

# BATTERY SELECTION GUIDE

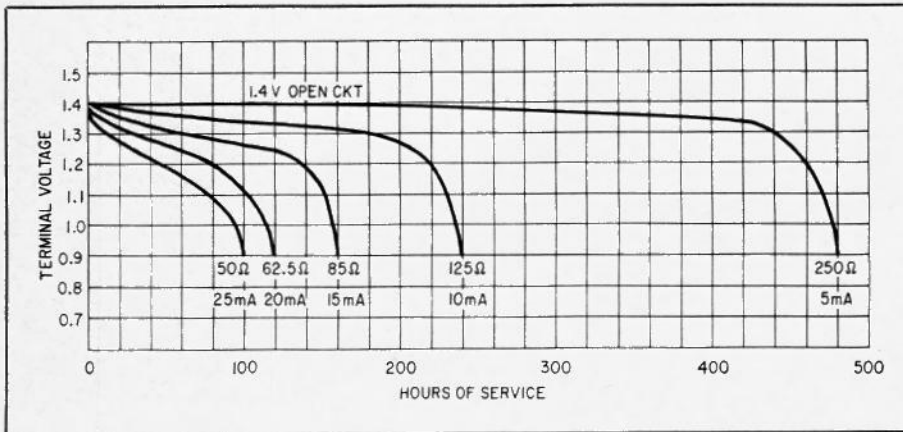


Fig. 1—These are typical voltage-discharge curves for a mercury cell, NEDA No. 15M.

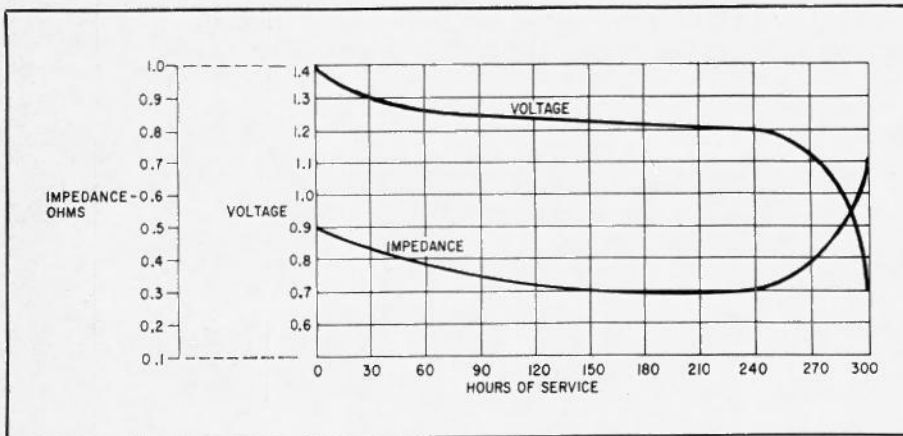


Fig. 2—Impedance (at 1 kHz) vs voltage, 15M mercury cell. As E drops, Z increases.

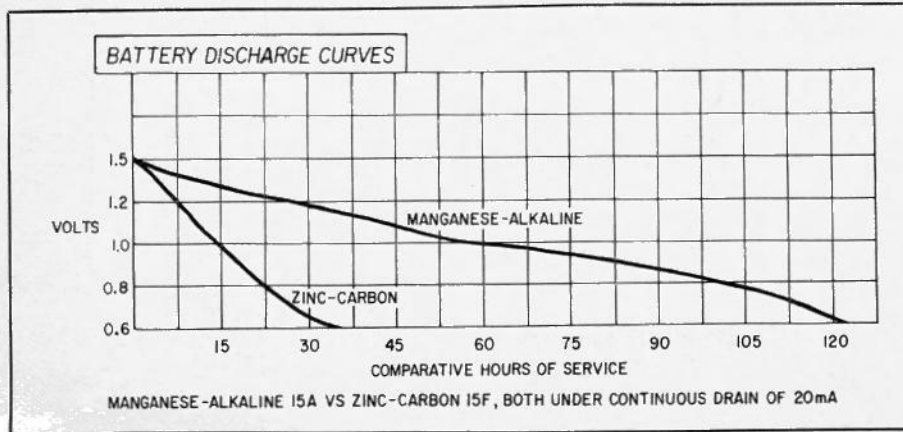


Fig. 3—Comparative service, manganese-alkaline 15A vs zinc-carbon 15F, 20 mA drain.

**There's a battery best suited to each application—depending on the current drain, hours of use, and above all the cost per cell**

WITH SO MUCH BATTERY-POWERED equipment in use today, and with so many types of batteries available, choosing a battery for a particular application can be a real puzzle. The accompanying chart will help simplify the problem.

Batteries are rated in watt-hours per pound (in practical terms, milliampere-hours per ounce). The rating indicates battery efficiency. Zinc-carbon cells yield 15 to 20 watt-hours per pound, manganese-alkaline cells give 30, and mercury units produce 45. However, in any application, the current drain should not exceed the battery rating, or metallic ions will not be able to go into solution fast enough. This causes a rise in internal resistance, and the battery dies before it has yielded its normal quantity of energy. This action makes battery selection difficult. Available milliampere-hours for a particular current drain can be computed only for mercury and cadmium cells. For other types—zinc-carbon and manganese-alkaline—service life can be estimated in advance only from published data derived from actual performance figures.

Ordinary zinc-carbon dry cells require frequent "rest" periods. During use, the cells' internal impedance increases due to the formation of hydrogen gas. This gas must be given a chance to dissipate or the useful life of the cells is shortened.

Zinc-carbon cells today are made in four types, depending on the intended service. The general-purpose variety is most common, and is usually called a flashlight battery. The second type is designed to operate under light drain and to maintain relatively constant terminal voltage for a longer period than can the first type. It's used in transistor circuits. The third special kind of cell is made for photoflash use,

where it's subjected to an intermittent but very high current drain. The fourth type was developed for heavy-duty industrial use.

Manganese-alkaline cells can be up to 75% more efficient than zinc-carbon cells. This efficiency is chiefly useful in high-current applications, as they were designed for such use. Further, precautions must be taken in substituting them for ordinary cells. They cause corrosion when in contact with aluminum or copper terminals if there is any leakage of the caustic potassium hydroxide electrolyte. Stainless or nickel-plated steel terminals should be used. In spite of this disadvantage, manganese-alkaline cells are being used increasingly in receivers and amplifiers. Because they have a relatively constant internal impedance, they can be discharged to lower-than-usual voltages without causing distortion.

Even better in this respect are mercury cells. A 15M, for instance, can give about 220 hours of service at a drain of 10 mA before its impedance begins to rise (Fig. 2).

Mercury cells are also better when stable operation is required. Their output voltage remains nearly constant throughout their useful life. Nor can their performance be surpassed when shock, vibration or moderate heat are problems. They are designed for use at room temperatures or above, and are excellent at body temperatures, as in hearing aids. (A special wound-anode type is available for use at low and freezing temperatures.)

A usual requirement of nickel-cadmium cells, because of their low voltage, is that the equipment be especially designed for their use. N-C's are economical only if you have facilities for recharging them.

On the other hand, when not discharged below 1.1 volts, they are able to take 200 to 300 recharges. Recharging can be done with a simple half-wave rectifier consisting of an inexpensive filament transformer, a diode and a 1-watt resistor. More elaborate circuits are sometimes used. Each size of N-C cell requires a different charging rate and therefore a different charging circuit. Recommended rates and circuits will be found in the various manufacturers' manuals.

These cells should not be used in emergency equipment since they have a poor storage life. At normal temperatures N-C's lose 12% of capacity in the first month, and they will be down to their cutoff voltage by the end of 2 months. They may of course be recharged to their normal capacity.

To select a battery from the chart,  
*continued on page 66*

BATTERY SELECTION CHART								
Type	Size	NEDA Number	Current Range mA	Per-Day Duty Hours	Current Drain mA	End-Point Volts	Service Hours	Approx. Price
Standard Zinc-Carbon, 1.5 volts	N	910F	0-20	2	1	1	440	\$0.08
					10	1	37	
	AAA	24F	0-20	2	5	1	108	0.10
					10	1	43	
	AA	15F	0-25	2	5	1	240	0.13
					10	1	110	
	C	14F	0-80	2	5	1	420	0.13
					10	1	220	
					2	1	40	
					4	1	240	
	D	13F	0-150	4	10	1	580	0.13
					30	1	185	
					50	1	96	
					100	1	36	
					10	1	530	0.19
				30	1	165		
				100	1	86		
				300	1	34		
				24	1	4.8		
				4	1	680	0.16	
				4	1	135		
				24	1	58		
				24	1	20		
				24	1	8.5		
Zinc-Carbon Transistor Types, 1.5 volts		15	0-25	2	5	1	275	0.16
	C	14	0-80	2	60	1	135	0.19
					120	1	50	
					160	1	20	
	D	13	0-150	2	60	1	95	0.19
				150	1	30		
				300	1	8.5		
Zinc-Carbon Transistor Types, 9 volts		1604	0-8	2	4	7.2	49	0.48
					10	7.2	17	
					15	7.2	9	
					4	6.0	78	
					10	6.0	32	
				2	5.4	38		
				2	4.2	34		
		1604D	0-8	2	12	4.2	47	0.65
				2	12	4.2		
Manganese-Alkaline, 1.5 volts	N	910A	0-85	24	10	1	52	0.27
	AAA	24A	0-100	24	5	1	139	0.33
					10	1	67.5	
					15	1	38	
	AA	15A	0-150	24	5	1	290	0.33
					10	1	155	
					50	1	25	
	(1/2 D)	927	0-300	24	30	1	105	0.33
					150	1	19	
	C	14A	0-480	24	30	1	133	0.40
				62.5	1	60		
				125	1	25		
				250	1	7		
	D	13A	0-650	24	10	1	1020	0.50
					30	1	340	
					63	1	164	
					125	1	63	
					250	1	28.5	
Mercury	N, 1.4V	910M	0-75	24	12.5	0.9	64	0.44
					25	0.9	32	
	AA, 1.4V	15M	0-200	24	5	0.9	13	0.64
					5	0.9	480	
	AA, 1.35V	Hg-502R <sup>†</sup> E502 <sup>†</sup>	0-200	24	10	0.9	238	0.87
					50	0.9	46.2	
				100	0.9	19		
	D, 1.4V	13M	0-1000	24	150	0.9	12.5	2.44
					250	0.9	59	
	(8.4V)	1604M	0-30	24	500	0.9	28	1.31
					15	5.4	38	
Nickel-Cadmium, 1.2 volts	AA	CD6 <sup>°</sup> C450 <sup>†</sup>	0-45	24	45	1.1	10	1.88
	C	CD14 <sup>°</sup>	0-190	24	190	1.1	10	3.40
	D	CD7 <sup>°</sup> C2 <sup>†</sup> CD10 <sup>°</sup> CH4 <sup>†</sup>	0-200	24	230	1.1	10	4.05
			0-400	24	400	1.1	10	5.70

<sup>°</sup>Burgess number  
<sup>†</sup>Eveready number

## BATTERY SELECTION GUIDE

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determine first the current requirement—let's say 4 mA. Next, experimentally reduce the voltage of the circuit until an end-point, or cutoff, voltage is found—for instance, 1 volt—below which the circuit will not operate efficiently. Now establish the minimum practical length of service that will be required before battery replacement; assume 3 months. This would call for 130 hours of service from a unit used 2 hours per day 5 days per week. The nearest approximation on the chart is the 15F zinc-carbon AA cell drained at 5 mA and yielding 240 hours. No more economical service can be obtained from a 15A manganese-alkaline cell. It can be used for 290 hours, but the increased cost offsets the extra life.

Note, however, that the data given for manganese and mercury cells are for *continuous* usage. Thus, if the duty cycle is changed to more than 2 hours per day and the size limited to an AA cell, then only manganese and mercury cells will fill the bill.

On the other hand, suppose that the end point is 1.2 volts and the usage is 4 hours/day. By raising the end point, we have reduced the total amount of current that can be drawn from the cell. This reduces the number of hours of service. For a 4-hour/day usage, the 14F size-C cell is shown on the chart as delivering twice the current expectable from the 15F size AA at 2 hours/day. Probably, then, the 14F size C is the best bet for a 1.2-volt end point. But a recheck with the chart shows that the same length of service is also obtainable from a 15A AA-size manganese-alkaline. The final decision must rest on the duty cycle, for the 14F size-C zinc-carbon is economical only if the estimated 4 hours/day is never exceeded.

The chart also enables you to effectively substitute one style of battery for another. For instance, suppose a tape recorder with six 15F cells for the amplifier has a maximum drain of 7.5 mA. Would it be cheaper to substitute a type 1604 9-volt transistor battery? No, since 15F cells will give 110 hours of service at 10 mA, and the 1604 only 17 hours at such a drain. In other words, the 1604 gives only 15% of the service for 62% of the cost. Here, in fact, is a case where the ordinary zinc-carbon cell is more economical than any other type, including even the manganese cell.

In another recorder, type 13F D cells drain at 135 mA and need fairly frequent replacement. At the specified

drain, heavy-duty zinc-carbon cells of the 13D type do not give better service than the ordinary 13F cells. Manganese cells might be the answer. As shown in the chart, the 13A gives 63 hours at a continuous 125 mA, as opposed to 36 hours at an intermittent 100 mA for the 13F cells. However, the recorder is never used for more than 4 hours at a stretch, and this is always followed by a 20-hour rest period. The question therefore arises, Wouldn't industrial flashlight cells of the 13C type be much more economical than manganese?

It turns out that they would. This becomes clearer when we consider the two types in terms of their available mA hours (at the drains in the chart that are closest to the recorder's drain of 135 mA). The 13C yields 5,800 mA-hr; the 13A, 7,875 (63 hr  $\times$  125 mA). There is apparently 74% as much power from the 13C for only 27% of the cost.

But unfortunately none of the manufacturers compared performance of the two types at the same drains with the result that the data on the manganese given in the chart are at a drain 25% higher than the 100-mA drain of the 13C. Therefore the 13A will yield more power at 100 mA. It computes out to about 8,700 mA-hr. Therefore, the 13A, when at 100 mA, yields about 50% more power than the 13C.

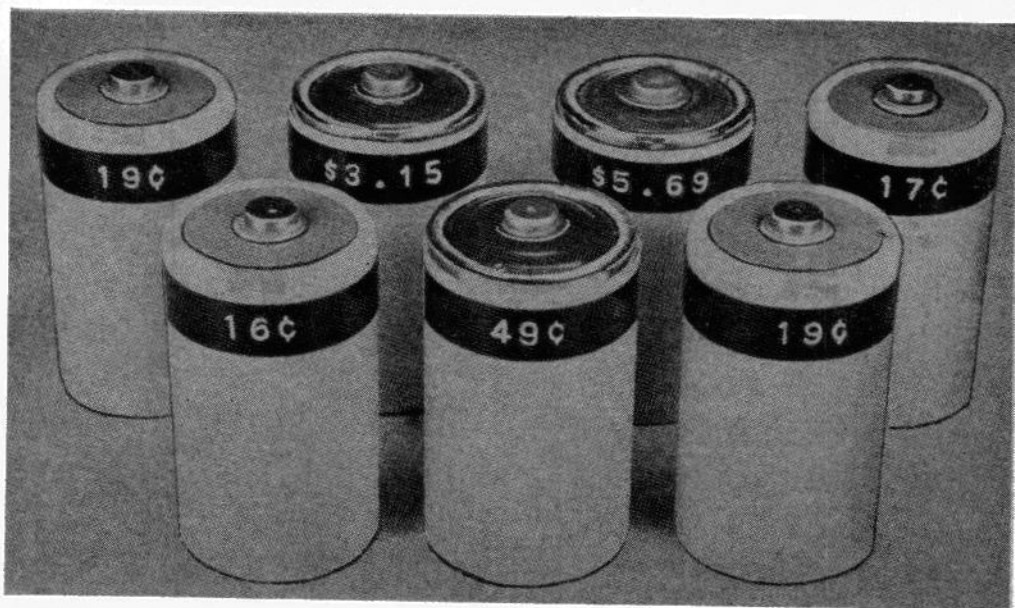
The cost of the cheaper battery times the percentage of better service of the more expensive battery equals the fair premium to pay for the extra service. Since the 13C costs about \$0.16 the fair value of the 13A for this service is  $0.16 + (0.50 \times 0.16)$ , which is \$0.24. Obviously, with the 13A selling at \$0.50, the 13C is the better buy for use under the particular conditions.

There is no simple answer to battery selection, as you can see. However, the chart will enable you to make good choices in most situations. Exact data on many drains, end points and duty cycles that are not given in the chart will be found in the Eveready, RCA and Burgess battery manuals.

Grateful acknowledgement is made to the Mallory Battery Company and Union Carbide Corporation for making special data available for use in this article. END

### References

1. Burgess Battery Company, *Burgess Engineering Manual*, 1966.
2. Mallory Battery Company, *The Characteristics and Applications of Advanced Design Dry Batteries*, 1965.
3. National Bureau of Standards, *Specification for Dry Cells and Batteries*, 1959.
4. Radio Corporation of America, *RCA Battery Manual*, 1966.
5. Union Carbide Corporation, *Eveready Battery Applications and Engineering Data*, 1964.



# Choosing the RIGHT Battery

ACCELERATED LIFE  
TESTS DEMONSTRATE  
BIG DIFFERENCES  
IN PER-HOUR COSTS

BY LEWIS A. HARLOW

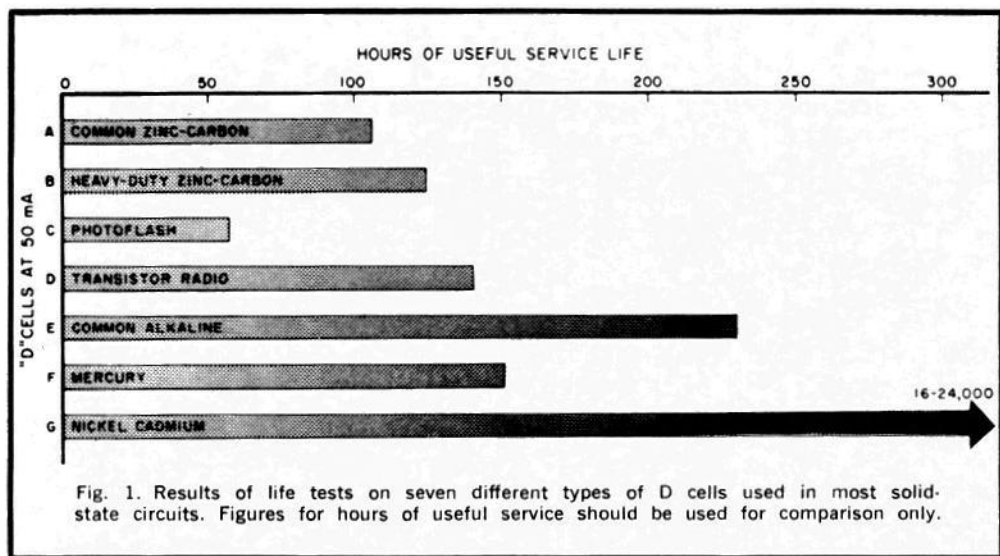
**W**HEN IT COMES to calling out the battery, the usual parts-list instruction is: Use an ordinary transistor radio battery. Of course, the voltage required is given—1.5, 3.0, 4.5, or 9.0 volts—but there are literally scores of batteries of all different sizes, shapes, and prices that fill this requirement. And, strangely enough, there appears to be no fixed set of rules for selecting the “right” battery. Even if you are replacing a battery in a portable radio receiver or transceiver, you must still choose between two or three different types of batteries—regardless of the physical volume and shape limitation!

To add insult to injury, there are identical batteries—in terms of external appearance—that have vastly different current-output ratings and life cycles. There is no perfect answer to the problem of battery selection, but there are

important guidelines, some new, some old, but all worth reviewing.

**First Things First.** If the physical size of the battery is not a hindrance, the one basic specification that you must know is how much current is going to be drawn from the battery. If you have designed your own circuit, you can estimate the current drain the hard way, or you can measure the drain from your low-voltage bench power supply from a temporary battery hookup. The answer should be in the range of 1 to 20 milliamperes—rarely more.

A current drain measurement should also be made on commercial gear; however, in this instance, try to use a fresh battery of a type similar to that recommended by the manufacturer. The answer you get is very helpful in making the right battery selection.



**Physical Size.** A primary principle of battery engineering is that batteries of the same chemical composition have a service life directly related to the weight of the battery. A good, big battery has a longer service life than a good, small battery of the same chemical makeup.

You can prove this to your own satisfaction by testing the three different sizes of the common 1.5-volt battery—the D cell, the C cell and the AA cell. The author tested three typical cells on the basis of four hours of service per day at a drain of 15 mA. The test was halted when the cell output under load dropped to 1.0 volt. The results were:

D cell—service life, 360 hours

C cell—service life, 180 hours

AA cell—service life, 38 hours

From this information we can safely assume that the D cell has approximately twice the service life of the C cell and almost nine times that of the AA cell. Since all three have essentially identical chemical compositions, service life is directly proportional to the physical size of the cell.

**Impedance.** This may seem to be a strange term to find in an article on battery selection, but the impedance of a dry cell is important in all solid-state applications. You want as little internal battery impedance as possible. Impedance and the voltage/current output of the

battery are, of course, related; the greater the internal impedance, the greater the internal voltage drop under load. When the internal impedance of the battery is too high it may become a source of audio-signal distortion or r.f. oscillator instability.

The internal impedance of a fresh zinc-carbon D cell at normal room temperature is 0.277 ohms. This figure rises sharply as the cell discharges. The internal impedance of a fresh alkaline D cell is 0.15 ohms and it remains fairly constant throughout the life of the battery. The impedances of mercury and nickel-cadmium cells are said to be even less than that of an alkaline cell.

**Shelf Life and Voltage Droop.** Although in many solid-state applications the shelf life of a battery is not an important problem, most battery users neglect to include in overall life expectancy the periods when the equipment in which the battery is installed is not in use. No battery lasts indefinitely, and the life of any battery is shortened by high temperatures—and, conversely, somewhat lengthened by low temperatures. Roughly speaking, an AA cell stored for 24 months at 70°F retains only 50% of its initial capacity. A mercury cell, on the other hand, retains nearly 90% of its initial capacity. Alkaline cells have shelf and storage lives similar to mercury cells,

but a nickel-cadmium cell generally loses more than 10% of its charge in one month and about 60% in one year.

**Comparative Service Life.** The author subjected seven different D cells—commonly used in solid-state projects—to identical service-life tests. A current-drain of 50 mA was chosen for this test. Admittedly, this is a high load level, but it is the lowest that includes the ratings of all seven D-cell types.

The bar chart in Fig. 1 shows the result of the author's tests. The figures for "hours of useful service life" should be used only for comparative purposes. All of the batteries used in the D-cell test (and in the 9-volt representative test) are identified in the interchangeability table.

The service lives of four zinc-carbon D cells are shown by bars A, B, C, and D in Fig. 1. In the accelerated test, the "usual" zinc-carbon D cell that had a service life at 15-mA load of 360 hours only survived 102 hours with a load of 50 mA. This is the 15-16¢ battery commonly seen in hardware stores, drug stores, etc. For only one or two cents more you can buy the so-called "heavy duty" D cell that had an accelerated service life represented by bar B. This is the D cell used by night watchmen and in the flashlights of gas, water and electric meter readers.

The surprisingly low service life of the battery represented by bar C is due to the fact that this battery was never destined to be used in solid-state circuits. Its chemical composition is adjusted to favor brief surges of maximum current. Consequently the battery is of greatest use to the photographer. It is listed here only because you may happen to wonder if this particular battery has any magic properties.

The last zinc-carbon D cell, the so-called "transistor radio" cell, is represented by bar D. In this instance, the chemical composition has been adjusted to favor long service at a reasonably low current drain, and in this respect it is the exact opposite of the photoflash D cell (bar C). The service life of this battery under the loads it is designed to handle is approximately 700 hours at 10 mA, 510 hours at 15 mA, and 300 hours at 25 mA.

**The Non-Zinc-Carbon D Cells.** Bar E in Fig. 1 represents the accelerated test for a common 50¢ alkaline D cell. Even with the accelerated drain of 50 mA the battery performed excellently for approximately 230 hours. The alkaline D cell has a low internal impedance and the output voltage remains reasonably stable throughout its life. The impedance and voltage stability minimize audio distortion and help stabilize oscillator performance in portable receivers. The service life at very low drains is almost astronomical. All things considered, the alkaline D cell is probably the best buy for solid-state projects.

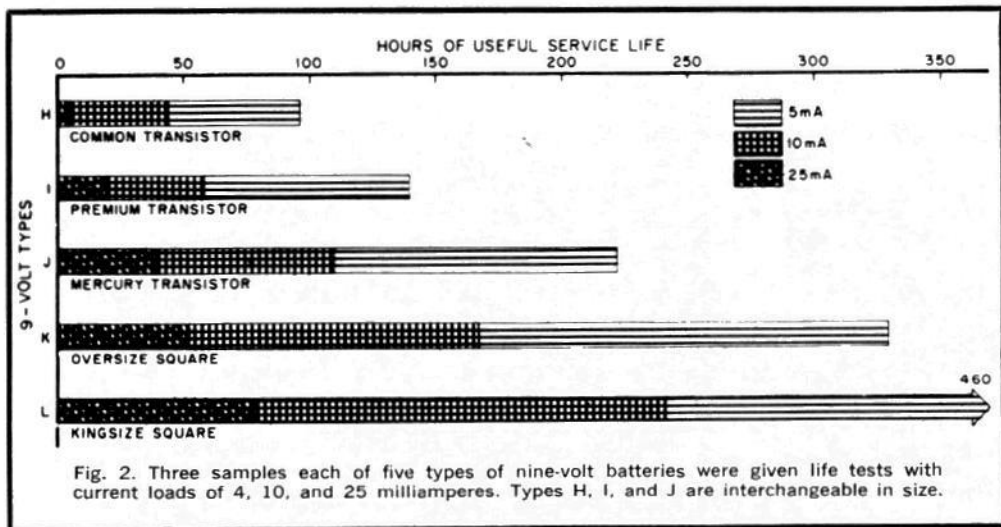
Where it is necessary to obtain a battery with a very low internal impedance and superb voltage stability, the mercury D cell is the obvious choice. The accelerated service life of a mercury D cell is shown in bar F. The figures are not too impressive—indicating 150 hours at 50 mA. The price of a mercury D cell exceeds \$3 and it is obvious that the real value of the mercury-type battery is not found in the D-cell size. However, mercury battery construction lends itself to miniaturization and miniature mercury batteries are the best choice for stable low-drain voltage requirements over very long periods of time.

It is difficult to approximate the "life" of a rechargeable nickel-cadmium D cell, which is represented by bar G in Fig. 1. A typical battery (costing about \$5.50) had a service life at 50 mA of only 80 hours. However, this life value must be multiplied by the 200 to 300 times that this type of battery can be recharged. On the other hand, recharging a nickel-cadmium cell is a critical operation and the charge rate is determined by the ca-

**BATTERY INTERCHANGEABILITY LIST**

	Burgess	Everready	RCA	Mallory	Ray-O-Vac	NEDA
A*	2	950	VS036	M13F	2D, 2LP	813, 13F
B	210	1150	—	M13X	3LP, 3D	13C
C	220	850	VS736	M13P	210LP	13P
D	230	1050	VS336	M13R	13	13
E	AL2	E95	VS1336	MN1300	—	813, 13A
F	Hg42R	E42N	—	RM42R	—	—
G	CD10	CH4	—	—	—	—
H	2U6	216	VS323	M1604	1604	1604
I	2MN6	222	—	—	M1604	1604D
J	Hg136R	E136N	—	TR136R	—	—
K	2N6	246	VS305	M1602	1602	1602
L	M6	266	VS322	M1605	1605	1605

\*Letters correspond to bars in Figs. 1 and 2.



capacity of the cell. Commercially available chargers are generally tailored to the needs of a specific size of battery cell and are therefore difficult to adapt to any other type of battery charging. This has resulted in the phenomenon of the cordless razor and cordless carving knife that are always sold with a "charging stand."

If you are not scared away by the complications of recharging, the nickel-cadmium battery is a very good buy for solid-state service. Internal impedance is low and stable. The battery holds its rated voltage output throughout most of the life of the charge. In the long term, the cost-per-hour of use of the nickel-cadmium battery is surprisingly low.

**The Nine-Volt Batteries.** The other standard of battery-powered solid-state equipment—one that is sold by the millions of units—is the 9-volt battery. There are not too many 9-volt batteries to test, but accelerated life tests of several different examples are represented by the bars in Fig. 2.

Bar H is the common low-cost 9-volt "transistor radio battery." Bar I is the better grade of the common zinc-carbon 9-volt battery. Although this premium battery is an exact physical replacement, it has a somewhat different internal structure. Equated at list prices the premium battery saves you only 0.04¢ an hour at the 5-mA rate.

Bar J represents the expected life of a mercury 8.1-volt battery replacement for the common "transistor radio battery." This battery offers the real advantage of very low internal impedance and excellent voltage stability. Don't be disturbed by the 8.1-volt rating of the mercury battery. The zinc-carbon 9-volt batteries drop to this voltage level as soon as they are put in operation, whereas the mercury battery delivers close to its full voltage rating throughout most of its life.

The batteries represented by bars H, I and J are all interchangeable, but if you have the physical room, the following larger 9-volt zinc-carbon batteries should be considered. In bar K we see the expected life of a square-type battery that costs about twice as much as the common "transistor radio battery." In bar L is another square-top zinc-carbon battery of somewhat greater physical dimensions. The cost between the batteries shown in bars K and L is only a matter of a few pennies.

We have shown what you can expect from 12 different types of 1.5- and 9-volt batteries. Since all batteries were purchased and tested as being "fresh" and given the same accelerated life test, the comparisons are felt by the author to be perfectly legitimate. Using the information here, however, you will know what to do when a schematic calls for a "1.5- or 9-volt battery."

# Battery Types and Their Characteristics

WHAT'S THAT BATTERY NUMBER THE SAME AS?

BY SAMUEL C. MILBOURNE

**A** CERTAIN amount of confusion exists with regard to battery types and numbers. Consequently, it is handy to have a chart that gives the specifications of the various batteries commonly used in such consumer equipment as transistor radios, toys, clocks, etc. Our table is limited to listings for 1.5- and 9-volt batteries. Since there are more than 400 battery types and thousands of manufacturers' numbers from which to choose, we make no pretense that the table is complete. However, the listings should cover most needs.

You will note that the batteries are divided into carbon-zinc, alkaline-manganese, and rechargeable alkaline-manganese types.

They are listed in the order of their current delivery capabilities from least to greatest. Too, each common battery type is supplied with such statistics as: size, American National Standards Institute (ANSI) and National Electronic Distributors Association (NEDA) numbers, etc.

In general, batteries of the same physical size and shape with the same voltage output and terminations can be substituted for each other so long as the maximum currents drawn by the circuits can be accommodated by the substitutes. So, you can put an alkaline type in place of a zinc-carbon battery, and a rechargeable alkaline in place of a regular alkaline battery.

Size/Volts	Current (mAh)	DIA X H or L X W X D*	ANSI Desig.	NEDA No.	Manufacturer Numbers				RCA
					Burgess	Eveready	Mallory	Ray-O-Vac	
<b>Carbon-Zinc</b>									
N/1.5	20	0.445 X 1.18	N	910F	NE	904	M904F	716	VS073
AAA/1.5	20	1 <sup>3</sup> / <sub>32</sub> X 1.75	AAA	24F	7	912	M24F	400	VS074
AA/1.5	25	7 <sup>1</sup> / <sub>16</sub> X 1 <sup>1</sup> / <sub>32</sub>	AA	15F	910	915	M15F	7AA	VS034A
C/1.5	80	1 <sup>1</sup> / <sub>2</sub> X 1 <sup>1</sup> / <sub>16</sub>	C	14F	1	935	M14F	1C	VS035A
C/1.5	80	1 <sup>1</sup> / <sub>2</sub> X 1 <sup>1</sup> / <sub>16</sub>	C	14	130	1035	M14R	14	VS335
D/1.5	150	1 <sup>1</sup> / <sub>2</sub> X 2 <sup>1</sup> / <sub>32</sub>	D	13F	2	950	M13F	2D	VS036
D/1.5	150	1 <sup>1</sup> / <sub>2</sub> X 2 <sup>1</sup> / <sub>32</sub>	D	13C	210	1150	—	3D	—
109/9	7	3/4 X 2	F17	1611	L6	206	M1611	—	VS327
127/9	9	1 X 1 <sup>1</sup> / <sub>16</sub>	F24	1600	P6	226	M1600	1600	VS300A
—/9	10	3 <sup>3</sup> / <sub>16</sub> sq X 1 <sup>2</sup> / <sub>32</sub>	—	1606	Y6	—	—	—	VS309A
117/9	15	1 <sup>1</sup> / <sub>2</sub> X 2 <sup>1</sup> / <sub>32</sub> X 1 <sup>2</sup> / <sub>32</sub>	F22	1604	2U6	216	M1604	1604	VS323
<b>Alkaline-Manganese</b>									
AAA/1.5	100	0.4 X 1.735	L30	24A	AL7	E92	Mn2400	824	VS1074
AA/1.5	150	7 <sup>1</sup> / <sub>16</sub> X 1 <sup>2</sup> / <sub>32</sub>	L40	15A	AL9	E91	Mn1500	815	VS1334
C/1.5	480	1 <sup>1</sup> / <sub>2</sub> X 1 <sup>1</sup> / <sub>16</sub>	L70	14A	AL1	E93	Mn1400	814	VS1335
D/1.5	650	1 <sup>1</sup> / <sub>2</sub> X 2 <sup>1</sup> / <sub>32</sub>	L90	13A	AL2	E95	Mn1300	813	VS1336
<b>Rechargeable Alkaline-Manganese</b>									
—/1.5	300	7 <sup>1</sup> / <sub>16</sub> X 1 <sup>2</sup> / <sub>32</sub>	AA	—	—	—	SA15AA	—	—
—/1.5	1000	1 <sup>1</sup> / <sub>2</sub> X 1 <sup>1</sup> / <sub>16</sub>	C	—	—	—	SA14C	—	—
—/1.5	2000	1 <sup>1</sup> / <sub>2</sub> X 2 <sup>1</sup> / <sub>32</sub>	D	—	—	—	SA13D	—	—

\*DIA X H = diameter X height; L X W X H = length X width X height. All dimensions in inches. Blank entry means no number or designation assigned or manufacturer does not make battery.



It is interesting to note that the current delivery of the more recent alkaline batteries is several times greater than the older carbon-zinc batteries. True, the initial cost of the newer batteries is much greater, but they do not need to be replaced nearly as often as carbon-zinc cells, and if the alkalines are rechargeable types (with higher prices than the regular type alkalines), they can be renewed several dozen times before replacement is needed.

Upon perusing our table, you will note that many categories of batteries are not listed. These include nickel-cadmium, mercuric-oxide, silver-oxide, and lead-acid types. These have not been included in the listing because of their much higher costs and the future likelihood of losing out, at least to some degree, to the rechargeable alkaline types.

We will not go into the subject of recharging batteries here since this topic has been amply covered in other articles. But you should bear in mind the following facts that apply to all types of batteries: First, do not allow batteries to run completely down; test them often under adequate loads. Second, do not attempt to recharge a "leaky" or "rusted" battery; the electrolyte is corrosive and will ruin charger contacts. And, third, do not recharge batteries at abnormally high currents; the batteries will heat up and may explode.

Testing a battery requires a resistive load that reflects the allowable battery discharge current and an accurate dc voltmeter. To illustrate, a Burgess No. 2 or Eveready No. 950 battery can accommodate a 150-mA load across its 1.5-volt poles. By using Ohm's Law ( $R = E/I$ ) you can determine that the proper test load for these batteries would be 10 ohms ( $1.5/0.15 = 10$ ). The resistor selected for the test can be rated at  $\frac{1}{2}$  watt. To make the test, place the load resistor across the battery's terminals or poles and connect the meter's leads, in proper polarity, across the resistor. The meter will then indicate between 1.5 and 0.9 volts if the battery's charge has not been irretrievably depleted. If you obtain a meter indication of less than 0.9 volt, discard the battery and replace it with a new unit.

Batteries should be recharged or replaced long before they are completely exhausted. It is not harmful to recharge a 1.5-volt cell before its charge drops to 0.9 volt. In fact, it is beneficial in that it provides longer total life from the battery. ◀

# BATTERY TECHNOLOGY

## PACKAGING MORE MUSCLE INTO LESS SPACE



Older power sources are threatened by new primary and secondary cells made of lithium, zinc-chloride, divalent silver-oxide, silver-cadmium, and silver-zinc, as well as gelled and 'starved' lead-acid electrochemicals

by Jerry Lyman, *Packaging & Production Editor*

### SPECIAL REPORT

□ As the increasing application of semiconductor technology reduces the power requirements of electronic equipment, ever more sophisticated batteries are being developed to replace larger power sources. At decreasing prices, these batteries have several advantages over their predecessors—more power per pound, longer shelf life, higher performance over a longer temperature range, and better packaging.

Inexpensive primary batteries suffice for many small electronic products, such as portable radios, calculators, and watches. However, at higher prices, rechargeable batteries eliminate the inconvenience of battery changing or provide reliable standby power for equipment, such as volatile computer memories, which would otherwise lose their effectiveness if the line power failed.

Three new primary batteries are now appearing: zinc-chloride batteries, which are improved Leclanche cells; divalent silver-oxide cells, which generate a large amount of energy in a small package; and lithium cells, which provide high energy density, long shelf life, and

excellent performance even in environmental extremes.

To simplify installation and replacement, battery designers are implementing some novel packaging ideas, including a cassette-type alkaline power pack, a thin, flat, zinc-carbon battery, and hybrid packages containing more than one battery type.

Among secondary batteries, the low cost, high capacity, and long storage capability are making the gelled-electrolyte lead-acid cell a serious competitor to the more expensive nickel-cadmium battery. And such expensive space-proved power supplies as silver-zinc and nickel-cadmium batteries are finding applications in down-to-earth equipment. New versions of the sealed nickel-cadmium cell can be charged in periods as short as 15 minutes to three hours.

#### Cutting the cord

As the power requirements of electronic equipment are reduced by use of MOS, complementary-MOS, and integrated injection logic, designers are moving to eliminate the expense of rechargeable batteries and built-in chargers. As a result, battery manufacturers are devel-



oping and starting to supply some fairly high-energy long-life primary systems, including divalent silver-oxide and lithium batteries. However, most of the market, estimated at \$500 million a year, is filled by zinc-carbon, zinc-chloride, and alkaline batteries, used for such applications as toys, cameras, hand-held calculators, cassette recorders, and portable radios.

Table 1 summarizes the electrical characteristics of all of today's commercially available batteries. As indicated, the selection is tremendously wide. Although characteristics, construction, and pricing of zinc-carbon and alkaline cells are fairly well known, capabilities of the recently developed zinc-chloride heavy-duty battery are not so well known. This can be an inexpensive alternative to either of the other systems.

Because of their capability to operate at high electrode efficiencies, the current output of zinc-chloride cells is usually higher, and they will operate at high current drains for longer periods than will Leclanche cells of the same size. The construction of the zinc-chloride cell (Fig. 1) is similar to that of the conventional carbon-zinc Leclanche cell, but the electrolyte system is

different. In a zinc-chloride cell, the electrolyte contains only the soluble salt, but a Leclanche cell also contains a saturated solution of ammonium chloride, along with the zinc chloride. Although omission of ammonium chloride improves the electrochemistry, the seals had to be improved to confine the vigorous action.

When all chemicals but zinc chloride are eliminated, electrode blocking by reaction products is avoided, and electrode polarization at high current densities is minimized. Because of the electrochemical reactions in the zinc-chloride cell, water is consumed along with the electrochemically active materials so that the cell is nearly dry at the end of its useful life. And unlike the zinc-carbon battery, which can cause extensive circuit damage by leakage, the zinc-chloride battery has excellent resistance to leaks. What's more, the zinc-chloride battery operates much better at low temperatures.

In a typical application for AA cells, a 75-cent alkaline cell lasts four times as long as a 30-cent zinc-carbon cell, and a 40-cent heavy-duty zinc-chloride cell will last twice as long as its zinc-carbon counterpart.

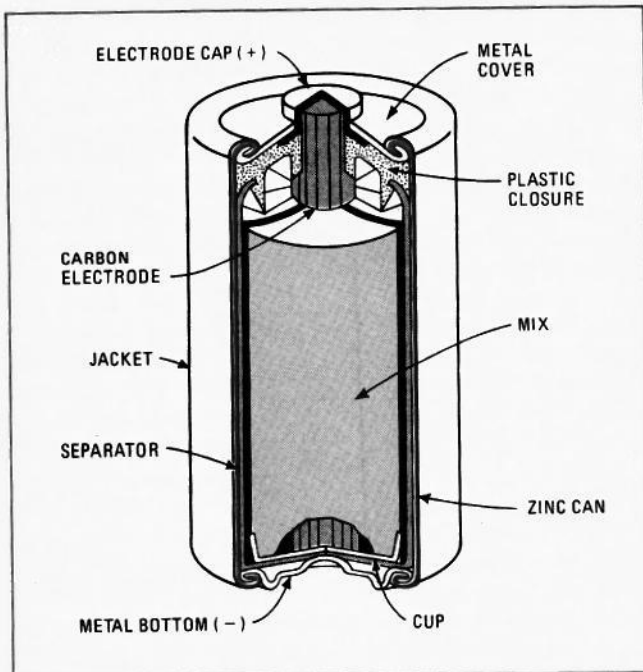
### Packaging the 'buttons'

The present sizes of such equipment as electronic watches, exposure meters, cameras, hearing aids, and pacemakers would be impossible if they had to use zinc-carbon, zinc-chloride, or alkaline batteries. These tiny products are powered by button-size mercuric-oxide cells, which are typically 0.125 inch high and 0.220 inch in diameter. These cells come in cylindrical, flat-pellet, and button configurations.

Mercury cells are divided into two basic types—one with a nominal voltage of 1.35 v, and the other with a

TABLE 1: ELECTRICAL CHARACTERISTICS OF PRIMARY BATTERIES

	Leclanche	Zinc-Chloride	Alkaline	Magnesium	Mercury-Oxide	Silver-Oxide	Divalent Silver-Oxide	Lithium
1. Energy output Watt-hours per lb Watt-hours per in. <sup>3</sup>	20 2	44 3	20 to 35 2 to 3.5	40 4	46 6	50 8	70 14	100 to 150 8 to 15
2. Nominal cell voltage	1.5	1.5	1.5	2.0	1.35 or 1.4	1.50	1.5	2.8
3. Practical drain rates Pulse High (>50 mA) Low (<50 mA)	Yes 100 mA/in. <sup>2</sup> Yes	Yes 150 mA/in. <sup>2</sup> Yes	Yes 200 mA/in. <sup>2</sup> Yes	No 200 to 300 mA/in. <sup>2</sup> Yes	Yes No Yes	Yes No Yes	Yes No Yes	Yes Yes Yes
4. Impedance Z <sub>i</sub>	Low	Low	Very low	Low (Delay on start up)	Low	Low	Low	Less than 1 Ω
5. Temperature range Storage Operating	-40 to 120°F 20 to 130°F	-40 to 160°F 0 to 160°F	-40 to 120°F -20 to 130°F	-40 to 160°F 0 to 160°F	-40 to 140°F 32 to 130°F	-40 to 140°F 32 to 130°F	-40 to 140°F 32 to 130°F	-65 to 160°F -40 to 130°F
6. Temperature vs capacity	Poor at low temperature	Good at low temperature compared to Leclanche	Fair to good at low temperature	Fair at low temperature	Good at high temperature poor at low temperature	Poor at low temperature	Poor at low temperature	Excellent
7. Shelf life at 68°F to 80% initial capacity (in years)	2 to 3	2 to 3	3 to 5	2 to 3	2 to 3	2 to 3	2 to 3	3 to 5 (estimated)
8. Shape of discharge curve	sloping	sloping	sloping	fairly flat	flat	flat	flat	flat



**1. Heavy duty.** Zinc-chloride cells can last as much as 2.5 times longer than zinc-carbon cells. This performance results from an electrolyte containing only zinc chloride, improved sealing techniques, and better construction.

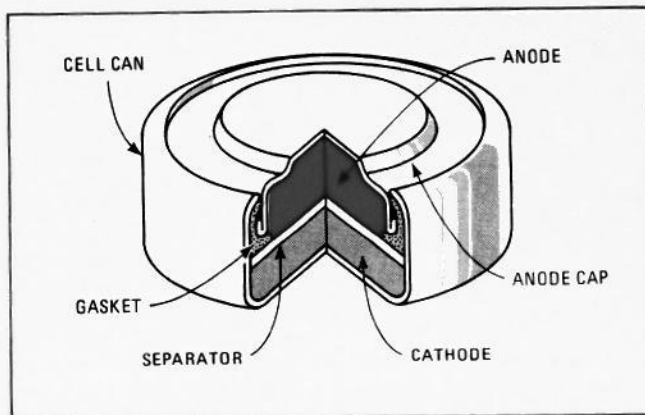
**1.4-v rating.** In general, the 1.35-v cells and batteries are recommended as voltage-reference sources for scientific and medical applications, and the 1.4-v cells are used mainly in consumer applications where a flat voltage characteristic is not needed. Mercury cells offer a flat-voltage discharge characteristic, good performance at high temperatures, good resistance to shock and vibration, and shelf life as long as two and a half years.

In all these cells, an ion-permeable barrier separates an anode, formed from high-purity amalgamated zinc, from the cathode of mercuric oxide and graphite. The ions of the electrolyte, which is a solution of alkaline hydroxide, act as carriers for the chemical action in the cell. To minimize corrosion, the cell containers are made of nickel-plated steel.

### Upgrading silver-oxide cells

Although a battery system using monovalent silver oxide (Fig. 2) has about the same energy density as a mercury cell, its 1.5-v output is higher. This makes it desirable for light-emitting-diode readouts in digital watches, as well as cameras and hearing aids. However, chiefly because of material costs, the silver-oxide cell is more expensive than the mercuric-oxide cell. Unlike the packaging of the mercury cell, silver-oxide cells are supplied chiefly in the button configuration.

During the past year, Ray-O-Vac, Madison, Wis., a division of ESB Inc., began manufacturing a line of batteries that supply as much as 40% more energy than earlier silver-oxide cells, and other companies have been developing similar products. The power output has been increased by use of a highly active divalent silver oxide to replace the monovalent type as a depolarizing cathode. The depolarizer converts hydrogen formed at



**2. Silver oxide.** A silver-oxide cell consists of a depolarizing silver-oxide cathode, a zinc anode having a large surface area, and a highly alkaline electrolyte. These small cells are extensively used in electronic digital watches.

the cathode to water. Service life of the two kinds of 1.5-v silver cells is compared in Fig. 3. The older RW-12 monovalent cell, 0.455 by 0.220 inch, has a rated capacity of 175 milliampere-hours. The RW-32 Silver II of the same size has a rated capacity of 245 mAh.

Of all the primary batteries, the volatile lithium cell has the greatest energy density by far—about 150 watt-hours per pound—and the highest cell voltage—about 3 v. Many researchers consider the nonaqueous lithium cell the battery of the future because of its superior characteristics, although it still has a few drawbacks.

### Evaluating the lithium cell

In addition to yielding more power and energy per unit of weight and volume, the lithium cell can operate from  $-65^{\circ}\text{F}$  to  $+165^{\circ}\text{F}$ , has longer shelf life than any other battery type, and has a flat voltage-time curve. But its high price has thus far restricted the lithium battery mostly to military-aerospace applications.

Two major obstacles have hindered development of a commercial cell—the tendency of lithium to react violently to even trace quantities of water and the need for an active cathode material that is compatible with both the lithium and the organic electrolyte. Both of the two lithium-battery manufacturers decline to reveal what cathode material they are using. And despite the need for a tight seal, the cell must have an emergency venting system to release excessive gas pressure if and when the circuit is shorted. A special elastomeric seal has been developed for that purpose.

But despite their drawbacks, lithium cells are being used for emergency crash-locator beacons, sonar pingers, sonobuoys, missiles, expandable jammers, and even animal telemetry—applications in which high energy at small size and weight is crucial. Power Conversion Inc., Mount Vernon, N.Y., has delivered several thousand batteries for balloon-borne radiosondes where low-temperature performance is vital. The cells are also being used in standby power systems for volatile memories and in smoke-detection systems. In time, lithium cells are expected to become price-competitive with other premium primary batteries.

The lithium battery, its spirally wound core packaged



in a steel case (Fig. 4), looks like any commercial D cell, but the performance differs greatly. One standard lithium D cell can power a flashlight continuously for 18 hours, whereas two comparable zinc/carbon cells would last only 15 minutes, points out Stewart Chodosh, marketing manager for Power Conversion.

Power Conversion, which has been producing lithium batteries for several years, offers eight standard cell types rated from 0.5 to 10 Ah. Mallory Battery Co., Tarrytown, N.Y., is sampling its version of the nonaqueous lithium cell.

Lithium cells operate efficiently at high discharge rates, a mandatory characteristic for applications having high current drain. The bar chart in Fig. 5 shows that a lithium D cell's energy, with a 1-A current drain at 70°F, is equivalent to four mercury-zinc D cells, five alkaline-manganese D cells, seven magnesium D cells, or 30 carbon-zinc D cells. A comparison of lithium cell's flat voltage/time profile with other types of cells (Fig. 6) shows that it is clearly superior to the others.

### Packaging battery systems

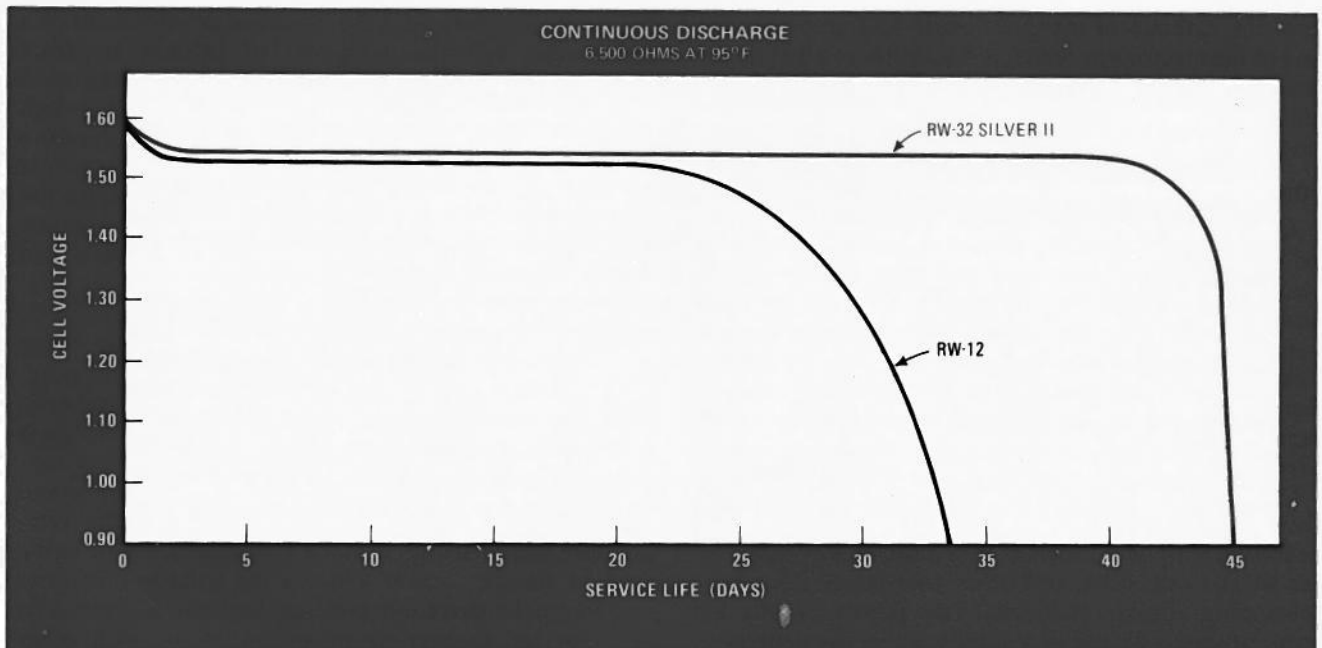
Anyone who has struggled to replace individual cells in the small battery compartment of a calculator, cassette recorder, or camera has hoped for a better way of doing it. Now Mallory and Ray-O-Vac have overcome

this time-consuming annoyance by packaging cells in cassettes, which also prevent incorrect installation and bent battery contacts. What's more, Mallory has packaged two different types of batteries together to take advantage of the best characteristics of each.

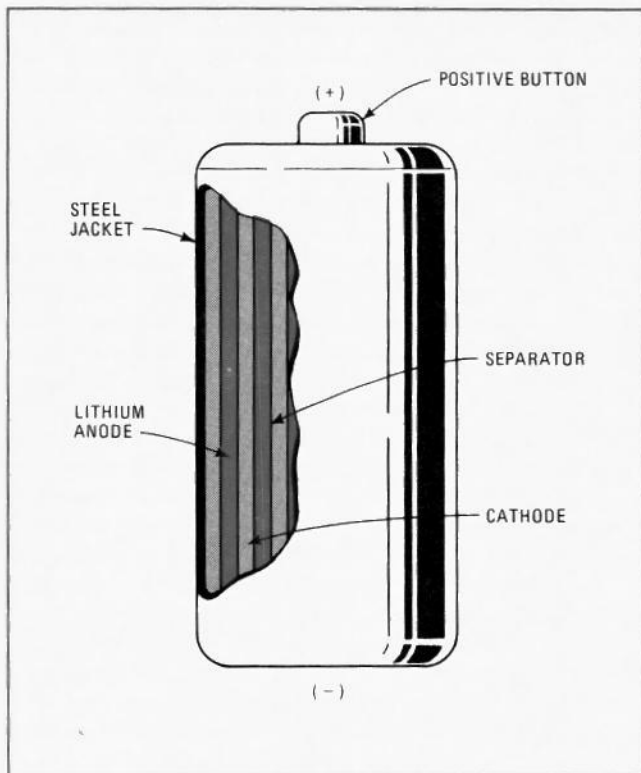
In Mallory's Flat-Pak (Fig. 7) several cylindrical alkaline cells are connected in series in an almost rectangular plastic container that has two metal battery posts on one end. This package slips into a battery compartment like a cassette. The Flat-Pak is aimed at the calculator and camera markets; one 6-v unit has already been designed for a Summit calculator.

Two 500-mAh versions of the Flat-Pak are now available. One is a 6-v unit in a package of 1.890 by 1.390 by 0.350 in., and the other is a 9-v unit in a package of 1.890 by 2.000 by 0.350. Also being developed is a long thin 500-mAh Flat-Pak in a package 4.925 by 0.750 by 0.270 in. Comparative dimensions of a standard 9-v 500-mAh alkaline battery for transistor radios is 1.766 by 1.031 by 0.656 in.

Mallory's hybrid cylindrical package was developed to power a smoke detector and give the required audible alarm when the batteries are nearing the end of their lives. Since a long-life mercury battery is the alarm's power source, triggering the required low-battery alarm is difficult because of the flat voltage/time characteristic (Fig. 8a). And because its discharge characteristic is flat, internal voltage regulation is not needed. However, if a cadmium-oxide battery were used, an appropriate low-voltage point could be designated on its stepped voltage/time curve (Fig. 8b) to trigger the signal. Unfortunately, the expensive cadmium-oxide batteries don't have adequate capacity. To power the smoke detector, Mallory has connected seven mercury and two cadmium cells in series in one cylindrical battery case. When the stepped curve of the cadmium cells is added to the flat characteristic of the



**3. Silver cells.** Replacing the monovalent silver-oxide depolarizer with divalent silver oxide improves energy density by 40%. Identically packaged monovalent (RW-12) and divalent (RW-32) silver-oxide primary batteries, measuring 0.455 by 0.220 in., are compared above.



**4. Lithium.** A nonaqueous lithium cell contains a high-energy lithium anode that reacts to even a trace of water. This cell must have both a nearly hermetic seal and a venting system to relieve gas pressure caused by excessive current discharge.

seven mercury cells, the result is the composite curve of Fig. 8(c), which drops from 11.8 v to 10.3 v at 630 mAh. A circuit senses this 1.5-v drop and activates the alarm while about 300 mAh are left to operate the alarm until the battery can be replaced.

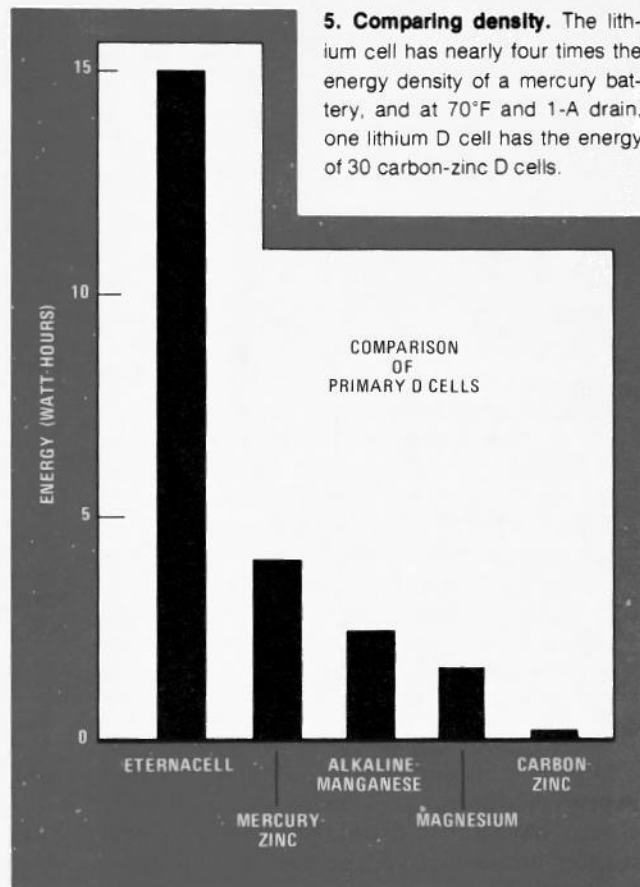
#### Customizing a zinc-carbon cell

Usually a designer must fit his equipment to one of the several standard cylindrical and flat configurations of commercial primary batteries of various sizes. An exception is the Polaroid SX-70 camera, for which Ray-O-Vac originally manufactured its P-70 flat-zinc-carbon battery pack. This company is now using the P-70 technology to develop a family of flat zinc-carbon power packs, called Strata-Pacs, for the calculator industry.

The Strata-Pacs are intended to be manufactured in several forms and voltages. The first one to be available is a 6-v 500-mAh unit measuring 3.5 by 2.9 by 0.25 in. Prices will be competitive with comparable alkaline batteries, Mallory says. Their low profile makes the Strata-Pacs suitable for cassette loading, and the large surface area of the equivalent battery plates enable this source to supply a high current drain. In calculator applications (Fig. 9), a Strata-Pac I has outperformed equivalent alkaline and heavy-duty zinc-chloride cells. Shelf life is equivalent to that of zinc-carbon batteries, Ray-O-Vac claims.

#### Considering rechargeable batteries

Designers frequently decide that their equipment justifies the higher price of secondary batteries, or re-



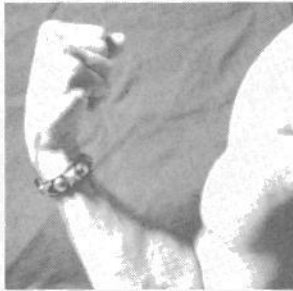
chargeable batteries are necessary to provide a reliable emergency power source. Four types dominate electronic applications—sealed nickel-cadmium, gelled-electrolyte lead-acid, silver-cadmium, and silver-zinc batteries (Table 2).

Electronics engineers most often use the sealed nickel-cadmium battery in applications ranging from consumer goods and portable test equipment to powering industrial, aviation, and aerospace equipment. In general, sealed nickel-cadmium cells are more economical when purchased in large quantities than other rechargeable types in the small sizes (AAA, AA, and C).

However, a silver-zinc cell, with the equivalent energy density of 45 Wh per pound, provides four times the energy of a nickel-cadmium cell and five times the gelled-electrolyte lead-acid cell's energy density. At 22 to 34 Wh per pound, a silver-cadmium cell has slightly less energy density than a silver-zinc unit, but its maximum life is three times as long as the typical 100 cycles for the silver-zinc cell. The typical discharge characteristics of these secondary battery systems is compared in Fig. 10.

At ratings of 1 Ah and higher, the lead-acid cells cost only one third to one fourth as much as comparable nickel-cadmium cells. But a silver-zinc cell is somewhat more expensive than its nickel-cadmium counterpart—4 Ah of nickel-cadmium power costs more than \$20, compared to less than \$12 for the same amount of power from a lead-acid battery.

Neither the silver-zinc nor the lead-acid cell has the "memory effect," which can be a drawback for nickel-



cadmium batteries that are operated at a certain low discharge levels for short, repetitive periods. The battery becomes conditioned to that level of operation and "forgets" its design capacity so that it delivers only the customary output when the demand for power is increased. To their credit, nickel-cadmium cells supply a high rate of current, have high energy density, are available in a wide range of sizes, operate over a long temperature range, and have a life expectancy of nearly 1,000 cycles, compared to 300 cycles for silver-cadmium cells. In addition, recently developed models can be charged quickly.

#### Quick-charging nickel-cadmium cells

On the debit side, nickel-cadmium cells are relatively expensive, can be permanently damaged by heavy discharge, have a high discharge rate during idleness, and register no distinct voltage rise to indicate when they reach full charge.

The 10-hour or C/10 rate has been accepted as the rate at which sealed nickel-cadmium cells can be safely charged. C is the ampere-hour capacity of the cell, and 10 is the number of hours required at maximum charge efficiency to fully charge a completely discharged cell. This formula requires 11 to 16 hours.

However, faster recharging is often demanded for

batteries used in such equipment as oscilloscopes, digital multimeters, and electronic photoflash guns. Most of the quick-charging systems depend on varying one or more of the functions of nickel-cadmium cell—voltage, pressure, or temperature.

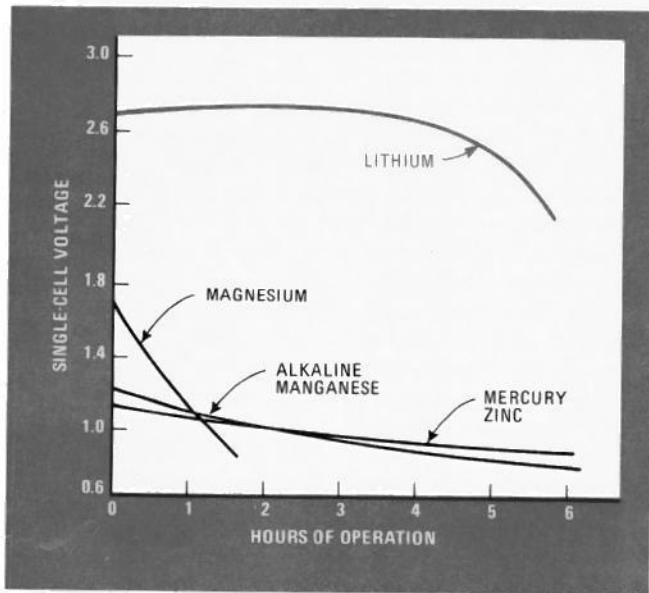
The General Electric Co. Battery Products section, Gainesville, Fla., and Union Carbide Corp., New York, have developed fast-charging nickel-cadmium cells. The fastest of the three is GE's Power-Up-15 battery, which can be charged to 90% of its capacity in 15 minutes. The accompanying charger senses both temperature and voltage, and when either reaches its limit, an electronic switch reduces the rate to the C/10 rate—a trickle.

Eveready's Hustler, which can be recharged in one to three hours, can withstand overcharge at a rate of C to 3 C long enough for the cell temperature, which rises when full charge is approached, to be sensed by a thermal-control element of the charger. The Hustler's charger, which is less sophisticated than that of the Power-Up-15, has only a temperature cutoff to prevent overcharge.

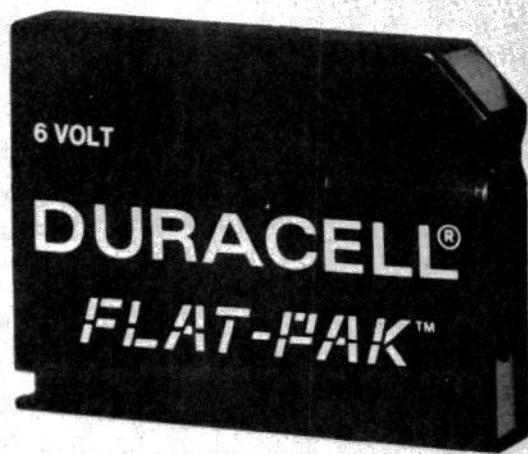
GE's Goldtop line can also be recharged faster than older types. By increasing the temperature range in these cells, they can be charged at the rate of 0.3C for three and a half to four hours with a conventional rectifier and without the need for thermal-sensing elements. Temperature tolerance was raised from the usual 50°C to 65°C by improving the plate design, the separator, and the seals.

#### Increasing energy density

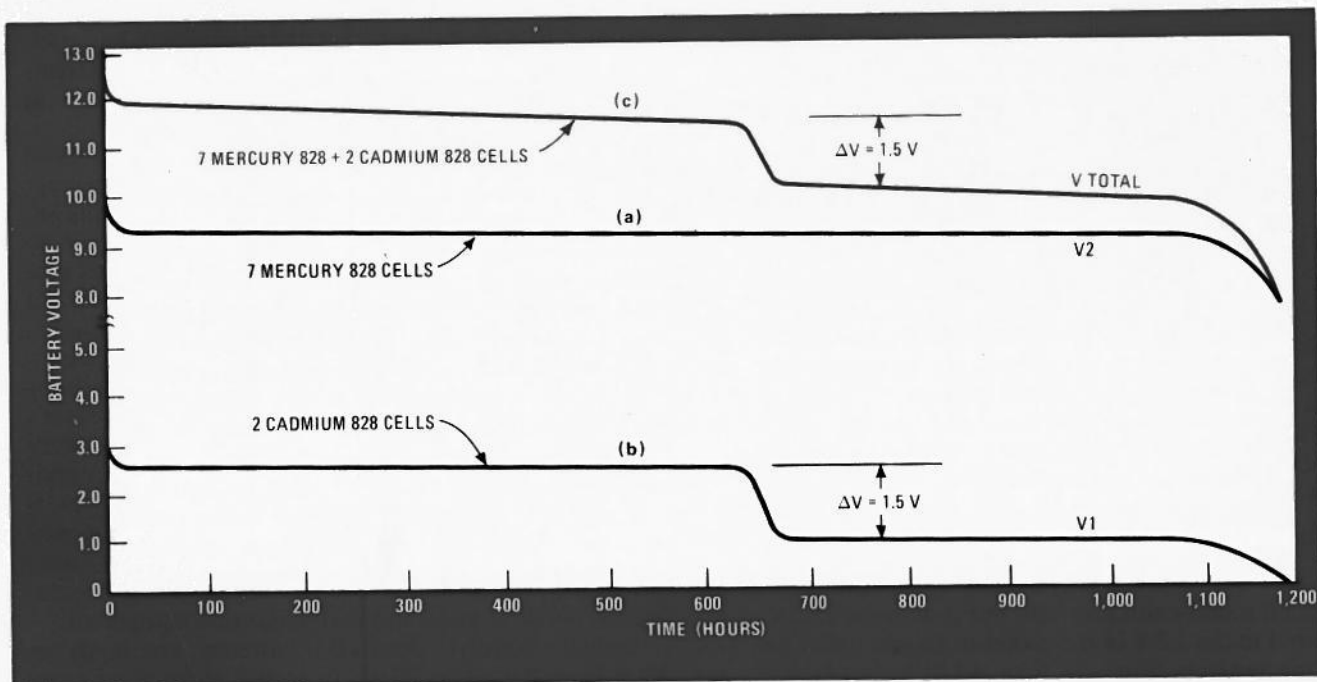
Many applications require a lighter, more powerful power source than the nickel-cadmium battery. These include powering portable television cameras, videotape recorders, airborne telemetering equipment, missiles, and electronic pipeline trouble-finders. Such tasks are usually performed by silver-zinc and silver-cad-



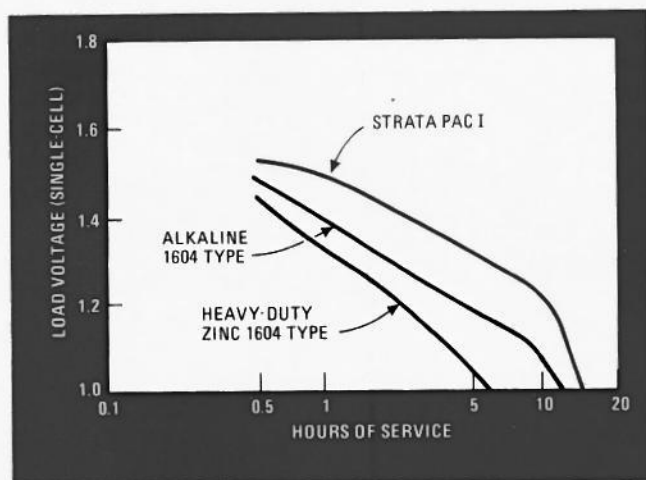
**6. Dependable.** At 1-A drain, the lithium D cell's voltage-time curve is flat for most of its useful life. Only the mercury-zinc cell, with a lower energy density and cell voltage, approaches the flat voltage characteristic of the lithium cell.



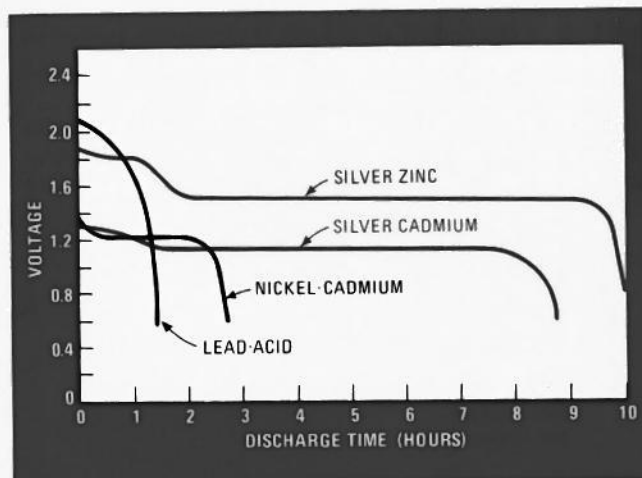
**7. Flat-Pak.** One of the newer battery packages is Mallory's 6-V, 500-mAh Flat-Pak, suitable for calculators and cameras. This unit measures 1.89 by 1.39 by 0.35 in. and has special cylindrical alkaline cells. A 9-V 500-mAh Flat-Pak version is also available.



**8. Exploiting characteristics.** Because of their flat voltage characteristic, there is meager warning when mercury cells near their full-discharge point. However, by adding two cadmium cells in series with seven mercury cells, an alarm can be activated to signal a low-battery condition because the hybrid registers a distinct 1.5-V drop at 630 mAh. At this point, about 300 mAh are left to operate the system.



**9. Calculator service.** With a typical calculator load (6 V at 30 mA), the Strata-Pac, an improved version of the SX-70 camera's flat zinc-carbon battery, outperforms competitive primary batteries.



**10. Discharging characteristics.** Typical discharge characteristics are compared for silver-zinc, silver-cadmium, nickel-cadmium, and lead-acid batteries of equal weight and current drain.

mium battery packs. The capacity of these power systems ranges from 0.1 Ah to 750 Ah.

In contrast to nickel-cadmium cells, silver-zinc and silver-cadmium cells are unhampered by the "memory" problem and will deliver full voltage on call. Both indicate when they reach full charge by a jump in voltage, a characteristic that eliminates the need for monitoring the temperature and pressure when charging. The silver-cadmium battery is the most expensive secondary battery, followed by silver-zinc, which is slightly higher than a nickel-cadmium system. The least expensive secondary battery for powering electronic equipment is the gelled-electrolyte lead-acid cell, largely because of the relative abundance of its materials.

Despite its well-known advantages, the wet lead-acid

battery has been restricted mostly to automotive and industrial applications because the liquid electrolyte requires special shipping, handling, storage, and maintenance. Most of these batteries also contain lead-antimony components, which causes high gassing rates during charging and high self-discharge during storage. Yet the lead-acid battery yields the highest voltage per cell of any secondary system, costs little per watt-hour of capacity, and can withstand high rates of charge and discharge. The cells can be connected both in series and in parallel to build up high-capacity power systems.

To exploit these advantages, Globe Union Inc., Milwaukee, in 1965 introduced the gelled-electrolyte lead-acid battery, the Gel/Cell, to this country. Since no water or electrolyte needs to be added, the battery is





sealed, and it can be installed in any position. Without spillage, the handling problems of the wet cell are eliminated, and the battery has an unusually long shelf life. When internal pressure rises past 1 pound per square inch during charging, one-way relief valves release the excess pressure and automatically reclose.

### Surpassing liquid electrolyte

The Gel/Gell's energy density approaches that of the sealed nickel-cadmium cell, but it delivers 2.12 v, compared to the 1.2 v of the nickel-cadmium cell. The operating range is from -76°F to +140°F, but capacity increases above 68°F and decreases below that level. The basic components of a fully charged Gel/Cell are lead-dioxide positive plates, a gelled sulphuric-acid electrolyte, and sponge-lead negative plates. When the Gel/Cell is connected to a load, it produces power as the positive and negative plates are converted to lead sulfate and water replaces the gelled electrolyte.

Because of the lead-calcium grids, the Gel/Cell loses only 2% to 3% per month in storage at room temperature, but at 95° F, the loss goes to 10% to 12% a month

and at 0°F, it drops to 0.5%. Other secondary batteries, including competitive gelled-electrolyte cell systems that have lead-antimony grids, lose their charge at higher rates (Table 2).

The gelled-electrolyte lead-acid battery is used in two basic types of applications—float service for uninterruptible power supplies and cycle service for portable instruments. Many manufacturers offer two models to meet these requirements. Globe's Type A Gel/Cell provides four to six years of service in a standby role for powering such equipment as solid-state volatile memories, computer-terminal memories, security systems,

A simple standby supply is often used to power MOS memories during momentary outages. The system's power supply normally trickle-charges the secondary cell. When the power goes off unexpectedly, the secondary cell is switched into the line immediately. Type B Gel/Cells provide 300 to 500 discharge cycles for portable instruments, portable television receivers, defibrillators, transceivers, remote telemetering instruments, portable tools, and data-collection equipment.

Gelled-electrolyte lead-acid batteries are made in sizes from 0.9 Ah to 20 Ah in sealed rectangular cases that are dissimilar to the configurations of consumer batteries. However, Gates Energy Products, Denver, is producing both 2.5-Ah D and 5-Ah X sizes of sealed lead-acid cells. These units are not gelled lead-acid cells, but use a "starved-electrolyte" system (the electrolyte is combined with an absorbent material) and have spiral-wound construction similar to that of the sealed nickel-cadmium cell. In addition, Ray-O-Vac is developing 2.5-Ah D and 4-Ah F rechargeable, nonspillable, lead-acid cells. □

TABLE 2: ELECTRICAL CHARACTERISTICS OF SECONDARY BATTERIES

	Gelled-electrolyte lead-acid	Nickel-Cadmium	Silver-Cadmium	Silver-Zinc
1. Energy output Watt-hours per lb Watt-hours per in. <sup>3</sup>	9 1.1	12 to 16 1.2 to 1.5	22 to 34 1.5 to 2.7	40 to 50 2.5 to 3.2
2. Nominal cell voltage	2.12	1.2	1.1	1.5
3. Cycle life	200 to 500	500 to 2,000	150 to 300	80 to 100
4. Temperature range Store Operate	-76 to 140° F -76 to 140° F	-40 to 110° F -20 to 140° F	-85 to 165° F -10 to 165° F	-85 to 165° F -10 to 165° F
5. Shelf life at 68°F to 80% of capacity	8 months (with lead-calcium grids)	2 weeks to 1 month	3 months	3 months
6. Internal resistance	low	low	very low	very low
7. Discharge curve	sloping	flat	flat	flat
8. Relative cost, rated on a scale of 4 for maximum	1	2	4	3

BATTERIES ARE BECOMING A BIGGER part of all our lives, and many innovative new products coming to market either use or contain them. Battery-powered products are no longer limited to just toys and handheld vacuums. Serious products—like handheld transceivers, portable scopes, or laptop computers—are often battery-operated. However, while batteries provide mobility, they're also often the culprits when a product fails.

Many of us still consider batteries to be the ultimate black boxes: mysterious devices that work only when they feel like it. However, they're really not that difficult to understand and use effectively. Here are some questions and answers to help you create better designs using them.

● **I know there are many kinds of batteries. What's the best type for my application?**

Choosing a battery type means knowing something about both

batteries and how they'll be used in your equipment. Batteries are commonly classed as either primary or secondary. Primary cells include the disposable varieties such as carbon-zinc, alkaline, and lithium cells that can't be recharged.

Secondary cells include the varieties based on either nickel-cadmium (Ni-Cd) or lead-acid cell chemistries, that are rechargeable several times without degradation. So first, consider your equipment. Specific questions include: What is the drain rate? How often will the equipment be used? And, finally, is recharging feasible?

Low current drain, short duty cycles, and remote operation favor the use of primary batteries for watches, hearing aids, garage door openers, and retrofit smoke detectors. Obviously, the application parameters for secondary batteries are basically the opposite of those for primary cells. In applications involving high

current drain or extended usage, the cost of replacement of disposable batteries may be prohibitive. Such applications are logical for rechargeable secondary batteries as long as recharging power can be provided.

● **Based on drain rate and duty cycle, my application could go either way. What are the performance differences among various battery types?**

Table 1 provides a comparison of various common battery types, both primary and secondary. The first point of interest is the nominal cell voltage; more sophisticated concepts like energy density will be covered later. Also, all batteries have one or more cells, operating at voltages fixed by the electrochemistry of a given cell. Note that the operating voltages are shown as decreasing in Table 1; the initial value refers to the fully charged state, while the final value refers to the end of runtime, or useful life.

# BATTERY TECHNOLOGY

**Here are some important Q&A's about batteries to enable you to use them more effectively.**

MARK DEWEY

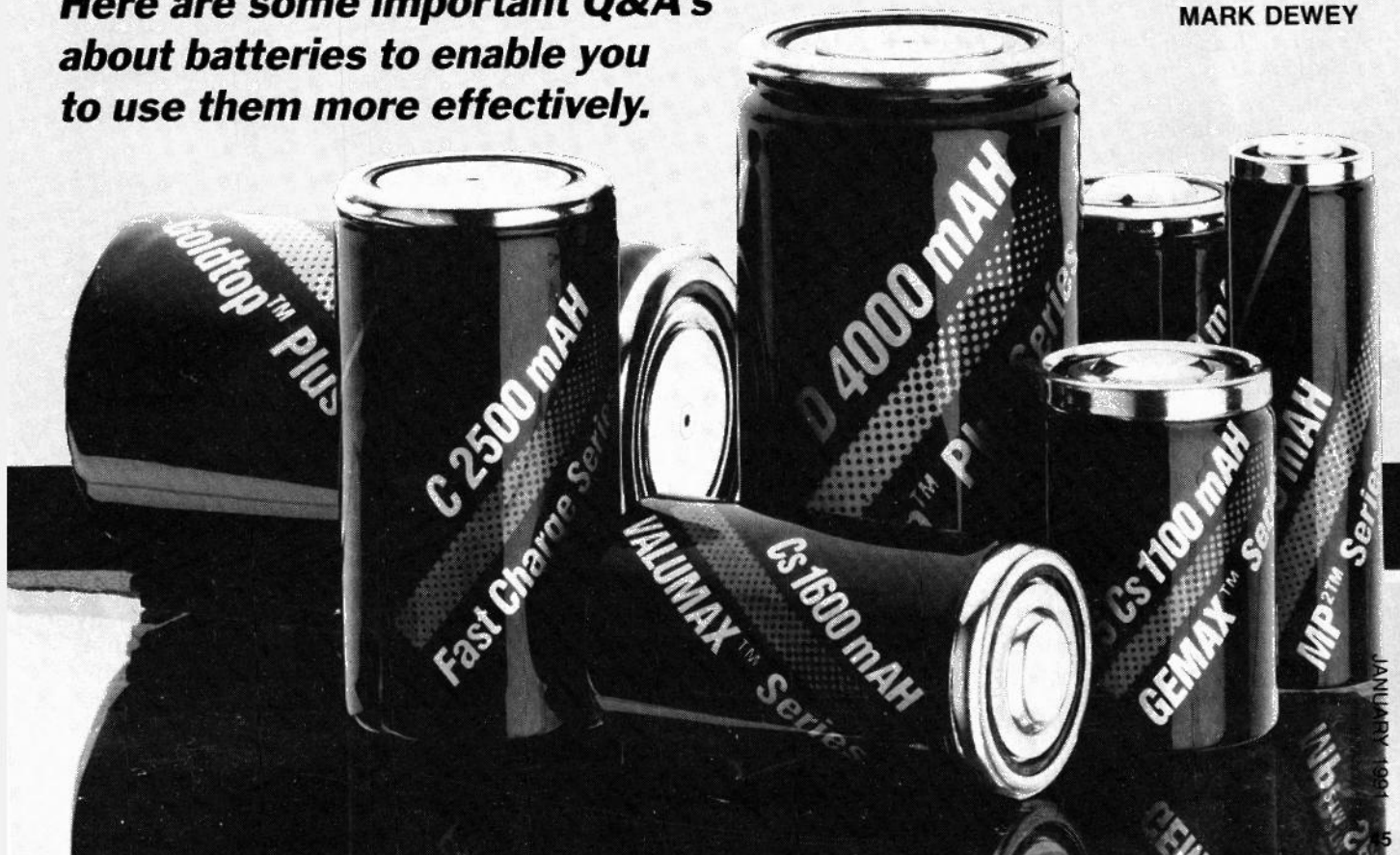


TABLE 1—CHARACTERISTICS OF COMMON BATTERY TYPES

Characteristic	Primary Cells		Secondary Cells	
	Carbon-Zinc (LeClanche)	Alkaline	Lead-acid (sealed (SLA), wound, gel.)	Ni-Cd (sealed, wound)
<b>Chemistry:</b>				
Anode	Zn	Zn	Pb	Cd
Cathode	MnO <sub>2</sub>	MnO <sub>2</sub>	PbO <sub>2</sub>	NiOOH
Electrolyte (all aqueous solutions)	NH <sub>4</sub> Cl and ZnCl <sub>2</sub>	KOH	H <sub>2</sub> SO <sub>4</sub>	KOH
<b>Cell voltage:</b>				
Nominal	1.5	1.5	2.0	1.2
Open-circuit	1.5–1.75	1.5	2.1	1.25
**Operating	1.25–1.15	1.25–1.15	2.0–1.5	1.25–1.00
End	0.8	0.9	1.75	0.9
<b>Operating temperature (°C)</b>	-5–45	-20–55	-40–55	-40–70
<b>Energy density (20°C) for cylindrical cells</b>				
*Wh/kg	85	85	35	30
*Wh/liter	100	220	70	80
<b>Advantages</b>	Lowest cost; good for non-critical use under moderate conditions; variety of shapes and sizes; readily available	High capacity compared with zinc-carbon; good low temperature	Low cost; readily available; good high-rate, high- and low-temperature operation	Sealed, no maintenance; good low temperature and high-rate performance, long cycle life
<b>Limitations</b>	Low energy density; poor low temp., high-rate performance	Moderate cost	Relatively low cycle life; limited energy density; poor charge retention; hydrogen evolution	Higher initial cost than lead-acid
<b>Major types available</b>	Cylindrical bobbin cells to 30 Ah; flat cells	Button and cylindrical cells to 20 Ah	Prismatic, cylindrical, wound cells, 200–400 Ah	Button cells to 0.5 Ah; cylindrical cells to 10 Ah

\*Wh: Watt-hour.

\*\*Values are deliberately decreasing

The nominal voltages of all cells are fixed by their electrochemistry (more below). The two major primary cells, carbon-zinc and alkaline, both produce 1.5 volts, while lithium versions produce 3.0 volts. The carbon-zinc cell is referred to in Table 1 as a "Leclanche" cell, named after the French chemist George Leclanche, who discovered it in 1866. Under the Ni-Cd cell listings, one of the the cathode material has the unusual formula of NiOOH, which is nickel oxy-hydroxide.

Of the major secondary cells, Ni-Cd cells produce 1.2 volts/cell, and lead-acid cells 2.0 volts/cell. Higher voltages, up to 240 volts, are commercially available from

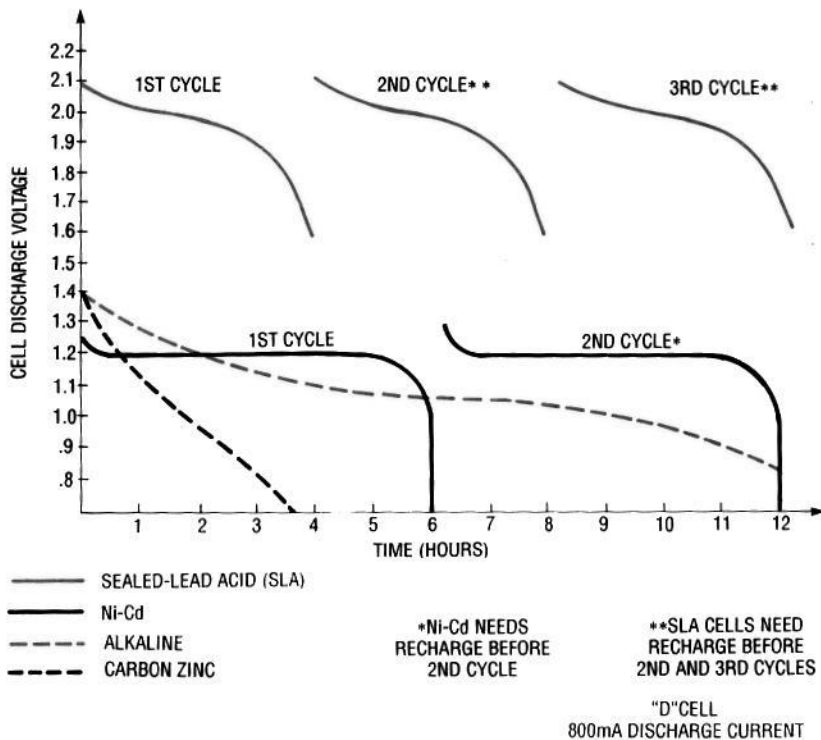
series cells. In 12-volt car batteries, all cells are connected internally. However, certain cell potentials, like 4 volts, may be possible from one cell type, but not from others.

Cell chemistry also causes voltage "droop" during discharge, which may affect a given application. While flashlights merely dim as their battery voltage decreases, many electronic circuits are highly sensitive to even slight drops in input voltage. Figure 1 compares the performance of primary carbon-zinc and alkaline "D" cells with secondary Ni-Cd and sealed-lead cells, for a discharge current of 800 milliamps.

The carbon-zinc voltage profile falls rapidly with discharge, with

a runtime under four hours. The voltage of an alkaline cell also falls off steadily, but its runtime is roughly quadruple that of a carbon-zinc cell. The Ni-Cd cell has a voltage profile that's nearly flat for most of its life, but only half the terminal potential of an alkaline cell. The Ni-Cd cell has a first recharge life that roughly equals the total life of an alkaline cell.

The stability of Ni-Cd cells at high current drains is why they're used in portable items; drills can draw up to 30 amps under load. The internal resistance of a Ni-Cd cell is 5–15 milliohms due to its construction, making such high current drains possible. A spiral nylon separator



**FIG. 1—THE VOLTAGE PROFILES OF PRIMARY and secondary D-cells are compared for a discharge current of 800 milliamps. The carbon-zinc voltage profile falls rapidly with discharge, with a runtime under four hours. Alkaline performance falls off steadily, but runtime is quadruple that of carbon-zinc.**

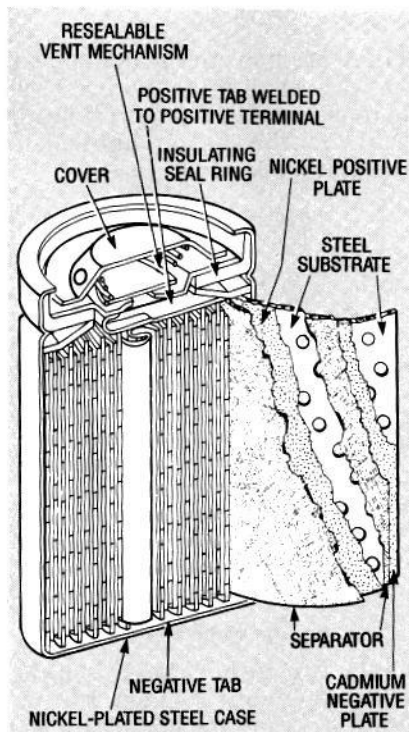
isolating the electrodes goes in a steel can used as the negative terminal, and is filled with electrolyte that transmits mobile charge. The steel it's sealed in is used as the positive terminal, as shown in Fig. 2.

Whereas Ni-Cd cells have a large anode-nylon-cathode surface area due to their spiral design, alkaline cells have an annular (or doughnut-shaped) cross section. Powdered anode material fills an inner ring, and compressed cathode material fills an outer ring. They're isolated by a porous fiber separator as shown in Fig. 3, giving a higher internal resistance, and limiting the available current drain.

Note that in Fig. 3, the top positive electrode is the cathode, while the bottom negative electrode is the anode. At first glance, that might seem odd, since most of us are normally accustomed to the reverse usage encountered with diodes. However, since a battery is an electrolytic (or electrochemical) cell, the labels for the terminals of a battery follow chemical, not electrical usage.

Earlier, there was a reference to how the electrochemistry of a battery fixes its terminal poten-

tial; let's now examine that aspect in more depth. The chemical process in a battery is an oxidation-reduction, also called a "re-



**FIG. 2—NI-Cd CELLS EXHIBIT an internal resistance of 5–15 milliohms due to their construction, making stable current drain possible.**

dox" reaction.

The anode is the terminal where material is oxidized, or where electrons are removed from or given up, and is usually called negative or minus ("−"), or where mobile electrons exit into a wire. The cathode is the terminal where material is reduced, or where electrons are accepted, and is usually called positive, plus ("+"), or the terminal where mobile electrons enter from a wire.

An electrolyte is the wet (or at least damp) ionic medium, through which mobile free electrons released by oxidation at the cathode travel to the anode, to propagate the electrolytic reaction of a battery. Table 1 lists the materials used for all three parts of the most common batteries.

The term "electrolytic" has the same meaning here that it has for capacitors, with certain variations. An electrolytic capacitor is polarized like a battery, and may well explode if its DC working voltage (WVDC) is exceeded (especially for reverse polarity), just as many primary nonrechargeable batteries will if recharged.

A battery, by contrast, is basically a fuel cell, maintaining terminal potential by electrochemical means until its fuel is exhausted. That is, the very selection of electrode metals and electrolyte is what determines the terminal potential of a battery, and a battery thus supplies charge *without* having to be charged initially.

All an electrolytic capacitor can do is store a charge fed into it, and dissipate the charge by generating an exponential current into a resistance. It stores charge (whereas a battery generates it spontaneously), and its potential decays exponentially, just as with any other capacitor. However, the electrolytic medium used allows the packaging of larger capacitance values than would otherwise be possible for a given volume. Nonetheless, batteries and electrolytic capacitors are at least second (or maybe even first) cousins.

● **What are cell capacity ratings based on?**

Battery manufacturers rate cell capacities in amp-hours (Ah), a unit of charge, not energy. A 1-

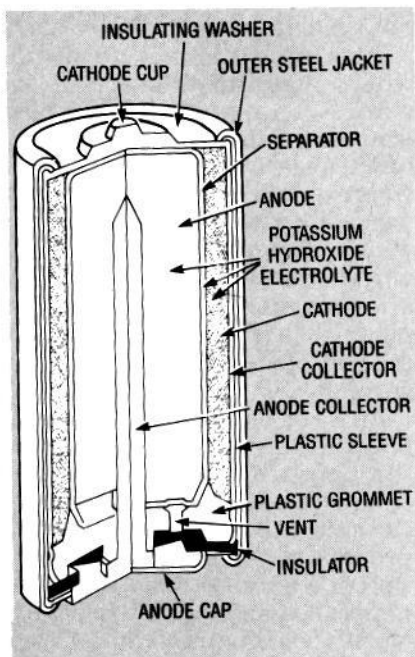


FIG. 3—THIS IS A CROSS section of an alkaline cell showing its annular construction.

amp current corresponds to the motion of 1 coulomb (C) of charge past a given point in 1 second (s), or

$$1 \text{ amp} = 1 \text{ C/s,}$$

where,

$$1 \text{ C} = 6.25 \times 10^{18} \text{ electrons/s.}$$

The individual electron is often denoted by the variable  $e^-$ , so the above relation would appear as

$$1 \text{ C} = 6.25 \times 10^{18} e^-.$$

The metric unit of charge is the coulomb, while that of energy is the joule (J). The potential energy (or potential work)  $W$  contained in a battery is related to its total available charge  $q$  and terminal voltage  $V$  by

$$W = q \times V.$$

The variable  $W$  is used for energy to avoid confusion with  $E$  and  $V$ , normally reserved for voltage, although many texts use  $E$  for total energy (kinetic and potential) and  $V$  for potential energy as well, so you should know the context to avoid confusion. Thus, an "AA" Ni-Cd cell that can maintain a 0.6-amp load for one hour is said to contain

$$\begin{aligned} q &= 0.6 \text{ Ah,} \\ &= (0.6) \times \\ &\quad \left( \frac{6.25 \times 10^{18} e^-}{\text{C}} \right) \left( \frac{1\text{C}}{\text{s}} \right) \left( \frac{3600\text{s}}{\text{hr}} \right) (1\text{hr}) \\ &= 1.35 \times 10^{22} e^-, \\ &= 2160 \text{ C} \end{aligned}$$

of available charge. Such a cell has a terminal potential of

$$V = 1.2 \text{ volts,}$$

so the total energy nominally available from it is

$$W = q \times V = 0.6 \text{ C} \times 1.2 \text{ volts} = 0.72 \text{ J.}$$

As discussed earlier, Table 1 mentions the concept of energy density of cylindrical batteries, and uses another energy unit called the unit watt-hour (Wh), used with the electric meter on most houses. Electric utilities measure energy in watt-hours, not joules, since the numbers are more convenient.

The watt (W) is a unit of power, not energy, defined as

$$1 \text{ W} = 1 \text{ J/s.}$$

The variable for power is  $P$ ; if

$$P > 0 \text{ W,}$$

then  $P$  normally refers to power expended or dissipated, like the loss from a resistor. Whereas, if

$$P < 0 \text{ W,}$$

the reverse is normally true, that power is being supplied, rather than expended. Thus, a watt-hour is equivalent to

$$\begin{aligned} 1 \text{ Wh} &= \left( \frac{1\text{J}}{\text{s}} \right) \left( \frac{3600\text{s}}{\text{hr}} \right) (1 \text{ hr}) \\ &= 3600\text{J,} \end{aligned}$$

There are two energy density values per cell in Table 1, one relative to mass, and the other to volume. Thus, for the carbon-zinc cell, for the value relative to mass

$$\begin{aligned} \frac{65\text{Wh}}{\text{kg}} &= \left( \frac{65\text{Wh}}{\text{kg}} \right) \left( \frac{3600\text{J}}{\text{Wh}} \right) \\ &= \frac{2.34 \times 10^5 \text{J}}{\text{kg}} \end{aligned}$$

A similar argument follows for energy density relative to volume.

However, the same cell, if providing less current, can provide more useful energy, since there's then less internal battery heat loss. If the same "AA" cell were discharged over five hours, it could sustain a 130-milliamp load, for an observed capacity of

$$q = 650 \text{ milli-Ah.}$$

Cells are generally marketed using five-hour ratings, but any comparison of cells from different manufacturers should use equivalent ratings.

Battery manufacturers define  $C$  as rated capacity; the italics are

used to avoid confusion with the coulomb. Charge and discharge currents are then discussed as multiples or fractions of  $C$ . The advantage is that we can discuss battery currents, not cell sizes or ratings;  $C$  for many manufacturers is based on a one-hour interval. Thus, an "AA" Ni-Cd cell has a rated capacity of

$$C = 600 \text{ milli-Ah.}$$

For example, under that convention, we could write

$$2 \times C = 1.2 \text{ Ah,}$$

or,

$$C/10 \text{ hours} = 60 \text{ milliamps.}$$

Ni-Cd cells are recharged by applying DC opposite to that generated during discharge, whether pure, half-, or full-wave rectified. Minimum commercial recharge rates used are about  $C/20$ , or taking 20 hours to recharge to rated capacity. But since charging isn't 100% efficient, especially when it's so slow, some 36–48 hours would realistically be needed.

### • Is there a danger of overcharging a Ni-Cd battery?

Recharging efficiency decreases as it nears completion. The final few percent is returned as the cell approaches "overcharge," where Ni-Cd cells generate gaseous oxygen ( $O_2$ ). At low recharge currents, continuous overcharge isn't damaging, since the cell electrochemically recombines the total oxygen volume, letting Ni-Cd cells be totally sealed.

For safety, venting is designed into the cell cover. If overcharged at current above a recommended limit, the oxygen is expelled via such a vent, which then reseals. Repeated venting does dry out water from the electrolyte, causing damage manifested as decreased lifetime for a given load.

Also distinguishing primary cells from Ni-Cd cells is the property of charge retention. Alkaline cells can maintain full charge in ambient environments for up to four years, especially if they're refrigerated, whereas most Ni-Cd cells will lose some 1–2% of their rated capacity per day. That's why many commercial Ni-Cd cell applications use trickle charging (as low  $0.02C$ ) when the battery reaches an overcharge condition.

● **I've heard a great deal about charge rates, especially "quick" and "fast" charging. What's the distinction?**

Battery manufacturers have met market demands for cells with faster recharge rates. "Standard" charging is at a rate of 0.1 C, or 16–20 hours. "Quick" charging is at a rate of 0.33C, or 4–5 hours. Cells are available that can sustain continuous overcharge, with 100% oxygen recombination, at up to 0.33C, eliminating the need for trickle charging. "Fast" charging has become the industry standard, being a rate of 1.0C or higher, up to 2C–4C; recharge shutoff is done to prevent oxygen venting, even though it does no damage.

● **Explain how cells are configured to make batteries. Don't I need certain additional knowledge about performance?**

Assembling cells into batteries can appear, at least superficially, to be a rather trite exercise. However, knowing correct cell performance doesn't necessarily guarantee uniform, successful battery performance. Experienced product designers and hobbyists alike are aware that battery assembly can involve some important concerns, not the least of which is cell reversal. Ni-Cd cells are typically series-connected for higher voltage, and capacity is achieved using cells of adequate size.

Ni-Cd cells are typically connected in series for batteries. Runtime, or capacity, is met by using cells of sufficient size to meet the requirement. Cells of even the same size and manufacture lot can exhibit actual capacities that vary up to 8% of a mean. In multicell batteries, such variances can cause some cells to give up the last of their usable capacity, while others are still viable. If the extent of discharge is deep enough to bring one or more cells to zero voltage, cell reversal can occur.

● **Explain cell reversal.**

The voltage of a cell is the stored potential or electromotive force (EMF) capable of driving current through a circuit. When a cell is reversed, its energy is expended to the point where any further current drain is into the

cell, such that the circuit drives the cell, instead of the reverse, as shown in Fig. 4. During reversal, cell voltage can go as low as -1.4 volts, generating gaseous hydrogen (H<sub>2</sub>), which doesn't recombine and has to be vented.

The solution to cell reversal is to understand and design for applications where cells have the potential for repeated reversal. Product designers can choose to use a cutoff circuit to terminate discharge based on battery voltage, to prevent cell reversal. Motorized products draw high current, so when their performance decays before the onset of reversal, they should be shut off. Modern Ni-Cd cells are more tolerant of cell reversal. Modern Ni-Cd cells repeatedly tested to 40% reversal at 10C have suffered no degradation.

Finally, if all Ni-Cd cells in a battery pack are overcharged, reversal is less likely since they all begin to discharge from the same

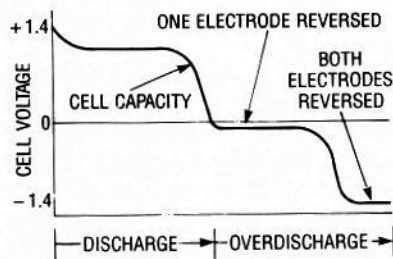


FIG. 4—IN CELL REVERSAL, the stored energy of a cell is expended to the point where the circuit drives the cell, instead of the reverse.

point. Building batteries from cells of equal capacities reduces the effect of individual cell variation at the end of discharge, and minimizes the chance of reversal.

● **Memory continues to be a much-discussed problem in Ni-Cd batteries. How is memory avoided?**

No discussion of Ni-Cd cells would be complete without mentioning the "memory" effect. The term memory was coined in the early 1960's during early NASA satellite flights. Satellite batteries have strict discharge/recharge regimes and receive very little overcharge. Such precise regimes were the result of NASA computer-controlled energy management, and are seldom duplicated commercially.

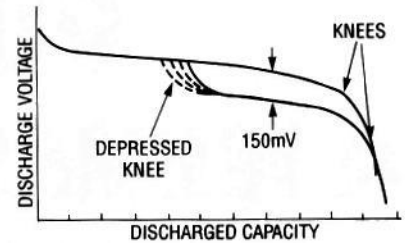


FIG. 5—IN NI-CD "MEMORY," cells repeatedly discharged only partially to the same extent, and then recharged soon won't discharge beyond the "memorized" level.

If Ni-Cd cells are repeatedly discharged only partially to the same extent (or thereabouts) and then fully recharged, they reach a point where they won't discharge further than the "memorized" location in their discharge profile. Today, the term "memory" is a misnomer, since it's now applied to a much wider range of similar problems.

Voltage depression and poor capacity are two common examples, often mistaken for memory, manifested as shortened runtime, as shown in Fig. 5. Devices frequently won't operate at voltages below a specific design value, or will exhibit reduced performance, at best. Causes include low recharging, excess recharge current, excess battery heat during recharge, improper recharge termination voltage, or wearout.

During standard or quick recharging, Ni-Cd cells need some overcharging, since recharging isn't 100% efficient. If they're not fully recharged, they can't deliver their rated capacity. Excessive overcharge currents can cause overheating in Ni-Cd battery packs. In overcharge, the energy provided to the battery is predominantly converted to heat, since the chemical conversions are complete, or nearly so. Such overcharging accelerates wearout or causes voltage depression or poor capacity, although improved Ni-Cd cell designs have lower sensitivity. Such improvements, along with careful application, insure long life.

● **Does the electrolyte in a Ni-Cd cell ever leak?**

Ni-Cd cells can undergo storage leakage, especially in radio applications, if left on. However, even if turned off, solid-state power supplies often allow leak-

continued on page 83

## BATTERY TECHNOLOGY

*continued from page 49*

age current. In other words, the battery is not completely disconnected from the load circuit even when the power is turned off. Over a period of time, ranging from one week to two months, leading to minor battery leakage. Even if designed to prevent such an occurrence, a minor short may occur, insufficient to affect performance even when turned on, but resulting in what's known as "creep" leakage.

In the above cases, "creep" usually manifests itself as white fuzz around the top seal of a cell. To avoid it, turn power switches off when equipment isn't in use. In radios unused for extended periods, remove the batteries, and replace them when needed. Even if creep does occur, a Ni-Cd cell can be recharged, with proper care.

**● Ni-Cd cells have been around a long time, and yet the application of that technology is growing and changing. What technology improvements, if any, have occurred that we should be aware of, and is there anything better available on the horizon?**

Ni-Cd manufacturers are continuously seeking to improve product capabilities and quality.

Increased capacity means longer run times; for many years, makers have boosted capacity by over 10% a year, itself driving research into new electrochemical couples. Rechargeable lithium and Ni-metal hydride cells are prominent contenders, with significant increases in energy density over Ni-Cd cells, but their availability is still limited.

Safety continues to impede broad acceptance of lithium cells. Metal-hydride is progressing steadily, and is also equivalent in voltage to that of Ni-Cd cells. Broad acceptance of metal-hydride depends on its ability to be successfully used in several environments. Ni-Cd cells offer such flexibility today, at reasonable prices. Also, the prices of newer technologies will further impede broad acceptance. In our next article, we'll spotlight some recent ingenious and innovative applications of batteries. **R-E**

# BATTERIES

PART 14 OF OUR COMPONENT SERIES LOOKS AT, PERHAPS, THE LEAST UNDERSTOOD AND MOST ABUSED OF ELECTRONIC COMPONENTS.

BATTERIES may be divided into two general classes; primary batteries and secondary batteries.

**Primary batteries or cells** (strictly speaking, a battery is a group of cells connected together, but the term battery is commonly used for either form), only has a single working life. In general, once discharged, their capacity to provide useful power ceases and they must be discarded. A primary cell can provide power as soon as it is assembled and requires no initial charging current.

Five types of primary cell are currently available. These are:—

- Leclanche (or carbon-zinc) cell
- Mercury cell
- Alkaline cell
- Zinc-Air cell
- Weston Cadmium cell

**Secondary batteries or cells** require an initial charging current before they can be used, in the opposite polarity (or direction) to their discharge current. They can go through many charge-discharge cycles throughout their useful life, and can be stored for considerable periods in a discharged condition without deteriorating. Secondary batteries are also referred to as storage batteries. Two types of secondary battery are in common use:—

- Lead-Acid battery
- Nickel-Cadmium battery (familarly called the Nicad).

## THE LECLANCHE CELL

The construction and composition of a cylindrical Leclanche cell is as follows. The cell's outer casing is formed from zinc and this acts as the negative electrode. A central carbon rod, which is

connected to an external metal cap, forms the positive electrode.

The carbon rod is surrounded by a mixture of manganese dioxide and powdered carbon in a porous sack. This is called the 'depolariser'. The rest of the cell is filled with a paste of ammonium chloride — the 'electrolyte'. The Leclanche or carbon-zinc cell, is commonly known as a dry cell.

These cells, have a no-load terminal voltage of 1.5 to 1.6 volts. The energy that they can supply is related to their size. Under-load the terminal voltage of dry cells gradually decreases and internal resistance rises. When the load is removed terminal voltage rises again, but not to the original value. Over a number of discharge-rest periods, the no-load terminal voltage will gradually decrease as will the amp-hour capacity of the cell (Fig. 1.)

Once the no-load voltage drops to 1 volt or so the cell has come to the end of its useful life and should be given a decent burial. Leclanche cells are best suited to applications that require intermittent use or low-drain use for long periods.

Heavy duty dry cells are available that will provide much higher discharge currents. These will supply several hundred milliamps for four to five hours at a time, whereas the ordinary cell will typically provide 100 mA or less for similar periods. As might be expected, they cost more than ordinary dry cells.

The heavy duty dry cell deteriorates more slowly than conventional cells and will undergo more discharge-rest cycles before requiring replacement. They are sometimes marketed as 'Longer-Life' batteries. Conventional and heavy duty dry cells are compared in Fig. 1.

Size is not the only factor which governs the life of a dry cell. The ratio of the period of use to the rest period is an important factor. The old door-bell batteries which were about the size of a drink can would last for years. They could supply up to one amp but their rest-to-use ratio was very high.

Temperature also affects the performance of dry cells. Optimum is between 20°C and 27°C. Terminal voltage and capacity is drastically reduced below 15°C, and almost useless below 5°C. Leclanche cells deteriorate when stored for long periods. Generally, the larger the cell, the less the deterioration.

Leclanche cells have a serious drawback. When left for long periods in a discharged condition the outer zinc container is gradually eaten away by the electrolyte which then finds its way to the outside, corroding surrounding equipment. Leak versions are available, but these should not be left too long discharged either.

The internal resistance of a Leclanche cell rises steeply as it discharges. This can give rise to low frequency instability ('motorboating') in amplifiers. A large value electrolytic (1000  $\mu$ +) across the supply rail will often eliminate this problem, and will often dramatically improve the sound reproduction from a transistor radio.

For resistances requiring six volts or more at low currents, the layer battery has been developed. These are made up of square or rectangular layer cells, their shape enabling them to be grouped together with minimum waste of space. The common 9V transistor radio battery is of this type. They suffer less deterioration than the round style dry cell. They are relatively low current devices. Round cells are better where fairly heavy consumption for fair periods is required.

## THE MERCURY CELL

The mercury cell was invented in World War II by Dr Samuel Ruben. It has an anode of high purity amalgamated zinc and a cathode of compressed mercuric oxide-graphite separated from the anode by an ion-permeable barrier. The cathode is in contact with a steel container which provides the terminal connection. The

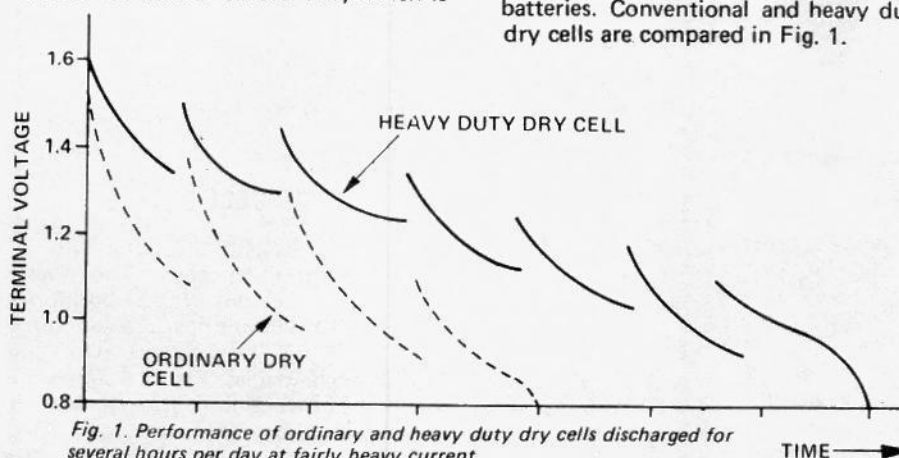


Fig. 1. Performance of ordinary and heavy duty dry cells discharged for several hours per day at fairly heavy current.



# BATTERIES

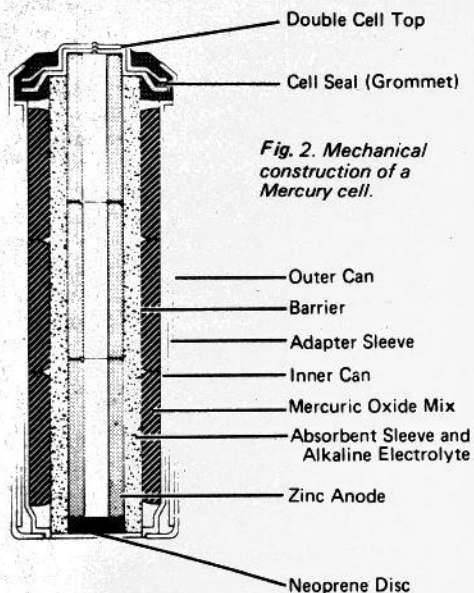


Fig. 2. Mechanical construction of a Mercury cell.

electrolyte is a solution of alkaline hydroxide, the ions of which act as carriers for the cell's chemical action. The electrolyte is not consumed during discharge. The cell containers are nickel plated steel and thus do not corrode.

Mercury cells are produced in a variety of forms, one of the most common is shown in Fig. 2.

The no-load terminal voltage of mercury batteries is 1.35 volts. This drops about 0.05 to 0.1 volt under load but unlike Leclanche cells remains very steady throughout the greater part of its

Battery Type	Nominal Voltage	Storage to 80% Capacity (months)	Watt-hours per kilogram	Watt-hr per cm <sup>3</sup>
Mercury	1.35-1.4	30	101	98.3
Alkaline	1.5	30	77	57.4
Leclanche	1.5	6-12	48	32.8

life. At the end of its life the terminal voltage falls away with increasing rapidity to less than 1.0 volt. Typical discharge curves are shown in Fig. 3.

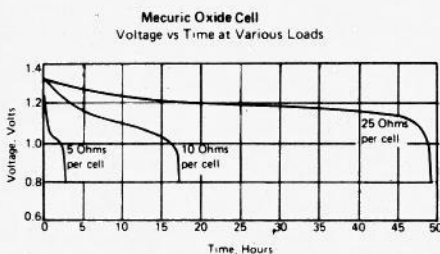


Fig. 3. Discharge characteristics of a typical mercury cell (Gould type 502R). Curves show voltage vs time at various loads.

Mercury batteries may be stored for up to three years with only slight deterioration in terminal voltage and amp-hour capacity. Maximum storage temperature is 30°C, optimum is 21°C.

The characteristics of these batteries are little affected by extremes in temperature. They work well down to -20°C and some at temperatures in excess of 100°C.

Mercury cells are capable of discharge rates much greater than equivalent Leclanche cells, the internal resistance being maintained until near the end of

their working life. Mercury cells do not leak if left for long periods. However, their price is several times that of equivalent sized Leclanche cells.

A range of voltages is available, typically 1.35, 2.5, 4 & 8 volts, in different sized packages.

A new cell may be used as a voltage reference with an accuracy of 0.02 V or better. Mercury batteries should always be used within the recommended discharge rate for which they are intended — they cannot be recharged.

Mercury batteries are used where voltage stability and long life are required. Their small size and high capacity are also advantageous in some applications.

## THE ALKALINE CELL

Alkaline-manganese cells are constructed similarly to mercury cells, and have similar characteristics in that their terminal voltage is much more constant than Leclanche cells and that they are largely unaffected by temperature extremes. Their energy capacity is also similar to mercury batteries.

A typical alkaline cell features a steel container which also forms the positive contact. This is in contact with the cathode which is a mixture of manganese dioxide and graphite compressed into cylinders that fit around the anode. The electrolyte is potassium hydroxide; the anode consists of zinc pellets.

No-load terminal voltage of alkaline batteries is normally 1.5 V. They cost more than conventional Leclanche cells but less than mercury cells. Table 1. compares alkaline, mercury and Leclanche cells on the basis of storage and energy capacity for given size and weight. The discharge characteristics of these three types of battery are illustrated in Fig. 4.

## THE ZINC-AIR CELL

Zinc-air cells are an outgrowth of research into fuel cells. They were invented by Leosona Moos laboratories in the USA and are now manufactured under license by various US and Japanese companies. Figure 5 shows the basic construction. The anode is amalgamated zinc powder and incorporates the negative terminal. The

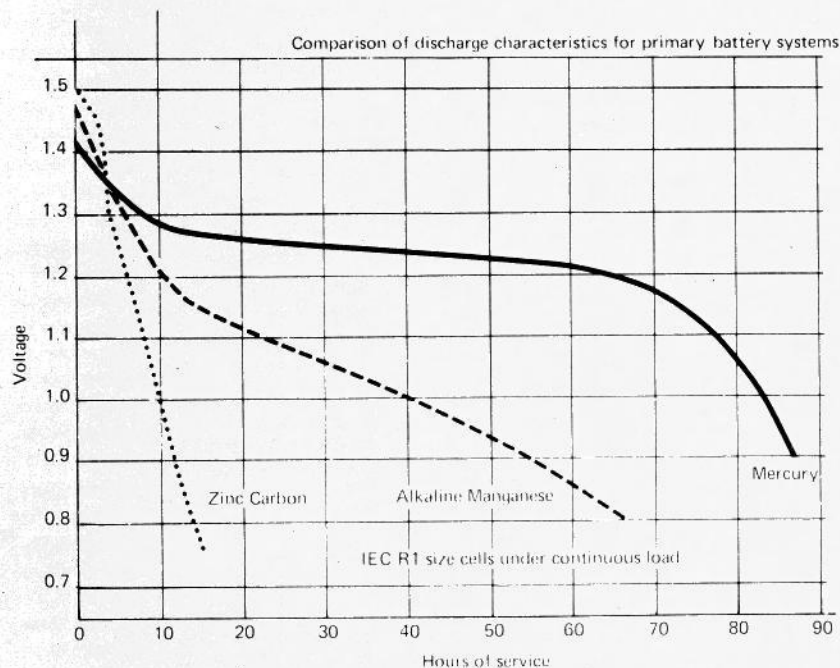


Fig. 4. Graph shows discharge performance of zinc-carbon, alkaline manganese and mercury batteries.

concentrated solution of zinc oxide, is in contact with the electrolyte. This construction allows large discharge currents without serious polarisation of the anode occurring. The anode structure is held in a tough plastic case.

The cathode is constructed in several layers, held in a plastic frame. The outermost layer is a micro-porous PTFE plastic film. This allows atmospheric oxygen to come in contact with the electrolyte. The PTFE will allow air into the cell but will prevent the electrolyte escaping. Thus, the battery may be used in any position. On the inner face of the PTFE is a layer of catalyst. This is also

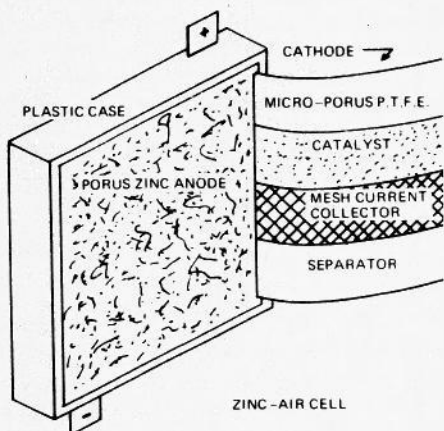


Fig. 5. Section of rectangular zinc-air cell.

in contact with the electrolyte and aids the chemical action of the cell without itself being consumed. The catalyst used provides a high current density at the cathode.

A metal mesh collects the current generated by the cell and is the positive terminal connection. A permeable separator allows free passage of ions within the cell but prevents direct electrical contact between anode and cathode.

Zinc air cells find most use in

applications requiring continuous or semi-continuous service at high currents. They have high energy to weight and volume ratios and have higher current output and amp-hour capacities than equivalent size alkaline or mercury cells.

The maximum current capability of zinc-air primary cells is dependant on cathode area. Their amp-hour capacity is dependant on the volume of the zinc anode. The cathode will operate continuously provided its surface has sufficient access to the air.

Depending on the application, a zinc-air cell may produce six to eight times the output of an equivalent high power Leclanche cell or a weight saving of the same order for equivalent power outputs. (Leclanche cells are not of course capable of the high discharge rates of the zinc-air cells).

Zinc-air cells can deliver high currents continuously at a voltage which remains nearly constant throughout the discharge system. A comparison of the discharge characteristics of various cells and zinc-air batteries of equivalent size is given in Fig. 6.

Zinc-air cells have a nominal terminal voltage of 1.4 V on no-load dropping to 1.2V-1.1V under load with an end point voltage of 0.9 volts (discharged). Very small cells (AA size) can provide continuous discharge currents of 250 mA and up to 500 mA peak. This size cell would typically have a capacity of 2.5 amp-hours after three months storage. Leclanche cells of equivalent size have a capacity measured in milliamp-hours. Zinc-air cells can provide 185 watt-hours per kilogram — compare this with the other primary cells in Table 1.

Their main drawbacks are cost and availability.

### THE WESTON CADMIUM CELL

This cell is used *only* as a primary voltage standard or reference. It is unable to supply useful current — in fact a discharge current greater than about one milliamp will ruin it. The

terminal voltage of a Weston Cadmium cell is 1.01864 volts at 20°C. It's not what you would call a handy figure to work with (especially using it in calculations!), its advantage lies in the fact that it can be quoted within plus or minus ten microvolts.

The cathode (+ve) of the weston cell is mercury and mercurous sulphate paste. The anode (-ve) is an amalgam of cadmium and mercury in saturated cadmium sulphate.

The cell is usually contained in an H-shaped glass vessel as illustrated in Fig. 7. To maintain the accuracy of the output voltage, the cell is often constructed in a temperature regulated container.

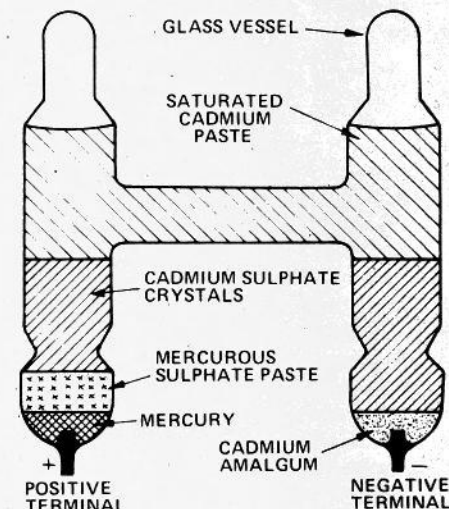


Fig. 7. The Weston Cadmium cell.

### THE LEAD-ACID BATTERY

We shall now deal with the two most common types of secondary cell.

The lead-acid battery has a long and honourable history. The car battery is probably the most familiar example. High current capabilities, long life and relatively low cost are attractive advantages. A forty amp-hour capacity car battery can supply several hundred amps for periods of a few seconds (i.e.: for a car starter motor).

The lead-acid cell consists of a lead and litharge (lead oxide) anode and a lead and red-lead cathode immersed in a liquid electrolyte of dilute sulphuric acid. This is contained in a hard rubber or polypropylene case. A filler cap for the electrolyte is provided and a vent hole for the release of gas during charging. For this reason, conventional lead-acid batteries can only be used in the upright position.

Lead-acid batteries are obtainable in a wide variety of sizes and amp-hour capacities. Some are designed for heavy duty service while others are designed for light or intermittent duty.

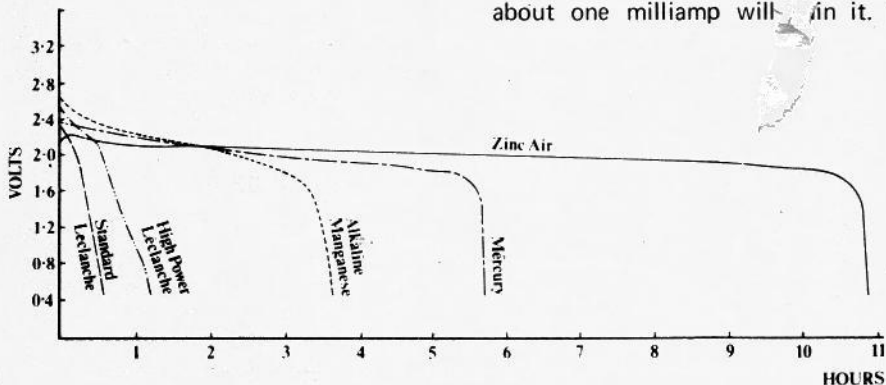


Fig. 6. Discharge curves of various types of cell compared to a zinc-air battery of the same physical size.

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They are of course produced for innumerable applications other than the starting, lighting and automobile ignition applications.

The fully-charged, no-load terminal voltage of a lead-acid cell is between 2.3 – 2.4 volts. This drops under load to about 2.0 – 2.2 volts. When discharged, the cell voltage is typically 1.85 volts. The amp-hour capacity is determined from a 10 hour discharge rate. The current required to discharge the battery to its end-point voltage of 1.85 V/cell is multiplied by this time. e.g. a 40 AH battery will provide 4 amps for 10 hours before requiring recharge. Note however that the amp-hour capacity varies with the discharge current. The same battery discharged at a rate of 10 amps will not last four hours, on the other hand if it is discharged at 1 amp it will last somewhat longer than 40 hours. The discharge characteristics are shown in Fig. 8.

Lead acid batteries may be operated over a wide range of temperatures, from  $-20^{\circ}\text{C}$  to  $+35^{\circ}\text{C}$ . At low temperature, amp-hour capacity and discharge current are reduced and there is the possibility of the electrolyte freezing, depending on the specific gravity of the electrolyte. Preferred operating temperature is about  $+20^{\circ}\text{C}$  to  $+25^{\circ}\text{C}$ .

A direct indication of the state of charge in a lead-acid battery is the specific gravity of the electrolyte. This is measured with a hydrometer. These can be obtained calibrated specifically for use with lead-acid batteries. The hydrometer reading for full charge will lie somewhere between 1.210 and 1.275, depending on the type of service for which the battery was intended.

Table 2 shows the values of specific gravity expected in the various types of Lead-Acid batteries.

TABLE 2	
S.G.	USE
1.210	emergency lighting, low duty.
1.245	light and intermittent duty.
1.260	car batteries.
1.275	heavy discharge, truck and tractor batteries.

Charging is a fairly simple operation. The unfiltered output of a rectifier (dirty dc) may be used or any power supply that will provide the appropriate current at a voltage a little above the battery's fully charged terminal voltage. Some means of varying the charging current is necessary. High wattage, low

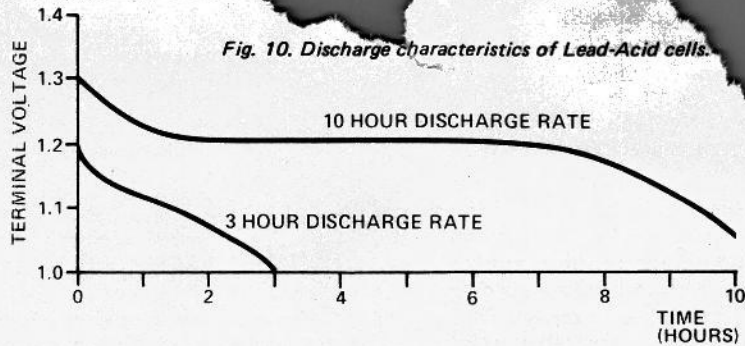


Fig. 10. Discharge characteristics of Lead-Acid cells.

voltage lamps in series with the battery are suitable for the raw dc type of charger.

The initial charging current for the fully discharged battery (cell voltage under 2.0 V), should be about 20 amps per 100 amp-hours of capacity (i.e.: 8 amps for a 40 AH battery). Once the electrolyte begins to gas rapidly, the cell voltage will be around 2.3 volts and rising rapidly. At this point, the charging current should be reduced to somewhere between 4-8 amps per 100 AH until charging is complete. Check the specific gravity at half-hourly intervals. At the end of charging, cell voltage may rise to about 2.6 volts or more but this decreases slowly after the charger is removed, the terminal voltage then usually reading around 2.4 volts per cell (Fig. 9).

Slower charging rates can be used, the battery taking longer to recharge. A continuous low-rate charge can be used ('trickle charging'). A constant current charger is best in this application, providing between 100 mA and 300 mA per 100 AH capacity.

During charging, the electrolyte temperature should not be allowed to rise above  $38^{\circ}\text{C}$  ( $100^{\circ}\text{F}$ ). If the battery is hot and gassing rapidly, reduce the charging current.

Hydrogen is released during charging. This is highly explosive. Keep flames and cigarettes away and avoid electrical

sparks by turning off the charger when connecting or disconnecting leads to the battery terminals.

Lead-acid batteries should be charged in an open area where small electrolyte spillages and fumes cannot affect nearby materials. Cotton and synthetic materials are attacked by sulphuric acid and mysterious holes appear where the material has come into contact with battery electrolyte.

The level of the electrolyte in each cell of a battery must be kept above the top of the plate. The loss of water by evaporation and decomposition during charging should be made up with distilled water. Do not use tap water as it usually contains minerals and traces of chemicals that contaminate the electrolyte. Distilled water is best added when the cells are gassing to ensure thorough mixing.

If a lead-acid battery is used at relatively light duty then it should be periodically discharged through a dummy load, at its normal rate, and then immediately recharged.

Lead-acid batteries should not be overcharged at high current as this causes the plates to buckle and slake (which may result in a short circuit). Neither should they be left in a discharged state as the lead sulphide produced during discharge may undergo a generally irreversible physical change resulting in reduced battery capacity.

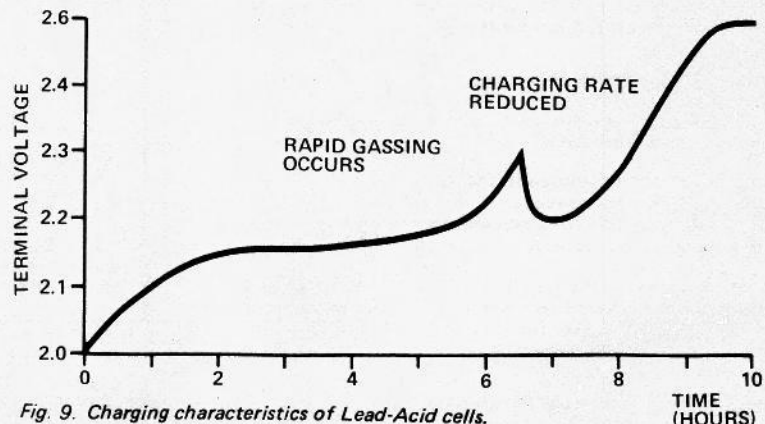


Fig. 9. Charging characteristics of Lead-Acid cells.

condition are referred to as sulphated cells. This condition may be remedied, at least partially, by trickle charging for a considerable period. Eventually, sulphated cells self-discharge.

In normal operation, lead-acid batteries should be overcharged from time to time, at about half the normal rate, until half-hourly readings of the terminal voltage and electrolyte specific gravity show no further increase. This action removes sulphate and restores the plates to their normal condition.

Spilled electrolyte should be neutralized with an alkaline solution. This is simply made up by dissolving 4-6 tablespoons of common baking soda (sodium bicarbonate) per litre of water, using as much water as necessary. When applied to spilled electrolyte, foaming occurs. When the foaming has stopped the residue should be washed away with clean water. If washing down the top of a battery with this solution, do not let any into the cells!

## THE NICKEL-CADMIUM CELL (Nicad)

Nicad cells use a potassium hydroxide electrolyte. In a typical unit the positive and negative plates are both perforated

and the positive plate is filled with nickel hydroxide, the negative plate with finely divided cadmium mixed with a little iron to prevent it flaking and losing porosity. The electrolyte has a specific gravity of 1.15-1.2, depending on the type of service, it does not undergo any chemical change during discharge. Very little electrolyte is needed and the positive and negative plates are very closely spaced.

Nicad batteries are made in a wide variety of sizes and amp-hour capacities, miniature ones for use in cameras, calculators etc up to large heavy duty types similar to car batteries. They may be operated over a wide temperature range - similar to that of lead-acid

batteries. At low temperatures, the amp-hour capacity does not diminish as much as with lead-acid batteries. However, the electrolyte may freeze.

As Nicad batteries may be sealed, they can be used in any position. The no-load terminal voltage of a nickel-cadmium cell is typically 1.3-1.4 volts. This drops to about 1.2 volts under load, and to about 1.1 volts when discharged. As the electrolyte does not change during discharge (as it does in lead-acid batteries), the number of amp-hours obtained from a Nicad battery is much less affected by the discharge rate than are lead-acid batteries (Fig. 10).

As Nicad batteries can be made quite small, and can be recharged, they are

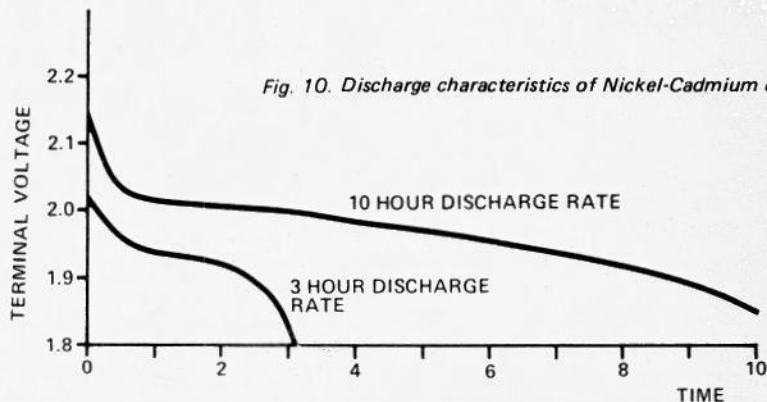
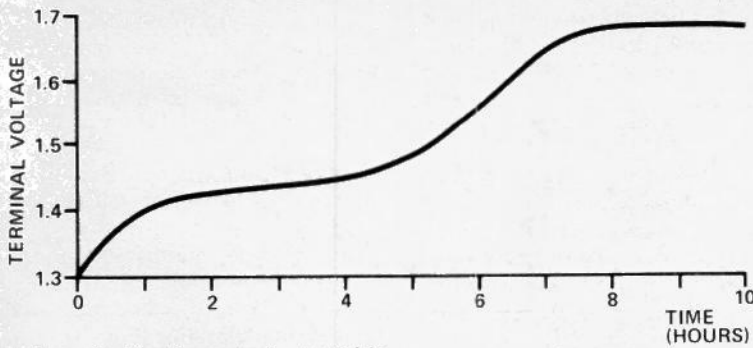


Fig. 10. Discharge characteristics of Nickel-Cadmium cells.

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Fig. 11. Charging characteristics of Nickel-Cadmium cells.



eminently suitable for use in portable electronic equipment such as calculators, tape recorders, hand-held transceivers, camera flash units etc. They can withstand considerable vibration, are free from sulphating or similar problems, and can be left in any state of charge without ill effect.

Charging should be done with a constant-current charger. The charging rate for the quickest charge should be no more than 1.5 times the 10 hour discharge rate. Most manufacturers recommend a charge rate and a trickle or 'float' charge rate and this is best adhered to. Charging characteristics are shown in Fig. 11.

One method of producing a constant current charger is to place a resistor in series with a supply having a voltage three or four times the battery voltage.

A better method is shown in Fig. 12. Junction FETs are selected on test for similar  $I_{dss}$  currents and a number are connected in parallel as shown to supply the rated charge current. The FETs are in series with the rectifier output and the drain-source characteristics provide a constant current output. The maximum output voltage should be limited by a zener diode to about 1.2 times the rated battery voltage.

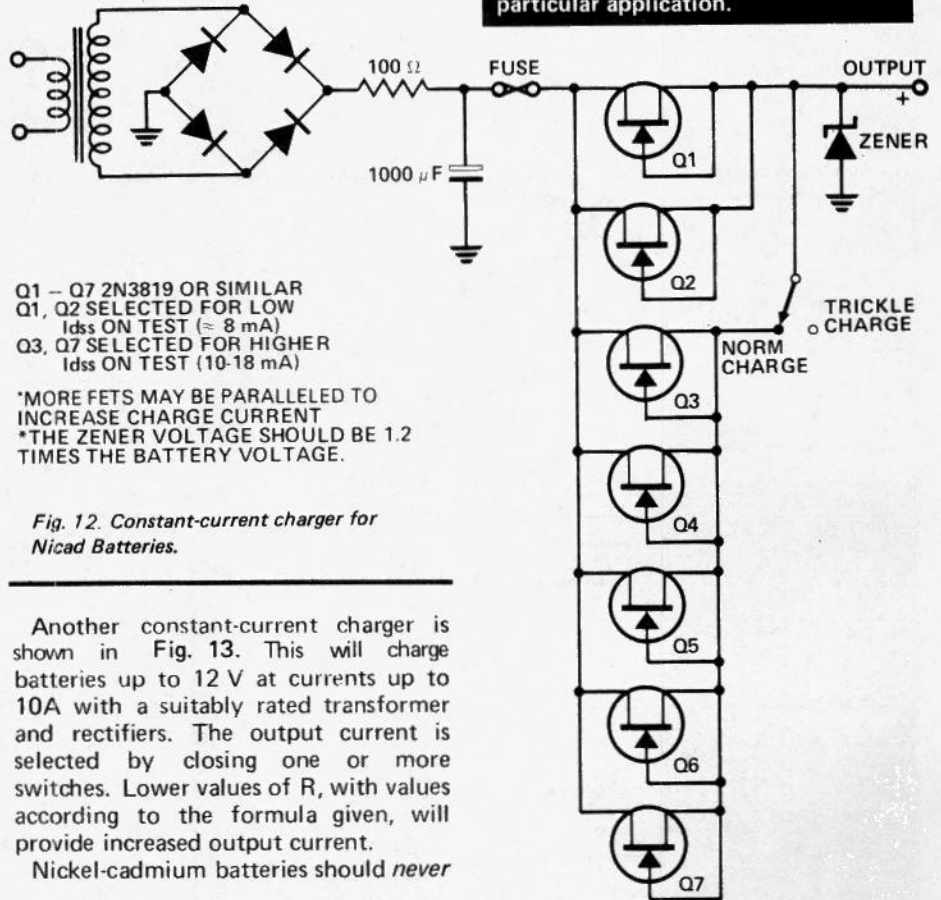


Fig. 12. Constant-current charger for Nicad Batteries.

Another constant-current charger is shown in Fig. 13. This will charge batteries up to 12 V at currents up to 10A with a suitably rated transformer and rectifiers. The output current is selected by closing one or more switches. Lower values of R, with values according to the formula given, will provide increased output current. Nickel-cadmium batteries should *never*

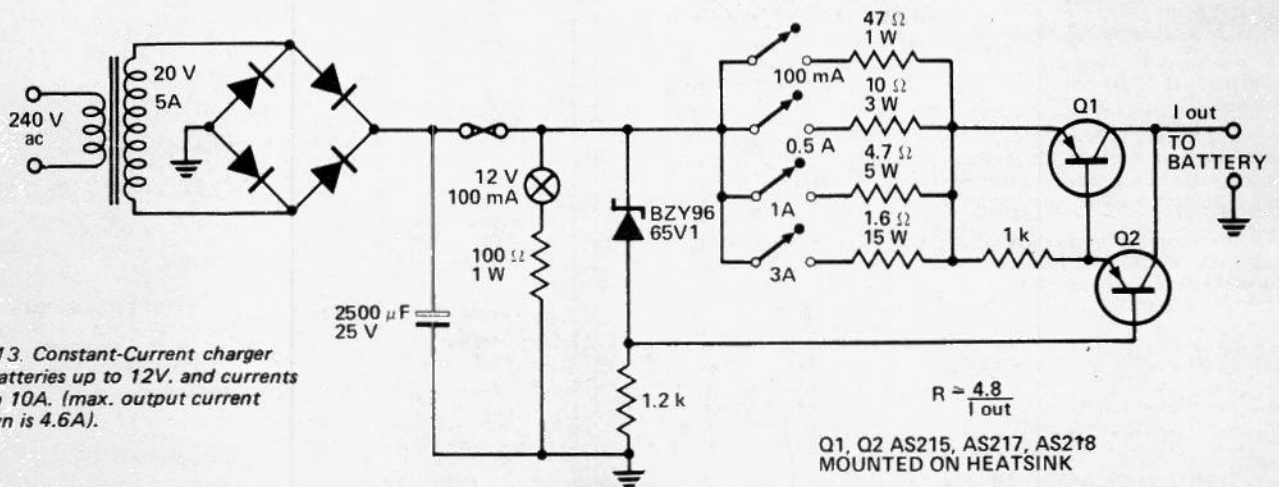


Fig. 13. Constant-Current charger for batteries up to 12V, and currents up to 10A. (max. output current shown is 4.6A).

be short circuited. This overheating and the battery may explode.

Never dispose of Nicad batteries in a fire or incinerator. This too will cause them to explode!

The nickel-iron battery is an earlier counterpart of the Nicad and has similar characteristics.

ETI

In this article we have tried to give enough information on the many different types of battery available. This, it is hoped, will allow the right type of battery to be selected for any particular application.