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Review: Testing Sanyo's Eneloop Rechargeable Battery

A set of four Sanyo Eneloop AA cells in their reusable storage pack.

Late in 2006, I found out about Sanyo's new Eneloop Nickel Metal Hydride (NiMH) rechargeable batteries, available in AA and AAA cell sizes. Unlike regular NiMH offerings from other vendors (e.g. Duracell, Energizer, Gold Peak), Sanyo claimed the following benefits for their Eneloops:

- Very low self discharge rate, meaning one can charge them any time, store them until needed, and then use them.
- Because of the previous characteristic, Sanyo sells them pre-charged, so one doesn't have to charge them before their first use.
- Lower internal resistance, meaning higher voltage reaching equipment that uses high currents (such as digital cameras).

One disadvantage of the Eneloops over normal NiMH cells is lower capacity. For the AA size, Sanyo claims a capacity of 2000mAh. Normal NiMH AAs are available with capacities of up to 2700mAh nowadays, but when you consider self discharge rate, such NiMH cells stored for about 30 days will drop to 2000mAh.

As an avid radio controlled (R/C) model airplane enthusiast, I've been using rechargeable batteries for a long time. My radio equipment uses AA sized cells and my planes are powered by high-discharge Sub-C sized cells. In the R/C field, Sanyo has a long history of reliable and powerful cells, first Nickel Cadmium (NiCd) and more recently NiMH, so I was confident that their new Eneloop cells would be every bit as good as they claimed. I immediately went to the nearest Circuit City store (called The Source here in Canada) and purchased a 4-pack of AA cells. They are also available in packs of 8 from Amazon.com.

Out-of-the-box Capacity

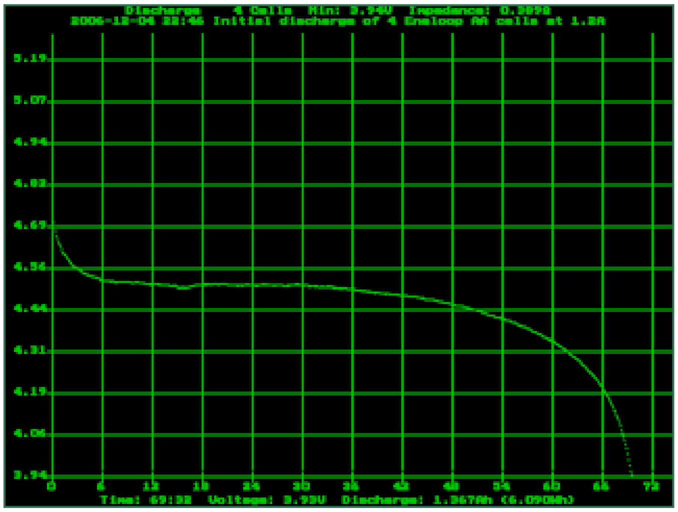
Sanyo claims a self-discharge rate of about 15% per year (compared with about 1% per day for regular NiMH offerings). Because of this, they can pre-charge them before packaging them up and expect them to still be close to fully charged by the time you buy them. This means you can buy a pack because you need batteries **now**, use them, and then recharge them hundreds of times.

The first thing I did after I purchased my Eneloops was to fully discharge them in order to measure their capacity. I have a home-made computer-controlled battery charger/discharger/tester that I've used on my R/C batteries for years, so I used that to perform the tests. I chose a discharge rate of 1.2 Amps (1200mA), with the following results:

Measurement	**Four Cells**	**One Cell**
Measured Capacity @ 1.2 A	1367 mAh	
Total Energy @ 1.2 A	6090 mWh	1523 mWh
Average Voltage Under Load	4.45 V	1.11 V
Internal DC Resistance	0.389 Ω	0.097 Ω

Characteristics of a 4-pack of AA Eneloop cells discharged at 1.2A, fresh out of the package.

The discharge current that I chose is higher than that used by Sanyo to rate the capacity. Manufacturers typically use a discharge current of C/5, which means the battery capacity divided by 5. For a 2000mAh battery, this would be 400mA, or 0.4A. Discharging at higher current typically results in a lower capacity. However, I've done **all** my tests at 1.2A, so the comparisons will be valid. Here's a graph of that first discharge:



Discharge curve of a 4-pack of AA Eneloop cells at 1.2A, fresh out of the package.

The average voltage under load is only 1.11V per cell, but that's not surprising since voltage always drops somewhat later in the discharge cycle. Since the cells started out already partially discharged, the average voltage will be lower than the expected 1.2V of a typical NiMH cell. Furthermore, the relatively high current that I used also significantly reduces the voltage. At a more typical 400mA load, the average voltage would have been 1.19V (computed using the measured internal resistance).

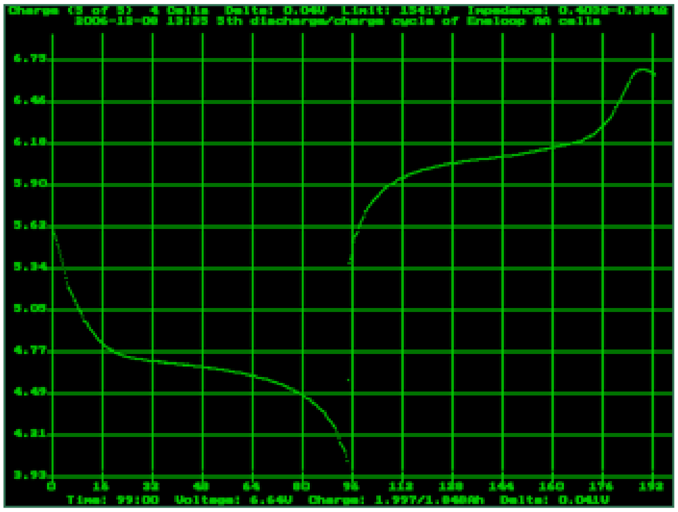
Available Capacity

After completing the discharge tests, I cycled the 4-pack times. Cycling is the process of repeatedly fully discharging and fully recharging, the purpose being to exercise the battery. Most batteries require three to five cycles before they reach their rated capacity. After five such cycles, the following results were observed:

Measurement	Four Cells	One Cell
Measured Capacity @ 1.2 A	1848 mAh	
Total Energy @ 1.2 A	8644 mWh	2161 mWh
Average Voltage Under Load	4.68 V	1.17 V
Internal DC Resistance	0.384 Ω	0.096 Ω

Characteristics of a 4-pack of AA Eneloop cells after five discharge/charge cycles at 1.2A.

With a capacity (at 1.2A) of 1848mAh, the out-of-the-box capacity of 1367mAh represents an initial charge of 74%. This pack of AAs was manufactured in June of 2006, so they were six months old at the time I tested them. This is worse than Sanyo's claim of 90% capacity after six months, but far better than a normal NiMH battery, which would be down to about 16% capacity after that much time. Here's the graph of the fifth discharge/charge cycle:



Fifth discharge/charge cycle of a 4-pack of AA Eneloop cells at 1.2A.

Once again the average voltage is less than the typical 1.2V per cell, but this is due to the high load. With a 400mA load, the voltage would have been 1.25V per cell.

[**May 2007 Update:** According to Sanyo, Eneloops are only charged to about 75% capacity at the factory. This implies that the battery lost almost no capacity between the factory and my workshop.]

Self Discharge

Based on the results so far, I was sufficiently pleased with the Eneloops to start using them in my Garmin GPSMAP 60C, which sits for a week or two at a time in my flight bag, and then has to work for several hours when I take it flying. I also bought six more to use in my Nikon Coolpix 8700 camera (with the optional MB-E5700 battery pack designed to accept 6 NiMH cells).

However, I wasn't done testing yet, so on January 14, I cycled the original 4-pack a few times to make sure it was fully charged, after which it had the following characteristics:

Measurement	Four Cells	One Cell
Measured Capacity @ 1.2 A	1799 mAh	
Total Energy @ 1.2 A	8413 mWh	2103 mWh
Average Voltage Under Load	4.68 V	1.17 V
Internal DC Resistance	0.382 Ω	0.096 Ω

Characteristics of a 4-pack of AA Eneloop cells after a few more discharge/charge cycles, prior to a seven week rest.

I then set it aside in my workshop (which is usually at about 18°C or 64°F). Seven weeks later, I performed a discharge test and achieved the following results:

Measurement	Four Cells	One Cell
Measured Capacity @ 1.2 A	1636 mAh	
Total Energy @ 1.2 A	7252 mWh	1813 mWh
Average Voltage Under Load	4.43 V	1.11 V
Internal DC Resistance	0.470 Ω	0.118 Ω

Characteristics of a 4-pack of AA Eneloop cells after a seven week rest.

A capacity of 1636mAh is 90.9% of the 1799mAh it had when I set it aside. In other words, it lost 9.1% of its charge over the course of 7 weeks. This translates to the following results for differing time periods:

Time Period	Charge Retention	Charge Loss
Day	99.8%	0.2%
Week	98.7%	1.3%
Month	94.3%	5.7%
Six Months	70.2%	29.8%
Year	49.3%	50.7%

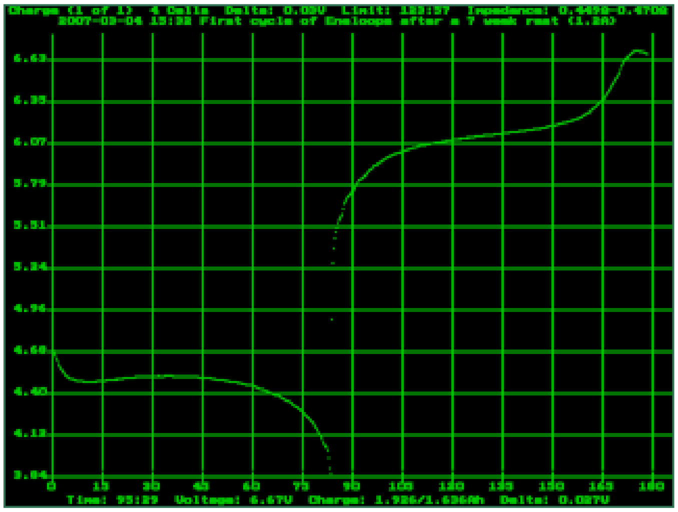
Charge retention and loss characteristics of AA Eneloop cells for various periods of time. (Six month and one year values are predictions.)

These results are not as good as Sanyo's claim of 90% charge retention over the course of six months, but still far better than what one would expect of ordinary NiMH cells. Even after one year, the Eneloops would still have half their rated capacity, whereas a regular NiMH battery would be virtually dead. Notice that the predicted six-month capacity matches very closely the capacity I measured on the six month old just-purchased cells.

Sanyo doesn't specify what the optimal storage conditions are for fully charged cells. Perhaps they'd do better stored at warmer temperatures, or maybe storing them in the freezer would be best. Additional testing is required to determine this.

[**May 2007 Update:** Sanyo has told me that the rate at which the battery discharges decreases over time. Thus, my extrapolation from the seven week discharge is overly pessimistic. They are also best stored at cool temperatures, as low as -20°C (-4°F).]

Here's the graph of the discharge and charge after seven weeks:



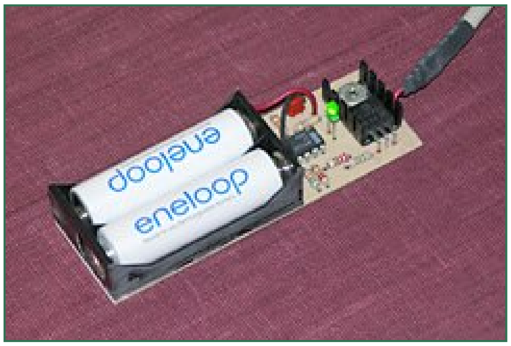
Discharge/charge cycle of a 4-pack of AA Eneloop cells at 1.2A after seven weeks of rest.

There's an interesting observation here. Notice that the voltage initially drops quite low, to about 4.48V, and then rises a bit to about 4.52V. This is likely caused by the initial low temperature of the cells. After about 30 minutes of discharging, they would have warmed up (from internal I^2R losses).

This also accounts for the relatively high internal resistance reported by my battery analyzer. The analyzer measures the resistance either immediately, or when the battery first drops below 1.2V per cell. If it had waited until the cells "woke up", it would probably have seen better results.

Charging

Eneloop cells can be charged in any normal slow or fast charger designed for regular NiMH cells. Personally, I would steer away from the super-fast chargers that work in under an hour (some as fast as 15 minutes). Although we use such chargers for R/C model power batteries, the cells in those batteries have a very low internal resistance (typically about 0.004Ω per cell) and can handle the high charge rates. With the approximately 0.1Ω resistance of the Eneloops, an 8A charge rate (which is needed to produce a 15 minute charge) would cause about 6.4W of heat to be generated in each cell, which will make them **very** hot.



Eneloop cells can be charged in any standard Nickel Metal Hydride (NiMH) charger, including this do-it-yourself USB-powered one.

Like any rechargeable battery, Eneloops should not be left connected to a low current "wall-wart" type slow charger indefinitely. Fortunately, the main reason for doing this has been to ensure there are always charged batteries on hand. With the Eneloops' slow self discharge rate, this is not really necessary.

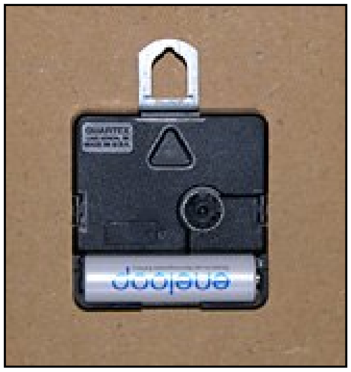
Unlike traditional NiMH AAs, Eneloops are a good choice for remote controls.

Eneloops are probably best charged with a 1 to 5 hour quick charger (like this do-it-yourself USB powered one) that automatically turns off on charge completion, and then removed and stored until needed. If left unused, they can be recharged every few months to top them off.

[**May 2007 Update:** Sanyo will be introducing their own USB powered Eneloop charger on May 21.]

Applications

Traditionally, I've used rechargeable cells in equipment that gets used for a short period and then sits around until its next use. I'd recharge the battery just before using it again. For other battery powered devices, such as wall clocks, flashlights, and TV remotes, disposable alkalines made more sense because rechargeables would run down more quickly from self discharge than due to the power needed by the device.



With the Eneloops still maintaining about half their capacity after a year, it's now feasible to use them in such long-term applications. When they do run down, I can just insert freshly charged ones and recharge the old ones. This has enormous potential environmental benefits, since it can virtually eliminate the need for disposable batteries.

Like regular NiMH AA batteries, Eneloops are also a great choice for high-current devices like digital cameras that like to eat batteries. I recently purchased a Nikon MB-E5700 external battery pack for my Coolpix 8700 camera. This attaches to the bottom of the camera and holds six AA cells. I put a freshly charged set of Eneloops in them before our trip to Florida. One and a half months and 160 photos later, the camera's battery indicator is still

Because of their low internal resistance, Eneloops are also ideal for high-current devices. This is the battery pack for my Nikon Coolpix 8700 digital camera.

showing "full".

Eneloops are also suitable for long-running devices like this battery operated clock.

[**May 2007 Update:** I finally had to recharge the Eneloops after three months and 320 pictures.]

At this point, Eneloop technology is still relatively new. It remains to be seen how long they will last. Just because an Eneloop cell might last a year in a clock before needing recharging, and it can be recharged hundreds of times, doesn't mean it will last hundreds of years. All battery technologies wear out, even when their full capabilities are not being used. However, these **are** a form of NiMH technology, which is very reliable and stable. I have a 10 year old NiMH battery that can still achieve about 85% of its original capacity, so I have confidence in the Eneloops' longevity.

Where to Buy Them

Sanyo's Eneloop batteries are available from a number of North American retailers including Circuit City, Fry's Electronics, and the Ritz Camera Centers family of stores. They are also available on-line at Amazon.com:

- Package of 8 AA
- Package of 4 AA
- Package of 4 AA with Charger
- Package of 4 AAA
- Package of 2 AA with Compact Charger

For purchase in Europe, please see the Sanyo Component Europe web site.

Other Articles of Interest

If you found this article useful, you may also be interested in:

- USB Powered Charger for Two AA NiMH/NiCd Cells
- Handheld GPS Glareshield (or Dashboard) Mount with Power Supply

About a month after first posting this review, I received a very nice e-mail from Mr. Taetow, Vice President General Affairs at SANYO Component Europe GmbH, expressing appreciation for my independent review and addressing a few points, which I've summarized below:

1. The Eneloop batteries are sold charged, but not necessarily 100% fully charged. In Europe we charge them about 75%. I am not sure to which degree they are charged before being sold in Canada. Thus it is rather vague to estimate the discharge rate by calculating backwards to the production date. Also, the storage conditions (transport, warehouse, shop, etc.) are unknown (see point 3 below).
2. Several long term tests have shown that the self-discharge rate decreases over time. This means that Eneloop batteries discharge relatively fast at the beginning and relatively slower the longer you store them. To get real (long-term) test results, you have to store them and wait. An estimation of long-term discharge rate by extrapolating short term storage results is not correct and leads to rather poor results. This may explain the differences you have seen.
3. Storage temperature is of high importance if you measure self-discharge rate. Higher temperatures substantially increase self-discharging. It is best to store Eneloops as cool as possible to keep the charge in the battery. As a rule-of-thumb, every 10°C increase in storage temperature is equivalent to doubling the storage time. Some R/C pilots in Europe put Eneloops in the freezer, with rather good results.

In short, the Eneloops may be even better than my tests show. Without more testing, I can't confirm this, but my results show they are already far better than traditional NiMH rechargeables.

Mr. Taetow also saw my home-made USB Powered AA Charger (which can be used for Eneloops) and informed me that Sanyo is introducing their own USB powered Eneloop charger, scheduled for release on May 21, 2007.

May 2007: Comparison with Traditional NiMH Rechargeables

Over the course of the last seven weeks, I repeated the above experiments with a set of 2500mAh NiMH cells of a well respected brand. After an initial set of four cycles, these had the following characteristics:

Measurement	Four Cells	One Cell
Measured Capacity @ 1.2 A	2172 mAh	
Total Energy @ 1.2 A	9745 mWh	2436 mWh
Average Voltage Under Load	4.49 V	1.12 V
Internal DC Resistance	0.430 Ω	0.108 Ω

Characteristics of a 4-pack of AA traditional 2500mAh NiMH cells after four discharge/charge cycles, prior to a seven week rest.

Seven weeks later (less two days), I performed a discharge test and achieved the following results:

Measurement	Four Cells	One Cell
Measured Capacity @ 1.2 A	1360 mAh	
Total Energy @ 1.2 A	5647 mWh	1412 mWh
Average Voltage Under Load	4.15 V	1.04 V
Internal DC Resistance	0.499 Ω	0.125 Ω

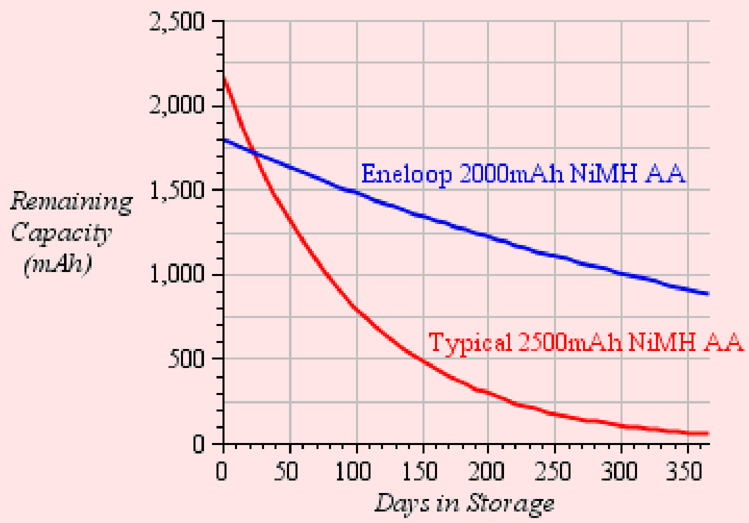
Characteristics of a 4-pack of AA traditional 2500mAh NiMH cells after a seven week rest.

This works out to a capacity retention of 62.6% (a loss of 37.4%) over the course of 47 days, which translates to the following results for differing time periods:

Time Period	Charge Retention	Charge Loss
Day	99.0%	1.0%
Week	93.3%	6.7%
Month	73.8%	26.2%
Six Months	16.2%	83.8%
Year	2.6%	97.4%

Charge retention and loss characteristics of traditional 2500mAh AA NiMH cells for various periods. (Six month and one year values are predictions.)

Although these cells start out with about 20% more capacity than the Eneloops, they lose their capacity more quickly. After only three weeks of storage, the Eneloops have more capacity remaining. After about 3½ months, the Eneloops will have twice the capacity of the traditional cells.



After only three weeks of storage, traditional 2500mAh NiMH cells will have less capacity remaining than 2000mAh Eneloops.

Last updated Tuesday June 19, 2007.

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