The Ni-Cd Battery

Myths and mastery of nickel-cadmium rechargeable batteries are explored

By Anthony J. Caristi

More and more households use Ni-Cd batteries to power their portable radios, photo flash guns and other equipment due to their recharging attributes. Unfortunately, Ni-Cds are often discarded before their useful life is over. This article will show you how to bring "dead" Ni-Cd batteries back to life, as well as clear up some misconceptions about these popular power sources.

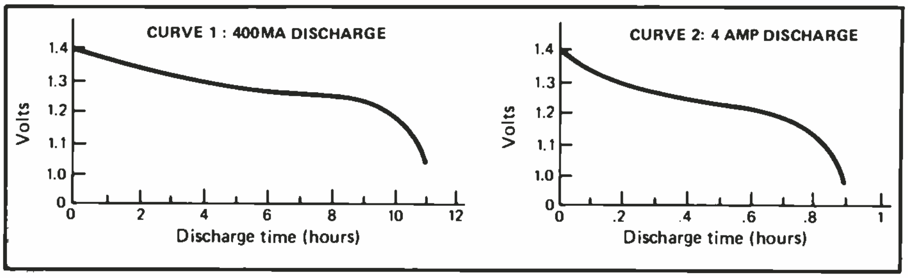


Fig. 1. Discharge curves of typical 4-ampere-hour D cell when discharged at 10-hr (curve 1) and 1-hr (curve 2) rates. The 1-hr rate yields fewer AH of service.

The Ni-Cd cell has several important advantages over the common dry cell, such as the zinc-chloride and alkaline types. The most obvious one is that the Ni-Cd can be recharged over and over again while the others cannot be successfully recharged back to their original capacity. Manufacturers of Ni-Cds estimate that ordinary Ni-Cd batteries have a charge/discharge cycle life of about 1000 times before capacity is reduced to below 80% of their original value.

The Ni-Cd can deliver much higher energy levels are compared to dry cells and provides an almost constant 1.2-volt output over most of its discharge cycle. It can deliver an awesome short-circuit current that is so powerful that it can easily burn delicate wiring or printed-circuit conductors if improperly handled. For example, a 4-ampere-hour D size Ni-Cd cell can deliver currents of 50 amperes and more!

How Ni-Cds Are Rated

When a single cell is freshly charged its terminal voltage will be about 1.4 V, which quickly reduces to 1.2 V when the cell is placed in service. You'll see Ni-Cd batteries rated at 2.4 volts or more, of course. These consist of two or more cells connected in series. Technically speaking, a battery is two or more cells connected in series to produce a voltage which is higher than that available from a single cell. However, it is common to refer to a single cell as a battery.

Ni-Cds are rated in ampere hours (AH): the product of current in amperes and time in hours. However, the amount of energy that can be extracted from a given Ni-Cd battery is a function of the total amount of discharge time. This is illustrated in Fig. 1, which shows two discharge curves of the same D-size Ni-Cd cell rated at 4 AH. Note that the total number of ampere hours delivered by the cell is greater when it is discharged over an 11-hour period at 400 milliamperes than when it is discharged over a 54-minute period at 4 amperes.

In order to compare one Ni-Cd cell to another, especially those from different manufacturers, you must consider the discharge rate as well as the cut-off voltage when the cell is considered to be totally discharged. In the case of Ni-Cds, the voltage falls dramatically below 1.2 volts when the cell becomes discharged, so cut-off voltage is not a critical parameter.

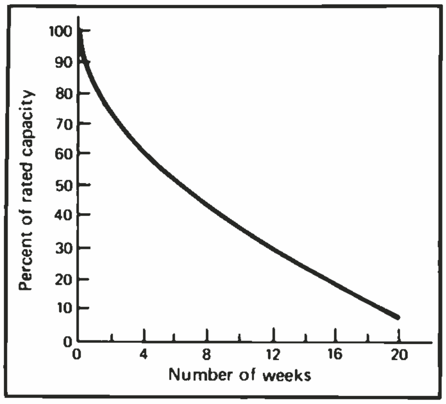


Fig. 2. Typical self-discharge curve of Ni-Cd cell at 70° F (21° C). Fully charged cell retains about 10% capacity when unused for about 20 weeks.

To illustrate how one manufacturer rates Ni-Cds, the capacity is specified as the current that can be delivered by the cell for a one-hour period to a cut-off voltage of 1.0 volt. Obviously, another manufacturer could rate the exact same cell at the 10-hour rate and come up with a higher ampere-hour rating.

Like all batteries, Ni-Cds will lose a percentage of their charge when left

“Ni-Cds can deliver an awesome short-circuit current.”

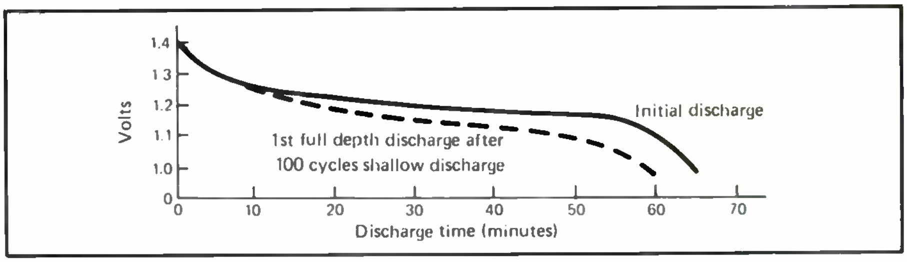


Fig. 3. Memory effect of Ni-Cd cell. First full-depth discharge after 100 cycles of 40% discharge yields only about 80% of rated capacity of typical Ni-Cd cell.

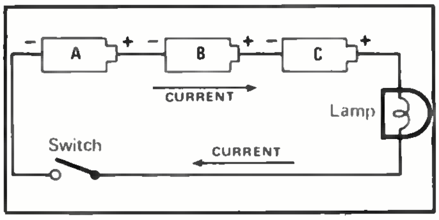


Fig. 4. This is the circuit of a three-cell flashlight.

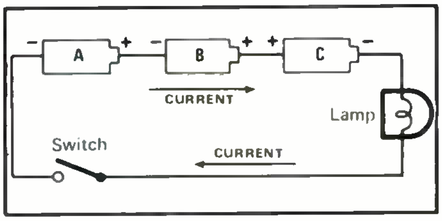


Fig. 5. Shown here is a depleted C cell being reverse charged.

idle. This loss in charge is heavily dependent upon ambient temperature . . . and increases as temperature rises. Figure 2 illustrates the loss in charge of a typical Ni-Cd cell at room temperature. Not all Ni-Cds will lose the same amount of charge in the same time; you probably will find differences between brands of Ni-Cds. Although a Ni-Cd will, theoretically, not be damaged if left for long periods of time in an uncharged state, it is recommended that it be brought up to full charge at least twice a year so that it will always be in some state of charge and therefore won't tend to develop short circuits.

Ni-Cd Memory Phenomenum

"Memory" is a characteristic of Ni-Cd cells that prevents full deep discharge of the cell after repeated shallow discharges. In recent years, battery manufacturers have been able to reduce the memory effect to a relatively small amount, as shown in Fig. 3. Shown here is the initial deep discharge of a full charged cell.

After this curve was taken, the cell was subjected to 100 shallow discharges of 40% of capacity. The cell was then recharged and given a deep discharge, which is illustrated by the second curve. Note that the cell could deliver less than full capacity due to memory effect. Subsequent recharges, followed by deep discharges, would eventually wipe out the memory and bring the cell back to its original capacity.

Cell Polarity Reversal

It might seem, after noting memory effect above, that it would be a good idea to run Ni-Cd batteries down to zero voltage before recharging them. This can lead to two significant problems: cell polarity reversal and shorted cells.

Battery manufacturers recommend that Ni-Cds not be left in a zero state of charge for any length of time, even though there is no theoretical damage done to the cell in this state. But a cell that has no charge can develop a short circuit much more readily than a partially or fully charged one. The reason for this is that short circuits that may develop within a cell could start out as a "whisker" that grows from one of the electrodes and touches the other. If the cell has no charge this whisker could become firmly implanted and result in a shorted cell. But if there is charge remaining in the cell, the short circuit will be vaporized away as it is happening. The moral to this story is: Keep your Ni-Cds fully charged at all times, except when they are being used, of course.

The second problem that may occur if you run a Ni-Cd battery down to zero voltage is the possibility of polarity reversal. This can happen in a battery consisting of two or more cells connected in series. Consider the following: Figure 4 is a circuit diagram of three cells connected in series, as you would have in a typical three-cell flashlight. If the flashlight is operated until the light produced is obviously dim due to exhausted cells, the following develops:

One of the cells must have started out with less capacity than the other two, since no two cells can have exactly equal capacities. Let's assume that cell C has less capacity than cell A or cell B. This means that C will reach a zero state of charge before A and B, and its terminal voltage will be zero. Let's redraw the circuit to illustrate what happens (see Fig. 5).

Note that the remaining charge in A and B is driving current into C, but in such a direction that C is being charged backwards. Its negative electrode becomes positive and its positive electrode becomes negative. You can easily visualize this since the direction of current through C is opposite to a normal charging current, which would be fed into the positive side, not the negative.

When a Ni-Cd becomes reverse polarized in this manner, gas pressure is generated within the cell and it will eventually vent or burst. Some battery manufacturers have designed their Ni-Cds to withstand some amount of polarity reversal, but if the cell should vent, some of its precious fluid will be lost forever, reducing cell capacity. Thus, when your flashlight or other equipment indi-

"A cell may be shorted, but perhaps not permanently."

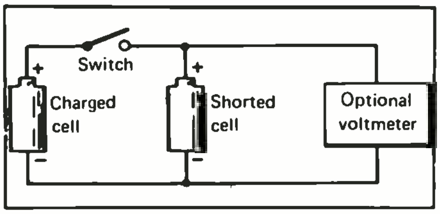
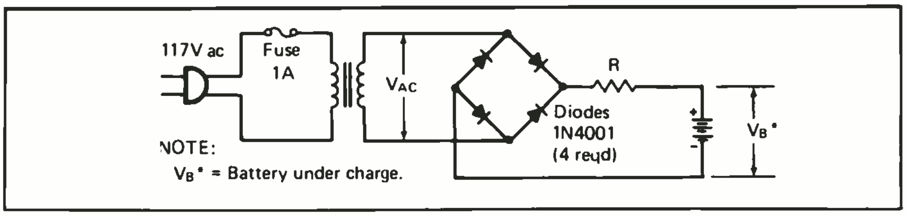


Fig. 6. Shorted cell can be restored by current from freshly charged cell.



NOTE:
V_B* = Battery under charge.

Fig. 7. Recommended constant-current charging circuit; V_{AC} across the transformer's secondary should be about twice V_B at the output.

cates that battery voltage is low, recharge immediately.

Shorted Cells: Not Necessarily The End!

Although you may place a discharged Ni-Cd cell in a charger and its terminal voltage remains at zero regardless of how long you leave it on charge, the cell is not necessarily bad. What has happened is that the cell is shorted, but perhaps not permanently. The problem here is that the charger current is not sufficient to overcome the short and begin charging the cell.

The best and easiest way to cure a shorted cell is to take another cell of the same size, freshly charged to full capacity, and connect it in perallel with the shorted cell. The connection is shown in Fig. 6. Note that plus is connected to plus; minus to minus. Use heavy wire for the connection since the current delivered to the shorted cell will be very high until the short circuit is burned away. Once this happens, the current will automatically reduce to a very low value. Then place the cured cell in a charger right away to fully charge it.

This method of restoring a shorted cell is safe because the driving voltage of the charged cell is the same as the terminal voltage of the discharged cell (once the short is burned away). However, it is possible that this one-to-one treatment will not work for a stubborn cell, and it must be "zapped" by a larger voltage.

To do the foregoing, you could take two fully charged cells, connect them in series, and use this 2.4-volt battery to restore the shorted cell. When attempting this two-for-one method do not apply the current for more than a few seconds, especially if the shorted cell does not respond. The heavy current will heat up both the driving cells and the driven cell. If they should get too hot, there is the possibility of them bursting. If your shorted cell does not respond to this, it is probably beyond repair.

Charging Ni-Cds

Probably the most misinformation on Ni-Cd batteries relates to recharging. Unless you use special precautions to monitor the temperature of a Ni-Cd while it is being charged at a rate higher than C/10, Ni-Cds should be charged only by a constant current source at a rate of C/10 or less. C/10 is the capacity of the cell or battery in ampere hours, divided by 10. Thus, a 4-ampere-hour battery should be charged at 400 milliamperes. When using the C/10 rate, the charger should be left on for 14 to 16 hours to ensure that the Ni-Cd is brought up to full charge. At the C/10 rate, it is permissible to overcharge the Ni-Cd for two or three days without damage, since the gases produced on overcharge are recombined within the cell and, thus, venting should not occur. When a Ni-Cd reaches full charge as it is being charged at the C/10 rate, it generally will feel warm to the touch.

It is not recommended to use a charger that delivers a current very much less than the C/10 rate, since totally discharged Ni-Cds may not take on any charge at all no matter how long they are left on charge. This will give the false impression that the Ni-Cd is defective, when it is not. Low-capacity chargers are designed to be used for "trickle charging," which we'll discuss later.

Ni-Cd cells should not be charged in parallel unless you use series resistors for each cell to ensure that each one receives no more than the C/10 rate. Without such resistors it is possible that one or more of the cells will be charged at an excessive rate and will overheat when it reaches full charge. This would lead to gas venting and possibly a burst cell. Always connect your Ni-Cds in series to charge them, and be sure not to mix cells of different capacity.

Ordinary Ni-Cd batteries such as used in consumer appliances should be charged with a constant-current charger. Figure 7 illustrates such a circuit. It's called a constant-current circuit because the open-circut voltage of the charger (when it is not connected to a battery) is much greater than the terminal voltage of the battery it is to charge, and a resistor is used to determine the value of the current. Thus, the current delivered to the battery will remain almost constant as the Ni-Cd cells increase in voltage from 1.2 to 1.4 as the battery reaches full charge. In comparison, a constant-voltage charger, such as used for lead-acid batteries, would not have the resistor and would deliver a large current when first connected to a discharged battery. The current would then taper off to a small value as full charge is reached.

Figure 8 illustrates the value of resistor *R* in the circuit of Fig. 7 for several different batteries and charging currents, using a common 12.6-volt transformer available at any electronics parts supplier. (Example: Ra-

Nominal Voltage	No. of Cells	Charging Current		
		50 mA	120 mA	400 mA
1.2	1	85 Ω	40 Ω	13 Ω
2.4	2	80 Ω	37 Ω	11 Ω
4.8	3	75 Ω	32 Ω	9 Ω

Fig. 8. Select appropriate resistor value when using Fig. 7 circuit, which requires a 12-volt transformer.

dio Shack #273-1505.) Bear in mind that the transformer secondary rms current rating for this circuit (and that of Fig. 9) must be at least 2.5 times the desired dc current fed to the battery. A transformer will overheat if the current rating is too small and, possibly, produce less current than desired.

Should you wish to build a charging circuit different than that illustrated in Fig. 8, you can easily do so by using the following guidelines: Use a transformer with a secondary voltage rating of about twice the voltage of the battery you want to charge. Resistor *R* may then be selected to deliver the required C/10 rate. The current through *R* can be calculated using the expression $I = E/R$, where *E* is the voltage measured across *R* using a dc voltmeter. Even though the current through *R* is not pure dc, the voltage measurement will yield an accurate calculation of the current. Once you have determined the resistor value, be sure to calculate the power dissipated in the resistor using the expression, $P = I^2R$. Employ a resistor that has a power rating of about twice what is calculated.

If you would like to build a more sophisticated constant-current charging circuit that's independent of the number of cells placed on charge, use the cirucit of Fig. 9. This is a constant-current circuit that uses a readily available fixed 5-volt IC regulator chip. The current delivered by this circuit into the battery will always be equal to 5/*R*, as long as there is sufficient voltage at the input of the chip. The required input voltage will be equal to maximum battery voltage you wish to charge plus 8 volts.

This circuit will deliver a fixed current for any number of cells placed on charge, up to the maximum you have selected. To make this circuit even more useful, you could use a multiposition selector switch to change the value of *R* for different constant currents. Then you would have an all-purpose charger that can handle every kind of Ni-Cd you own.

Trickle Charging

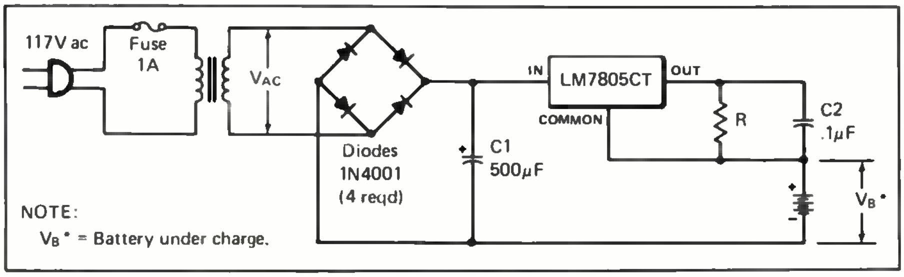
The charging circuits described discuss charging your Ni-Cds at the C/10 rate, which brings them up to full charge in 14 to 16 hours. But once you have fully charged your batteries, how do you keep them from losing their charge as a result of self discharge? The answer to this is the trickle charger, which keeps Ni-Cds in a fully charged state until they are placed in service.

Manufacturers of Ni-Cds specify that these batteries may be trickle charged at a C/30 to C/50 rate continuously without deterioration of the cells. One manufacturer has shown that a constant trickle charge for two years resulted in no loss of battery capacity when it was subjected to the first full discharge.

To calculate the proper current for trickle charge, divide the ampere hour rating of the Ni-Cd by 30 or 50. The resulting current is the proper trickle charge for that battery. For example, if you have a 1.2 ampere hour battery, the proper trickle charge will be between 24 and 40 milliamperes, respectively.

It is a simple matter, therefore, to have the charging circuits of Figs. 7 and 9 deliver the required trickle charge by using the correct resistor value. The best way is to include a single-pole, double-throw toggle switch that can select either one of two resistor values, one for normal charging and one for trickle charging. That way you can have the best of both worlds. **ME**

Fig. 9. This constant-current charging circuit delivers same current to one or more cells connected in series. Dc voltage across C1 should be at least $V_B + 8$ volts. Resistor R yields 5 volts/charge current.



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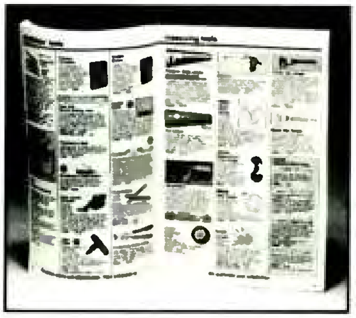

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