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Proper Care Extends Li-Ion Battery Life

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Li-ion battery lifetime depends on battery chemistry, depth of discharge, battery temperature and battery capacity termination level.

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Rechargeable Li-ion and Li-ion-polymer batteries are ubiquitous, and the reason is well justified. Compared to other rechargeable batteries, Li-ion batteries have a higher energy density, higher cell voltage, low self-discharge and very good cycle life, and are environmentally friendly as well as simple to charge and maintain. Also, because of their relatively high voltage (2.9 V to 4.2 V), many portable products can operate from a single cell, thereby simplifying an overall product design.

Depending on the application, there can be an argument as to what is the most important battery characteristic. Too much emphasis has been put on increasing Li-ion battery capacity to provide the longest product run-time in the smallest physical size. There are times when a longer battery life, an increased number of charge cycles or a safer battery is more important than battery capacity.

Before covering the battery charger's role in extending battery life, let's review the Li-ion battery's characteristics. Lithium is one of the lightest metals, is one of the most reactive and has the highest electrochemical potential, making it the ideal material for a battery. A Li-ion battery contains no lithium in a metallic state, but instead uses lithium ions that shuttle back and forth between the cathode and anode of the battery during charge and discharge, respectively.

Although there are many different types of Li-ion batteries, the most popular chemistr now in production can be narrowed down to three, all relating to their cathode materia Lithium-cobalt chemistry has become more popular in laptops, cameras and cell phon mainly because of its greater charge capacity. Other chemistries depend on the need fo high discharge currents or improved safety, or where cost is the driving factor. Also, ne hybrid Li-ion batteries are in development, based on a combination of cathode materia incorporating the best features of each chemistry.

Unlike other battery chemistries, Li-ion battery technology is not yet mature. Research is ongoing with new types of batteries that have even higher capacities, longer life and improved performance than present-day batteries. The **table** highlights some important characteristics of each battery type.

Li-Ion Polymer Batteries

With characteristics similar to a standard Li-ion battery, you can charge and discharge a Li-ion polymer battery in a similar manner. The main difference between the two is that a solid ion conductive polymer replaces the liquid electrolyte used in a standard Li-ion battery, although most polymer batteries also contain an electrolyte paste to lower the internal cell resistance. Eliminating the liquid electrolyte allows the polymer battery to be housed in a foil pouch rather than the heavy metal case required for standard Li-ion batteries. Li-ion polymer batteries are gaining popularity because of their cost-effective manufacturing flexibility, which allows them to be fabricated in many different shapes, including very thin.

All rechargeable batteries wear out, and Li-ion cells are no exception. Battery manufacturers usually consider the end of life for a battery to be when the battery capacity drops to 80% of the rated capacity. However, batteries can still deliver usable power below 80% charge capacity, although they will produce shorter run-times.

The number of charge/discharge cycles is commonly used when referring to battery life, but cycle life and battery life (or service life) can be different. Charging and discharging will eventually reduce the battery's active material and cause other chemistry changes, resulting in increased internal resistance and permanent capacity loss. But permanent capacity loss also occurs even when the battery is not in use. Permanent capacity loss is greatest at elevated temperatures with the battery voltage maintained at 4.2 V (fully charged).

For maximum storage life, batteries should be stored with a 40% charge (3.6 V) at 40°F (refrigerator). Perhaps one of the worst locations for a Li-ion battery is in a laptop computer when used daily on a desktop with the charger connected. Laptops typically run warm or even hot, raising the battery temperature, and the charger is maintaining the battery near 100% charge. Both of these conditions shorten battery life, which could be as short as six months to a year. If possible, the user should be instructed to remove the battery and use the ac adapter for powering the laptop when used as a desktop computer. A properly cared for laptop battery can have a service life of two to four years or more.

There are two types of battery capacity losses: recoverable loss and permanent loss. After a full charge, a Li-ion battery will typically lose about 5% capacity in the first 24 hours, then approximately 3% per month because of self-discharge and an additional 3% per month if the battery pack has pack-protection circuitry. These self-discharge losses occ when the battery remains around 20°C, but will increase considerably with higher temperature and also as the battery ages. This capacity loss can be recovered by recharging the battery.

Permanent capacity loss, as the name implies, refers to permanent loss that is not recoverable by charging. Permanent capacity loss is mainly due to the number of full charge/discharge cycles, battery voltage and temperature. The more time the battery remains at 4.2 V or 100% charge level (or 3.6 V for Li-ion phosphate), the faster the capacity loss occurs. This is true whether the battery is being charged or just in a fully charged condition with the voltage near 4.2 V. Always maintaining a Li-ion battery in a fully charged condition will shorten its lifetime. The chemical changes that shorten the battery lifetime begin when it is manufactured, and these changes are accelerated by high float voltage and high temperature. Permanent capacity loss is unavoidable, but it can be held to a minimum by observing good battery practices when charging, discharging or simply storing the battery. Using partial-discharge cycles can greatly increase cycle life, and charging to less than 100% capacity can increase battery life even further.

The letter “C” is a battery term used to indicate the battery manufacturers stated batter discharge capacity, measured in milliamp-hours. For example, a 2000-mAhr rated battery can supply a 2000-mA load for one hour before the cell voltage drops to its zer capacity voltage. In the same example, charging the battery at a C/2 rate would mean charging at 1000 mA (1 A). C is important in battery chargers because it determines the correct charge current required and the length of time needed to fully charge a battery. When discussing minimum charge-current termination methods, a 2000-mAhr battery using C/10 termination would end the charge cycle when the charge current drops below 200 mA.

Boosting Battery Life

Usually, a combination of several factors increases or decreased battery life. For increased cycle life

- **Use partial-discharge cycles**

  Using only 20% or 30% of the battery capacity before recharging will extend cycle life considerably. As a general rule, 5 to 10 shallow discharge cycles are equal to one full discharge cycle. Although partial-discharge cycles can number in the thousands, keeping the battery in a fully charged state also shortens battery life. Full discharge

- **Avoid charging to 100% capacity**

  Selecting a lower float voltage can do this. Reducing the float voltage will increase cycle life and service life at the expense of reduced battery capacity. A 100-mV to 300-mV drop in float voltage can increase cycle life from two to five times or more. Li-ion cobalt chemistries are more sensitive to a higher float voltage than other chemistries. Li-ion phosphate cells typically have a lower float voltage than the more common Li-ion batteries.

- **Select the correct charge termination method**

  Selecting a charger that uses minimum charge-current termination (C/10 or C/x) can also extend battery life by not charging to 100% capacity. For example, ending a charge cycle when the current drops to C/5 is similar to reducing the float voltage to 4.1 V. In both instances, the battery is only charged to approximately 85% of capacity, which is an important factor in battery life.
- **Limit the battery temperature**

  Limiting battery-temperature extremes extends battery life, especially prohibiting charging below 0°C. Charging below 0°C promotes metal plating at the battery anode, which can develop into an internal short, producing heat and making the battery unstable and unsafe. Many battery chargers have provisions for measuring battery temperature to assure charging does not occur at temperature extremes.
- **Avoid high charge and discharge currents**

  High charge and discharge currents reduce cycle life. Some chemistries are more suited for higher currents such as Li-ion manganese and Li-ion phosphate. High currents place excessive stress on the battery.

- **Avoid very deep discharges (below 2 V or 2.5 V)**

  Very deep discharges will quickly, permanently damage a Li-ion battery. Internal metal plating can occur causing a short circuit, making the battery unusable and unsafe. Most Li-ion batteries have protection circuitry within their battery packs that open the battery connection if the battery voltage is less than 2.5 V or exceeds 4.3 V, or if the battery current exceeds a predefined threshold level when charging or discharging.

Charging Methods

The recommended way to charge a Li-ion battery is to provide a ±1% voltage-limited constant current to the battery until it becomes fully charged, and then stop. Methods used to determine when the battery is fully charged include timing the total charge time, monitoring the charge current or a combination of the two.

The first method applies a voltage-limited constant current, ranging from C/2 to 1C for 2.5 to 3 hours, thus bringing the battery up to 100% charge. You also can use a lower-charge current, but it will require more time. The second method is similar, but it requires monitoring the charge current. As the battery charges, the voltage rises, exactl as in the first method. When it reaches the programmed voltage limit, which is also called the float voltage, the charge current begins to drop. When it first begins to drop, the battery is about 50% to 60% charged. The float voltage continues to be applied unti the charge current drops to a sufficiently low level (C/10 to C/20), at which time the battery is approximately 92% to 99% charged and the charge cycle ends. Presently, there is no safe method for fast charging (less than one hour) a standard Li-ion battery to 100% capacity.

Applying a continuous voltage to a battery after it is fully charged is not recommended, as it will accelerate permanent capacity loss and may cause internal lithium metal plating. This plating can develop into an internal short circuit, resulting in overheating and making the battery thermally unstable. The length of time required is months.

Some Li-ion battery chargers employ a thermistor to monitor battery temperature. Such a monitor's main purpose is to prevent charging if the battery temperature is outside the recommended window of 0°C to 40°C. Unlike NiCd or NiMH batteries, Li-ion cell temperature rises very little when charging. **Fig. 1** shows a typical Li-ion charge profile charge current, battery voltage and battery capacity versus time.

The main determining factor for float voltage is the electrochemical potential of the active materials used in the battery's cathode, which for lithium is approximately 4 V. The addition of other compounds will raise or lower this voltage. The second factor is a tradeoff between cell capacity, cycle life, battery life and safety. The curves in **Fig. 2** show the relationship between cell capacity and cycle life.

Most Li-ion manufacturers have set a 4.2-V float voltage as the best balance between capacity and cycle life. Using 4.2 V as the constant voltage limit (float voltage), a battery can typically deliver about 500 charge/discharge cycles before the battery capacity drops to 80%. One charge cycle consists of a full charge to a full discharge. Multiple shallow discharges add up to one full-charge cycle.

Although charging to a capacity less than 100% using either a reduced float voltage or minimum charge-current termination will result in initial reduced battery capacity, as the number of cycles increases beyond 500, the battery capacity of the lower float voltage can exceed the higher float voltage. **Fig. 3** illustrates how the recommended float voltage compares with a reduced float voltage with regard to capacity and the number of charge cycles.

Because of the different Li-ion battery chemistries and other conditions that can affect battery life, the curves shown here are only estimates of the number of charge cycles and battery-capacity levels. Even a similar battery chemistry from different manufacturers can have dramatically different results due to minor differences in battery materials and construction methods.

Battery manufacturers specify a charge method and a float voltage the end user must use to meet the battery specifications for capacity, cycle life and safety. Charging above the recommended float voltage is not recommended. Many batteries include a battery-pac protection circuit, which temporarily opens the battery connection if the maximum battery voltage is exceeded. Once opened, connecting the battery pack to the charger w normally reset the pack protection. Battery packs often have a voltage printed on the battery, such as 3.6 V for a single-cell battery. This voltage is not the float voltage, but rather the average battery voltage when the battery is discharging.

Selecting a Battery Charger

Although a battery charger has no control over a battery's depth of discharge, discharge current and battery temperature, all of which affect battery life, many chargers have features that can increase battery life.

A battery charger's role in extending battery lifetime is mainly determined by the charger's float voltage and charge termination method. Many Li-ion chargers feature a ±1% (or lower) fixed float voltage of 4.2 V, but there are some offerings in 4.1 V and 4 V, as well as adjustable float voltages. Using battery chargers that feature a reduced float voltage can increase battery life when used to charge a 4.2-V Li-ion battery.

Battery chargers that do not offer lower float-voltage options are also capable of increasing battery life. Chargers that provide minimum charge-current termination methods (C/10 or C/x) can provide a longer battery life by selecting the correct charge-current level at which to end the charge cycle.

A C/10 termination level will only bring the battery up to about 92% capacity, but there will be an increase in cycle life. A C/5 termination level can double the cycle life although the battery charge capacity drops even further to approximately 85%. A number of charger ICs provide either a C/10 (10% current threshold) or C/x (adjustable current threshold) charge termination mode.

Run-Time Versus Battery Life

With present battery technology and without increasing battery size, you can't get both longer run-time and longer battery life. For maximum run-time, the charger must char the battery to 100% capacity. This places the battery voltage near the manufacturer's recommended float voltage, which is typically 4.2 V ±1%. Unfortunately, charging and maintaining the battery near these levels shortens battery life. One solution is to select lower float voltage, which prohibits the battery from achieving 100% charge, although this would require a higher-capacity battery to provide the same run-time. Of course, i many portable products, a larger-size battery may not be an option.

Also, using a C/10 or C/x minimum charge-current termination method can have the same effect on battery life as using a lower float voltage. Reducing the float voltage by 100 mV will reduce capacity by approximately 15%, but can double the cycle life. At the same time, terminating the charge cycle when the charge current has dropped to 20% (C/5) also reduces the capacity by 15% and achieves the same doubling of cycle life.

As expected, during discharge, the battery voltage will slowly drop. The discharge voltage profile versus time depends on a number of factors, including discharge current, battery temperature, battery age and the type of anode material used in the battery. Presently, most Li-ion batteries use either a petroleum-based coke material or graphite. The voltage profiles for each are shown in **Fig. 4**. The more widely used graphite material produces a flatter discharge voltage between 20% and 80% capacity, then drops quickly near the end, whereas the coke anode has a steeper voltage slope and a lower 2.5-V cutoff voltage. The approximate remaining battery capacity is easier to determine with a coke material by simply measuring the battery voltage.

For increased capacity, Li-ion cells are often connected in parallel. No special requirements are needed, other than the batteries should be the same chemistry, manufacturer and size. Series-connected cells require more care because cell-capacity matching and cell-balancing circuitry are often required to assure that each cell reaches the same float voltage and the same level of charge.

Connecting two cells (that have individual pack-protection circuitry) in series is not recommended because a mismatch in capacity could result in one battery reaching the overvoltage limit, thus opening the battery connection. Multi-cell battery packs should purchased assembled with the appropriate protection circuitry from the battery manufacturer.

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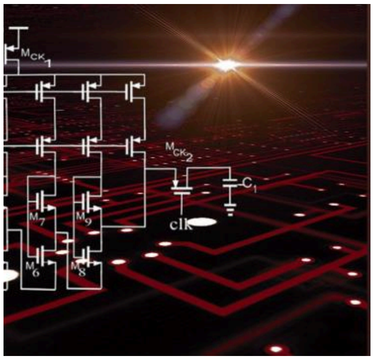

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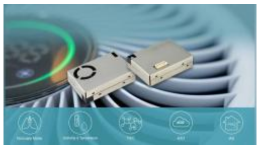

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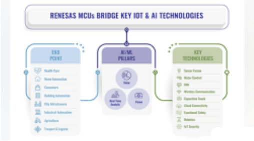

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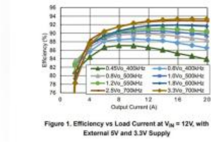

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