Lithium-ion battery technology: Getting the most from Smart Batteries

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Abstract

This paper tells HP notebook users how to get the most out of their lithium-ion rechargeable batteries in terms of run time and lifespan. Detailed in this document are important facts about Li-Ion batteries, information about HP Smart Battery Technology, and proper battery care practices.

Introduction

One of the most common questions asked by notebook computer users is "How long will the battery last?" The answer is not simple. Users inevitably discover that battery run time varies depending on how and where the notebook is used; however, most users don't understand why the battery sometimes does not last as long as predicted by the battery fuel gauge (Power Meter). The temperature of the battery, the applications running on the notebook, any attached devices, the brightness of the display, and the notebook power management settings all determine the run time and lifespan of the battery.

As mobile computing becomes more prevalent, users need to understand how environmental and usage factors impact battery run time and lifespan. This paper explains these factors, describes the Smart Battery Technology built into HP notebooks, and recommends practices to maximize battery life.

Lithium-ion batteries

A lithium-ion (Li-Ion) battery pack is made of multiple cells connected in series and in parallel based on the voltage and current requirements of the device. HP notebooks use 3 different types of Li-Ion battery cells: cylindrical, prismatic, and polymer. The cylindrical cells are approximately 18 mm (0.7 in) in diameter by 65 mm (2.6 in) in length, and they are commonly referred to as 18650 cells. These cells are frequently used in battery packs that are about 20 mm (0.8 in) thick. Prismatic cells have a slim, rectangular form factor; the most common types are 6-cell and 8-cell Li-Ion battery packs that are about 12 mm (0.5 in) thick, such as HP MultiBay and tablet PC batteries. Polymer cells are thinner than prismatic cells. They are often used in products such as the IPAQ Pocket PC and some ultra-portable PCs, which require battery packs less than 10 mm (0.4 in) thick.

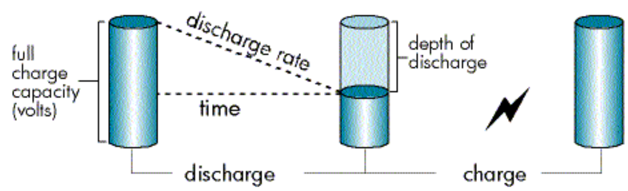
Li-Ion batteries are lighter, store more energy, and retain their charge longer than nickel-based batteries of comparable size. Also, Li-Ion batteries can be charged before they are fully discharged because they are not susceptible to the memory effect.

A typical 6-cell Li-Ion battery pack takes 2.5 to 3 hours to fully charge to its maximum voltage with the system in off mode. After the battery is fully charged, current flow to the battery is stopped by a built-in protective (charge control) circuit. The protective circuit prevents the battery from being charged or discharged beyond safe limits. Although the protective circuit uses a small amount of energy from the battery to operate, the Li-Ion battery self-discharge rate is a fraction of that of nickel-based rechargeable batteries. Some conditions that increase the self-discharge rate of Li-Ion batteries, and should be avoided, are described in the "Battery capacity" section.

Battery cycle life

Battery cycle life is the total number of discharge-charge cycles (Figure 1) a battery yields before it can no longer hold a useful amount of charge. Estimating the cycle life of a rechargeable Li-Ion battery is difficult because cycle life is affected by the average operating temperature of the battery and its energy discharge rate. Basically, higher temperatures and higher energy discharge rates decrease battery cycle life. The operating temperature of the battery depends on the air temperature as well as the heat generated by the notebook itself and by its immediate environment, such as a docking station. The energy discharge (drainage) rate depends on the type of applications running on the notebook and by its power management settings. For example, running compute-intensive applications such as CAD, gaming, and DVD movies drains the battery faster and decreases its cycle life more than running word processing applications.

Figure 1. A cycle for a rechargeable lithium-ion battery is the cumulative amount of discharge approximately equal to its full charge capacity. For example, 10 occurrences of a 10% depth of discharge or 2 occurrences of a 50% depth of discharge represent one cycle.

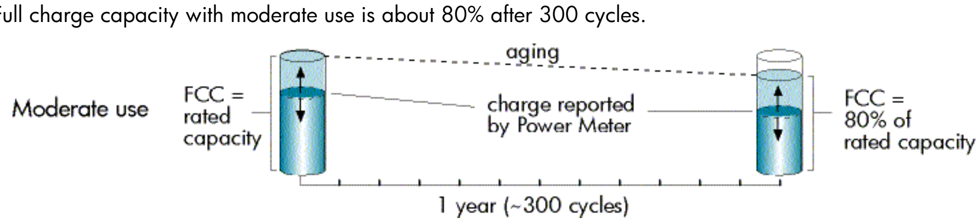


Battery capacity

Battery capacity is expressed in ampere-hours (Ah). Battery energy, expressed in watt-hours (Wh), is the product of the battery capacity (Ah) and the battery voltage (V). The operating voltage range of a Li-Ion battery pack remains relatively constant throughout its useful life; however, its capacity begins to decrease in a roughly linear manner as soon as it is put into service. New batteries are classified by their rated capacity. Over time, the actual battery capacity decreases due to electrochemical inefficiencies within each cell. This loss in capacity (aging) is irreversible; it cannot be restored by cycling the battery. Gradually, less and less active material is available within each cell to electrochemically store a charge. Consequently, the user experiences reduced computer run time.

A practical way to express the actual capacity of a battery over time is called full charge capacity (FCC). FCC is expressed as a percentage of the initial rated capacity of the battery. FCC is influenced by the typical discharge load on the battery and by the user profile. Under normal discharge loads, Li-Ion batteries have a lifespan of between 300 and 500 cycles. With moderate use, Li-Ion batteries are expected to deliver approximately 80% of their rated capacity after 300 cycles or about one year of use (Figure 2). This estimate covers typical users who completely cycle the battery each working day by running low to medium power applications (word processing, e-mail, and spreadsheets) in wired or wireless modes.

Figure 2. Full charge capacity with moderate use is about 80% after 300 cycles.



Warranty period

HP provides a 12-month warranty for Li-Ion batteries. The warranty period is based upon the expectation that the battery will deliver 80% of its initial capacity after 300 cycles at low to moderate power loads. High power loads may cause a battery to reach 80% of initial capacity in less than the 12-month warranty period. Li-Ion batteries will continue to operate below the 80% capacity threshold; however, the capacity (run time) delivered between charges will continue to decrease.

Table 1 summarizes FCC projections after one year based on 2 user profiles and various power loads. The first profile is for a mobile user who fully discharges and charges the battery almost every working day (300 cycles per year) in a normal environment. The second profile is for a stationary user who only cycles the battery once per week in a high-temperature environment, such as in a docking station. As shown in the table, the additional heat generated by running high power applications or by using a docking station accelerates the loss of capacity.

Table 1. Full charge capacity projections after one year of use

Power load (applications)	**Full charge capacity (% of initial capacity) after one year**	
	Mobile user **Battery cycled daily (25°C, 77°F)**	**Stationary user (with docking station)** **Battery cycled weekly (>35°C, 95°F)**
Low (word processing, Internet, e-mail)	>80%	80%
Moderate (wireless, spreadsheets, database management)	80%	70%
High* (CAD, 3D games, DVDs, high LCD brightness)	60%	50%

**High power applications may also reduce the battery cycle life by as much as 25%.*

Smart Battery Technology

Estimating battery run time is further complicated by the inaccuracy of the system that monitors and reports the battery charge status to the user. Some notebooks estimate the battery charge state based on manufacturer testing of the specific product model with a particular configuration. This method is inaccurate when another battery with a different state-of-charge is inserted, because charge status of each battery is estimated based on its history in the system.

To aid users in monitoring and managing Li-Ion batteries, HP Compaq notebooks provide accurate and instantaneous status information using Smart Battery Technology. HP Smart Battery Technology is based on the Smart Battery System (SBS), which was established by major battery manufacturers in 1995 to promote an industry standard for rechargeable battery technology[1]. The SBS features a Smart Battery that maintains and reports its own status, thus providing users with accurate information, whether they use different batteries in the same notebook or the same battery in different notebooks.

Smart Battery calibration

Repeated short discharges and recharges cause increasing inaccuracy between the state-of-charge of the battery and the Power Meter readings. Periodically, the battery needs to be calibrated to "relearn" its usable capacity so it can synchronize its charge status with the Power Meter. The calibration procedure maximizes the notebook run time by giving the user an accurate estimate of the remaining battery charge. Calibration also prevents data loss that can occur during the Hibernation process if sufficient power is not available to complete critical save-to-disk operations.

Smart Batteries calibrate their FCC each time they undergo a full discharge-charge cycle, whether they are recharged in the notebook or in a stand-alone charger/conditioner. Calibration using the notebook is less convenient because it can take up to 4 hours; however, it can lead to more relevant results than using a stand-alone charger. Calibration results using the notebook are more relevant because the battery relearns its FCC while undergoing a realistic power load. In a stand-alone charger, the battery is discharged using a fixed load. If the fixed load is less than the load typically experienced by the notebook, the learned capacity of the battery may be higher than its actual capacity. In other words, the newly calibrated battery may not deliver the run time predicted by the Power Meter if it is subjected to a greater load than the load used to calibrate the battery.

The accuracy of today's Smart Battery IC enables precise calibration when the battery is discharged to about 5% of its remaining capacity. Consequently, the user can set the battery alarm at 5% of remaining capacity so that the Smart Battery will calibrate its capacity during normal use. The user simply has to periodically discharge the battery until the 5% capacity alarm is received. The need to perform this procedure will vary with individual use. In general, a Li-Ion battery should be calibrated a minimum of once every 3 months. A battery that is seldom discharged completely should be calibrated about once a month.

[1] For more information about the Smart Battery System, go to http://www.sbs-forum.org/.

Battery care practices

After reading the information presented in this paper, users should be aware of conditions that negatively impact battery run time and lifespan. In summary:

- Li-Ion battery cells suffer gradual, irreversible capacity loss with each discharge-charge cycle. Such aging occurs more rapidly as temperature and discharge loads increase.
- The self-discharge rate of a Li-Ion battery is higher if the battery is left in an unpowered notebook.
- During prolonged storage or non-use, the battery charge will decrease below its recommended low-voltage level. Leaving the battery in a depleted condition for an extended period will accelerate the decrease in FCC.
- Leaving the battery at a high level of charge in a high-temperature environment for extended periods (for example, running a notebook computer in a docking station under a heavy load) will also accelerate the loss of capacity.
- Running high-end applications using the battery accelerates the loss of capacity. For example, playing 3D games will lower FCC faster than using word processing applications.

Recommendations for battery use and storage are covered in the HP User Guides for each model. Additional battery care practices are as follows:

- Store Li-Ion batteries between 20°C and 25°C (68°F and 77°F) with 30% to 50% charge.
- Do not leave batteries exposed to high temperatures for extended periods. Prolonged exposure to heat (for example, inside a hot car) will accelerate the deterioration of Li-Ion cells.
- Remove the battery if the notebook will be stored (turned off and not plugged into AC power) for more than 2 weeks.
- Remove the battery from the notebook if the notebook will be plugged into AC power continuously (via a wall adapter or docking station) for more than 2 weeks.
- Use the type of battery with the highest capacity (Ah) rating if the notebook will run high-end applications on battery power.
- Periodically calibrate the battery based on the usage model. Under normal usage, batteries should be calibrated a minimum of once every 3 months; however, a battery that is rarely discharged fully should be calibrated about once a month.

For more information

For additional information, refer to the resources detailed below.

Resource description*	Web address
Commercial Notebook Batteries: Performance Optimization white paper contains instructions on calibrating Li-Ion batteries	ftp://ftp.compaq.com/pub/supportinformation/papers/155l-0601a-wwen.pdf
Smart Battery System Implementers Forum	http://www.sbs-forum.org/

**The information provided by these resources may not apply to all systems.*

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