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Charging lithium-ion batteries *(BU12)*

There is only one way to charge lithium-based batteries. The so-called 'miracle chargers', which claim to restore and prolong batteries, do not exist for lithium chemistries. Neither does super-fast charging apply. Manufacturers of lithium-ion cells have very strict guidelines in charge procedures and the pack should be charged as per the manufacturers "typical" charge technique.

Lithium-ion is a very clean system and does not need priming as nickel-based batteries do. The 1st charge is no different to the 5th or the 50th charge. Stickers instructing to charge the battery for 8 hours or more for the first time may be a leftover from the nickel battery days.

Most cells are charged to 4.20 volts with a tolerance of +/?0.05V/cell. Charging only to 4.10V reduced the capacity by 10% but provides a longer service life. Newer cell are capable of delivering a good cycle count with a charge to 4.20 volts per cell. Figure 1 shows the voltage and current signature as the lithium-ion cell passes through the charge stages.

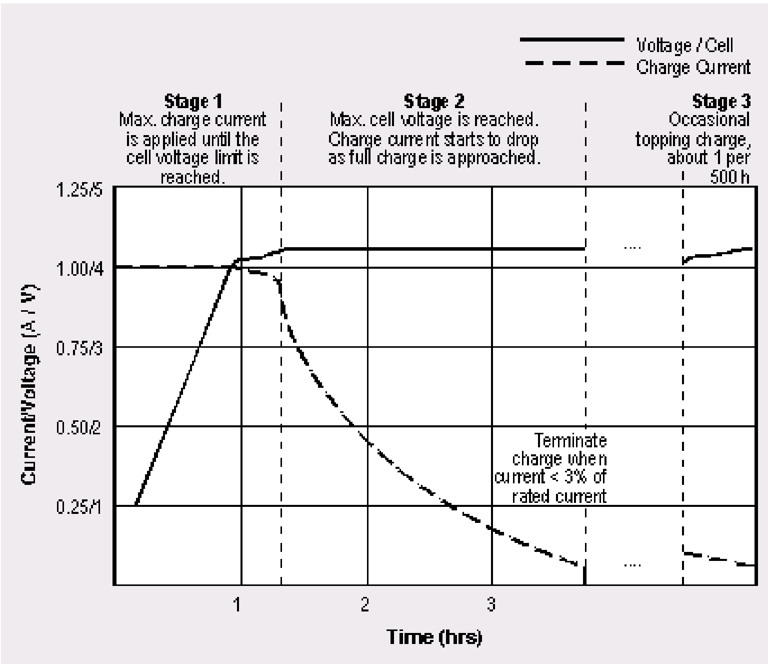

Figure 1: Charge stages of a lithium-ion battery. Increasing the charge current on a lithium?ion charger does not shorten the charge time by much. Although the voltage peak is reached quicker with higher current, the topping charge will take longer.

The charge time of most chargers is about 3 hours. Smaller batteries used for cell phones can be charged at 1C; the larger 18650 cell used for laptops should be charged at 0.8C or less. The charge efficiency is 99.9% and the battery remains cool during charge. Full charge is attained after the voltage threshold has been reached and the current has dropped to 3% of the rated current or has leveled off.

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Some chargers claim to fast-charge a lithium-ion battery in one hour or less. Such a charger eliminates stage 2 and goes directly to 'ready' once the voltage threshold is reached at the end of stage 1. The charge level at this point is about 70%. The topping charge typically takes twice as long as the initial charge.

No trickle charge is applied because lithium-ion is unable to absorb overcharge. A continuous trickle charge above 4.05V/cell would causes plating of metallic lithium that could lead to instabilities and compromise safety. Instead, a brief topping charge is provided to compensate for the small self-discharge the battery and its protective circuit consume. Depending on the battery, a topping charge may be repeated once every 20 days. Typically, the charge kicks in when the open terminal voltage drops to 4.05V/cell and turns off at a high 4.20V/cell.

What happens if a battery is inadvertently overcharged? lithium-ion is designed to operate safely within their normal operating voltage but become unstable if charged to higher voltages. When charging above 4.30V, the cell causes plating of metallic lithium on the anode; the cathode material becomes an oxidizing agent, loses stability and releases oxygen. Overcharging causes the cell to heat up. If left unattended, the cell could vent with flame.

Much attention is focused to avoid over-charging and over-discharging. Commercial lithium ion packs contain a protection circuits that limit the charge voltage to 4.30V/cell, 0.10 volts higher than the voltage threshold of the charger. Temperature sensing disconnects the charge if the cell temperature approaches 90°C (194°F), and a mechanical pressure switch on many cells permanently interrupt the current path if a safe pressure threshold is exceeded. Exceptions are made on some spinel (manganese) packs containing one or two small cells.

Extreme low voltage must also be prevented. The safety circuit is designed to cut off the current path if the battery is inadvertently discharged below 2.50V/cell. At this voltage, most circuits render the battery unserviceable and a recharge on a regular charger is not possible.

There are several safeguards to prevent excessive discharge. The equipment protects the battery by cutting off when the cell reaches 2.7 to 3.0V/cell. Battery manufacturers ship the batteries with a 40% charge to allow some self-discharge during storage. Advanced batteries contain a wake-up feature in which the protection circuit only starts to draw current after the battery has been activated with a brief charge. This allows prolonged storage.

In spite of these preventive measures, over-discharge does occur. Advanced battery analyzers (Cadex C7000 series) feature a 'boost' function that provides a gentle charge current to activate the safety circuit and re-energize the cells if discharged too deeply. A full charge and analysis follows.

If the cells have dwelled at 1.5V/cell and lower for a few days, however, a recharge should be avoided. Copper shunts may have formed inside the cells, leading a partial or total electrical short. The cell becomes unstable. Charging such a battery would cause excessive heat and safety could not be assured.

Battery experts agree that charging lithium-ion batteries is simpler and more straightforward than the nickel-based cousins. Besides meeting the tight voltage tolerances, the charge circuit can be designed with fewer variables to consider. Full-charge detection by applying voltage limits and observing the current saturations on full charge is simpler than analyzing many complex signatures, which nickel-metal-hydride produces. Charge currents are less critical and can vary. A low current still permits proper full charge detection. The battery simply takes longer to charge. The absence of topping and trickle charge also help in simplifying the charger. Best of all, there is no memory but aging issues are the drawback.

The charge process of a lithium-ion-polymer is similar to lithium-ion. These batteries use a gelled electrolyte to improve conductivity. In most cases, lithium-ion and lithium-ion-polymer share the same charger.

Preparing new lithium-ion for use

Unlike nickel and lead-based batteries, a new lithium-ion pack does not need cycling through charging and discharging. Priming will make little difference because the maximum capacity of lithium-ion is available right from the beginning. Neither does a full discharge improve the capacity of a faded pack. However, a full discharge/charge will reset the digital circuit of a 'smart' battery to improve the state-of-charge estimation

State-of-charge reading based on terminal voltage

The open circuit voltage can be used to estimate the battery state-of-charge of lithium, alkaline and lead-based batteries. Unfortunately, this method cannot be used for nickel-based packs.

On a lithium-ion cell, 3.8V/cell indicates a state-of-charge of about 50%. It must be noted that utilizing voltage as a fuel gauge function is inaccurate because cells made by different manufacturers produce a slightly different voltage profile. This is due to the electrochemistry of the electrodes and electrolyte. Temperature also affects the voltage. The higher the temperature, the lower the voltage will be.

Hints to long battery life

- Limit the time at which the battery stays at 4.20/cell. Prolonged high voltage promotes corrosion, especially at elevated temperatures. (Spinel is less sensitive to high voltage than cobalt-based systems).
- 3.92V/cell is the best upper voltage threshold for cobalt-based lithium-ion. Charging batteries to this voltage level has been shown to double cycle life. Lithium-ion systems for defense applications make use of the lower voltage threshold. The negative is reduced capacity.
- The charge current of Li-ion should be moderate (0.5C for cobalt-based lithium-ion). The lower charge current reduces the time in which the cell resides at 4.20V. It should be noted that a 0.5C charge only adds marginally to the charge time over 1C because the topping charge will be shorter. A high current charge tends to push the voltage up and forces it into the voltage limit prematurely.

Note: In respect to fast-charging and topping charge, the charge behavior of lithium-ion is similar to lead acid. Here, the voltage threshold of 2.35V/cell during regular charge needs to be lowered to 2.27V/cell when the VRLA is on standby. Keeping the voltage at the high threshold would contribute to corrosion. A similar effect occurs with lithium-ion.

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About the Author

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