The Care & Feeding of NiCd Batteries

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How they work and how to use them correctly

NICKEL-CADMIUM batteries are becoming ever more popular in cordless consumer products and electronics building. Although initial cost may seem to be high, nickel-cadmium cells can be recharged so often that their per-unit-of-use performance actually makes them less expensive than almost any other type of battery in the long run. Aside from rechargeability and reasonable cost, these batteries can often directly replace ordinary disposable carbon-zinc cells.

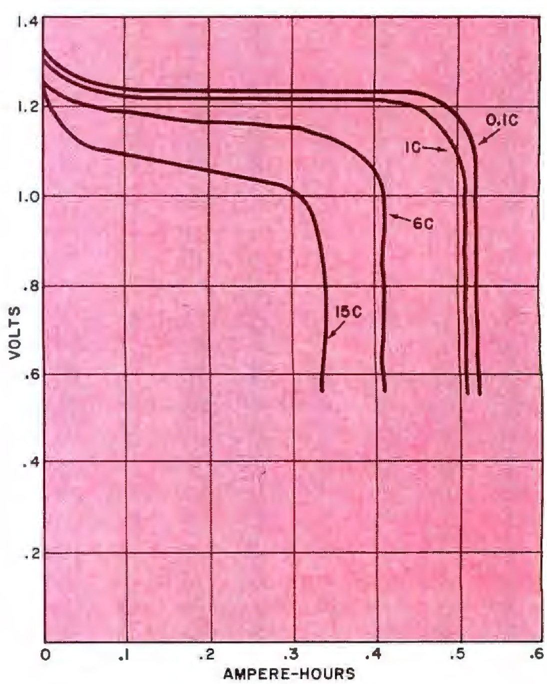
Just as there are differences between bipolar and field-effect transistors (although they are both transistors), there are basic differences between nickel-cadmium cells and other types. Indeed, there are different types of nickel-cadmium batteries, too. Just what are the differences? How do nickel-cadmium batteries work? And where are they best put to use? These and other questions will be explored.

General Details. The energy that a nickel-cadmium battery supplies is stored in the chemical compounds formed in the cell. The active material in the cell is nickel hydroxide in the positive plate and metallic cadmium in the negative plate. During discharge, the cadmium metal supplies electrons to the external circuit and becomes oxidized to cadmium hydroxide, while the nickel hydroxide accepts electrons from the circuit and goes to a lower valence state. The reverse process occurs during the recharging.

Both processes take place in an electrolyte of potassium hydroxide. The cell has a long useful life because the active plates remain as solids and do not dissolve while undergoing charging and discharging. During overcharge, when both plates have all their active metal storing as much energy as they can, gaseous oxygen is released at the positive and gaseous hydrogen at the negative plates.

The manner in which the gases are handled distinguishes the two major types of nickel-cadmium batteries from each other. In *vented* cells, the gas is simply released into the outside air. However, not just gas is released; so is some of the water from the cell. Consequently, more water must be added to the cell eventually, creating a maintenance problem.

The maintenance problem is eliminated in *sealed* cells, but at the price of lower energy density and higher internal resistance. The cells must be cap-



Discharge characteristics for a typical AA cell. They apply, in general, to other NiCd cells also.

TABLE I—TYPICAL CHARACTERISTICS

Size	Capacity (AH)	Internal Resistance (milliohms)	Max. Charge Rate (mA)	1C Rate (A)
AA	0.5	35	50	0.5
C	1.0	10	100	1
D	1.2	7	100	1.2
D*	4.0	5	350	4

*High power.

able of sustaining an overcharge because there is no convenient way of determining when they are fully charged (and also because people who use rechargable cells tend to forget to turn off the chargers).

In sealed cells, the gas problem is solved by making the negative plate's capacity higher than that of the positive plate. When the positive plate is fully charged and releasing oxygen, the negative plate has not yet come up to full charge. The oxygen is permitted to migrate over to the negative plate, where it combines with that plate and prevents it from further charging. Thus, hydrogen gas is never released, and the oxygen is completely used up. This procedure can continue indefinitely as long as it proceeds slowly enough to allow the oxygen time to get to the negative plate. Most sealed cells have an emergency high-pressure relief valve to prevent a heavily overcharged cell from bursting.

For the purposes of this article, our discussion will be limited to the sealed type of nickel-cadmium cell. It is this type of cell that is in most use in electronics.

Sizes and Capacities. There are several varieties of sealed cells. Some are designed to operate over wider temperature ranges than others, some have larger capacities, and others permit faster charging rates. However, all nickel-cadmium cells of the sealed variety are very similar in the general details of their care and use.

The most popular sizes of nickel-cadmium cells and some of their characteristics are listed in Table I. The information given here is very useful, but it does require some clarification. While the AH (ampere-hour) figures listed under "Capacity" might imply that any product of current in amperes and time in hours will yield the correct AH figure for a given cell, this is not strictly the case. A number of variables (like temperature, end voltage, current, and duty cycle) have an effect on the number used to represent the capacity of a cell. Fortunately, these effects are usually very small and can be ignored.

A procedure often used for measuring capacity is to select 0.5 V as the potential at which the cell is declared fully discharged and then select a current that will discharge the cell in one hour. This is termed the 1-hour rate and that current is called the 1C rate, which is the rate to which all other rates are referred.

The AA cell in Table I has a 0.5-AH capacity, which means that the terminal potential will be 0.5 V after a 1-hour drain at the rate of 500 mA. The 1C rate in this particular case is 500 mA. Ideally, this figure would mean that (for example) you could get 1A from the cell for a half hour before the potential drops to 0.5 V. But, as we shall see, this is not quite correct.

If you selected 1 V as the cutoff potential (the voltage at which the cell is considered to be completely discharged), you would expect to obtain less energy from the cell than if cutoff was at 0.5 V. Furthermore, 1 V appears to be a more practical cutoff point than 0.5 V. So, why not use 1 V? The answer is that the voltage characteristics of the cells are such that the 0.5-V figure produces a more reliable number than does a higher cutoff voltage.

Information on how a higher discharge rate and higher cutoff voltage affect the capacity of a typical nickel-cadmium cell is given in Table II. As an example of how to use this table, consider an AA cell that is to supply 5 A until its terminal potential is reduced to 1 V. From Table I, the discharge rate for an AA cell is 500 mA. Therefore, our rate is 10C. Moving along the 10C row in Table II until we get to the 1.0-V column, we find that, at a 10C discharge rate to 1.0 V, 10% of the cell's capacity is not available. We can expect to get only 0.45 AH (about 5 minutes of energy at this high rate) from the cell under these conditions. Because Table II is given in terms of multiples of the 1C rate, it can be used with all sizes of sealed nickel-cadmium cells. The table clearly shows that you can use nickel-cadmium cells at a 10C rate to an end potential of 1.0 V with very little reduction in capacity.

Discharge Characteristics. One of the welcome characteristics of nickel-cadmium cells is their excellent discharge characteristic. Their terminal potential remains a fairly steady 1.2 V until the cell is almost completely discharged, after which it drops off rapidly. The details of the discharge characteristics for an AA cell are shown in the diagram (previous page), which displays the voltage versus AH delivered at various discharge rates. While the plots are for a typical AA cell, they also give the main characteristics of the discharge curves for any sealed nickel-cadmium cell.

Note from the graph that the terminal potential reduces to 0.5 V when the cell has delivered 0.5 AH at the 1C rate. (Because the 1C rate is 500 mA for the AA cell, this will take 1 hour). At the 0.1C rate, which is 50 mA for an AA cell, you will obtain about 0.525 AH, or somewhat more than 10 hours of use because the cell will deliver more power at that slower rate. Similar calculations can be made from the curves for the other cells listed in Table I. The main feature illustrated by the curves is that the terminal voltage of any cell is about 1.2 volts for most of the time it is supplying (a wide range of) current.

TABLE II—INACCESSIBLE CELL CAPACITY AS A PERCENTAGE OF TOTAL CAPACITY TO 0.5 VOLT

Discharge Rate	Cutoff Voltage (V)		
	0.5	1.0	1.1
0.1C	0	3	5
1C	0	3	5
2C	0	4	7
5C	0	5	9
10C	0	10	30-40

Charging Characteristics. Sealed nickel-cadmium cells can be charged under a wide variety of conditions, but the chemical processes do place some limitations on the charging process. A little oxygen is generated at the positive electrode during charge and a lot during overcharge. This oxygen puts both an upper and a lower limit on the charge rate.

Sealed cells are designed to get rid of the oxygen generated during overcharge as quickly as it is generated, as long as the charge rate is kept below 0.1C, which means that current at the rate of 0.1C or lower can be supplied indefinitely to the cell. Higher current rates—up to 20C in special applications—can be accommodated as long as the positive plate of the sealed cell is not overcharged. It is difficult (but not impossible) to tell just when overcharging sets in. (Fast-rate chargers are complicated and expensive to build, which precludes them from this discussion.)

The amount of oxygen generated before the cell is fully charged is small, but it does compete with the desired oxidation of the nickel hydroxide. It is this reaction that defines the minimum charge current that will effectively charge a cell. A charge rate lower than 0.01C results in more current being used to generate oxygen than is used to convert the active material. Hence, currents smaller than 0.01C produce little increase in the charge contained in the cell.

Most chargers supply current at the 0.1C rate. This represents the rate that will recharge the ordinary cell in the least possible time without endangering the life of the battery if accidentally left connected for a long time. It is important to note that, while current at the 1C rate will discharge the cell in 1 hour, more than 10 hours are required to charge it at the 0.1C rate. The oxygen generated and losses in the cell's internal resistance are two reasons. In general, at the 0.1C rate, one must put in about 140% of the energy that the cell can store before a completely discharged cell can be considered fully charged.

There are several other facts about charging nickel-cadmium cells that are useful to know. If you charge at a 1C rate, only about 120% of the cell's capacity can be supplied before overcharging commences. If a 0.05C rate is used, the cell will be difficult to charge above 75% of its capacity. Allowing the temperature of the cell to reach about 50° C will cause difficulties when attempting to charge above 75% of capacity, even with a charge rate of 0.1C. Full charge is assured at 25° C. At very low temperatures, like 5° C, some hydrogen is generated at the negative plate of the cell during charging. There is no rapid recombination reaction to rid the cell of this gas, so it tends to increase the pressure inside the cell. If the cell must be recharged at low temperatures, the only way to overcome this problem is to derate the maximum permissible overcharge rate to 0.02C at −20° C.

Failure Modes. Because nickel-cadmium cells use active materials that are highly insoluble in their alkaline electrolyte, failure modes are few. Most sealed cells are guaranteed for 500 to 1000 charge/discharge cycles. This might appear to be a limited number, but when you consider 1000 cycles at a rate of two cycles per week, these cells will last 10 years.

In the case of sealed cells, the quality of materials used in making them has a marked effect on their useful life. Although failures are rare, they do occur (catastrophically) for two major reasons: internal shorts and loss of electrolyte.

Internal shorts develop when time and temperature cause decomposition of the materials that separate the positive and negative plates of the cell. Shorts are generally a low-charge phenomenon.

Loss of electrolyte reduces the capacity of the cell and increases its internal resistance. The electrolyte is usually lost in some combination of two ways. Even the best of hermetic seals will allow some hydrogen and oxygen to escape. In the case of high-quality seals, 10 years or more will elapse before an appreciable amount of electrolyte is lost. If the cell is abused by excessive overcharging or reverse charging, excessive gas in the cell will cause the safety valve to vent the excess pressure into the atmosphere. Needless to say, the hermetic seal is now broken and evaporation of the electrolyte will be much faster. Even if the safety valve is resealable (quite common), a significant amount of vapor will escape with the excessive pressure and eventually cause the cell to dry out with continued venting.

There are also non-catastrophic failures common to nickel-cadmium cells. These, however, are reversible so that the cell can be restored to full capacity.

One reversible failure mode is due to long and continued overcharging (as when a standby power supply is kept on float charge for a month or more without discharging it). The effect is accentuated by high temperatures. The second reversible failure mode appears in cells used in a regular cycle. If a group of cells is regularly called upon to deliver, say, 25% of their full capacity and then recharged, they will eventually "memorize" that only 25% of capacity will be required of them and become incapable of supplying the remaining 75% of capacity. This phenomenon is most likely to occur if a cell is rarely overcharged, the rate of discharge is great, and/or the temperature is high.

Non-catastrophic failures can be reversed by completely discharging the cell at a low discharge rate and then recharging it at a 0.1C rate for 20 hours at 25° C (80° F). One or two reconditioning cycles like this are generally all that is needed to restore a cell to its full capacity.

Storage Characteristics. Sealed nickel-cadmium cells readily lend themselves to prolonged storage, whether in a partially or fully charged state or completely discharged. If stored in a charged state, the cell will self-discharge, at a rate that depends on cell design and storage conditions. In general, a cell will lose about 1% of its charge per day so that at the end of about three months an initially fully charged cell will be completely discharged. If stored at high temperatures (50° C or higher), the cell will lose up to 5% of its charge per day, with the charge lasting less than a month.

The lack of a charge in a cell when it is put into storage has no effect on the cell's life. The cell can be put back into service after one or two charge/discharge cycles. Over a wide range of temperatures (−50° C to 50° C), nickel-cadmium cells can be stored for years with no significant degradation in performance.

Closing Comment. Sealed nickel-cadmium cells have a number of outstanding characteristics that make them good first choices for everyday use. They are reusable, permitting up to 1000 charge/discharge cycles. Their terminal voltage during discharge holds relatively constant. And they require no special care.

There are, of course, some minor disadvantages. High initial cost is one, although it is counterbalanced by the fact that the cells are reusable. Another is that the typical nickel-cadmium cell, when compared with the same-size carbon-zinc cell, has a lower capacity and a lower terminal voltage (1.2 V as opposed to 1.5 V for the carbon-zinc cell). The balance, however, is in the nickel-cadmium cell's favor when it comes to long life, convenience of use, and reliability. ◈