The Care & Feeding of NiCd Batteries

BY ALEX BURR

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.

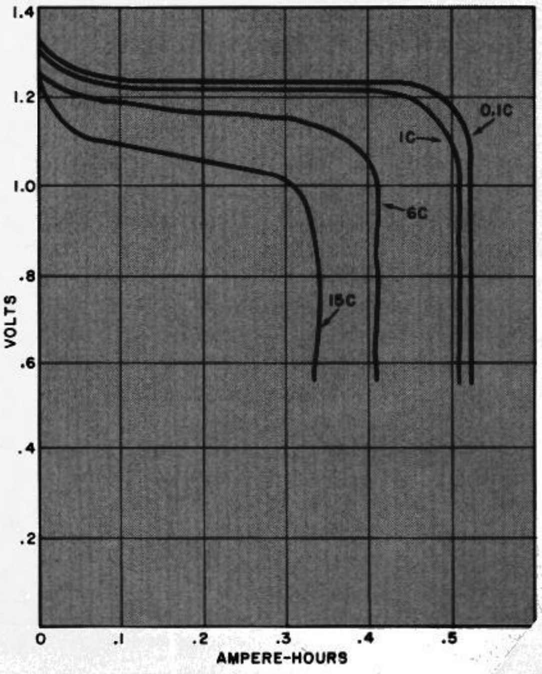
Just as there are differences between bipolar and field-effect transistors (although they are both transistors), there are basic differences between nickel-cadmium cells and other types. Indeed, there are different types of nickel-cadmium batteries, too. Just what are the differences? How do nickel-cadmium 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. ◆

Ni-Cads

Rechareable NiCad Batteries: The perfect solution if your electric pile driver runs on D Cells. Shane Dunne explains.

ALL HOBBYISTS, at one time or another, consider using rechargeable batteries in their projects. Few actually do, however, because good information on nickel-cadmium and other types is too hard to come by. Most of the available information is either hopelessly general or too highly technical, and either type is useless.

This article is an attempt to provide a good working knowledge of nickel-cadmium power systems. The characteristics of nicad cells and batteries will be dicussed, and it will be shown how these characteristics affect the design of chargers and power systems. As an example, the complete design procedure will be given for a blackout-proof computer power supply.

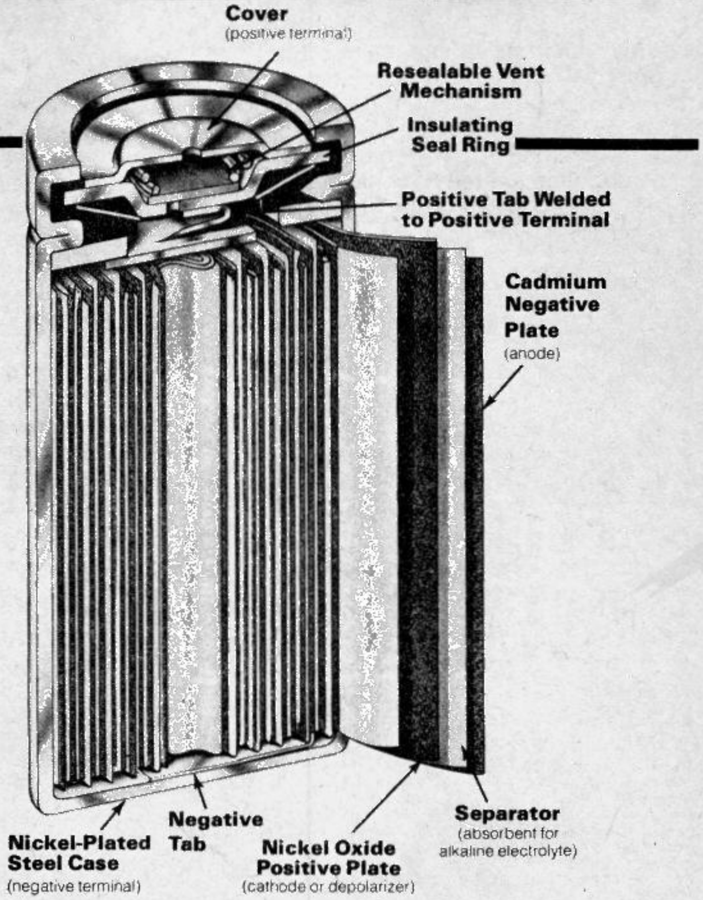
Why Use Nicads?

Nickel-cadmium batteries or "nicads" have two major advantages over conventional types: They are rechargeable, and also capable of storing and delivering very high currents. Nicads are also lighter and more reliable than ordinary "dry cells". Their principal disadvantage is their initial cost, since the cells themselves are expensive and a charger must be purchased or built to make them useful. Of course, since one nicad can replace over a thousand dry cells, they are quite economical in the long run.

In contrast to other types of rechargeable batteries such as lead-acid or sealed-lead ("gel-cell") systems, nicads are superior in terms of weight, maintenance requirements (or more specifically, the lack of them), and general ruggedness. Lead-acid batteries are a better choice only when extremely high currents are required, and when weight and size are not important.

How Nicads Work

Fig. 1 shows the construction of a typical sealed nicad cell. The electrolyte, a liquid solution of a strong base such as potassium hydroxide, is more conductive than the paste electrolytes used in so-called "dry" cells. This results in a lower figure of internal resistance (see later) for these cells. Note that the electrodes or plates are rolled up to provide a large area of active chemicals in contact with the electrolyte and a very tight spacing between the plates. This design is used in the majority of sealed nicads because it allows the cells to work at maximum efficiency and further lowers the internal resistance. The plates themselves are porous and soak up the electrolyte, so that the actual surface area of contact between the plates and the electrolyte is considerably larger than the area of the plates themselves.



Nickel-Cadmium Cell

Fig. 1: reprint from "Packaged Power", page 33. Cutaway view of a typical nicad cell. Note how the electrodes or plates are rolled up to provide a large are of contact with the electrolyte, combined with tight spacing between cathode and anode. This design minimizes internal resistance. (Courtesy Duracell Products)

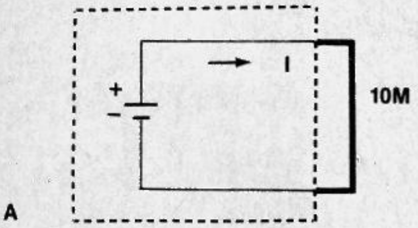
Internal Resistance

The design techniques which lower the cell's internal resistance are highly important, because this resistance determines the maximum current that the cell deliver to a load. Imagine a 1.5 Volt cell short-circuited by a heavy wire whose resistance is only 10 milliohms, as in fig. 2A. Ohm's law tells us that the current in this little circuit will be

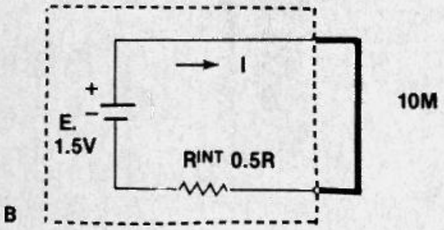
$$I = \frac{V}{R} = \frac{1.5\text{ V}}{0.01\text{R}} = 150 \text{ Amperes!}$$

In practice the current can never be this great. The material of which the cell is composed and its chemical efficiency combine to present an effective resistance to current flow within the cell. To an external circuit, the cell therefore "looks" like an ideal voltage source E (a quite imaginary beast capable of supplying infinite current) in series with this internal resistance. This is shown in fig. 2B. E is is referred to as the open-circuit voltage of the cell, since it is the voltage which would appear at the terminals if no load were connected.

Analyzing the circuit of fig. 2B by the rules of series circuits reveals some interesting things. The current in the circuit is limited not only by the resistance of the wire, but by the internal resistance of the cell as well.



Internal Resistance: Shorting a 1.5 Volt battery with a heavy wire, one would expect a massive current (A), but in practise the current is severely limited by the battery's own internal resistance (B).



Furthermore, the two resistances form a voltage divider, so the voltage across the cell's terminals must be less than 1.5 volts. To see the extent of these two effects, a numeric value for the internal resistance is needed, which might be 0.5 Ohms for a typical dry cell. The current in the cicuit of fig. 2B is therefore

$$\frac{1.5\text{V}}{0.5\text{X} + 0.01\text{R}} = 2.9 \text{ Amperes}$$

which is considerably less the previous estimte. Each of the resistances will produce a voltage drop which may be calculated by Ohm's law. The drop across the cell's internal resistance is

$$V_{RINT} = 2.99\text{A} \times 0.5\text{R} = 1.47 \text{ Volts}$$

So all that is left to appear across the cell's terminals is

$$1.5 - 1.47 = 0.03 \text{ Volts}$$

Not much! This is why the internal resistance of any power source must by kept as low as possible for high-current applications. Nicads, with a typical internal resistance of about 28 milliohms when fully charged, are hence ideal for such applications.

Charging and Discharging

Nicads are rechargeable because they are powered by easily reversible chemical reactions. These reactions occur between the electrolyte and the plate surfaces to provide electrical current during discharging, at the expense of chemical energy within the cell. Forcing current from an external (charging) source causes these reactions to occur in reverse, restoring chemical energy to the cell.

It is theoretically possible to recharge any type of cell in this way. Practically, however, some cells cannot be recharged because in discharging they undergo a physical change as well as a chemical one. A conventional carbon-zinc cell, for example, discharges when its electrolyte literally dissolves its zinc casing. Forcing current back through the cell would plate some of the dissolved zinc back onto the casing, but such an atttempt at recharging would be inefficient and dreadfully slow. (Furthermore, the cell would have been structurally weakened and might explode from internal heat and pressure.) In nicads, the charging and discharging reactions merely change the chemical state of the electrode surfaces, and the electrolyte is unaffected. Hence the reactions are easily reversible without risk.

Discharge Characteristics

The graph of Fig.3 shows how the output voltage of a nicad cell varies as it is discharged into a constant load such as a resistor. The voltage remains fairly constant over nearly the entire discharge time, a feature which makes nicads extremely useful with voltage-sensitive circuitry. The slow decrease in output voltage is due to a gradual lowering of the cell's efficiency, and hence a decrease in the open-circuit voltage (E in fig. 2B). When the cell is almost completely discharged, its internal resistance rises sharply, causing the sudden decrease in output voltage at the end of the curve. By contrast, ordinary carbon-zinc cells show changes in both internal resistance and open-circuit voltage as they discharge. Their discharge curve has a much more pronounced downward tendency, as shown by the dashed lines in Fig. 3.

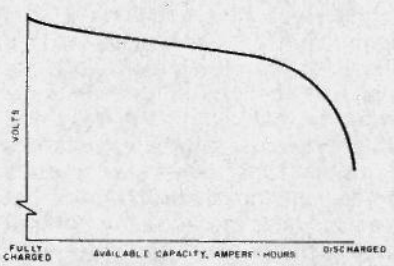


Fig. 3: reprint from GE nicad handbook, page 6-1. The curve shows how the voltage of a typical nicad varies as it is discharged.

The time that the nicad produces usable output current, multiplied by the amount of current delivered, yields an important figure of merit for the cell. This is called capacity and is given in Ampere-hours (A-h). A nicad rated for one Ampere-hour could deliver one ampere to a load for one hour, or one-half ampere for two hours, and so on. Another important figure for nicads is the C rate in amperes, numerically equal to the capacity. As will be shown, expressing charge and discharge currents in terms of the C rate is useful in cell selection and charger design.

Charge Characteristics

The graph of Fig. 4 shows how the terminal voltage of a nicad varies as it is charged at the C/10 rate (for a 500 mA-h cell, C/10 would be 50 mA). Within minutes after the start of charging, the voltage rises to about 1.4 Volts and stays fairly constant as the cell draws energy from the charger. As the cell approaches full charge, the voltage rises slightly again.

During the actual charging time (under the level portion of the curve in Fig. 4) the cell undergoes chemical reactions which are the reverse of those which will provide power during discharging. Once the cell is fully charged, and its active materials have been restored to their original

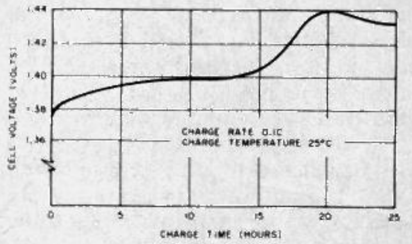


Fig. 4: reprint from GE nicad handbook, page 4-10. During charging, the voltage across the terminals of a nicad rises quickly at the start of the cycle and remains nearly constant until the end, at which point it rises slightly again. This final voltage rise may be detected and used to switch off a charger. (Courtesy General Electric)

chemical state, different reactions occur if the charging current is continued. This condition is called overcharging. The most important overcharging reaction is the electrolysis of the water in the cell's electrolyte, breaking up the water into its component gases. Sealed nicads are designed to re-absorb these gasses, but they can only do so at a fixed rate. The recharging current must therefore be limited during overcharging, so that gases are not generated faster than they can be absorbed. Most nicads can withstand an overcharge current of C/10 indefinitely, although "quick-charge" types are available which can withstand up to C/3.

Charging Methods

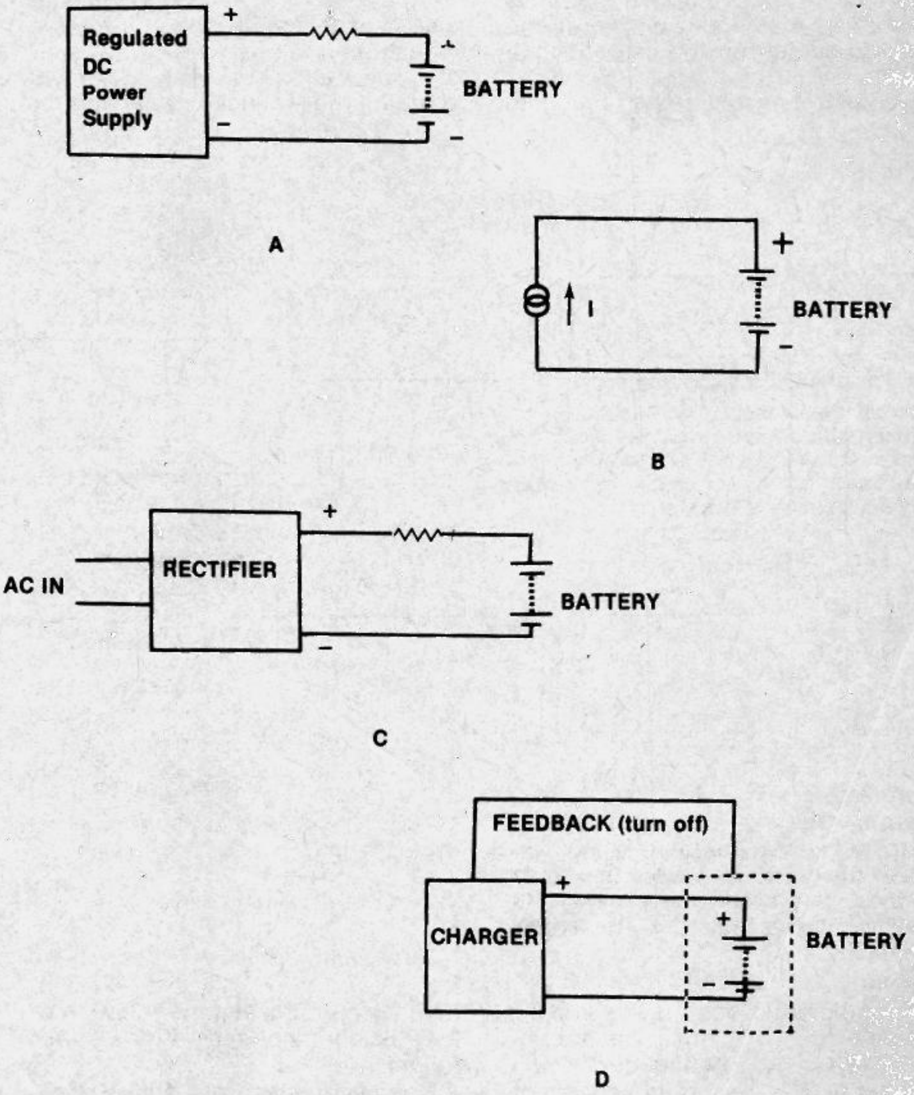
There are four basic categories of charging methods for nicads. Constant-potential, constant-current, "fast", and timed.

Constant-potential charging is used only for large "vented" nicads, typically in aircraft applications. These cells can withstand high overcharge currents because their design allows gases to escape through a low-pressure vent. In contant-potential charging, the cell or battery is connected through a resistor to a regulated power supply as in Fig. 5A. The output voltage of the supply is adjusted so that it will be cancelled out by the battery's voltage as it rises at the end of the charging cycle.

Constant-current charging is the most common method of charging sealed nicads, and is used in most consumer products, such as calculators. In some cases, a transistor constant-current source is used as in Fig. 5B, but usually a simple unregulated and unfiltered supply is connected through a resistor to the nicad to be charged, as in Fig.5C. This last approach is called "modified constant-current" charging, because the charging current involved varies somewhat over the charging cycle.

Filtering and regulation are not really necessary because nicads themselves act as very good ripple filters. The current variations over the charging cycle are also unimportant, because only the overcharge current requires limiting. Modified constant-current charging is usually done at the "slow" rate of C/10 so that the nicad can simply be connected to the charger and left alone for an indefinite period.

Full charging at the slow rate usually takes 12 to 14 hours. The so-called "quick-charge" cells can be completely charged at the "quick" rate of C/3 in 3 to 5 hours. For standby power system, nicads are often kept charged at a "trickle" rate between C/10 and C/100. Such a rate is too low to efficiently recharge a discharged cell, but very good for keeping a charged one at full capacity without risk of damage.



Four charging configurations: (A) constant potential; (B) constant-current; (C) modified constant current; (D) fast charging with automatic shut-off.

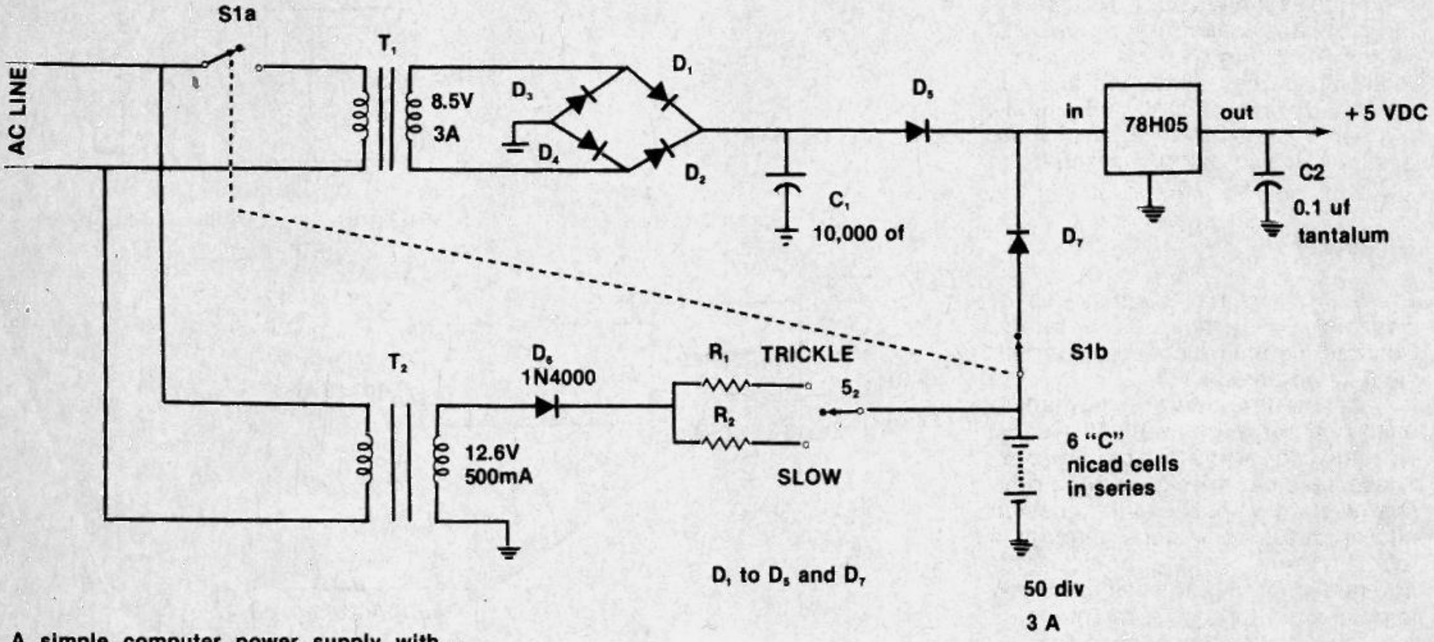
"Fast" charging implies that a rate of C or greater is used, and that some form of feedback device limits the current once overcharging begins. This is shown in block form in Fig. 5D. The feedback may be from a precisely-calibrated voltage comparator (activated by the small rise in cell voltage at the beginning of overcharging), or from a thermistor (activated by heat generated within the cell during overcharging), or from a pressure sensor within the cell.

Timed charging involves "dumping" a very high current into a nicad for a controlled time, and is the fastest way to partially recharge nicads. Calculation of the current and time interval require knowledge of all the characteristics of the cell or battery, and its initial state of discharge.

Charger Design

Only the modified constant-current

approach will be discussed further, because it is the easiest and most economical. Serious experimenters should consult some of the references at the end of this article for information on the other techniques.



A simple computer power supply with nicad battery backup. Diodes D5 and D7 form a current-steering network to smoothly switch from AC to battery power.

Fig. 6 is a circuit for a regulated, blackout-proof 5-volt power supply, suitable for use with a small computer. Dissection of this circuit will reveal the most important aspects of nicad charger and power system design.

T1, D1 to D4, C1, C2 and VR1 form a simple regulated 5-volt power supply which can deliver up to 5 Amps, depending on the size of transformer used. T2, D6, R1 and R2 form a modified constant-current charger, similar to that in Fig. 5C, for the battery of six C cells in series. The simple current-steering circuit, consisting of D5 and D7, allows the supply to switch from AC to battery power without noise spikes occuring at the output. Normally, the AC-powered supply produces a higher voltage than the battery, keeping D7 reverse-biased and preventing current from being drawn from the battery. When the AC line fails, however, D7 conducts and battery power is delivered to the regulator.

Note that T2 is connected directly across the AC line, so the battery is always kept charging. Power switch S1 controls AC power to T1 (S1a) and also isolates the battery from the regulator (S1b) while the AC-powered supply is "off". S2 selects one of two charging rates: "trickle" charging for normal operation and the "slow" rate for efficient recharging after a power failure.

General electric's Nickel Cadmium Battery Application Engineering Handbook supplies the following information for determining the values of R1 and R2. In order that these may be within the normal range of resistor values, the rather high value of 12.6 VAC was selected for transformer T2. For any half-wave, modified constant-current charger, the value of the charging resistor is given by

$$R = \frac{0.45\, E_S K_1}{I_{CH}}$$

where E_S is the RMS voltage of the transformer (12.6 Volts), K_1 is a constant from the graph of Fig. 7, and I_{CH} is the desired over-charge current. The formula is the same for both R1 and R2, so the full design procedure will be given for R1 (trickle rate) only. The C size nicads used have a capacity of 1.5 A-h and hence a "C" rate of 1.5 A. The trickle rate of C/100 is therefore 15 milliamps, which is the value used for I_{CH}.

K_1 is found in terms of

$$\frac{E_B + E_D}{E_S}$$

Where E_D is the voltage drop of the diode D6 and E_B is the battery voltage during charging (recall Fig. 4). For

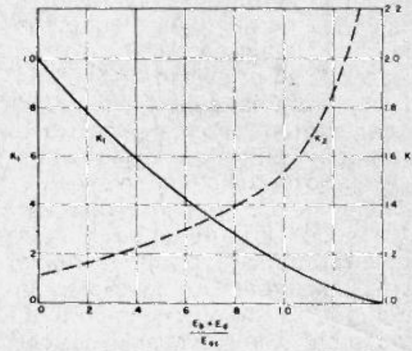


Fig. 7: reprint from GE nicad handbook, page 5-6. Graph provides constants to simplify design of nicad charger circuits. (Courtesy General Electric)

Continued on page 70

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design purposes this is usually taken to be 1.45 volts per cell. So

$$\frac{E_B + E_0}{E_S} = \frac{(6x1.45) + 0.6}{12.6} = 0.74$$

and from fig. 7, K_1 is about 0.32. Putting this into the formula for R1,

$$R1 = \frac{0.45\ E_S\ K_1}{I_{CM}} = \frac{0.45x12.6x0.32}{0.015} = 121 \text{ ohms}$$

so a standard 120R resistor may be used for R1. The RMS current in the charger circuit is needed to find the power dissipated in R1, and is given by

$$I_{RMS} = 2\ K_2\ I_{CM}$$

K is found from Fig. 7 in the same way as K, and is about 1.35. I_{CM} is 15 mA, and I_{RMS} works out to be about 29 mA. Hence the power rating of R1 must exceed

$$P = (I_{RMS})^2\ R = (0.029)^2 \times 120 = 0.1 \text{ watt}$$

so a ¼ watt resistor will be adequate.

Using the same methods, the value of R2 for the slow recharge rate of C/10 may be calculated. It works out to 12R at just under one watt, but a two-watt resistor should be used to provide a margin of safety.

The cicuit of Fig. 6 will provide 3 amps to an OSI Superboard or similar computer for 15 to 20 minutes during a power failure. This should be sufficient time to save the precious RAM contents on cassette tape, but the charger could be re-designed to work with larger cells, to keep the system running even longer.

Summary

Nicad-based power systems are quite easy to design, knowing only the capacity of the batteries to be used. Nicads can be cost-effective replacements for conventional batteries, and can also be used in stand-by power applications where other types of batteries are unfeasible. With this article and a little imagination, readers should be able to design nicad power systems for just about any application.

References:

1. *Nickel-Cadmium Battery Application Engineering Handbook*, copyright 1971 by the General Electric Co. (Publication No. GET-31481). This or a newer edition is available from General Electric Battery Products Division, P.O. Box 114, Gainesville, Florida 32601.

2. *Characteristics and uses of Nickel-Cadmium Batteries*, copyright 1966 by the International Nickel Company of Canada Ltd. Available from International Nickel Co., Toronto-Dominion Centre, Toronto, Ontario.

3. *Packaged Power*, copyright 1979 by Duracell Products Co. Available from Duracell Batteries Ltd., 2333 North Sheridan Way, Clarkson, Ontario.

4. *Nicad Batteries*, copyright 1976 by Gould Inc. Available from Gould, INc. Portable Battery Division, 931 North Vandalia Street, St. Paul, Minnesota 55114.

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(If this wasn't getting to a problem, we could have had a cartoon in this space.)

service clinic

NiCad batteries. *An early death can be reversed if you follow this simple procedure.*

JACK DARR, SERVICE EDITOR

WE HEAR A LOT ABOUT "MEMORIES" IN electronics today: RAM's, ROM's and PROM's, and even the one I use, the SAM (*S*eldom *A*ccessed *M*emory; not electronic!) Here is something similar that might be called BWM for "*B*attery *W*ith *M*emory." However, this doesn't mean memory in the regular sense; it refers to a problem found in some NiCad (nickel-cadmium) batteries that showed up first during satellite test programs.

Under certain conditions these batteries would show a reduction in capacity, causing a much shorter life than normal. They simply seemed to "forget how to take a charge!" This problem caused a whole lot of research to be started. G-E and others worked on it and, luckily, found a very simple way of detecting and curing it.

After a normal charge time, the "memory" battery would drop to about 1.0 volt after 25% of the rated life. With a symptom like this, the first thing to suspect is a bad battery. This *will* be true in some cases, of course. The key clue here would be a check of each individual cell in the battery, to make sure that none has reversed in polarity, a sure sign of battery trouble. If all cells check about the same, this could be a memory problem.

First, a quick review of definitions: A "cell" is one unit; a "battery" is always a *group* of cells. In NiCads these cells are practically always in series. The normal voltage for one cell is 1.25. Right after charging, it may read up to 1.4 volts, but will very quickly drop to 1.25 volts. When the cell voltage under load drops to 1.1, the battery is considered discharged and should be recharged. (See upper curve in Fig. 1.)

This column is for the service technician's problems–TV, radio, audio or industrial electronics. We answer all questions submitted by service technicians on their letterheads indi- dually, by mail, and the more inter- ting ones will be printed here.

If you're really stuck, write us. ll do our best to help you. Don't et to enclose a stamped, self- ssed envelope. If return postage included we cannot process estion. Write: Service Editor, Electronics, 200 Park Avenue New York, NY 10003

A good NiCad battery will hold the voltage up to 1.25 per cell over at least 85% of full-rated life. Cells with a memory problem will drop to about 1.0 volt after only about 25% of life. Note that this is below the 1.1-volt level of normal discharged cells. (See lower curve in Fig. 1.)

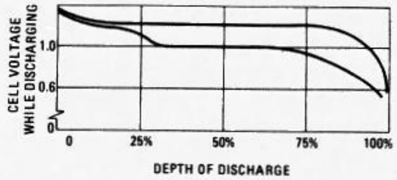

FIG. 1

There are two major types of NiCad batteries: the sintered-plate type that includes all the more common small batteries used in consumer electronics, and the "pocket-plate" type used only for larger units. The latter ones are the same as lead-acid car batteries, and use a liquid electrolyte.

The sintered-plate type of NiCads are made almost exactly the same way as the familiar Leclanche zinc-carbon dry cell. The cylindrical types use the "jelly-roll" construction, with foil electrodes separated by an insulator, rolled up into a cylinder. An electrolyte is used just as in the dry cells. The positive plate (uncharged) is made of nickelous hydroxide, which is converted to nickelic hydroxide when fully charged. The negative plate is made of cadmium hydroxide that becomes metallic cadmium when charged. The electrolyte is a potassium hydroxide solution.

The material of both plates is "sintered," meaning it is ground to a very fine powder and then formed. This produces a crystalline structure with a greater surface area, similar to an etched-plate electrolytic capacitor.

This crystalline plate structure turned out to be the cause of the memory problem. It took a scanning electron microscope to find it, though! The capacity of the battery depends on the *type* of crystalline structure. In the normal cell, the crystals were still very fine. In cells with memory problems, the crystals had become a great deal larger.

Because this change takes place every time the cell is discharged and recharged, the researchers were able to find a simple solution. When a battery shows memory problems, the remedy is to run it down to a "deep discharge" which means a 0.6-per-cell voltage instead of the normal 1.1-volt cutoff. The battery is then recharged using only one-half the normal charging current. If this fails to clear up the problem, the procedure is repeated. A maximum of three cycles seems to clear up even the worst cases.

To do this in the shop, discharge the battery through a suitable resistor so that the maximum current isn't exceeded. You can find the maximum current by checking the battery specifications. Each battery will be rated at a certain number of mAH (*M*illi*A*mpere-*H*ours). Most are rated for 10 hours; a battery with a 500-mAH rating delivers a 50-mA current for 10 hours, etc. Be sure to check the voltage of each cell under load to make sure that none is reversed in polarity, which would indicate the cell is no good. If they all check out pretty close, go ahead. While discharging, monitor the voltage of one cell until it reaches 0.6 volt, or deep discharge; then stop.

Next, recharge at the 20-hour rate, or one-half the normal charge rate. Monitor this current. To recharge a NiCad battery, it is necessary to put back 140% of the energy taken out. In other words, charge for 14 hours at the 10-hour discharge rate, or 28 hours at one-half the 10-hour rate.

Then, recheck the battery for normal life. You can use automotive incandescent lamps for test loads; there are types that draw the necessary current and give a visible indication at the same time. Discharge current should be monitored and the time noted. For example, if the battery is fully recovered, it will deliver a full output voltage for at least 80% to 85% of normal life. Watch for a sudden drop to about 1.0 volt after only 25% of life; this means that the memory problem hasn't been cleared up yet. However, if the battery runs to 50% of normal life before dropping, this is a good sign. Repeat the deep-discharge/charge cycle until it clears up.

The Eveready *Battery Application Engineering Handbook* does *not* recommend trickle-charging or constant charging for NiCad cells. A fairly deep discharge, followed by a full recharge is preferred. If you must trickle-charge, keep the current to a bare minimum; the

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30- or 50-hour rate is recommended. If you have NiCad cells that have been unused for, let's say, six months, do *not* put them in the charger before use! Discharge them fully, then recharge them at one-half the normal rate, or C/20. However, this would only be necessary for small button-type cells, not for the larger types.

Full details of the memory experiments can be found in an article by Saverio F. Pensabene and James W. Gould II in the September 1976 issue of IEEE *Spectrum*. Another useful book is the *Nickel-Cadmium Battery Applications Handbook*, General Electric, P.O. Box 861. Gainesville FL 32602. **R-E**

Nickel-cadmium cells

Experiments in reviving cells you would otherwise discard

by K. C. Johnson, M.A.

The use of nickel-cadmium cells in tape-recorders, pocket calculators and other "cordless" appliances is increasing rapidly. They owe their popularity to the fact that they are both rechargeable and sealed. This is possible because they contain a built-in chemical constant-voltage action, like a sort of zener diode, which enables them to continue to carry current after they have reached full charge with only a small rise in voltage and without any net internal effects. Thus they can operate satisfactorily when connected in series in a battery, no gases are evolved, no water need be added and, according to the manufacturers, they last more or less for ever.

Unfortunately, though, many users tell a different story and this type of cell has acquired a reputation for being unreliable and rather short lived. Since the cells are far from cheap this seems to be an unsatisfactory state of affairs, and the author wondered whether there was any simple explanation. It seems possible that there is, and that cells are being thrown away unnecessarily. Readers may like to help prove or disprove my theories. The secret seems to be to "treat' 'em rough". The manufacturers get good life results when they test under severe conditions, while it is the cells that have an easy time that die.

In this type of cell the negative plate is cadmium. As the cell is discharged this material is oxidised from the metallic form to an insoluble hydroxide. The positive plate is nickel, but this is never in the metallic form at any stage. As the cell is discharged it changes from one hydroxide to another, both being insoluble. When the cell is charged both these reactions are reversed and metallic cadmium is reformed. This reversible process is associated with the normal voltage, of about 1.25V, between the plates.

If the charging process is continued after this reaction has gone to completion, the makers arrange that it is the nickel side which is exhausted first. Thus oxygen ions arrive but can find no aterial left to oxidise. They therefore to oxygen molecules and go into the electrolyte where they diffuse around the cell. In due course they reach the cadmium and are able to oxidise the metal. Thus current is carried across the cell by the recirculation of oxygen, which flows as negative ions in one direction and as neutral molecules in the other. Because of the pressure required to keep sufficient gas in solution the current in this overcharge state must be limited to about 0.1C, the ten hour rate.* A voltage of about 1.30V is associated with the recirculation process, so that it provides a very convenient limiting mechanism.

Over-discharge

If a cell is over-discharged, as can happen if it is the first to go flat in a multi-cell battery, then damage may be done. If the nickel side is again exhausted first, then damage may be done. If the nickel side is again exhausted first, as it normally will be, then hydrogen gas will be formed at a voltage a little below zero. Once formed into gas the hydrogen can never be recovered and represents a permanent loss of electrolyte. In some cells the makers put a bit of cadmium hydroxide in the positive plate alongside the nickel, and if this is done the cell will pass current at a voltage of almost exactly zero until this material is in turn exhausted and the generation of hydrogen starts. Clearly if all the cells in a battery are balanced within the appropriate margin the chance of damage will be much reduced. It would seem likely that a semiconductor diode connected across each cell could offer similar protection even if the cells were not carefully balanced.

What then is the mysterious mechanism that makes cells fail prematurely when they are given gentle treatment? It seems that the trouble is that cadmium, like zinc, is a metal that has a "hexagonal", rather than a "cubic", crystal structure. Thus, if it is allowed the choice, it will prefer to form crystalline whiskers rather than a smooth surface, and the atoms in these whiskers will be just a tiny bit, a few tens of millivolts perhaps, less chemically active than those in more randomly built metal. Although the electrolyte is alkaline, cadmium ions will still have some slight solubility and will be able to move about the cell in small numbers. Thus the metal will slowly form itself into crystals even if the cell is left idle, while gentle cycles of charging and discharging are likely to accelerate the process.

If these whiskers build up until they actually penetrate the inter-plate barrier they can obviously cause internal short-circuiting. But as soon as the current rises high enough to give a voltage drop down a whisker equal to the few tens of millivolts energy difference growth will cease. Each whisker thus provides a steady leak of a very small current only. When the cell is discharged, though, the growth can be resumed and a solid short-circuit becomes possible.

Normally the whiskers will grow as the cell is being charged, so that a cell in the early stages of the disease may behave perfectly well until it is perhaps half charged. The whiskers will reach across and bypass the current so that little further charging takes place. After the full charge time the cell is put into service and goes flat much too soon. It is said to have "lost capacity". Only later does it become obviously impossible to get any charge in at all and only then is the cell said to be "short-circuit". It will probably be thrown away as worthless.

Reviving process

If readers have any cells of this type that they are about to discard after this sort of trouble they might like to try to revive them by a process that I have used with some success. Make sure that each cell has the customary safety vent, or beware of explosions if a high gas pressure is generated inside. If a cell is open-circuit then it has probably lost electrolyte, due to leakage or excessive current in either direction, and there is no point in giving it this treatment.

Take each reject cell and apply the usual 0.1C (ten hour rate) charge current to it. Watch the voltage with a meter, but there is no need to worry if

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* See Appendix

no significant amount appears at this stage. Arrange to be able to add a very much larger charge current, 10C (six minute rate) perhaps, to just one cell at a time. A connection across the headlamp switch of a car might be suitable, or two charged healthy cells in series with an appropriate resistance. Arrange also a dummy load that will discharge a normal voltage cell at about the 10C rate. This may well be a metre or so of quite thick copper wire and will get fairly warm in use. Use this dummy load to make sure that the cell under treatment is in fact flat before starting to charge it.

Now add the heavy charge current to the low one for bursts of about five seconds, allowing intervals of perhaps fifteen seconds between the bursts to avoid undue heating. Don't worry too much about the voltmeter reading while the heavy current is flowing — remember that you were going to throw the cell away — but notice the voltage to which the cell settles between bursts. This may start at zero, but even the most obstinate cell will "come unstuck" after a few bursts and will reach a value of around 1.25 volts. After perhaps twenty bursts the cell ought to be a little more than a quarter full and it is unwise to go much further at the heavy current as the cell will lose electrolyte and be permanently damaged if it reaches full charge. Use the dummy load then to discharge the cell completely, again working in bursts to avoid undue heating.

The theory behind this rough treatment is that the heavy charge current will melt any whiskers causing short-circuits, thus destroying their crystal structure or fusing them altogether, while depositing cadmium metal back on the plate to give a useable amount of charge. The heavy discharge will then oxidize the metal in any remaining whiskers first, despite the lower activity of the crystalline material, simply because the metal offers a much lower electrical resistance path than the electrolyte.

Now recharge the cell to the quarter full state with a further twenty bursts of the heavy current. Then leave it on just the low current for ten hours or more, and if the treatment has been successful it will go through to the oxygen regeneration state. It is difficult to establish for sure when this has been achieved, but measure the voltage carefully and then, without disturbing the charge current, discharge the cell with the dummy load for about 30 seconds and compare the voltage to which it recovers in a minute or so. If this is significantly lower, say 50mV, then the cell was probably fully charged and will be so again after a further hour on charge. In any case it seems that this sort of discharge will probably do the cell good, and it is certainly a good thing to leave a cell which has had short-circuit trouble on low current overcharge for at least another 24 hours.

This is because the most effective whisker removal action comes only when the oxygen recirculation process is established. The dissolved oxygen diffusing across from the nickel plate finds the troublesome whiskers first and will attack the cadmium in them. Any metal ions which may be formed are then driven back towards their proper electrode by the electric field. Even detached pieces of metal will be oxidized and so returned for further service. Only during overcharge is the field in the right direction to pack the cadmium down on its plate while the metal is being oxidized and may go into solution as ions.

More drastic

When a cell that was on the point of being rejected reaches the overcharge state, as several of mine have done, it can be considered to have been successfully rehabilitated. If a cell fails to respond to the treatment described, then, before you throw it away, try more drastic treatment. If it never made volts at all, try a larger initial current to "unstick" it. If it charged but never reached overcharge, continue the bursts of heavy charge current until it is half full or even more before discharging it. The author has only been able to experiment on a very few cells of a single type. The experience of readers may help to improve the process and make it more successful.

In any case, if only a small fraction of the cells treated recover sufficiently to be of further service it will still be well worth trying, as the cells are expensive and the treatment is comparatively simple. The results may not be quite as good as new cells, but they may be very much better than scrap.

Appendix

Typical capacities and charging currents are as follows:

Cell size	Capacity	0.1C current
AA, R6 or U7	500 mAH	50 mA
C, R14 or U11	1500 mAH	150 mA
D, R20 or U2	3500 mAH	350 mA

Announcements

Ritro Electronics (UK) Ltd has been formed as a fifty-fifty partnership between Ritro Electronics bv, component suppliers of Holland and Belgium, and Tahold Investments Ltd to distribute electronic components in the UK. Tahold is a company formed by Peter Tagg (a founder and former managing director of GDS Sales Ltd) and he is the major shareholder. Ritro is at Grenfell Place, Maidenhead, Berks.

Syston-Donner have appointed Electroplan of Royston UK distributor for four of their range of pulse generators, the model 99, the 100A, the 110B and 110C.

NRK, Oslo, the Norwegian broadcasting authority, have ordered a £100,000 non-computerised routing control system from Prowest. The system provides switching for forward and reverse vision, forward

REVIVING NICKEL-CADMIUM CELLS

I ran across Mr Johnson's article on reviving NiCd cells in the February issue and used the method successfully to rejuvenate a set of four cells which had been in the discard bin for some months.

These four AA cells had perished when a young visitor left my pocket calculator on, a fact which went unnoticed for a week or so. When I found they would then not hold a charge, they were replaced and left on the back of the bench for about six months. After reading the article, I checked them and, sure enough, each cell was shorted and read zero volts.

I first processed one cell as described, with a battery charger as the current source and an ammeter as the load – the only deviation being that the low-current was removed during the high-current phases. The cell came "unstuck" after the first jolt, eventually responded to the overcharge state, and provided 500 mAh on slow discharge. I then processed the other three cells as a series unit and achieved the same results, in much less time than it would have taken to do each one individually. Perhaps I was fortunate in having cells in approximately the same condition.

After a 24-hour normal 50mA charge, all four cells in series were drained across a dummy load at 50mA, and lasted close to eleven hours, with the No. 1 cell going dead first. Two more charge-discharge cycles were then tried, this time with a portable radio drawing 10-15 mA as a load; with intermittent use of 4-5 hours per day, the cells provided approximately 500mAh each time, with the No 2 cell going dead first in these cases. Fully charged voltage was 1.30V (1.35 in overcharged state); at the time of one cell going down the remaining three read 1.25-1.27V.

The cells are completely anonymous, no type of manufacturer's marking, so I do not know what quality they represent. The fact is, though, that thanks to Mr Johnson's article, they represent a handsome salvage.

B. G. Doutre,
Montreal,
Quebec, Canada.