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Comparison of NiMH, Li-Ion, and LiPo Batteries

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In modern portable electronics, the choice of battery technology is crucial for optimizing performance, longevity, and user experience. Three of the most common types of rechargeable batteries used today are Nickel-Metal Hydride (NiMH), Lithium-Ion (Li-Ion), and Lithium Polymer (LiPo) batteries. Each of these battery types has its own set of characteristics, making them suitable for different applications. For context, Lithium-Ion is named for its active materials; either fully written or shortened by their chemical make-up (PPU uses Lithium Manganese Oxide). Lithium polymer is essentially the same as Lithium-Ion in chemistry and systems but typically refers to prismatic or pouch cells (PPU uses prismatic).

The following compares these three battery technologies across various parameters, including energy density, lifespan, charge cycles, safety, and cost.

ENERGY DENSITY

Energy density refers to the amount of energy stored in a battery per unit of weight or volume. We will also mention specific power, which compares power output to its mass (also known as power-to-weight ratio) and specific energy, which is how quickly a cell can deliver power. These are key factors in determining how long a device can operate on a single charge.

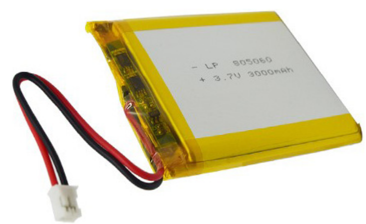
NiMH Batteries

NiMH batteries have a relatively lower energy density compared to lithium-based batteries meaning they are heavier for the same amount of stored energy. NiMH batteries have 30–40% higher capacity than Nickel Cadmium (NiCd) but require 4–8 formation charge cycles (discharge and charge) before reaching their full capacity. They are less prone to memory than NiCd and can be rejuvenated if significant capacity loss occurs. They do generate heat during high-load discharges.

Li-Ion Batteries

Li-Ion batteries offer a significantly higher energy density compared to NiMH, allowing devices to run longer without increasing weight. They boast a low self-discharge rate but are affected by capacity fade. Li-Ion batteries can also offer more specific power but at the cost of capacity.

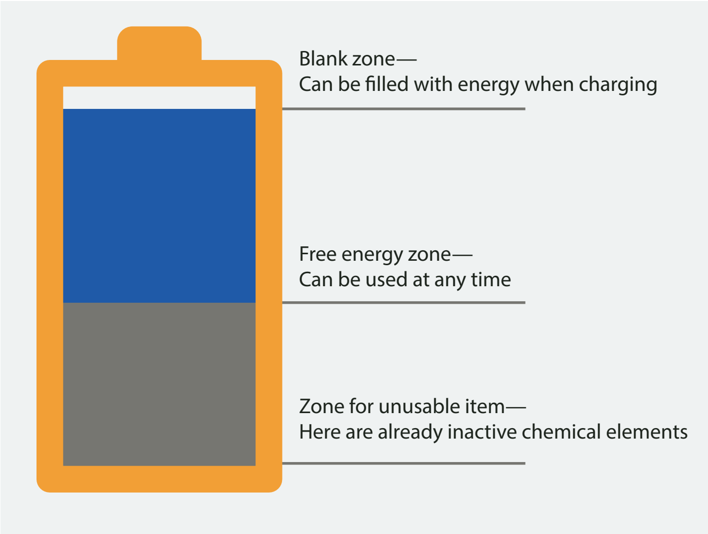
Li-Po Batteries



LiPo batteries only have slightly higher energy density than Li-Ion but higher specific energy allowing them to power devices requiring high loads. Their primary advantage is in their flexible form factor, which reduces their weight by more than 20% over classic hard shell and allows them to be shaped according to the design requirements of a device. Prismatic LiPo cells are encased in aluminum or steel for stability and are shaped similarly to a pack of chewing gum.

LIFESPAN

Lifespan refers to the total time a battery remains functional before it needs to be replaced, often measured in charge cycles (the complete discharge and charge of a battery). Cycle count is not entirely conclusive to measuring the lifespan of a battery as other factors can affect the service life of a battery, such as heavy usage or unfavorable temperatures.



NiMH Batteries (charge cycles: 300–500 cycles)

NiMH batteries typically have a moderate lifespan, with a limited number of charge cycles before they start to lose capacity. This number can be reduced if the battery becomes deeply discharged. They also suffer from a higher self-discharge rate, which means they lose charge more quickly when not in use. They will typically lose 10–15% of their charged capacity in the first 24 hours after charge, then 10% per month after.

Memory was first used with NiCd batteries and meant that the battery could remember how much energy was drawn on previous dischargers and would deliver the same amount of energy on repeat discharges, which would cause the voltage to suddenly drop if more energy was demanded. The term is now used to refer to the natural formation of crystals in the cells over time. While NiHM is less prone to memory, it can still affect service life. If a NiMh battery is left on a charger for a prolonged period of time or repeatedly charged without a periodic discharge, crystals will form and can ingrain themselves in the cells and reduce capacity. A 1 volt per cell discharge periodically should be done every 1–3 months to prolong the service life (known as exercise).

If a Nickel-based battery is not properly maintained, then a full recondition might be required. Recondition is a slow discharge that drains the battery to about 0.4 volt per cell and lower to break up the crystal formations.

Li-Ion Batteries (charge cycles: 300–700 cycles)

Li-Ion batteries generally have a longer lifespan and can endure more charge cycles compared to NiMH batteries. They retain their charge well over time and are more suitable for devices that are frequently used. Depth of discharge (DoD) determines the cycle count of a battery. Li-Ion battery life can be prolonged at smaller discharges and frequent charges between uses. A partial discharge is fine, but it is important to try and avoid full discharges. A lithium-ion cell should not be discharged below 2.50 V and typical battery packs contain at least 2 cells so the battery should not fall below 5.00 V. This puts the cells to “sleep” which causes the protection circuit to turn off and most chargers will not recognize the battery to charge it.

They are also susceptible to capacity loss when exposed to heat and when kept in a full state-of-charge for an extended period of time due to stress on the cells.

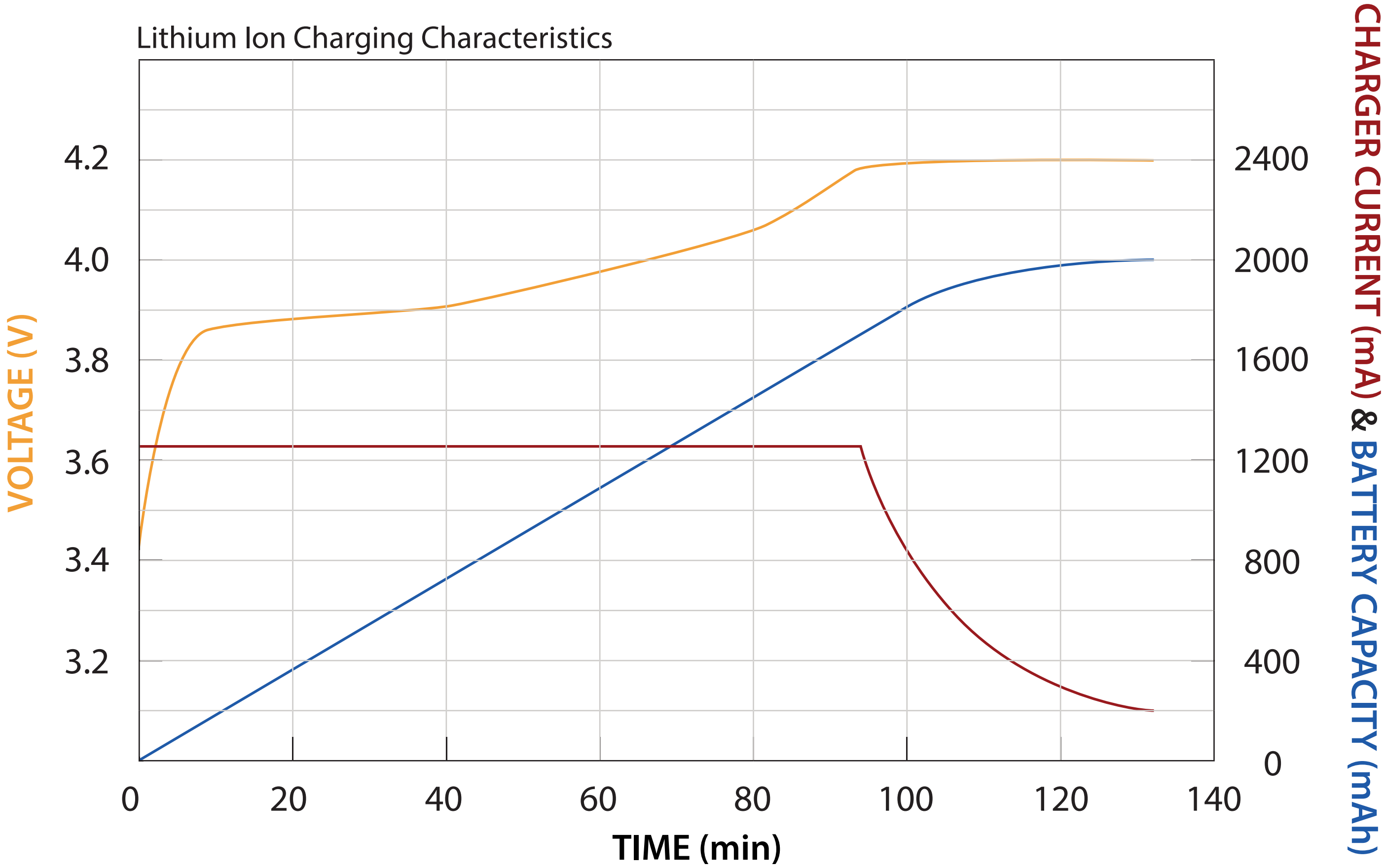
Even with proper maintenance, Li-Ion batteries will experience from capacity fade over their lifespan. As the battery is used and ages, the cells oxide which reduces the available energy portion that can be refilled, similar to a bar of soap shrinking as it is used in the shower.

Li-Po Batteries (charge cycles: 300–500 cycles)

LiPo batteries share characteristics with Li-Ion but have shorter lifespan than a cylindrical cell, with a similar number of charge cycles to NiMH batteries. Their degradation is more dependent on environmental conditions and usage patterns due to the flexible design making the cells less durable.

They are very susceptible to temperature; high temperatures will cause cell degradation and lower temperatures will prevent them from charging properly. They are also less efficient in thermal management, this can cause them to generate heat while in use, which in turn can lead to increased cell degradation. This means that LiPo batteries that experience heavy usage will have a shorter lifespan.

Since LiPo batteries are lithium based, they also experience capacity fade due to cell oxidation, but it is more obvious due to their housing. As the cells oxidize, they release gases and, while a cylindrical Li-Ion cell has a rigid housing designed with a gas release vent, LiPo’s prismatic housing cannot build in an opening for gas release and is instead designed for gas build up. As the cells age and oxidize, the gas builds up causes



it to swell and, potentially, enough gas will build up to cause cracking or damage to the exterior housing of the battery pack. Once there is visible swelling, immediately take the battery out of service. Proper care is essential to maintaining their performance and lifespan.

All lithium and nickel-based batteries are considered end of life and should be replaced once their capacity drops below 80% of their rating.

CHARGING CHARACTERISTICS

Charging characteristics include the time it takes to recharge the battery and how the battery behaves during the charging process. This is dependent on the battery capacity and charger.

NiMH Batteries (charging time: 3-6 hours, depends on capacity and charger)

NiMH batteries typically take longer to charge compared to lithium-based batteries as they require a more complex charging algorithm but are the best at fast charging. Chargers that support both NiCd and NiMH batteries rely on tracking the temperature increase of the battery to know when to terminate charging. It is best practice to wait until a NiMH battery is at room temperature before charging and to not put the charger in a room that fluctuates in temperatures since high and low temperatures can cause under and overcharging of the battery.

Other NiMH chargers rely on a voltage signature to know when to terminate charging. Overall, NiMH batteries are sensitive to overcharging and require a much lower trickle charge rate than other batteries. If the battery is warm to the touch, remove it from the charger. Do not leave the battery in the charger for more than a few days in order to prevent the formation of crystals.

Li-Ion Batteries (charging time: 2–5 hours)

Li-Ion batteries charge relatively quickly, and chargers rely on a strict voltage signature to know when to terminate charging as Li-Ion cannot accept overcharging. Li-Ion has four stages during the charging cycle but the first two are the most important: constant current charge and saturation charge. The first stage, constant current, applies a constant current between 0.5–1ºC until the battery reaches about 70–85% capacity, during which some pack may experience a temperature increase. Once the battery reaches its voltage threshold, it moves to stage 2, saturation charge, where the charge current decreases to a trickle charge until the battery is fully charged and ready for use.

Li-Ion is also sensitive to temperature while charging and will not charge at all under 0°C (32°F).

Protection circuits are built into the pack and do not allow for overcharging but should they become damaged, and the cells are exposed to overcharging, it can cause the cells to breakdown, generate lots of heat, and rapidly disassembly.

Li-Po Batteries (charging time: 2–5 hours)

LiPo batteries have identical charging characteristics as Li-Ion batteries but due to their flexible design, the protection circuits are more vulnerable to damage.

Charging any battery while a radio is powered on is not recommended. The current drawn through the radio (known as the parasitic load) can distort the charge cycle of the battery and stress the cells, which decreases service life.

COST

Cost is a significant factor in battery selection, particularly for consumer electronics manufacturers.

NiMH Batteries (cost: low to moderate)

NiMH batteries are generally more affordable than lithium-based batteries, making them a cost-effective choice for applications where high energy density is not critical. They are also environmentally friendly and easily recyclable.

Li-Ion Batteries (cost: moderate to high)

Li-Ion batteries are more expensive than NiMH batteries due to their higher energy density and longer lifespan. However, their performance benefits often justify the higher cost in many applications.

LiPo Batteries (cost: moderate to high)

LiPo batteries tend to be slightly more expensive than Li-Ion batteries due to LiPo's specialized manufacturing process. Their cost is generally on par with or slightly higher than Li-Ion batteries, depending on the specific application.

SAFETY

Safety is a critical consideration, particularly for batteries used in consumer electronics and high-energy applications.

NiMH Batteries (safety: high)

NiMH batteries are generally considered very safe, with a lower risk of overheating and rapid disassembly than Li-Ion batteries. However, they can suffer from leakage if damaged or not properly maintained.

Li-Ion Batteries (safety: moderate)

Li-Ion batteries are safe when used with proper charging and built-in protection circuits mandated by IEC 62133. However, with millions of consumers using batteries, failures are bound to happen.

LiPo Batteries (safety: moderate to low)

LiPo batteries are more vulnerable to physical damage and overcharging, which can lead to swelling, leakage, or more extreme conditions. They require the same safety measures as Li-Ion, including mandated protection circuits and careful handling, to mitigate these risks.

CONCLUSION

The choice between NiMH, Li-Ion, and LiPo batteries depends largely on the specific requirements of the application. NiMH batteries are cost-effective and safe but lack the energy density needed for modern high-performance devices. Li-Ion batteries offer a balanced combination of energy density, lifespan, and safety, making them the preferred choice for most consumer electronics. LiPo batteries, with their flexible design and lightweight characteristics, are ideal for specialized applications where form factor and weight are crucial.

Understanding the strengths and weaknesses of each battery type allows manufacturers and consumers to select the most appropriate technology for their needs, optimizing performance, safety, and cost-effectiveness.

References

Buchmann, Isidor. Batteries in a Portable World: A Handbook on Rechargeable Batteries for Non-Engineers. 4th ed., Cadex Electronics Inc, 2016.

REVIEW BREAKDOWN

Characteristic	NiMH	Li-Ion	LiPo
Energy Density	Lower	High	Slightly higher than Li-Ion
Specific Power	Lower	High	Higher than Li-Ion
Specific Energy	Lower	Moderate	High
Charge Cycles	300–500	300–700	300–500
Self-Discharge Rate	High (10–15% in 24 hours, 10% per month)	Low	Low
Memory Effect	Less prone, but can occur	No	No
Charging Time	3–6 hours	2–5 hours	2–5 hours
Temperature Sensitivity	Moderate	High	Very high
Cost	Low to Moderate	Moderate to high	Moderate to high
Safety	High	Moderate	Moderate to low
Form Factor	Fixed	Fixed	Flexible
Weight	Heavier	Lighter	Lightest (20% less than Li-Ion)
Capacity Fade	Less affected	Affected	Affected, more visible
Overcharging Sensitivity	High	Very high	Very high
Environmental Impact	More environmentally friendly	Moderate	Moderate