living conditions of the lithium-ion battery.

The worst condition is keeping a fully charged battery at elevated temperatures, which is the case with running laptop batteries. If used on main power, the battery inside a laptop will only last for 12-18 months. I must hasten to explain that the pack does not die suddenly but begins with reduced run-times.

The voltage level to which the cells are charged also plays an important role to longevity. For safety reasons, most lithium-ion cannot exceed 4.20 volts per cell. While a higher voltage boosts capacity, the disadvantage is lower cycle life. Figure 2 shows the cycle life as a function of charge voltage.

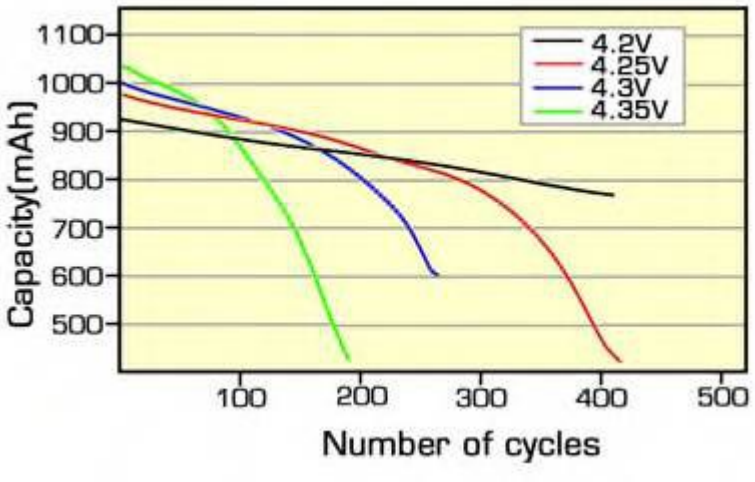

Figure 2: Effects on cycle life at different float charge levels *(Choi et al., 2002)*
Higher charge voltages boost capacity but lower cycle life.

There are no remedies to restore lithium-ion once worn out. A momentary improvement in performance is noticeable when heating up the battery. This lowers the internal resistance momentarily but the condition reverts back to its former state when the temperature drops. Cold temperature will increase the internal resistance.

If possible, store the battery in a cool place at about a 40% state-of-charge. Some reserve charge is needed to keep the battery and its protection circuit operational during prolonged storage. Avoid keeping the battery at full charge and high temperature. This is the case when placing a cell phone or spare battery in a hot car. Running a laptop computer on the mains has a similar temperature problem. While the battery is kept fully charged, the inside temperature during operation rises to 45°C (113°F).

Removing the battery from the laptop when running on fixed power protects the battery from heat. With the concern of the battery overheating and causing fire, a spokesperson for the U.S. Consumer Product Safety Commission advises to eject the battery of affected laptops and to run the machines on a power cord. It should be noted that on a power outage, unsaved works will be lost.

The question is often asked, should the laptop be disconnected from the main when not in use? Under normal circumstances, it should not matter with lithium-ion. Once the battery is fully charged, no further charge is applied. However, there is always the concern is malfunction of the AC adapter, the laptop or the battery.

A large number of lithium-ion batteries for cell phones are being discarded under the warranty return policy. Some failed batteries are sent to service centers or the manufacturer, where they are refurbished. Studies show that 80%-90% of the returned batteries can be repaired and returned to service.

Some lithium-ion batteries fail due to excessive low discharge. If discharged below 2.5 volts per cell, the internal safety circuit opens and the battery appears dead. A charge with the original charger is no longer possible. Some battery analyzers (Cadex) feature a boost function that reactivates the protection circuit of a failed battery and enables a recharge. However, if the cell voltage has fallen below 1.5V/cell and has remained in that state for a few months, a recharge should be avoided because of safety concerns. To prevent failure, never store the battery fully discharged. Apply some charge before storage, and then charge fully before use.

All personal computers (and some other electronic devices) contain a battery for memory back up. This battery is commonly a small non-rechargeable lithium cell, which provides a small current when the device is turned off. The PC uses the battery to retain certain information when the power is off. These are the BIOS settings, current date and time, as well as resource assignment for Plug and Play systems. Storage does shorten the service life of the backup battery to a few years. Some say 1-2 years. By keeping the computer connected to the main, albeit turned off, a battery on the PC motherboards should be good for 5-7 years. A PC should give the advanced warning when battery gets low. A dead back-up battery will wipe out the volatile memory and erase certain settings. After battery is replaced, the PC should again be operational.

Longevity of high-power lithium-ion

Generally speaking, batteries live longer if treated in a gentle manner. High charge voltages, excessive charge rate and extreme load conditions will have a negative effect and shorten the battery life. This also applies to high current rate lithium-ion batteries.

Not only is it better to charge lithium-ion battery at a slower charge rate, high discharge rates also contribute the extra wear and tear. Figure 3 shows the cycle life as a function of charge and discharge rates. Observe the good laboratory performance if the battery is charged and discharged at 1C. (A 0.5C charge and discharge would further improve this rating.)

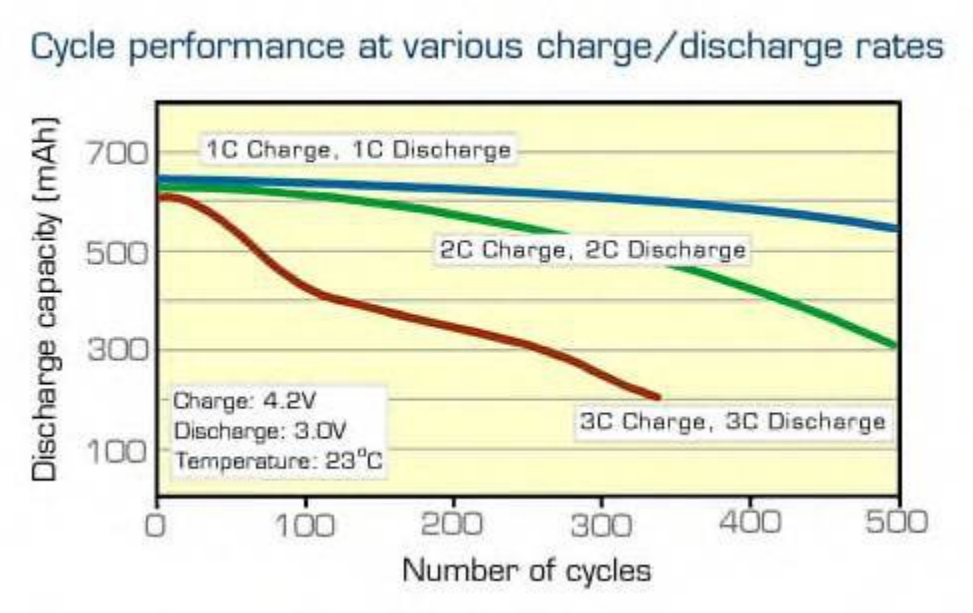

Figure 3: Longevity of lithium-ion as a function of charge and discharge rates.

A moderate charge and discharge puts less stress on the battery, resulting in a longer cycle life.

Battery experts agree that the life of lithium-ion depends on other factors than charge and discharge rates. Even though incremental improvements can be achieved with careful use of the battery, our environment and the services required are not always conducive to achieve optimal battery life. The longevity of a battery is often a direct result of the environmental stresses applied.

Simple Guidelines

- Avoid frequent full discharges because this puts additional strain on the battery. Several partial discharges with frequent recharges are better for lithium-ion than one deep one. Recharging a partially charged lithium-ion does not cause harm because there is no memory. (In this respect, lithium-ion differs from nickel-based batteries.) Short battery life in a laptop is mainly cause by heat rather than charge / discharge patterns.

- Batteries with fuel gauge (laptops) should be calibrated by applying a deliberate full discharge once every 30 charges. Running the pack down in the equipment does this. If ignored, the fuel gauge will become increasingly less accurate and in some cases cut off the device prematurely.

- Keep the lithium-ion battery cool. Avoid a hot car. For prolonged storage, keep the battery at a 40% charge level.

- Consider removing the battery from a laptop when running on fixed power. (Some laptop manufacturers are concerned about dust and moisture accumulating inside the battery casing.)

- Avoid purchasing spare lithium-ion batteries for later use. Observe manufacturing dates. Do not buy old stock, even if sold at clearance prices.

- If you have a spare lithium-ion battery, use one to the fullest and keep the other cool by placing it in the refrigerator. Do not freeze the battery. For best results, store the battery at 40% state-of-charge.