Battery Basics

An inside look at different battery types and guidance on which ones are best for particular applications

By Brent Gloege

Once used largely to power flashlights and toys, much of our state-of-the-art electronics now hinges on small-battery technology. In addition to old standbys, the regular zinc-carbon cell and heavy-duty zinc-chloride cell, there are alkaline, lithium, mercury, nickel-cadmium, and lead batteries.

There are also "button cells" used to power watches, hearing aids, calculators, and other tiny electronics. These are available not only in many of the above battery types, but also in two additional types, silver-oxide and zinc-air.

With all of these choices available, which battery do you choose for what application? Are rechargeables always best? Do alkalines really save you money over regular zinc-carbon cells? Let's take a look at the important properties of batteries and see which type of cell works best for each application.

Battery Characteristics

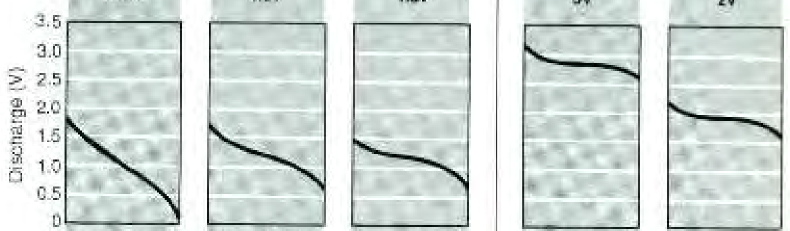
The first distinction to be made between batteries is whether they are rechargeable or can be used only once—what is commonly referred to as secondary vs. primary cells. Except for nickel-cadmium and lead batteries, all of the batteries we will be discussing are primary batteries; they cannot be recharged. (Some batteries can be "refreshed," a very limited form of recharging, but refreshing is not practical unless done under carefully controlled conditions.) There are also some new rechargeables on the horizon, such as rechargeable lithium cells, which are not yet widely available on the consumer market.

It takes about a dozen parameters to characterize a battery. Let's go through each to see what they mean.

The first parameter, listed in Table I, is the battery's voltage. Voltage is determined by chemical reaction that takes place in the cell. Common zinc-carbon cells generate approximately 1.5 volts when new. Alkaline and mercury cells are about the same.

Table I. Battery Discharge Curves

	Carbon-zinc	Zinc-chloride	Alkaline	LITHIUM MnO$_2$	LITHIUM Solid
Voltage	1.5V	1.5V	1.5V	3V	2V
Discharge curve	Most sloping	More sloping	Sloping	Flat	Flat
ENERGY DENSITY IN WATT-HOURS PER POUND/WATT-HOURS PER CUBIC INCH	20/2	40/3	45/4	100-150/ 6.5-10	50/6-8



Nickel-cadmiums (NiCds) are slightly lower, at 1.2 volts, and lead and lithium are somewhat higher, at 2 volts (3 volts for the MnO_2 lithium watch batteries).

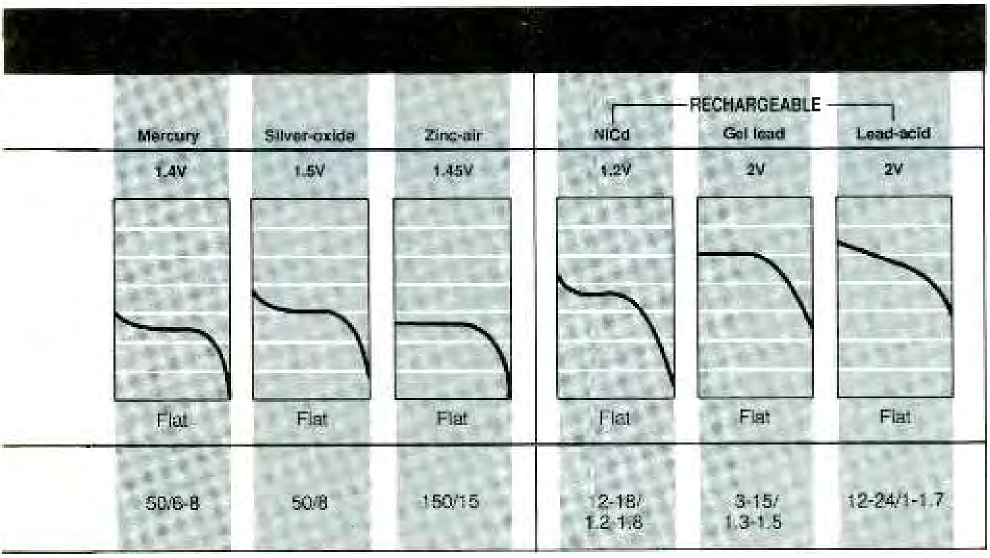
Voltage stated on a battery is the "nominal voltage." The actual voltage depends on two factors. First, a battery is not a perfect voltage source since it has internal resistance. Thus, voltage varies with the amount of current being drawn. Second, internal resistance of a battery increases with age, causing voltage at the battery's terminals to drop as the battery is discharged.

The "Discharge Curve" graph shows how voltage of each type of battery varies through its life cycle. For instance, while zinc-carbon cells start out at a little over 1.5 volts, they steadily drop in voltage as they are being used. Nickel-cadmium batteries, on the other hand, start out a little lower, at about 1.2 volts, but stay pretty much at that voltage until they are almost completely discharged. Manufacturers of battery-operated equipment know that zinc-carbon cells fall even lower than 1.2 volts toward the middle of their life, and so usually design their equipment to be able to operate at that voltage. That is why NiCds can usually be used to directly replace zinc-carbon cells; their voltage starts out low, but remains at that level during most of their discharge cycle.

The third parameter given in Table I is energy density. Technologically speaking, this is the most important parameter of a battery, though often some other factor, such as maximum current, shelf life, or cost, will be the overriding consideration in selecting a battery.

Batteries that have flat discharge curves have fairly easily determined energy densities because their voltage sharply falls at the ends of their lives. Batteries with sloping discharge curves have less special values for their energy densities because their voltage gradually falls off; the lower a voltage your device can tolerate, the greater the amount of energy you can get from the battery.

Energy density can be given in both energy (in watt-hours) per weight (in pounds) and per volume (in cubic inches). When building a battery-powered device from scratch, a designer is sometimes more concerned with how much volume the batteries will take up and sometimes more concerned with how much weight they will add. However, in cases where the container size is predetermined, whether it's a D cell, C cell, AA cell or something else, it is usually not important how much the cell weighs, just how much energy we can get out of that specific size battery.



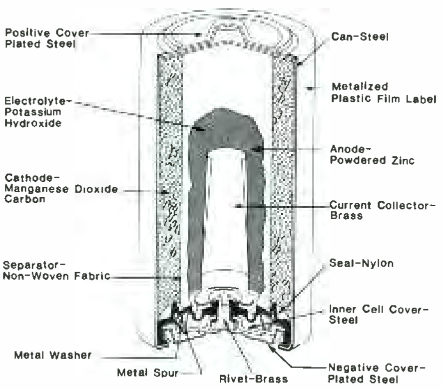
Energy densities for batteries range from about 12 watt-hrs per pound and 1 watt-hr per cubic inch for lead-acid cells, to over ten times that amount, 150 watt-hrs per pound and 15 watt-hrs per cubic inch, for zinc-air cells. Energy densities sometimes vary within battery type. For instance, alkaline battery designs have been constantly improving, with jumps as high as 30% or more with each generation.

Since material in nickel-cadmium batteries is so expensive, most manufacturers have been only partly filling their C- and D-type cells with electrolyte to keep their relatively high prices as low as possible. Even if the NiCd's don't have as long a life per charge as an alkaline cell, however, they can be recharged an almost unlimited number of times.

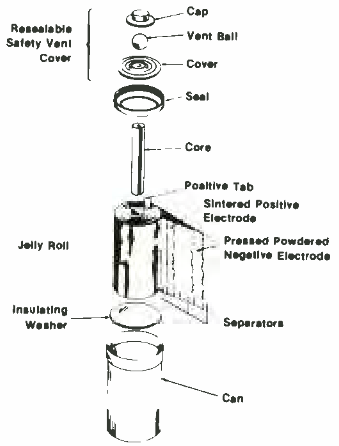
Now that the ground has been established, manufacturers are starting to introduce "hi-density" NiCd batteries—ones filled with electrolyte. Some of these have as much as four times the energy density as their low-density cousins (although it is still less than half that of the newest alkaline cells).

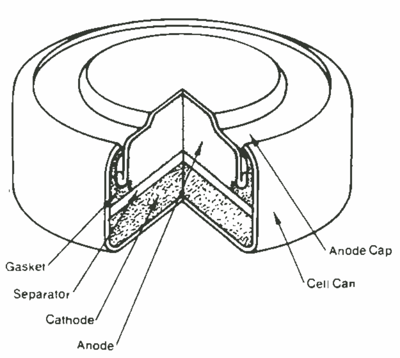
Table II lists the physical properties of the various types of batteries. The left-hand column shows the common battery size name (AA, C, D, etc.) along with actual volume in parentheses. To the right is the weight of each type of battery in their various sizes (not all batteries are available in all sizes). Where data is not applicable, NA is noted. This information is useful when designing equipment from scratch, where volume and/or weight of batteries may be important.

Table III shows ampere-hour (amp-hr) capacity of the various batteries. The amp-hr capacity simply tells you how many hours the battery will supply a certain current. For in-

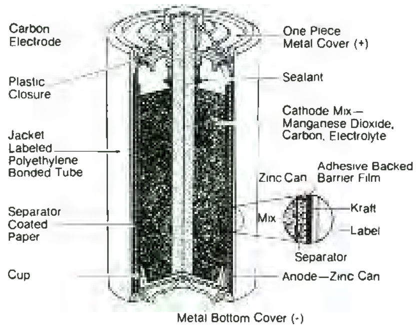


CUTAWAY OF CYLINDRICAL ENERGIZER ALKALINE CELL

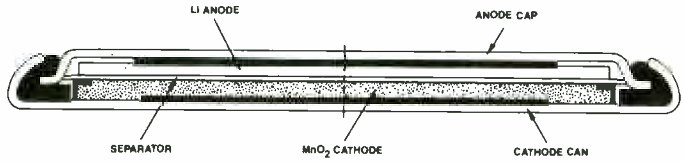




AQUEOUS MINIATURE CELLS



CUTAWAY OF SUPER HEAVY DUTY ZINC CHLORIDE CELL



3 VOLT LITHIUM MINIATURE CELLS

stance, if a battery has a rating of one amp-hr, it means you can draw one amp out of it for one hour before it is discharged; or ½ amp out for 2 hours; or 2 amps out for ½ hour, and so on. Theoretically, at least.

In reality, things are a little more complicated. Like many other battery parameters, the amp-hour capacity of a battery also has some variables. For instance, the ampere-hour capacity of a battery is higher at lower discharge rates. Thus, you can get more power out of a battery by drawing a small amount of current from it for a long time than you can by drawing a large amount of current for a short time. However, if you let the battery "rest," you can usually draw

(continued on page 22)

Table II. Physical Parameters (Weight in ozs)

				Lithium						Rechargeable	
Size Vol (in.³)	Carbon Zinc	Zinc Chloride	Alkaline	MnO_2	Solid	Mercury	Silver Oxide	Zinc Air	NiCd reg/Hi	Gel Lead	Lead Acid
Button (0.01-0.12)	.02-.25	NA	.02-.25	.02-.25	NA	.02-.25	.02-.25	.02-.06	NA	NA	NA
9V (1.3)	1.2	1.30	1.6	NA	NA	1.80	NA	NA	1.25	NA	NA
AAA (0.2)	0.3	0.33	0.4	0.46*	NA	NA	NA	NA	0.36	NA	NA
AA (0.5)	0.6	0.71	0.8	0.6*	NA	1.03	NA	NA	.75/1.0	NA	NA
C (1.5)	1.5	1.80	2.3	1.7*	NA	NA	NA	NA	1.8/2.5	NA	NA
D (3.2)	3.0	3.70	4.7	NA	NA	5.90	NA	NA	2.3/5.3	6.4	NA
6V (30)	22.0	22.0	30.0	NA	NA	NA	NA	NA	NA	26.0	6-60 lbs
12V (60-800)	50.0	NA	NA	NA	NA	NA	NA	NA	NA	10-40 lbs	15-50 lbs

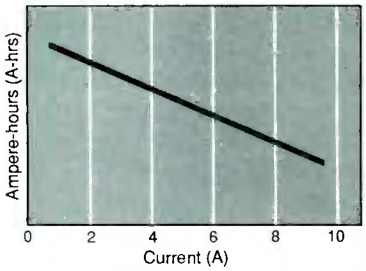
*Similar size for comparison only. Voltage too high (3V) for this size cell.

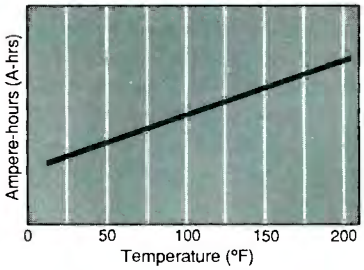
Table III. Amp-Hrs (at both low and high discharge rates)

	Carbon Zinc	Zinc Chloride	Alkaline	Lithium MnO$_2$	Lithium Solid	Mercury	Silver Oxide	Zinc Air	Rechargeable NiCd reg/Hi	Rechargeable Gel Lead	Rechargeable Lead Acid
Button	.03-.12	NA-	0.04-0.2	0.07-0.2	NA	0.02-0.3	0.01-.21	0.07-0.40	NA	NA	NA
9V (10mA)	0.30*	0.40	0.50	NA	NA	0.75	NA	NA	0.08	NA	NA
(50mA)		0.20	0.30			0.58			0.065		
AAA (20mA)	0.40*	0.60	0.80	1.0	NA	NA	NA	NA	0.19	NA	NA
(300mA)		0.40	0.50						0.15		
AA (20mA)	0.80	1.3	2.0	2.5	NA	2.5	NA	NA	0.55	NA	NA
(400mA)	0.30	0.7	1.2	1.5					0.45		
C (20mA)	2.5	3.0	6.0	7.75	NA	NA	NA	NA	1.35/2.0	NA	NA
(400mA)	0.70	2.0	4.5	5.0					1.1/1.6		
D (40mA)	5.0	8.0	11.0	NA	NA	14.0	NA	NA	1.4/4.3	2.7	NA
(700mA)	1.0	4.0	8.0						1.1/3.5	2.5	
6V (200mA)	7.0	9.0	14.0	NA	NA	NA	NA	NA	NA	6.5	50-125
(700mA)	4.0	6.0	9.5								
12V (5A)										5-50	30-100
(10A)											25-90
(15A)	**	NA	NA	NA	NA	NA	NA	NA	NA		20-80
(20A)											15-75
(25A)											10-70
(200A)											2-15

* This battery cannot put out this current for extended periods.

** Data not available





the remaining energy out of it later. Also, the amp-hour rate of a battery is temperature dependent. At low temperatures, the rating will be lower and at high temperatures it will be commensurately higher.

The amp-hr capacity of a battery is actually a form of energy density in a more useful form. The relationship between amp-hours, voltage, energy density, battery weight and volume is simply:

$$\frac{\text{amp-hrs} \times \text{voltage}}{\text{battery volume}} = \text{energy density per volume}$$

and

$$\frac{\text{amp-hrs} \times \text{voltage}}{\text{battery weight}} = \text{energy density per pound}$$

Table IV is very important in certain applications. It gives the maximum current a battery can provide. This is essentially a measurement of how much current will flow if you "short-circuit" the battery.

In most applications, maximum current available is not important. But in applications such as battery-powered tools, a battery may have to produce very high currents occasionally. Maximum current range from one amp for small zinc-carbon batteries to almost one thousand amps for larger lead batteries.

The maximum current a battery can generate also has two variables. The lower the temperature, the lower this number will be, and vice-versa. And the more discharged the battery is, the lower the number will be. Thus, depending on how you test, you will get different values for this number.

Maximum current can also be given as an internal resistance, since:

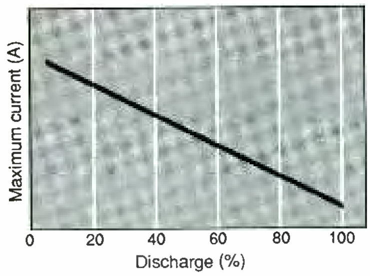
$$\text{internal resistance} = \frac{\text{battery voltage}}{\text{maximum current}}$$

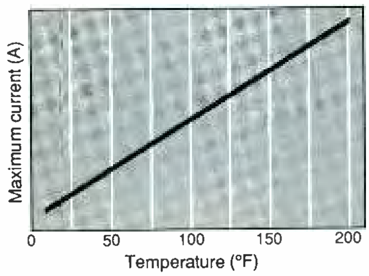
A battery's internal resistance is the least intuitive battery parameter, but is the key to many of the variables that we have encountered with batteries. Internal resistance is the

Table IV. Maximum Current (Amps)

	Carbon Zinc	Zinc Chloride	Alkaline	Lithium MnO₂	Lithium Solid	Mercury	Silver Oxide	Zinc Air	Rechargeable NiCd reg/Hi	Rechargeable Gel Lead	Rechargeable Lead Acid
Button	<< 0.05	NA	0.02	0.3	NA	0.02-0.5	0.02	.005-.012	NA	NA	NA
9V	0.8	0.8	10.0	NA	NA	*	NA	NA	1	NA	NA
AAA	4.0	4.0	8.0	*	NA	NA	NA	NA	1	NA	NA
AA	4.0	5.0	12.0	0.15	NA	*	NA	NA	5	NA	NA
C	5.0	7.0	13.0	0.3	NA	NA	NA	NA	10	NA	NA
D	6.0	9.0	15.0	NA	NA	*	NA	NA	10	200	NA
6V	8.0	9.0	30.0	NA	NA	NA	NA	NA	NA	50	200-1000
12V	6.0	NA	NA	NA	NA	NA	NA	NA	NA	800	200-1000

* Data not available





opposition to flow of electrical current within the battery, and is what prevents a battery from being a theoretically ideal voltage source.

This is the property that makes a battery's voltage vary with the amount of current drawn (V = I × R). Since internal resistance increases with age and with lower temperatures, it is also a property that makes the battery's voltage, maximum current, and amp-hour capacity vary with the battery's age and temperature.

Table V gives the internal resistance of all batteries whose manufacturers list it.

Notice that the internal resistance of a battery not only varies with the type, but also with its size. The larger the battery, the lower its internal resistance, and thus the greater the maximum current, as you would expect.

Table VI shows the temperature range and shelf life of the various battery types.

While a battery's performance varies with the temperature, there is also a minimum and maximum temperature in which it may be stored, and a minimum and maximum temperature in which it may be used. Usually, the latter range is narrower than the former.

If a battery is stored at a temperature that's too low, its electrolyte may freeze and destroy the battery. If the battery is stored at too high a temperature, chemicals in the battery may decompose or react with each other, using up the battery's stored chemical energy.

The working temperature of a battery is often narrower because the chemical reactions that generate the electrons are slowed down when temperature drops too low. Zinc-carbon batteries are a good example of this. They are pretty useless at temperatures below freezing (0°F) because chemical reaction will be too slow to generate very many electrons. When operating at temperature extremes, there are batteries available that do much better. For instance, gelled electrolyte lead cells can operate over a temperature range of −75 to +140 degrees F, and solid lithium cells are good over the range of −40 to +250 degrees F.

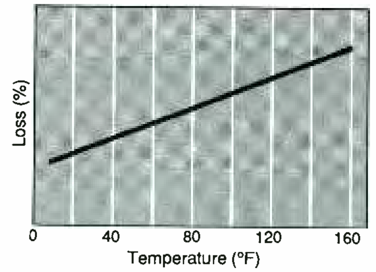
Batteries also vary enormously in their "shelf life"—how long they will remain ready to be used if left unused. Shelf life of some batteries is temperature dependent. If these are exposed to temperatures outside of a specified range, their life can be considerably shortened. This must be taken into account when estimating battery life. Within their temperature range, most batteries will have a longer shelf life if stored at lower temperatures.

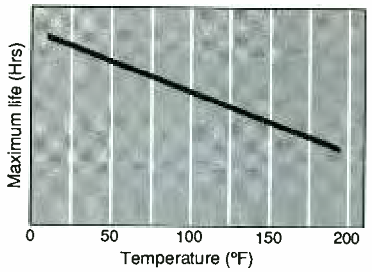
Another way of expressing a battery's life is the rate of loss of charge. Some batteries, like lithium cells, have a very low rate of loss—on the order of only 1% per year. Others, like nickel cadmium, have a very high loss—from 10 to 30% per month (if NiCds weren't rechargeable, they probably wouldn't be on the market). Again, the temperature will affect the rate of loss of charge. Lower temperatures will lower the loss rate and higher temperatures will raise it.

Batteries' maximum life varies from a couple of years for zinc-car-

Table V. Internal Resistance in ohms (fresh battery at room temperature)											
				Lithium					Rechargeable		
	Carbon Zinc	Zinc Chloride	Alkaline	MnO_2	Solid	Mercury	Silver Oxide	Zinc Air	NiCd reg/Hi	Gel Lead	Lead Acid
Button	*	NA	100.0	8-12	NA	3-80	100	3-5	NA	NA	NA
9V	35.0	35.0	3.0	NA	NA	*	NA	NA	9.0	NA	NA
AAA	0.7	0.5	0.4	*	NA	NA	NA	NA	1.2	NA	NA
AA	0.5	0.4	0.3	*	NA	*	NA	NA	0.24	NA	NA
C	0.4	0.3	0.2	*	NA	NA	NA	NA	0.12	NA	NA
D	0.3	0.2	0.15	NA	NA	*	NA	NA	0.12	0.01	NA
6V	0.8	0.7	0.2	NA	NA	NA	NA	NA	NA	0.02-0.03	0.01
12V	2.0	NA	NA	NA	NA	NA	NA	NA	NA	0.01	0.01

*Data not available





bon cells to about twenty years for solid lithium cells. Nickel-cadmium batteries have the unusual characteristic that their shelf life will almost always run out before their number of charge/discharge cycles have been exceeded.

In Table VII, we will look at a few properties which are meaningful only for the rechargeable batteries—nickel-cadmium, deep-cycle lead-acid, and gelled-electrolyte lead batteries.

Rechargeable batteries vary in the amount of time they require for recharging. This actually depends more on the particular model of battery than the type. For instance, there are NiCds that recharge in 16 hours, 3 hours, and 1 hour. The first entry in Table VII shows the various charge times for the three different types of rechargeable batteries.

Most of the batteries sold separately for consumer use take about 16 hours to fully recharge. Batteries that are sold as part of a tool vary from a very slow 30 hour charge to a very quick 1 hour charge.

The rechargeables also vary in the number of recharge cycles they have. This is shown in the second entry in Table VII.

In the case of NiCd batteries, they have virtually an unlimited number of cycles during their lifetime because the battery's maximum life is usually exceeded long before the number of recharge cycles is reached.

Lead batteries are more complex. The deeper they are discharged, the fewer number of recharge cycles they will have. If discharged almost completely, lead battries can have as few as 200 cycles. But if discharged only 25% each time, they can give as many as 2000 cycles.

Rechargeable batteries have a few other characteristics to consider, as shown in the last three entries in Table VII.

Rechargeables are sometimes fussy about how they are charged or discharged. Most nickel-cadmium cells do not perform as well if they are only partially discharged before recharging. They are not damaged, but they do "remember" how much they were used before recharging, and tend to act as if that is all the capacity that they now have. This can be cured by cycling them completely a few times. (The best way to use NiCd batteries is as follows: If your batteries are not yet completely discharged, but you need to have a fully charged set for the next time you will use them, leave the device turned on until the batteries are discharged, and then recharge them. You are not wasting a recharge cycle as NiCds have more recharge cycles than can be used in their lifetime.)

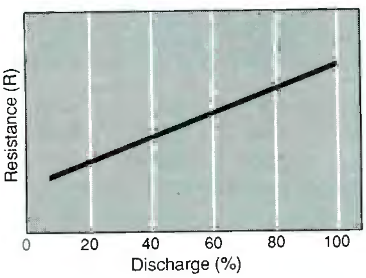
Lead cells have no memory, and so do not care if they are only partially discharged. In fact, they will give a greater number of recharge cycles if only partially discharged. But they, too, are fussy about how they are recharged. If not recharged immediately after use, they will have a *shorter* than expected life span.

The last peculiarity of rechargeable batteries is their possible susceptibility to damage by *reverse polarity*—a condition which can occur when a set of batteries is accidentally left on until *completely* discharged. The vulnerability to this depends on the particular model of battery. In general, NiCd's and lead-acid batteries are more vulnerable than gel-lead batteries.

Table VI. Temperature (°F)

	Carbon Zinc	Zinc Chloride	Alkaline	Lithium MnO₂	Lithium Solid	Mercury	Silver Oxide	Zinc Air	Rechargeable NiCd reg/Hi	Rechargeable Gel Lead	Rechargeable Lead Acid
Storage	−40+120	−40+160	−40+120	−40+140	*	−40+140	−40+140	−40+140	−40+140	*	*
Use	+20+130	0+160	−20+130	−40+140	−40+250	−15+130	32+130	0+140	−5+115	−75+140	*
Charge Loss at 70°F (%/month)											
	0.7%	0.7%	0.4%	0.1%	0.1%	0.8%	0.25%	0.25%	10-30%	2-3%	*
Yrs — of Original Charge at 70°F											
1/10	99%	99%	99%	99%	99%	99%	99%	99%	70-90%	97%	*
1	92%	92%	95%	98%	98%	90%	97%	97%	*	*	
2	85%	85%	90%	95%	95%	80%	94%	94%			
3	77%	77%	85%	93%	93%	70%	90%	90%			
4	70%	70%	80%	90%	90%	60%	86%	86%			
10	NA	NA	NA	75%	75%	NA	NA	NA			
Max. Life (yrs)	3-5	3-5	4-6	5-10	20	*	*	.15**	3-5	3-8	2-6

*Data not available
**Battery should be used within 60 days after opening (may be stored sealed for several years)



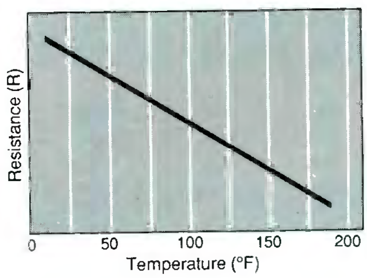


Table VII. Rechargeable Battery Properties

	NiCd	Gel Lead	Lead Acid
Charge Time:			
Regular	16	12	30
Fast	3	2	
Quick	1	1	
Cycles:			
100%	1000	200	**
50%	1000	500	
25%	1000	1000-2000	
Memory	Yes*	No	No
Recharge Immediately?	No	Yes	Yes
Reverse Polarity?	Yes*	No	Yes

*Some of the newest NiCd batteries reportedly eliminated these defects
**Data not available from manufacturers

The last, and obviously major consideration for all batteries is their cost. As Table VIII shows, one can look at the cost in several ways.

There is the initial cost of the battery, of course. As you might expect, this is often the only cost people consider. Usually, a better consideration is the cost per watt-hour of power. Often, batteries that are more expensive to buy initially are actually cheaper to use. This must be taken into account when calculating the cost of rechargeable batteries. While much more expensive to buy initially, they are far more economical than conventional batteries in the long run if used often.

Note that in many cases, one battery type may be more economical for a light load, and another type more economical for a heavy load. Often, the more expensive battery types are most economically used for heavy loads. Notice also that, within a given battery type, the larger the battery, the less expensive per watt hour it generally is to use.

Discounts on popular batteries will affect both the initial and cost per watt-hr., of course. Only "list" prices are considered in Table VIII.

So which battery do you choose?

If you need batteries for a non-critical or low-current application, then regular zinc-carbon or heavy-duty zinc-chloride batteries may be the best choice.

If you will be using a device that will have the same batteries remain-

Table VIII. Battery Cost

*	Carbon Zinc	Zinc Chloride	Alkaline	Lithium MnO$_2$	Lithium Solid	Mercury	Silver Oxide	Zinc Air	Rechargeable NiCd reg/Hi	Rechargeable Gel Lead	Rechargeable Lead Acid
Button											
Initial	0.50	NA	0.90	1.75	NA	0.50	1.00	0.80	NA	NA	NA
light	6.50	NA	6.00	5.75	NA	1.60	3.30	1.30	NA	NA	NA
heavy	**	NA	**	**	NA	**	**	**	NA	NA	NA
9V											
Initial	0.60	1.00	2.00	NA	NA	5.00	NA	NA	10.00	NA	NA
light	0.22	0.28	0.45	NA	NA	0.75	NA	NA	0.02	NA	NA
heavy	NA	0.55	0.75	NA	NA	0.95	NA	NA	0.03	NA	NA
AAA											
Initial	0.25	0.35	0.75	5.00	NA	NA	NA	NA	2.00	NA	NA
light	0.40	0.40	0.60	3.30	NA	NA	NA	NA	0.01	NA	NA
heavy	**	0.60	1.00	NA	NA	NA	NA	NA	0.02	NA	NA
AA											
Initial	0.30	0.40	0.80	8.00	NA	2.00	NA	NA	2.00	NA	NA
light	0.25	0.20	0.30	2.10	NA	0.53	NA	NA	0.01	NA	NA
heavy	0.65	0.40	0.40	3.50	NA	NA	NA	NA	0.01	NA	NA
C											
Initial	0.35	0.55	1.25	11.00	NA	NA	NA	NA	3/5	NA	NA
light	0.10	0.12	0.14	0.95	NA	NA	NA	NA	0.01	NA	NA
heavy	0.35	0.18	0.18	1.50	NA	NA	NA	NA	0.01	NA	NA
D											
Initial	0.35	0.55	1.25	NA	NA	10.00	NA	NA	3/7	6.00	NA
light	0.05	0.05	0.08	NA	NA	0.48	NA	NA	0.01	0.01	NA
heavy	0.25	0.10	0.10	NA	NA	NA	NA	NA	0.01	0.01	NA
6V											
Initial	3.00	4.00	11.00	NA	NA	NA	NA	NA	NA	20.00	15-90
light	0.07	0.07	0.13	NA	NA	NA	NA	NA	NA	0.01	0.01
heavy	0.12	0.11	0.19	NA	NA	NA	NA	NA	NA	0.01	0.01
12V											
Initial	10.00	NA	NA	NA	NA	NA	NA	NA	NA	30-70	40-90
light	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.01	0.01
heavy	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.01	0.01

* Initial (average list price w/o discounts)
Light (cost per watt-hour with light load)
Heavy (cost per watt-hour with heavy load)

** This battery is not suitable for heavy loads

ing in it for long periods of time, as in the case of an emergency flashlight or a camera, then alkaline batteries would be a better choice. This is especially true if the device is expected to perform under temperature extremes, for extended periods of time, with high reliability, or with high output current capabilities. Rechargeable batteries would be inappropriate in this case because you would never recover the initial cost, and the rechargeable's lower energy density and relatively high self-discharge will give you less time per battery charge.

If, for a special application, you need a lot of power in a small size, look into the lithium cells. While they are very expensive, and are most commonly available only in odd sizes, they are just the ticket for special high-energy-density applications.

If you need an enormous amount of economical power, look at the deep-cycle lead-acid motorcycle or car-sized batteries. They are the most powerful rechargeable batteries currently available.

If you will be using the device on an infrequent but regular basis, say, once a month, then gelled electrolyte lead batteries would be the best choice (you may not always have the option in this case because the gelled lead batteries are not as readily available in various sizes as are nickel-cadmium batteries).

If you use batteries frequently and heavily (discharge them deeply), NiCd's are the clear choice. Since most prefer to be cycled deeply, you should match the amount of drain that you put on them with their capacity. If you only discharge them to the point that the regular NiCd's will go, then they would be the most economical choice; if you need more time than the regular NiCd's can provide per charge, then you should select the "Hi-Capacity" NiCd's.

Finally, if you are regularly using a lot of batteries, you might find it useful to convert entirely to a rechargeable system. Therefore, if you will be using the batteries for less frequent, shallow discharges, choose gelled electrolyte lead batteries. If you will be using batteries for frequent, deep cycles, choose NiCd batteries. The following shows where each battery is at its best.

	Use	
Charge	**Infrequent**	**Frequent**
Deep	Lead	NiCd
Shallow	Lead	Lead

It might seem surprising that NiCd's have the advantage in only one out of the four possible situations, since NiCd's are the most common type of rechargeable battery. But its use is also the most common for rechargeable batteries—namely, frequent, deep cycling.

When using rechargeable batteries, you will need to have back-up batteries for when your batteries are recharging. There are two methods of providing backups. If you won't be using a lot of batteries, it is most economical to use alkalines as the backup batteries; when used only while your main batteries are charging, they should provide years of service. If you plan to have a lot of rechargeable batteries in use, or a smaller set in constant use, it will pay to have your backup batteries rechargeable, too. All you need is one additional set of each size that you are using. Whenever a set of batteries runs out of power, replace them with your spare set and place the drained set in the recharger. This way, you will get the most efficient use out of your recharger, too.

As far as which type of charger to use, if you are using only a few batteries of only one size, consider using one of the dedicated chargers (for instance, one which will recharge four AA cells at a time). If you will be using different sizes of batteries, you should consider one of the general rechargers that will recharge four to eight or more batteries of different sizes at a time.

By selecting the right battery for the right job, you will find that you will get the most out of your battery dollars, and always have fresh batteries on hand.

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