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Introduction

The number of portable battery operated electronic devices has grown tremendously. Consumers can be confused as to which battery to buy for these devices. This handbook will provide a better understanding of rechargeable Nickel Metal Hydride (NiMH) batteries, their use, and advantages for the consumer.

Many battery applications are well suited to be powered by NiMH rechargeable batteries. In general, devices that require large amounts of energy and are used frequently are well matched to the performance characteristics of NiMH batteries. Examples of these devices would include digital cameras, GPS units, and MP3 players.

Early AA NiCd rechargeable batteries provided approximately 25% of the capacity of alkaline non-rechargeable batteries. However, the latest AA NiMH batteries provide approximately 75% of the capacity of alkaline AA batteries at low drain rates and can surpass alkaline performance in high drain applications (i.e. digital cameras).

The true advantage of NiMH batteries can be found in the cycle life (reuse after charging). Typically NiMH batteries can be recharged hundreds of times, potentially allowing them to be equivalent to hundreds of alkaline batteries in total service over their lifetime. However, battery life is limited to 5 years or less. This can make rechargeable NiMH batteries a cost effective power source for many frequently used battery operated devices found in the home or office.

Some of the advantages of the nickel-metal hydride battery are:

- Energy density which can be translated into either long run times or reduction in the space necessary for the battery.
- Elimination of the constraints on battery manufacture, usage, and disposal imposed because of concerns over cadmium toxicity.
- Simplified incorporation into products currently using nickel cadmium batteries because of the many design similarities between the two chemistries.
- Greater service advantage over other primary battery types at low temperature extremes operating at -20°C.

Typical Applications

The nickel-metal hydride battery is currently finding widespread application in those high-end portable electronic products where battery performance parameters, notably run time, are a major consideration in the purchase decision.

History of NiMH Batteries

Nickel-metal hydride batteries are essentially an extension of the proven sealed nickel-cadmium battery technology with the substitution of a hydrogen-absorbing negative electrode for the cadmium-based electrode. While this substitution increases the battery's electrical capacity (measured in ampere-hours) for a given weight and volume and eliminates the cadmium which raises toxicity concerns, the remainder of the nickel-metal hydride battery is quite similar to the nickel-cadmium product. Many application parameters are little changed between the two battery types. (Table 1) compares key design features between battery chemistries.

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Typical Application Features	NiMH vs. Lithium Primary	NiMH vs. Alkaline
Rated Voltage	1.25V vs. 1.5V	1.25V vs. 1.5V
Discharge Capacity	NiMH will not last as long as primary lithium (single cycle)	NiMH lasts longer in high drain, less in light drain devices than alkaline
Recharge Capability	Several hundred cycles for NiMH, N/A for lithium primary	Several hundred cycles for NiMH, N/A for alkaline primary
Discharge Voltage Profile	Both relatively flat discharge	NiMH is flat vs. sloped for alkaline
Self Discharge Rate	NiMH retains 50-80% @ 12 months Lithium retains >90% @ 20 years	NiMH retains 50-80% @ 12months Alkaline retains 80% @ 10 years
Low Temperature Performance	Lithium better than NiMH	NiMH better than alkaline
Battery Weight	Lithium is lighter	Alkaline is lighter
Environmental Issues	Recycling options available for NiMH and lithium	Recycling options available for NiMH and some alkaline

Table 1 - Summary Comparison of AA-AAA Nickel-Metal Hydride, Primary Lithium and Alkaline

General Characteristics

- Typically can be recharged hundreds of times.
- Efficient at high rate discharges.
- Significantly higher capacity than nickel-cadmium batteries.
- Typical expectancy life is 2 to 5 years.
- Operates well at a wide range of temperatures:
  Charging 0° C to 50° C
  Discharging 0° C to 50° C

Battery Description

The nickel-metal hydride battery chemistry is a hybrid of the proven positive electrode chemistry of the sealed nickel-cadmium battery with the energy storage features of metal alloys developed for advanced hydrogen energy storage concepts. This heritage in a positive-limited battery design results in batteries providing enhanced capacities while retaining the well-characterized electrical and physical design features of the sealed nickel-cadmium battery design.

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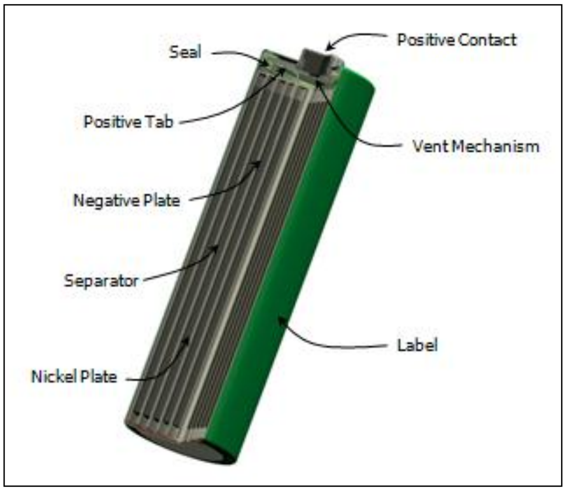
A cutaway (Fig. 1) of a typical cylindrical NiMH battery is illustrated in the following diagram:
Click here for larger view



(Fig. 1) Typical NiMH Battery

Electrochemistry:

The electrochemistry of the nickel-metal hydride battery is generally represented by the following charge and discharge reactions:

Charge
At the negative electrode, in the presence of the alloy and with an electrical potential applied, the water in the electrolyte is decomposed into hydrogen atoms, which are absorbed into the alloy, and hydroxyl ions as indicated below.

Alloy + H_2O + e` ‹› Alloy (H) + OH`

At the positive electrode, the charge reaction is based on the oxidation of nickel hydroxide just as it is in the nickel-cadmium couple.

$Ni(OH)_2$ + OH` ‹› NiOOH + $H_2O$ + e`

Discharge
At the negative electrode, the hydrogen is desorbed and combines with a hydroxyl ion to form water while also contributing an electron to the circuit.

Alloy (H) + OH` ‹› Alloy + $H_2O$ + e`

At the positive electrode, nickel oxyhydroxide is reduced to its lower valence state, nickel hydroxide.

NiOOH + H_2O + e` ‹› $Ni(OH)_2$ + OH`

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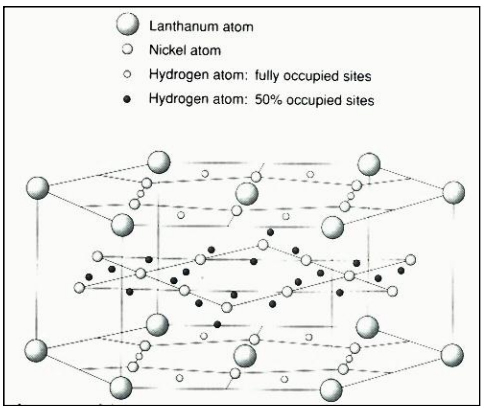
Negative Electrode

The basic concept of the nickel-metal hydride battery negative electrode emanated from research on the storage of hydrogen for use as an alternative energy source in the 1970s. Certain metallic alloys were observed to form hydrides that could capture (and release) hydrogen in volumes up to nearly a thousand times their own volume. By careful selection of the alloy constituents and proportions, the thermodynamics could be balanced to permit the absorption and release process to proceed at room temperatures. The general result is shown schematically in (Fig. 2) where the much smaller hydrogen atom is shown absorbed into the interstices of an alloy crystal structure. The metal hydride electrode has a theoretical capacity >40 percent higher than the cadmium electrode in a nickel-cadmium couple. As a result, nickel-metal hydride batteries provide energy densities that are >20 percent higher than the equivalent nickel-cadmium battery.

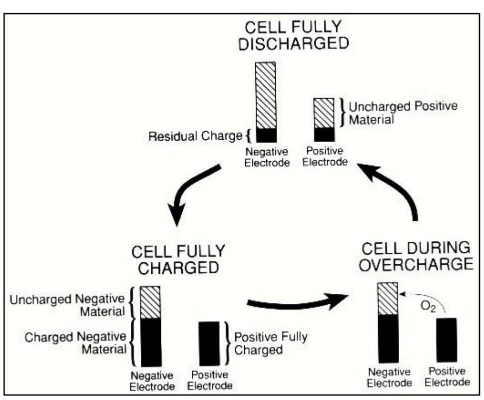


(Fig. 2) Schematic of Metal-Alloy Structure Within NiMH Negative Electrode

Positive Electrode

The nickel-metal hydride positive electrode design draws heavily on experience with nickel-cadmium electrodes. These electrodes are economical and rugged exhibiting excellent high-rate performance, long cycle life, and good capacity. The present standard NiMH positive electrode is pasted and includes a Ni-foam carrier.

The balance between the positive and negative electrodes is adjusted so that the battery is always positive-limited as illustrated in (Fig. 3). This means that the negative electrode possesses a greater capacity than the positive. The positive will reach full capacity first as the battery is charged. It then will generate oxygen gas that diffuses to the negative electrode where it is recombined. This oxygen recombination cycle is an efficient way of handling low to moderate overcharge currents.



(Fig. 3) Relative Electrode Balances During Discharge/Charge/Overcharge

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Electrolyte

The electrolyte used in the nickel-metal hydride battery is alkaline, a 20% to 40% weight % solution of alkaline hydroxide containing other minor constituents to enhance battery performance.

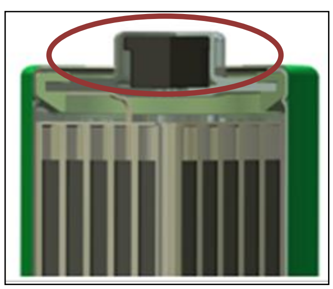
Separator

The baseline material for the separator, which provides electrical isolation between the electrodes while still allowing efficient ionic diffusion. Typically this is a non-woven polyolefin.

Battery Construction

The nickel-metal hydride couple lends itself to the wound construction shown in (Fig. 1), which is similar to that used by cylindrical nickel-cadmium, LI ion and primary lithium batteries. The basic components consist of the positive and negative electrodes insulated by separators. The sandwiched electrodes are wound together and inserted into a metallic can that is sealed after injection of electrolyte.

Nickel-metal hydride batteries are typically sealed designs with metallic cases and tops that are electrically insulated from each other. The case serves, as the negative terminal for the battery while the top is the positive terminal. Finished battery designs may use a plastic insulating wrapper shrunk over the case to provide electrical isolation between cells in typical battery applications. Nickel-metal hydride batteries contain a resealable safety vent built into the top, as shown in (Fig. 4). The nickel-metal hydride battery is designed so the oxygen recombination cycle described earlier is capable of recombining gases formed during overcharge under normal operating conditions, thus maintaining pressure equilibrium within the battery. However, in cases of extended overcharge or incompatible battery/charger combinations for the operating environment, it is possible that oxygen, and hydrogen, will be generated faster than it can be recombined. In such cases the safety vent will open to reduce the pressure and prevent battery rupture. The vent reseals once the pressure is relieved. The expulsion of gas thru the resealable vent can carry electrolyte, which may form crystals or rust once outside the can.



(Fig. 4) Picture of Resealable Vent Mechanism

Discharging Characteristics

The discharge behavior of the nickel-metal hydride battery is generally well suited to the needs of today's electronic products - especially those requiring a stable voltage for extended periods of operations, or high rate discharge.

Definitions of Capacity

The principal battery parameter of interest to a product designer is usually the run time available under a specified equipment use profile. While establishing actual run times in the product is vital prior to final adoption of a design; battery screening and initial design are often performed using rated capacities. Designers should thoroughly understand the conditions under which a battery rating is established and the impact of differences in rating conditions on projected performance. The standard battery rating, often abbreviated as C, is the capacity obtained from a new, but thoroughly conditioned battery subjected to a constant-current discharge at

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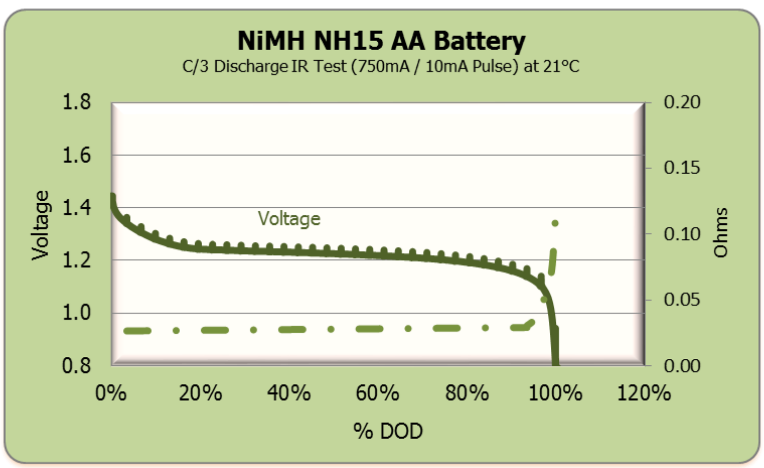
room temperature after being optimally charged. Since battery capacity varies inversely with the discharge rate, capacity ratings depend on the discharge rate used. For nickel-metal hydride batteries, the rated capacity is normally determined at a discharge rate that fully depletes the battery in five hours. Up to five cycles are allowed to reach full capacity.

Many charge and discharge parameters are normalized by the C rate since battery performance within a family of varying battery sizes and capacities is often identical when compared on the C basis.

Internal Resistance

NiMH batteries have a relatively low internal resistance (IR) due to the wound construction, enhanced contacts and large surface area of the electrodes. The low battery IR allows NiMH batteries to have excellent high rate performance. The IR of fresh, fully charged NiMH batteries is typically less than 50 milliohms. During discharge, the battery IR will stay relatively constant until near end of life where it will rise sharply.

The graph below (Fig. 5) shows the calculated IR (change in voltage ÷ change in current) during a 750 mA discharge with a 10 mA pulse every 6 minutes. The IR of NiMH batteries will increase with age and use. This would typically be seen in a lower operating voltage as well as a higher voltage during charge. IR is also increased as you cycle the battery based on age and use.



(Fig. 5) Calculated IR

Voltage During Discharge

The discharge voltage profile, in addition to the transient effects discussed above, is affected by environmental conditions, notably discharge temperature and discharge rate. However, under most conditions the voltage curve retains the flat plateau desirable for electronics applications.

Shape of Discharge Curve

A typical discharge profile for a battery discharged at the 5-hour rate (the 0.2C rate) is shown in (Fig. 6). The initial drop from an open-circuit voltage of approximately 1.4 volts to the 1.2 volt plateau occurs rapidly.

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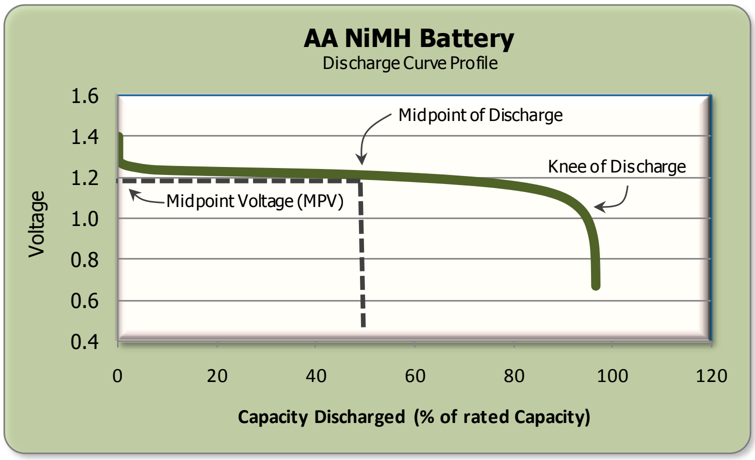
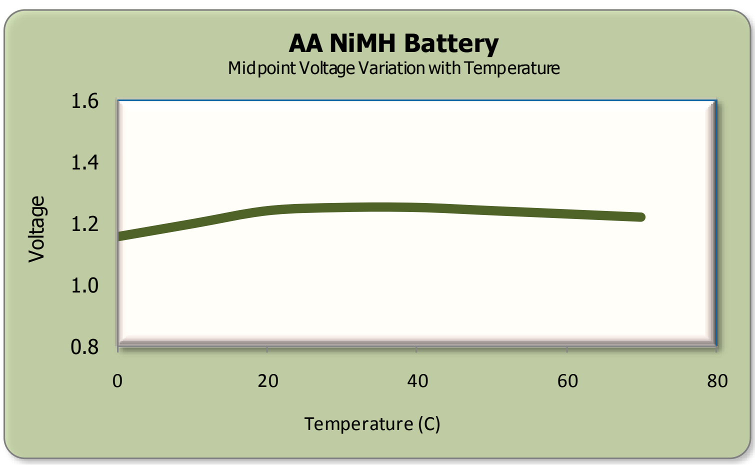


(Fig. 6) Typical Discharge Profile / NiMH Battery

Similar to lithium AA primary batteries, the nickel-metal hydride battery exhibits a sharp "knee" at the end of the discharge where the voltage drops quickly. As can be seen by the flatness of the plateau and the symmetry of the curve, the mid-point voltage (MPV - the voltage when 50 percent of the available capacity is discharged) provides a useful approximation to average voltage throughout the discharge.

Environmental Effects

The principal environmental influences on the location and shape of the voltage profile are the discharge temperature and discharge rate. As indicated in (Fig. 7), small variations from room temperature (± 10^{o}C) do not appreciably affect the nickel-metal hydride battery voltage profile. However major excursions, especially lower temperatures, will reduce the mid-point voltage while maintaining the general shape of the voltage profile.



(Fig. 7) Midpoint Voltage Variation with Temperature

The effect of discharge rate on voltage profile is shown in (Fig. 8). There is no significant effect on the shape of the discharge curves for rates under 1C; for rates over 1C; both the beginning and ending transients consume a larger portion of the discharge duration.

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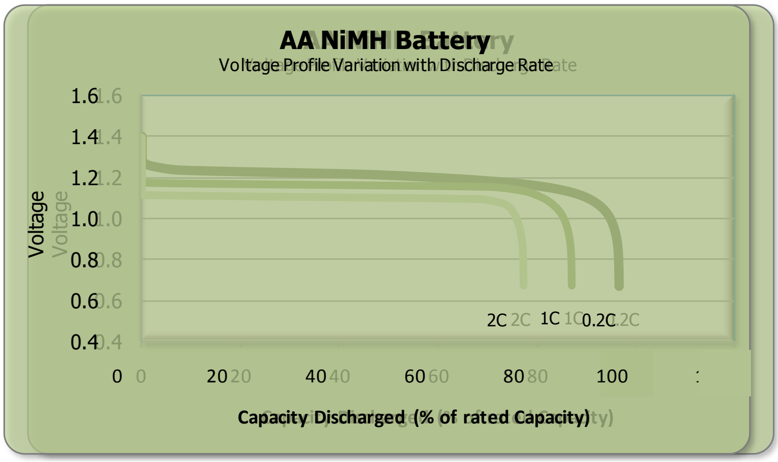


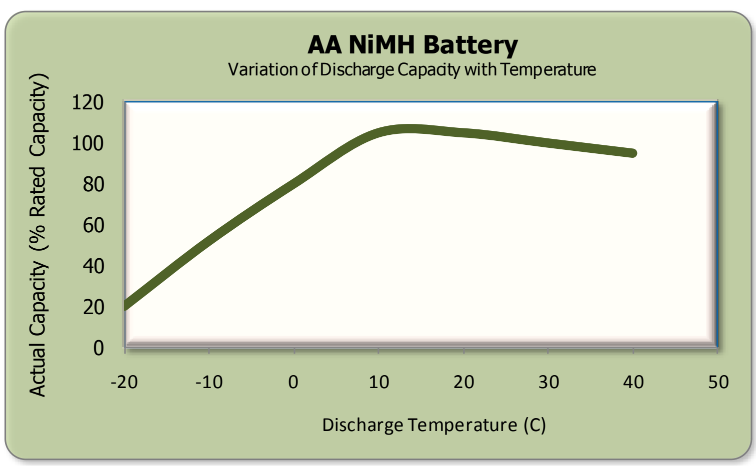
(Fig. 8) Voltage Profile Variation with Discharge Rate

Discharge Capacity Behavior

As with the voltage profile, the capacity available during discharge is dramatically affected by the battery temperature during discharge and the rate of discharge. The capacity is also heavily influenced by the history of the battery, i.e. the charge/discharge/storage history of the battery. A battery can only discharge the capacity which has been returned to it from the previous charge cycle less whatever is lost to self discharge.

Effect of Temperature

The primary effects of battery temperature on dischargeable capacity, assuming adequate charging, are at lower temperatures (<0°C) as shown in (Fig. 9). Use of nickel metal hydride batteries in cold environments may force significant capacity derating from room-temperature values.



(Fig. 9) Variation of Discharge Capacity with Temperature

(Fig. 10) illustrates the influence of discharge rate on total capacity available. There is no significant effect on capacity for discharge rates below 1C. At discharge rates above 1C and below the current maximum discharge rate of 4C, significant reductions in voltage delivery occur. This voltage reduction may also result in capacity reduction depending on the choice of discharge termination voltage.

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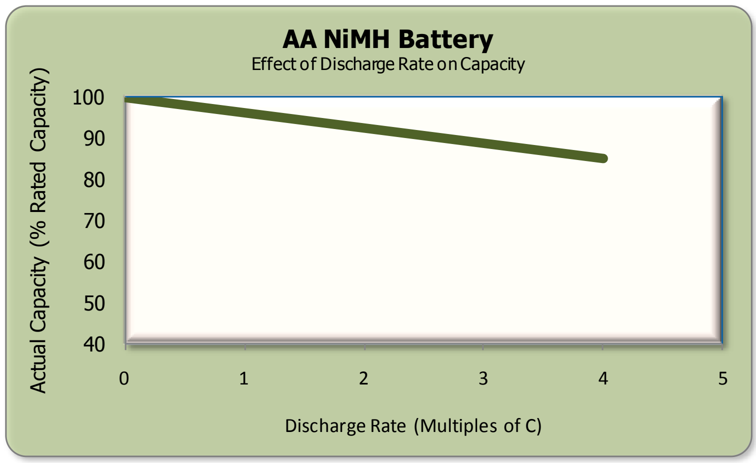

(Fig. 10) Effect of Discharge Rate on Capacity

State-of-Charge Measurement

A major question for users of portable electronics is the run time left before they need to recharge their batteries. Users want some form of "fuel gauge" to help them determine when they need to charge again. A variety of schemes for measuring state-of-charge have been suggested. The flatness of the voltage plateau under normal discharge rates, and due to dependence on cycles and time parameters, voltage sensing cannot be used to accurately determine state-of-charge.

To date, the only form of state-of-charge sensing found to consistently give reasonable results is coulometry—comparing the electrical flows during charge and discharge with self discharge compensation to indicate the capacity remaining.

Memory/Voltage Depression

Again, this is no longer a concern. The issue of "memory" or voltage depression was a concern for many designers of devices, using nickel-cadmium batteries. In some applications where nickel-cadmium batteries are routinely partially discharged, a depression in the discharge voltage profile of approximately 150 mV per battery has been reported when the discharge extends from the routinely discharged to rarely discharged zones. While the severity of this problem in nickel-cadmium batteries is open to differing interpretations, the source of the effect is generally agreed to be in the structure of the cadmium electrode. With the elimination of cadmium in the nickel-metal hydride battery, memory is no longer a concern.

Discharge Termination

To prevent the potential for irreversible harm to the battery caused by battery reversal in discharge, removal of the load from the battery prior to total discharge is highly recommended. The typical voltage profile for a battery carried through a total discharge involves a dual plateau voltage profile as indicated in (Fig. 11). The voltage plateaus are caused by the discharge of first the positive electrode and then the residual capacity in the negative. At the point both electrodes are reversed, substantial hydrogen gas evolution occurs, which may result in battery venting as well as irreversible damage.

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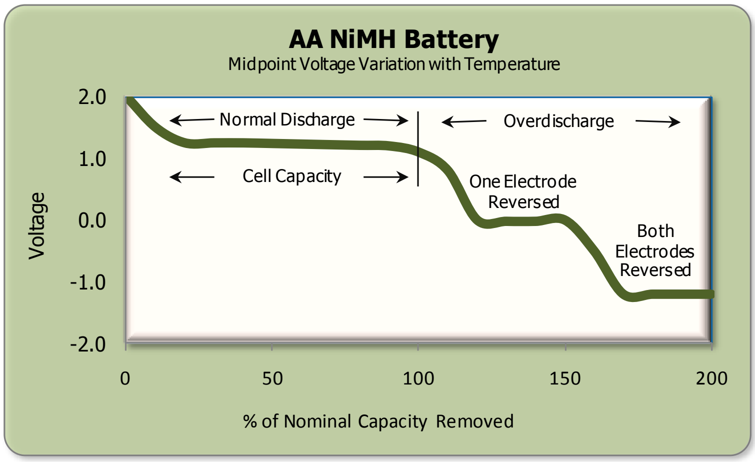

(Fig. 11) Nickel-Metal Hydride Battery Polarity Reversal Voltage Profile

A key to avoiding harm to the battery is to terminate prior to reaching the second plateau where damage may occur. Two issues complicate the selection of the proper voltage for discharge termination: high-rate discharges and multiple-cell applications.

Voltage Cutoff at High Rates

Normally discharge cutoff is based on voltage drops with a value of 0.9 volts per battery (75 percent of the 1.2 volt per battery nominal mid-point voltage) often being used. 0.9 volts is an excellent value for most medium to long-term discharge for individual battery applications (<1C). However, with high drain-rate usage (1-4C), the change in shape in the voltage curve with the more rounded "knee" to the curve means that an arbitrary 0.9V/battery cutoff may be premature, leaving a significant fraction of the battery capacity untapped. For this reason, a better choice for voltage cutoff in high-rate applications is 75 percent of the mid-point voltage at that discharge rate. Note, however, that this choice of end-of-discharge voltage (EODV) is dictated only by considerations of preventing damage to the battery.

There may be end-application justification for selection of a higher voltage cutoff with the resulting sacrifice of some potential additional capacity.

Cycle Life

Many factors can affect NiMH (charge / discharge) cycle life. Some of these factors do include battery capacity, temperature, depth of discharge, design materials, charge and discharge current, exposure to overcharge and over discharge, storage conditions, and age. Some of these factors can cause gas generation within the battery which can lead to activation of the safety vent and subsequent permanent deterioration of the battery. Under ideal controlled conditions, up to one thousand cycles can be obtained with NiMH batteries. However, in real world use, the factors mentioned above can have a negative impact on the number of total cycles that may be experienced.

Charging Characteristics

Proper charging of nickel-metal hydride batteries is a key factor to satisfaction with performance. Successful charging balances the need for quick, thorough charging with the need to minimize overcharging, a key factor in prolonging life. In addition, a selected charger should be economical and reliable in use. See charger manual for additional information on charging techniques and termination.

In general, the nickel-metal hydride battery is more sensitive to charging conditions than the nickel-cadmium battery. Under charging can cause low service where overcharging can cause loss of cycle life.

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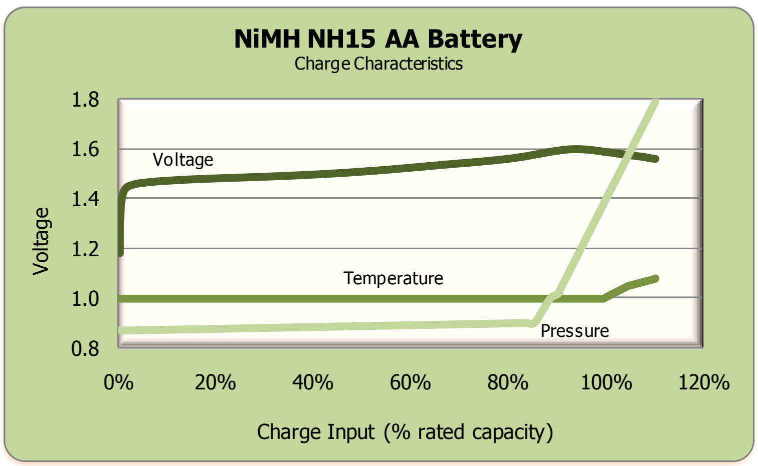
Nickel-metal hydride batteries operate on an exothermic, hydrogen-based charging and oxygen recombination process. Precautions should be taken to avoid venting. Should venting occur, the vent gases must be properly managed.

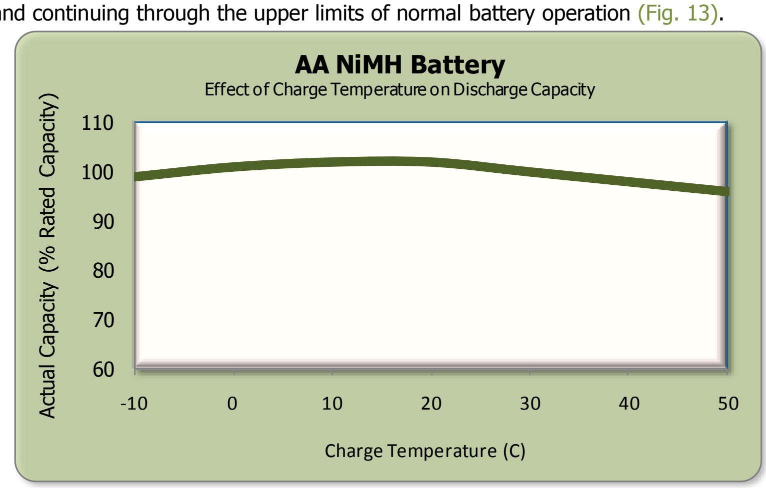
(Fig. 12) sketches typical behavior of a nickel-metal hydride battery being charged at the C rate. These curves both indicate why charge control is important and illustrate some of the battery characteristics used to determine when charge control should be applied.

The voltage spikes up on initial charging then continues to rise gradually through charging until full charge is achieved. Then as the battery reaches full charge, the voltage peaks and then gradually trends down. Since the charge process is exothermic, heat is being released throughout charging giving a positive slope to the temperature curve. When the battery reaches overcharge where the bulk of the electrical energy input to the battery is converted to heat, the battery temperature increases dramatically. Battery pressure, which increases somewhat during the charge process, also rises dramatically in overcharge as greater quantities of gas are generated at the C rate than the battery can recombine. Without a safety vent, uncontrolled charging at this rate could result in physical damage to the battery.



(Fig. 12) Increasing Battery Pressure

Charge acceptance in the nickel-metal hydride battery decreases with rising temperature beginning below 20°C and continuing through the upper limits of normal battery operation (Fig. 13).



(Fig. 13) Effect of Charge Rate on Charge Acceptance

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Recommended Charging Rates

Typically a moderate rate (2 to 3 hour) smart charger is preferred for NiMH batteries. The batteries are protected from overcharge by the smart charger circuitry. Extremely fast charging (less than 1 hour) can impact battery cycle life and should be limited to an as needed basis. Slow overnight timer based chargers are also acceptable and can be an economical alternative to smart chargers. A charger that applies a 0.1 C rate for 12 to 14 hours is well suited for NiMH batteries. Finally a maintenance (or trickle) charge rate of less than 0.025 C (C/40) is recommended. The use of very small trickle charges is preferred to reduce the negative effects of overcharging.

Storage

This guidance is not intended for bulk transportation or bulk storage of NiMH batteries.

Essentially all batteries gradually discharge over time whether they are used or not. This capacity loss is typically due to slow parasitic reactions occurring within the battery. As such, the loss rate (self-discharge rate) is a function of the battery chemistry and the temperature environment experienced by the battery. Due to the temperature sensitivity of the self-discharge reactions, relatively small differences in storage temperature may result in large differences in self-discharging rate. Extended storage with a load connected not only speeds the discharge process, but may also cause chemical changes after the battery is discharged, which may be difficult or impossible to reverse.

Battery storage issues of concern to most consumers relate either to the speed with which the cells lose their capacity after being charged or the ability of the cells to charge and discharge "normally" after storage for some period of time

Self Discharge

NiMH batteries will self discharge due to slow internal electrochemical reactions that continually take place within batteries. These reactions gradually drain the battery over time. NiMH batteries will typically retain approximately 50% to 80% of their capacity after 12 months of storage. NiMH batteries that are stored at high temperatures will self discharge faster due to the increased reaction rates caused by the elevated temperature.

Recommended Storage Conditions for Maximum Battery Performance

- Store at the lowest feasible temperatures (-20°C to 30°C being the generally recommended storage temperatures).
- Store batteries open-circuit to eliminate loaded storage effects (see next page).
- Store in a charged condition (except for large bulk volumes).
- Store in a clean, dry, protected environment to minimize physical damage to batteries.
- Use good inventory practices (first in, first out) to reduce time batteries spend in storage.

Capacity Recovery After Storage

In normal practice, stored batteries will provide full capacity on the first discharge after removal from storage and charging with standard methods. Batteries stored for an extended period or at elevated temperatures may require more than one cycle to attain pre-storage capacities. Consultation with the manufacturer is recommended if prolonged storage and rapid restoration of capacity is planned.

Consumer usage batteries intended for storage for extended periods of time (past the point where they are fully discharged) should be removed from the device. In particular, many portable electronic devices place a very low-level drain requirement on their batteries even when in the "off" position. These micro-current loads may be sustaining volatile memory, powering sense circuits or even maintaining switch positions. Such loads should be eliminated when storing batteries for protracted periods. When nickel-metal hydride batteries are stored under load, small quantities of electrolyte can ultimately begin to seep around the seals or through the vent. This creep leakage may result in the formation of crystals of potassium carbonate, which detract cosmetically from the appearance of the battery. In extreme cases, creep leakage can result in corrosion of batteries, or the device components. Although such occurrences are rare, positive methods of electrically isolating the battery, such as an insulating tape over the positive terminal or removal from the device are suggested for applications requiring extended storage of batteries.

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Factors Affecting Life

The way the nickel-metal hydride battery is used by consumers can have dramatic effects on the life of the battery. This is especially true of the choice of the charger to ensure adequate return of charge while minimizing overcharge. In fact, effective control of overcharge exposure, time and charge rate is the way of enhancing battery life. Expected battery life is two to five years.

Degree of Overcharge
Establishing the appropriate degree of overcharge for a battery-powered application is dependent on the usage scenario. Some overcharge of the battery is vital to ensure that all batteries are fully charged and balanced, but maintenance of full charge currents for extended periods once the battery has reached full charge can reduce life.

Exposure to High Temperatures
In general, higher temperatures accelerate chemical reactions including those, which contribute, to the aging process within the battery. High temperatures are a particular concern in the charging process as charge acceptance is reduced. Sensing the transition from charge to overcharge is also more difficult at higher temperatures.

Battery Reversal
Discharge of nickel-metal hydride batteries to the degree that some or all of the batteries go into reverse can shorten battery life, especially if this over discharge is repeated routinely.

Prolonged Storage under Load
Maintaining a load on a battery past the point of full discharge may cause irreversible changes in the battery chemistry and promote life-limiting phenomena such as creep leakage.
Limiting Mechanisms
The life of any battery is determined by a combination of abrupt failure events and gradual battery deterioration. With the nickel-metal hydride battery, abrupt failures, typically mechanical events resulting in the battery either shorting or going open-circuit, are relatively rare and randomly distributed. Battery deterioration can take two forms:

- Oxidation of the negative active material that increases battery internal resistance resulting in reduction of available voltage from the battery (mid-point voltage depression). This also affects the balance between electrodes within the battery and may possibly result in reduced gas recombination, increased pressure, and ultimately, battery venting.

- Deterioration of the positive active material results in less active material being available for reaction with the consequent loss of capacity.

Both phenomena result in a loss of usable capacity, but pose differing design issues. Mid-point voltage depression requires that the application design be able to adapt to variations in supply voltage from cycle to cycle. Capacity reduction simply requires that initial battery selection be sized to provide adequate capacity at end-of-life for the desired number of batteries.

The actual mechanism that will determine battery life may vary depending on application parameters and the battery characteristics. Development work has reduced oxidation in the negative electrode reducing the depression in mid-point voltage as the battery ages.

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Materials of Construction
The materials of construction for the nickel-metal hydride battery external surfaces are largely comprised of nickel-plated steel, and therefore, are resistant to attack by most environmental agents.

Orientation
The device can be designed with nickel-metal hydride batteries in any orientation as long as proper polarity is observed.

Temperature
Like most other batteries, nickel-metal hydride batteries operate optimally in a near-room-temperature environment (25°C); however, with careful attention to design parameters, they remain functional even when exposed to a much wider range of temperatures.

Operating
Nickel-metal hydride batteries can be used in temperatures from 0 to 50°C with appropriate derating of capacity at both the high and low ends of the range. Design charging systems to return capacity in high or low temperature environments without damaging the battery. Overcharge requires special attention.

Household Storage
Consumer use household batteries are best stored in temperatures from 0 to 30°C although storage for limited periods of time at higher temperatures is feasible. (Not for bulk transportation or storage)

Shock and Vibration
Nickel-metal hydride batteries can withstand the normal shock and vibration loads experienced by portable electronic equipment in day-to-day handling and shipping.

Battery Cavity Design (Not for bulk transportation and storage)
The primary gases emitted from the nickel-metal hydride battery when subjected to excessive overcharge or over-discharge is hydrogen and oxygen. Although venting of gas to the outside environment should not occur during typical use, isolation of the battery compartment from other electronics (especially mechanical switches that might generate sparks) and provision of adequate ventilation to the compartment are required to eliminate concerns regarding possible hydrogen ignition. Battery compartment should not be air tight. Isolation of the battery from heat-generating components and ventilation around the battery will also reduce thermal stress on the battery and ease design of appropriate charging systems.

Care and Handling

This guidance is not intended for bulk transportation or bulk storage of NiMH batteries.

Nickel-metal hydride batteries for consumer use and device designs should be handled with care.

General Safety Precautions for Device Design

Nickel-metal hydride batteries are safe; however, like any battery, they should be treated with care. Issues in dealing with nickel-metal hydride batteries include the following:

- For devices with tightly sealed or water proof battery compartments, hydrogen gas generation under normal or abusive conditions needs to be addressed as a potential safety issue to prevent the accumulation of dangerous levels of hydrogen gas within the device.
- Nickel metal hydride batteries can generate high currents if shorted. These currents are sufficient to cause burns or ignition of flammable materials.
- The active materials in the negative electrode can ignite on exposure to air. They electrolyte is also corrosive and capable of causing chemical burns. For these reasons, the battery should be maintained intact.

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Disposal and Recycling

This guidance is not intended for bulk transportation or bulk storage of NiMH batteries.

Contact your local waste disposal management authority for guidelines concerning NiMH disposal. Each community can have their own procedures which need to be followed. A few basic Energizer guidelines are:

- Discharge fully prior to disposal.
- Do not incinerate.
- Do not open or puncture batteries.
- Observe all national, state, and local rules and regulations for disposal of rechargeable batteries.

Recycling

Through a national program, Call2Recycle™, the Rechargeable Battery Recycling Corporation (RBRC) can help you recycle your used portable rechargeable batteries and old cell phones. RBRC can be contacted at 1-800-8-BATTERY or at http://www.rbrc.org/call2recycle

Shipping/Transportation Guidelines

This guidance is not intended for bulk transportation or bulk storage of NiMH batteries.

Please contact Energizer for further details and recent guidelines at
1-800-383-7323 USA/CAN - http://www.energizer.com/pages/enr-contact.aspx