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Rechargeable Batteries in a Consumer Electronics World

Tony Olson, January 2009

1) Common Types of Rechargeable Batteries

There are a growing number of portable consumer electronic devices that rely on batteries. These include laptop computers, net-books, smart phones, cell phones, digital cameras, camcorders, MP3 players, and more recently, batteries are being used as the primary driving force for power tools and even automobiles. All of these devices require rechargeable batteries to provide effective and efficient portable power. Today, batteries for these devices are principally made using either Nickel or Lithium. The primary Nickel batteries are Nickel Cadmium (NiCd) or Nickel Metal Hydride (NiMH). The primary Lithium battery is Lithium Ion (Li-Ion). Other battery technologies do exist but, since these are the main batteries used in portable devices we will concentrate on only these three here.

2) Characteristic Comparison

The characteristics of these three types of batteries are very different. Chart 1 below shows a direct comparison between these three battery chemistries for a number of key areas of consideration.

	Energy Density	Memory Effect Problems?	Environmentally Friendly?	Chemical Volatility	Charge Storage Life	# of Charge Cycles	Recharge Time	Discharge current	Maintenance Requirements
NiCd	100%	yes	No (has heavy metals)	strong	Longest	~1500	Slow	high	Frequent
NiMH	200%	some	Yes	strong	Long	~300	Faster	moderate	Periodic
Li-Ion	300%	none	Yes	explosive	Shortest	~500	Fast	lower	None

Chart 1

Energy Density – is the amount of energy you can get out of a battery considering its size. For this measure, the bigger the number, the better that battery technology. NiMH can deliver twice the energy of a NiCd battery of the same size. Or, a Li-Ion battery of 1/3 the size of a NiCd battery can deliver the same energy. **Li-Ion wins this category hands down**.

Memory Effect – This is a bad condition that will occur in some batteries if they are not maintained properly. If NiCd batteries are regularly only half discharged and then topped off with a charge, the battery will "forget" that it has the other half of its capacity. It becomes half the battery it once was. Many people don't realize it, but NiMH batteries do have the memory effect problem to a lesser degree than NiCd. Li-Ion does not have the memory effect problem. **Li-Ion wins again**

Environmentally Friendly – The Cadmium in NiCd batteries is nasty. Exposure to Cadmium can cause cancer, impair the function of the lungs and the kidneys, and impact reproduction and infant development in humans and animals. It requires recycling and special handling so as not to damage the environment. Of course all batteries should be disposed of properly, but neither NiMH nor Li-Ion are hazardous to the environment. **Winners: tie between Li-Ion & NiMH**.

Chemical Volatility – Li-Ion batteries are explosive! This is one down side to having the highest energy density. If not designed properly, these batteries can be considered little bombs. To see the full extent of Li-Ion's dangerous capabilities, see the demonstration we created. It is posted on YouTube at http://www.youtube.com/watch?v=WeWq6rWzChw. If you watched the video, you may have sworn off the use of Li-Ion. But with the proper protection circuitry, these batteries can be safe. NiMH and NiCd batteries do not require the same level of caution. **Winners: tie between NiMH & NiCd.**

Charge Storage Life – This is how long can a battery be kept on the shelf and still be useful. This is directly dependent on the amount of charge in the battery and the temperature. Storing a battery with partial charge, say 40% and in cooler temperatures will maximize the shelf life. Do not put your batteries in the freezer. There is a real possibility that they will be ruined. Even with all this careful attention, Li-Ion batteries will only last 2 to 3 years. This is a relative secret in the battery industry. Time alone is a killer of Li-Ion batteries. This means that you should not buy extras and just store them for the future. You also need to be careful when you buy replacement batteries. There are numerous stories out there of people buying replacement batteries for their cell phones or PCs only to have those batteries die in a few months. You need a "born on" date on your replacement battery packs even more than on your cans of beer. The big loser here is Li-Ion. **The winner is NiCd.**

# of Charge Cycles – is the number of times that the battery can be used fully and then recharged fully before it wears out. The paper specifications say that NiCd wins hands down with ~1500 cycles. But the Li-Ion specification of ~500 cycles is misleading. Some experts state that Li-Ion can handle a very large number of change cycles, according to Apple's Knowledge Base . **The winner here is Ni-Cd.**

Recharge Time – is the amount of time it takes a battery that has been fully drained of power to safely recharge to full capacity. NiCd clearly takes the longest. Some tools that use these types of batteries require the device to charge the battery for 24 hours after it is been completely drained. Li-Ion is the fastest to recharge. Li-Ion can also take a partial charge well. These two characteristics are useful when you are in a rush and your battery dies, or you forgot to charge it last night. **The winner here is Li-Ion.**

Discharge Current – Current is one component of energy. Discharge is the rate of delivery of that energy. Some devices, like flashlights, take a constant current discharge. Easy, all batteries can handle that requirement. Some devices energy requirements are constantly changing. Laptops for example, have energy requirements that change every microsecond, but the changes in current are relatively small. Power tools on the other hand, require relatively huge changes in current, for example when a motor starts up. When a device calls for current, if the battery can't deliver, the voltage the battery can supply will immediately start to fall (see figures 2b and 5 below). If the voltage drops far enough the device may shut down prematurely. **The clear winner here is Ni-Cd.**

Maintenance Requirements – because of the life shortening impact of the memory effect problem described earlier, the Nickel battery technologies require proper maintenance to achieve maximum life. Ni-Cd batteries are the worse of the two. They require constant attention. They should be completely discharged before they are placed on charged again. This can be quite inconvenient. Ni-MH batteries are a little more forgiving. They don't require the constant vigilance that Ni-Cds do, but they should be fully discharged regularly, every two to four weeks. The Li-Ion battery doesn't exhibit any memory effect. However, some devices have fuel gauges that read out how much battery energy is remaining at any given time. These gauges can occasionally get confused. For this reason, it is a good idea to occasionally drain your Li-Ion battery completely before a recharge. This will help the fuel gauge circuit reset for a proper reading. **The clear winner here is Li-Ion.**

3) Battery Life – What Impacts Life Expectancy?

So, what causes a battery to wear out? Much like a human beings health, a battery's health starts to deteriorate immediately after they are made. The aging process is both chemical and mechanical in nature. All batteries are perishable. It is the rate of aging where you can have some impact. The temperature, the charge method, the depth of discharge, maintenance procedures and just plain time all play a role in the life of a battery.

If you have already read through section 2 above, you may think that Li-Ion is the no-brainer winner for most applications that require a rechargeable battery. Well hold on. Let's take a look at what happens when the real world hits the battery. Consider one of the most common usage models for a laptop computer. It is as a desktop replacement. The unit is plugged into the AC outlet, with the battery fully charged. The laptop power profile in this mode is typically cranked to maximum performance. You don't need to worry about the battery draining, because it is plugged in. Sounds great, right? Well this is the absolute worst case scenario for Li-Ion life expectancy. The battery is basically sitting in storage with a full charge and at a very high temperature since the unit is running full-bore. Some people recommend that you take out your battery and just run the laptop off AC power alone. But that defeats the built-in UPS feature that laptops have with the battery installed. With the battery, the system can handle power glitches and even complete power outages without losing any of your work. For useful tips on extending your battery life, see section 4 below.

Getting back to the general case, batteries usually just don't up and die. They slowly lose health. This is demonstrated by their ability to store and/or deliver a full amount of energy. There are four major areas that impact battery health: 1) Declining Capacity, 2) Increasing Internal Resistance, 3) Increasing Self Discharge, and 4) Premature Cut-off. We also show the cumulative effect of all of these problems.

1. Declining Capacity

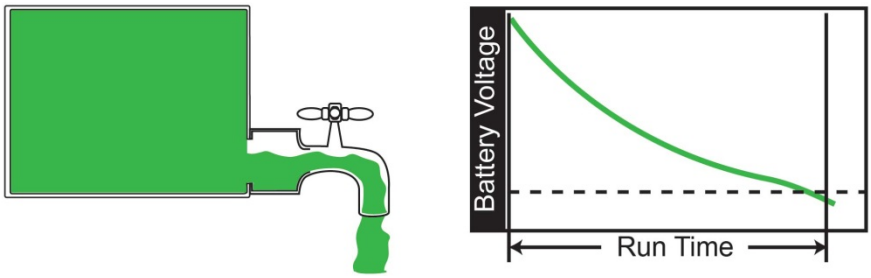

Figure 1 (a) A Full Fresh Battery

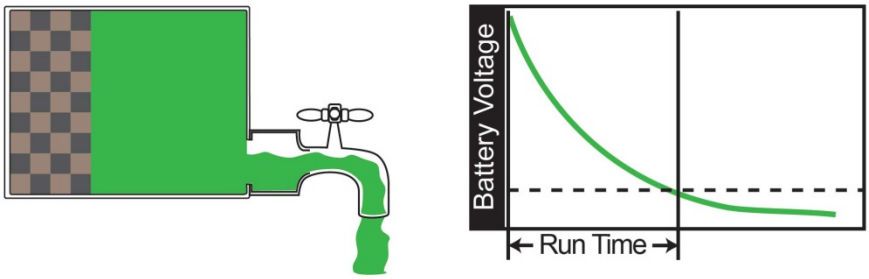

Figure 1 (b) Battery with Diminished Capacity

In Nickel batteries, the cause for declining capacity is the memory effect described above. If the memory effect is caught in time, a deep discharge may be able to restore the capacity. But after a few months, if the memory effect is not fixed, the effects become irreversible. In Li-Ion batteries this happens with age.

2. Increasing Internal Resistance

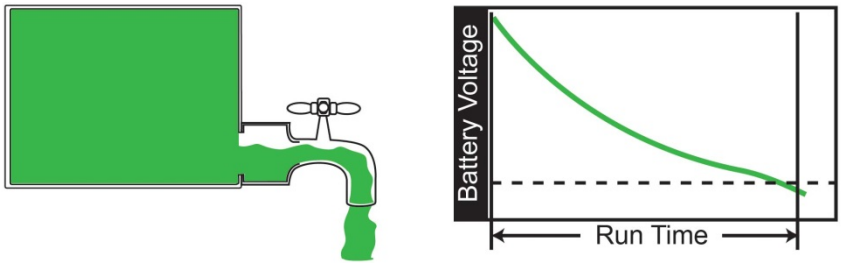

Figure 2 (a) A Full Fresh Battery

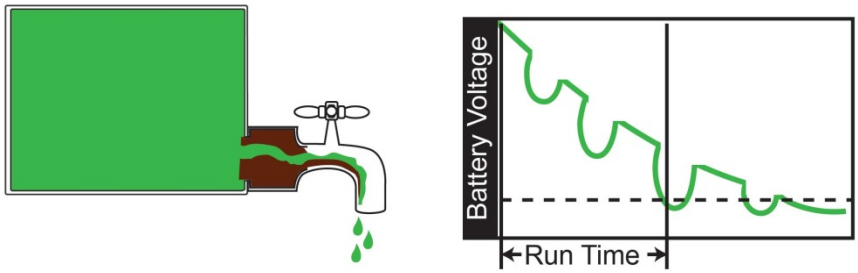

Figure 2 (b) A Battery with Increasing Internal Resistance

Aging of lithium-ion is an issue that is often ignored. An in-use lithium-ion battery typically lasts 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.

3. Increasing Self Discharge

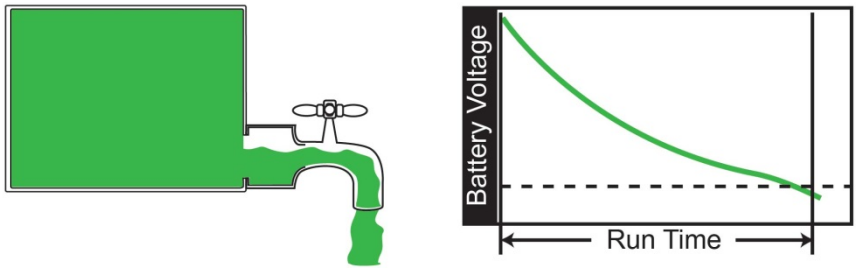

Figure 3 (a) A Full Fresh Battery

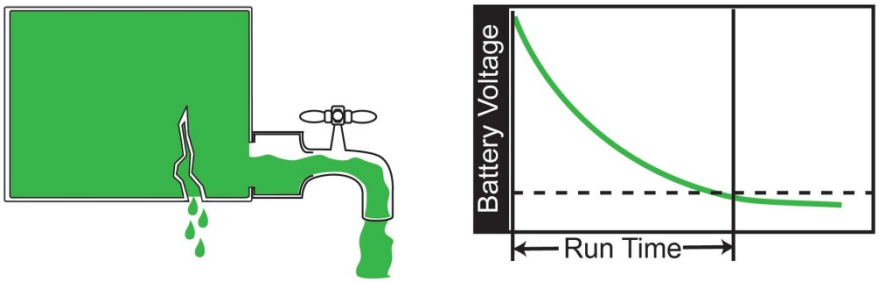

Figure 3 (b) A Battery with Increasing Self Discharge

Self discharge happens in all batteries. Higher temperature increases the loss. The energy loss is greatest right after a full charge. In this area, Ni-Cd batteries are the worse and Li-Ion batteries are the best.

4. Premature Cut-off

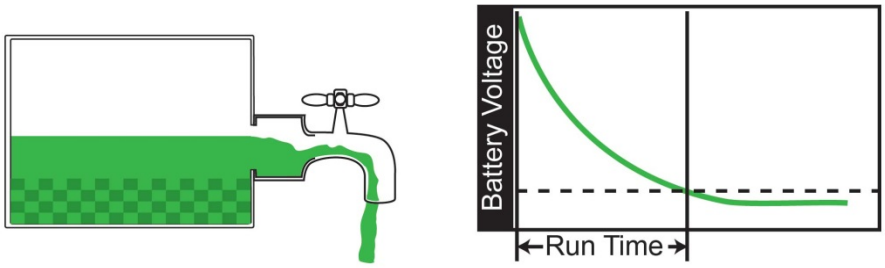

Figure 4 - A Battery with Unusable Energy

5. Cumulative Effect

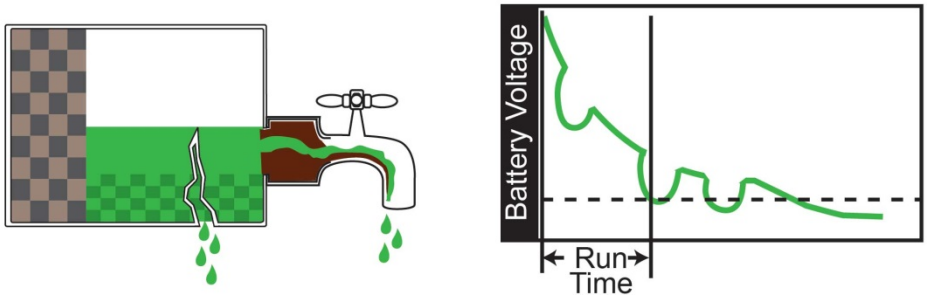

Figure 5 - A Battery with Lots of Problems
(Time to get a new one)

4) Looking for the Most Bang for your Buck? (yes that was a geeky Li-Ion pun)

If you look at battery types relative to the new applications emerging, the current volume of usage, and the new research being conducted and you would believe that Li-Ion batteries are the clear winner for portable electronic devices.

Yet, the Li-Ion technology has not yet reached its full potential. New metal and chemical combinations are being worked on that will increase both the battery useful life and further increase the energy density. Given this, let's look specifically at how you can maximize the length of you Li-Ion battery's life.

Do's and Don'ts on Battery usage for a long life

1) **Don't** leave your battery plugged into the charger forever (i.e. using a laptop computer only in desktop mode). The worst condition for rapid aging of a Li-Ion battery is to keep it fully charged and at elevated temperatures. This is exactly the laptop in a desktop mode scenario.
2) **Do** use it on battery power only and charge it regularly. Like many other things in life, if you don't use it you lose it.
3) **Do** shut off your device when not in use. This will lower the temperature of the battery and prolong its life (and you will stop wasting energy).
4) **Don't** leave your device in a hot environment. (e.g. on the seat or dashboard of a hot car)
5) **Don't** drain the battery fully between every single charging.
6) **Do** allow (force) a full discharge approximately once a month to devices that use battery fuel gauges. This will force the fuel gauge to recalibrate itself and prevent premature cut-off from occurring.
7) When not in use, **do** store the battery in a cool place with about a 40% charge.
8) **Don't** purchase spare Li-Ion batteries just to have around. The life clock is ticking.
9) **Do** be very careful of static electricity around the battery pack and charger circuits. If the protection circuit becomes damaged, the battery could become dangerously unstable.

Once your Li-Ion battery is worn out

1) **Don't** try to shock it, or freeze it, or heat it back to life. There is no reviving it.
2) **Don't** throw your old battery in the garbage or even worse, a fire.
3) **Do** recycle your old battery.
4) **Do** go get a new battery.

When buying a replacement battery

1) Look for a "born on date". There are numerous stories that are starting to come out now where people have purchased "brand new" replacement batteries, only to have them die in a few months. Remember, while that Li-Ion battery has been sitting on the shelf, in the warehouse or on a slow boat from Asia, the life countdown is running.
2) Buy a reputable brand and from a reputable retailer to ensure that the battery pack has the proper protection circuitry. Without it the Li-Ion battery could explode. Some Internet only shops sell batteries where the specs have been cut to save cost. This is very risky. (see YouTube video)