TECHNOLOGY

ALL ABOUT BATTERIES

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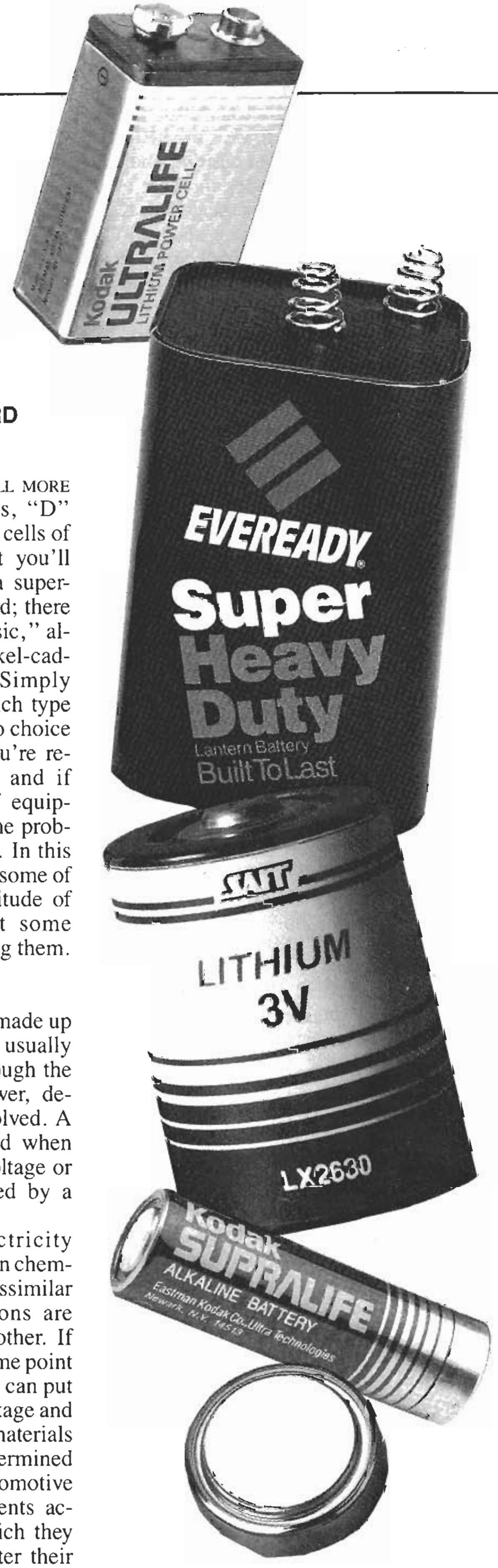
BATTERIES, BATTERIES, AND STILL MORE batteries. There are "C" cells, "D" cells, "AA" cells, and button cells of all varieties. The assortment you'll find, even just hanging on a supermarket rack, boggles the mind; there are regular, heavy-duty, "classic," alkaline, lithium, mercury, nickel-cadmium, and air-zinc cells. Simply making a decision about which type to use, even when you have no choice about the size of the cell you're replacing, can be confusing; and if you're designing a piece of equipment for battery operation, the problem is magnified enormously. In this article we'll try to make clear some of the reasons behind the multitude of battery types, and present some guidelines for choosing among them.

A short course

To begin with, a battery is made up of *cells*. An individual cell usually outputs about 1.5 volts, although the figure may be higher or lower, depending on the materials involved. A battery of cells must be used when you need to produce more voltage or current than can be delivered by a single cell.

A battery produces electricity through an oxidation-reduction chemical reaction involving two dissimilar materials, in which electrons are transferred from one to the other. If you extract the electrons at some point along their path of travel, you can put them to work for you. The voltage and current that a given pair of materials will produce are largely determined by their places in the electromotive series, which lists the elements according to the degree to which they react with oxygen. The greater their separation along the series, the greater the potential they will produce.



Selecting the right batteries for a particular application can be frustrating, especially when you have to choose between so many different types. This article will help you make your next selection.

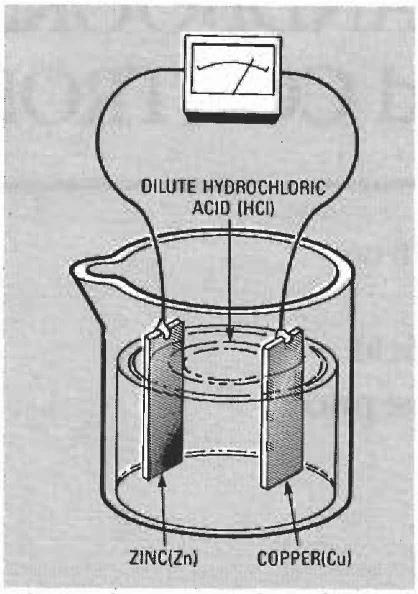


FIG. 1—A SIMPLE ENERGY-PRODUCING cell can be constructed from two dissimilar metals such as copper and zinc immersed in an acid electrolyte.

Any high-school chemistry book can provide you with detailed information on how the electron-producing reactions work. And, if you have fillings in your teeth and have ever bitten down on a coin or a piece of gum-wrapper foil, you have experienced (and tasted) firsthand how a simple battery works.

A simple, lab-experiment energy cell is illustrated in Fig. 1. In principle, all energy-producing cells have the same three principal components. They are:

Anode: the material that is oxidized and gives up electrons during the chemical reaction. The anode is usually marked with a " – ."

Cathode: the material that is reduced (releases oxygen) and accepts electrons during the reaction. It is usually marked with a " + ."

Electrolyte: the conductor through which electrons travel from the anode to the cathode as ions. The electrolyte is usually a "wet," or at least a damp material.

Note that, contrary to customary usage in electronics, the anode is the *negative* electrode of an energy cell and is indicated with a " – ." The positive electrode, marked with a " + ," is the *cathode*. In a rechargeable device, the functions of the electrodes are reversed during charging however, and conventional terminology then applies.

Cells and batteries are divided into two types: *primary* and *secondary*. Primary cells, which include the common throw-away "flashlight battery" types, expend their energy and, when their chemicals are exhausted, they must be discarded. Secondary cells are rechargeable (the chemical action is reversed by forcing a reverse flow of electrons), and include nickel-cadmium types and the lead-acid batteries used in automobiles.

Leclanche cells

Figure 2 shows the construction of an ordinary carbon-zinc D-size cell. The anode, cathode, and electrolyte are just a few of the components of a modern-day dry cell. Many of the others, though, such as the paper separator, serve just to "fine-tune" the performance of the device. That type of dry cell belongs to a class called "Leclanche cells" (sometimes pronounced Le-clan-SHAY) cells. They are named after Georges Leclanche, the Frenchman who produced the first carbon-zinc cell in 1866.

Because carbon-zinc cells are in

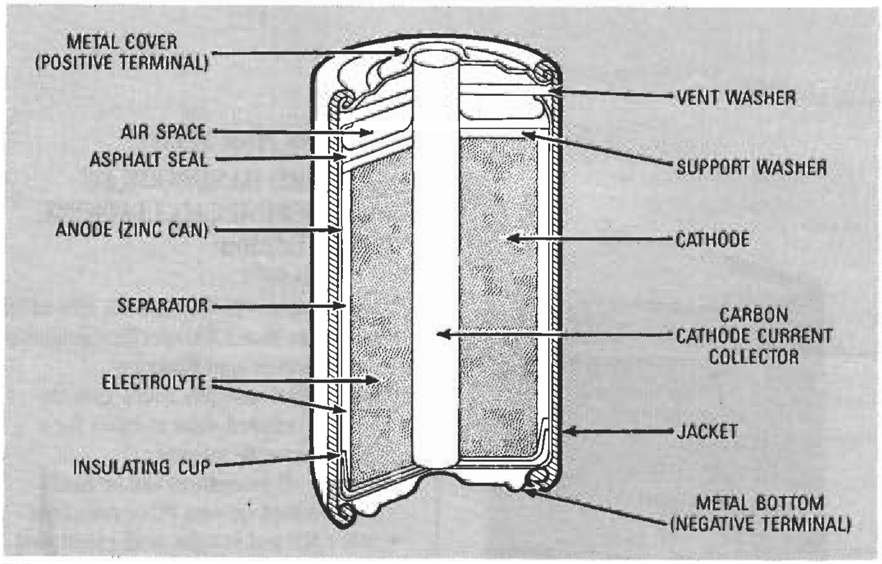


FIG. 2—THE "CLASSIC" DRY CELL uses a zinc can as anode, an ammonium/zinc-chloride electrolyte, and a manganese-dioxide cathode mix. The carbon rod plays no active part in the electron-producing reaction.

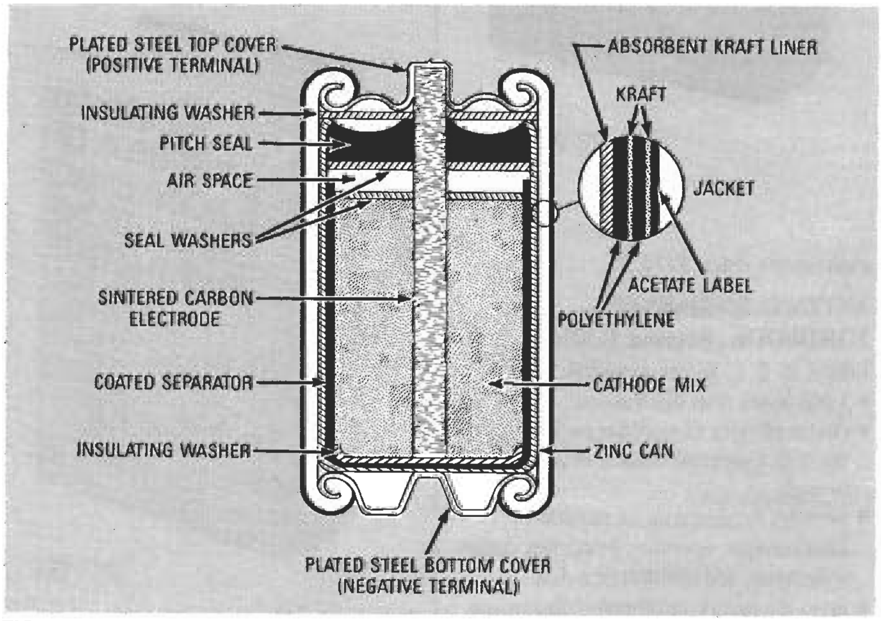


FIG. 3—THE PAPER SEPARATOR used in more recent dry-cell designs requires less space than the older paste-type, thus allowing the inclusion of more cathode mix and making possible a greater energy density.

such widespread use, it will pay to devote a paragraph or two to a discussion of the elements of which they are comprised. Figures 2 and 3 show carbon-zinc cells using paste and paper separators, respectively. (Because a paper separator occupies less space than the paste type, paper-separator cells can contain more reactive materials and produce about ten percent more power.)

The anode is a zinc can, zinc being one of the two reactive materials in the cell. The can also serves as a container for the other cell materials. Today, zinc cans are usually enclosed in a steel jacket, which increases durability and helps to contain leakage, should that occur.

Lining the inside of the can is the paste or paper separator. Its purpose is to physically and electrically isolate the positive and negative electrodes while permitting electrolytic or ionic conduction to take place through the electrolyte. The paste contains electrolyte and a gelling agent such as starch or flour. The paper-type separator is coated with a gelling agent and impregnated with electrolyte that is squeezed out of the cathode material during manufacture. Ordinary general-purpose Leclanche cells use an electrolyte made of ammonium chloride (NH_4Cl), zinc chloride ($ZnCl_2$), and water. In "heavy-duty" cells, the electrolyte is almost entirely zinc chloride and water.

The bulk of the cell consists of the cathode mix, also known as the "bobbin," "black mix," or "depolarizer." Its constituents are manganese dioxide (MnO_2), carbon black, and electrolyte. The purpose of the carbon is twofold: it holds the electrolyte and adds electrical conductivity to the mix. Some cells use a very pure electrolytically derived form of MnO_2 known as EMD (*E*lectrolytic *M*anganese *D*ioxide). Although that makes them more expensive, it also makes for an extra-heavy-duty device. A carbon rod is inserted at the center of the bobbin, which is the cell's current collector (electron source). The semi-porous rod also acts as a vent for hydrogen gas.

Note that although the Leclanche cell is frequently called a carbon-zinc (or zinc-carbon) type, carbon does not take part in the chemical reaction that produces electricity. The active ingredients are zinc and the manganese compound(s).

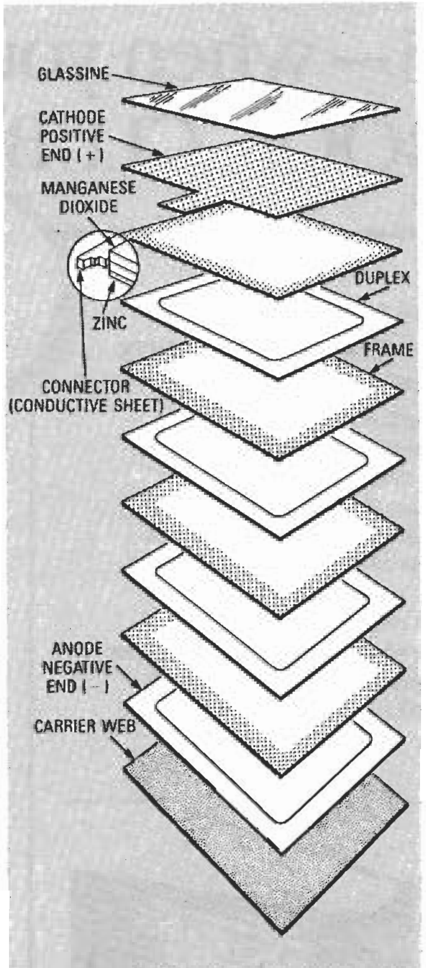


FIG. 4—THE LARGE ELECTRODE area of the *Polapulse* battery gives it the power to deliver enormous quantities of current.

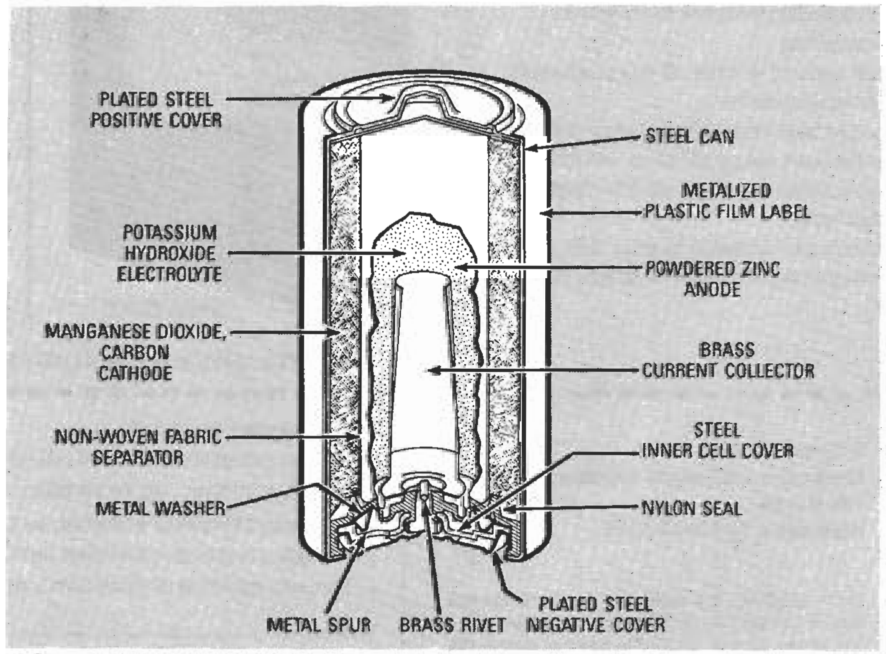


FIG. 5—TYPICAL OF MANY alkaline cells is "inside-out" construction, where the cathode material is exterior to that making up the anode.

The no-load voltage developed by a carbon-zinc cell is nominally 1.5 volts, although a brand-new one may be measured as high as 1.75–1.8 volts. A general-purpose Leclanche cell has an energy density of about 30 watt-hours per pound.

A special form of the carbon-zinc design is the *Polapulse* battery (Fig. 4) used to power Polaroid instant cameras. Its thin, flat construction makes possible electrodes with large surface areas. That, in turn, gives it a large capacity—as much as 19 amperes of instantaneous current! A Polapulse experimenter's kit is available from Powercard Corporation, 391 Totten Pond Road, Waltham, MA 02154 (617) 890 6789. The P100 Designer's Kit contains five P100 batteries and a special holder for them; it costs $17.50, and Massachusetts residents must add proper sales tax.

Alkaline cells

Alkaline cells derive their name from the fact that their electrolyte is the highly caustic base, potassium hydroxide (KOH), rather than a slightly acidic one containing a salt such as ammonium- or zinc-chloride. The design of an alkaline cell, although superficially similar to that of a carbon-zinc one, is really significantly different, as can be seen in Fig. 5.

The cathode material of an alkaline cell is EMD, the electrolytically derived manganese dioxide sometimes used in carbon-zinc cells to improve performance. It is mixed with water,

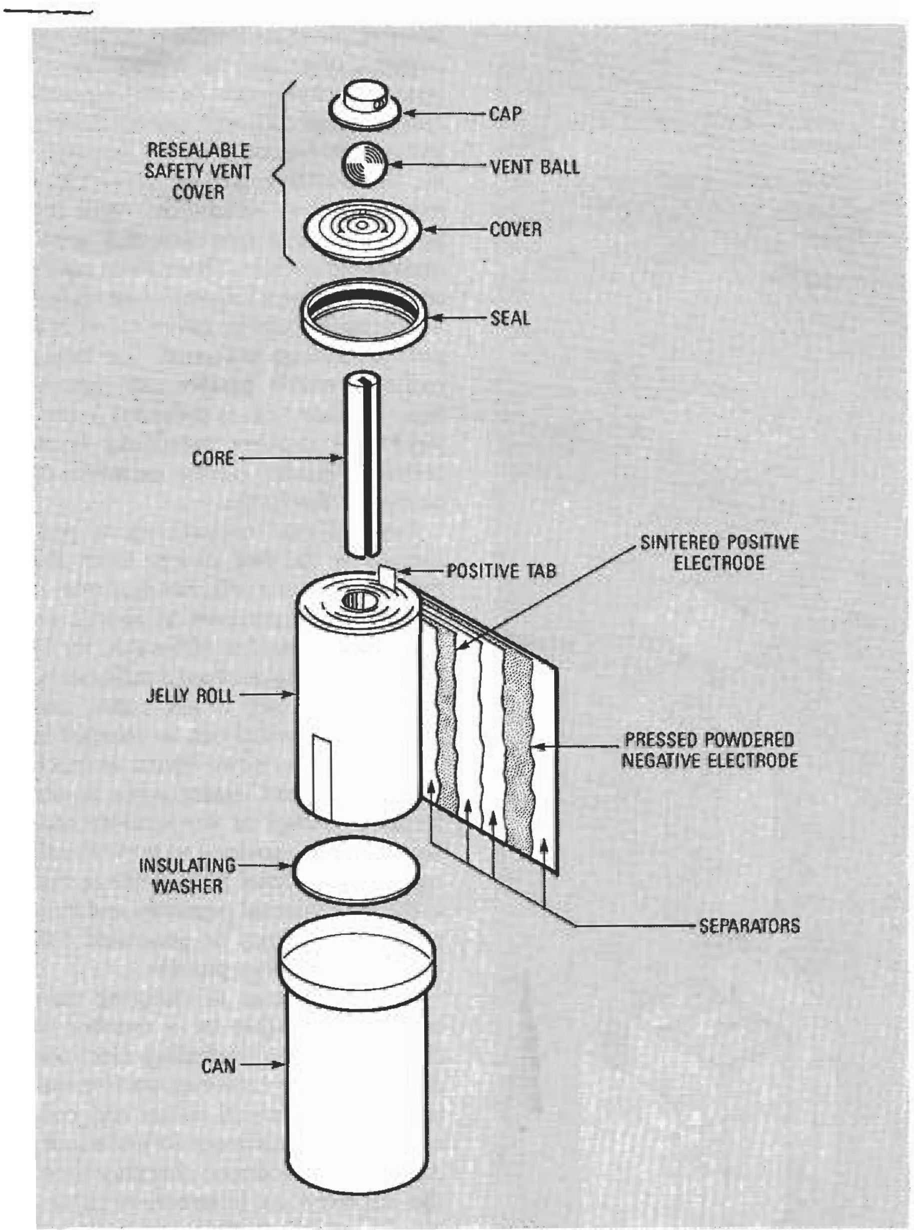


FIG. 6—THE "JELLY ROLL" construction of a typical nickel-cadmium cell gives it a large electrode area. Note the vent mechanism to protect against cell rupture resulting from the generation of gases during charging.

carbon or graphite (ten percent or a bit more), and some potassium-hydroxide electrolyte. As in a Leclanche cell, the anode is made of zinc, but the metal is in finely powdered form and the cell is contained in a steel jacket. The highly purified zinc powder is treated with mercury to form an amalgam; that greatly reduces the production of hydrogen, caused by the metal reacting with the potassium hydroxide electrolyte that pervades it. The separator that is used is made of a porous woven, felted, or bonded material.

In a cylindrical alkaline cell, the central element is the anode collector, not the cathode collector used in carbon-zinc cells. That piece, which may be made of brass, is mechanically and electrically connected to the bottom (−) terminal of the cell. That sort of "inside-out" construction is frequently used in dry-cell designs.

Alkaline cells have an open-circuit rating of about 1.52 volts, and an energy density of about 45 watt-hours per pound. Their performance at temperature extremes exceeds that of carbon-zinc types. Their low-current-drain performance is also better, but where alkalines are best where moderate-to-high currents are drawn over an extended period.

Making a choice

Carbon-zinc and alkaline cells are available in a wide variety of packagings and voltages. Fortunately, if it's just a replacement battery you're looking for when you walk into the store, you don't have to worry too much about your decision. The equipment into which the replacement cell or battery will be inserted can take only a particular size, and that size is usually keyed to the voltage. What you have to concern yourself with is the way the replacement performs—its behavior at various temperatures and, more important, its ability to deliver the current that your application requires. The literature provided with a dry-cell-operated device frequently recommends a specific type of cell or battery, but does not explain why that particular sort is called for. The next few paragraphs will help you to make a more informed decision about replacement cells, and in choosing a power source for something you may be designing.

Although alkaline cells have largely replaced carbon-zinc types in most applications, there are still some places where the latter will give a better price-performance ratio than the more glamorous type. Such situations are typically those where current drain is light but constant (no surges of current are called for by the device) and the operating temperature is a comfortable one. Carbon-zinc cells have a relatively short shelf or storage life, so they are best suited to applications where they will be used immediately; not where they will be expected to remain quiescent for long periods awaiting emergency use.

In a C-cell-powered wall clock it may prove more economical to install a regular carbon-zinc cell than an alkaline one; while the alkaline cell may last a bit longer, its extra cost will offset any economy that might be gained from its somewhat longer life. Heavy duty carbon-zinc cells made with somewhat higher-quality materials can even be used to power small transistor radios, provided not too much demand is made of them.

Alkaline cells, with their ability to source heftier currents than carbon-zinc ones and to depolarize, or recover, more quickly after heavy use, are better suited for the workload presented by much of today's consumer-electronics equipment; cassette players, boom-boxes, portable TV's, and the like. Devices that might suck carbon-zinc cells dry in twenty minutes can run for several hours on alkalines.

An Eveready brand called the "Conductor" promotes itself as being best for audio applications. While that was the case when it was first introduced, due to the use of premium components, the design of "ordinary" alkaline cells is today virtually identical to that of the Conductor brand, and there is little, if any, difference in performance.

Other properties of alkaline cells may also make them the better choice in certain applications. They have a longer shelf or storage life, and their output voltage falls off less rapidly than does that of carbon-zinc cells. Incidentally, you can extend the storage life of carbon-zinc cells by keeping them refrigerated to slow the chemical reactions that take place in them even when they are not being used. Because those reactions take place much less actively when alkaline cells are not in use, alkaline cells do not benefit as much from refrigerated storage.

Low temperatures cause voltage drop-offs in all types of energy-producing cells and batteries. Again, alkaline cells provide greater reliability over a greater temperature range than do carbon-zinc ones. As the temperature of a carbon-zinc cell drops below freezing, its voltage, and particularly the current it is capable of delivering, fall rapidly to unusable levels. While alkaline cells are similarly affected by low temperatures, their performance is better than that of even the best carbon-zinc cells.

Don't be swayed by those commercials that say things the likes of "Ours last 30 percent longer than..." The comparison is probably being made between the manufacturer's current production and the same product as he formulated it several years ago—not between his and somebody else's products. Virtually all alkaline cells produced today by the major manufacturers are considerably longer-lasting than those of a few years back due to the fact that changes in the construction of the shell (namely, reducing it to a single steel container with a thin plastic overcoating) has resulted in the ability to cram more reactive material inside. The voltage, of course, doesn't change, but the ability to deliver current does.

Rechargeable cells

Are you tired of replacing worn-out dry cells all the time? Maybe you're tempted to replace them entirely with rechargeable nickel-cadmium cells. But nickel-cadmium cells (commonly called "Nicads," although that's actually a trademark owned by one manufacturer, Saft) have their pros and cons.

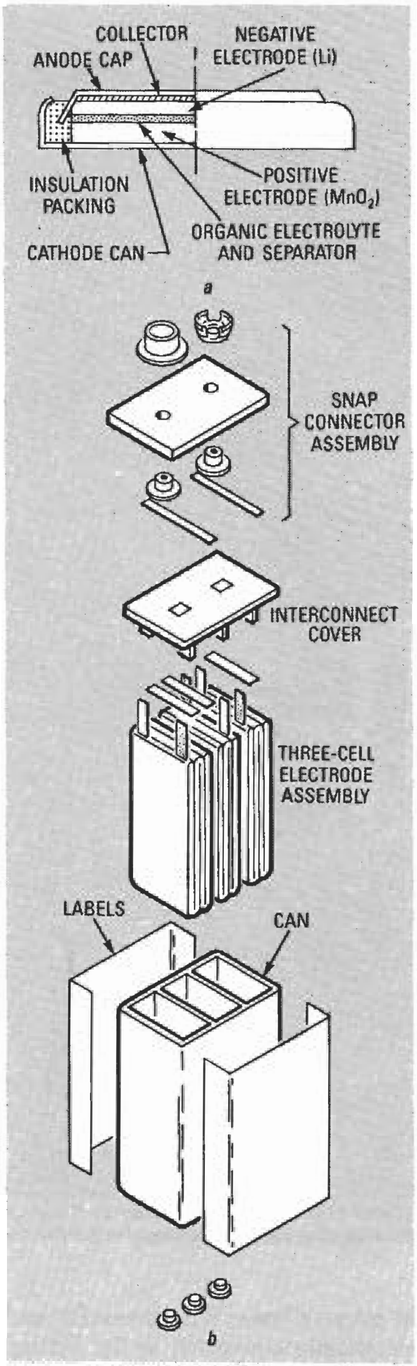


FIG. 7—LITHIUM CELLS have extremely high energy densities. The button-style packaging shown in *a* provides a large electrode area. Three 3-volt lithium cells are connected in series to make a 9-volt transistor-type battery (*b*).

The internal details of a typical nickel-cadmium cell are shown in Fig. 6. The active materials are nickel oxide (NiO), which forms the cell's positive plate; cadmium (Cd) for the negative plate; and the highly caustic potassium hydroxide (KOH) electrolyte. Several different manufacturing techniques may be used but, in general, the positive and negative electrodes form a "sandwich" with the potassium-hydroxide-saturated separator in the middle. Those three layers are wound into a jelly-roll-like spiral. The separator can be either nylon or a polypropylene material; the latter makes possible greater cell capacities. A safety vent is provided to prevent cell rupture resulting from pressure buildup during extremes of charge or discharge.

Normal-rate recharging is performed at the rate of one-tenth the rated current of a cell. For example, it takes 60 milliamperes to charge an AA-size cell rated at 600 mAh, for 14 to 16 hours. Quick-charge cells can be recharged in four to six hours, and fast-charge devices can be charged in as little as one or two hours, at much higher currents. Safeguards in the form of voltage or temperature sensors must be provided to prevent cell rupture or internal plate damage due to the high internal pressures and temperatures that may be generated during the fast-charge process.

The differences in charging rates are made possible by a number of different factors, including electrode design, and the choice of reactive materials; they are still nickel and cadmium, but in different formulations. Aside from a reduced charging time, the differences between regular-, quick-, and fast-charging cells are more or less transparent to the user. There is, however, a slight reduction in internal resistance in fast-charging cells, resulting in a nominal (on the order of millivolts) voltage increase, and the ability to better provide surge current.

Nickel-cadmium cells have a much flatter voltage-drop curve over their working life than do Leclanche and alkaline designs—a fact that may be worth considering. Immediately after charging, their open-circuit voltage is about 1.4 volts, which drops almost immediately to about 1.25 volts, a level that is maintained until their charge is nearly depleted. They can provide very large amounts of current when needed, and hold up well under conditions of continuous drain. Nickel-cadmium cells also provide good power output under extremes of tem-

FIG. 8—RECHARGEABLE lithium cells are intended principally for maintaining the contents of solid-state memories.

perature range.

Nickel-cadmium cells perform best when worked hard. If discharged just shallowly and then charged immediately, they will develop a "memory" for that sort of use and eventually lose some of their capacity. However, because of slight changes in cell chemistry, that's far less of a problem than it was just a few years ago. Most manufacturers insist that memory effects no longer exist. The working life of a nickel-cadmium cell on a single charge is only about 70 percent of that of an equivalent-size alkaline cell.

Nickel-cadmium cells are most useful where they can be built into a device and the charging current supplied from the outside through a jack, or internally, directly from it. If rechargeables are used as replacements for throwaway primary cells, you generally face the inconvenience of removing them from the device for charging, and then removing them again from the charger and replacing them in their compartment for use. When replacing old or worn-out cells in a nickel-cadmium battery pack, replace them all at once—mixing old and new ones can lead to the weakest of them reversing its polarity and affecting the life and performance of the entire pack.

Rechargeable lead-acid cells and batteries (similar to the one in your car, but smaller) use lead, lead oxide, and sulphuric acid, and come with a gelled electrolyte that allows them to be used in portable equipment without fear of spillage. Lead-acid technology is also available in the form of sealed D-size cells. The nominal voltage of a lead-acid cell is 2.0 volts, and it is capable of sustaining very high rates of discharge. The performance of lead-acid cells falls off at cold and very warm temperatures. Unlike nickel-cadmium cells, lead-acid cells must be kept well-charged if you expect them to perform efficiently over a long lifetime.

Lithium cells

Lithium is an extremely reactive metal, and its high place in the electromotive series makes it an excellent candidate for inclusion in energy cells. Unfortunately, its high degree of activity (it reacts violently with water, for example) makes it difficult to work with. Many of the difficulties have been overcome, however, and lithium-based cells are now found widely in watches, cameras, calculators, and in situations where a small trickle of current is required to maintain the contents of solid-state memory in a standby state. Lithium cells are very efficient, with energy densities on the order of 90 watt-hours per pound. The major reason lithium cells are not more widely used (although that is changing) is the difficulty in manufacturing large-size ones that are safe to use.

Although there are a number of lithium-cell formulations, the one using lithium, manganese dioxide (MnO_2) and a lithium perchlorate ($LiClO_4$) electrolyte in an organic solvent (water cannot be used, remember) makes up about 70 percent of the lithium-cell market. Carbon monofluoride is also used. Much of the remaining portion consists of cells made using a lithium-carbon-thionyl chloride ($SOCl_2$) formulation. Figure 7-*a* shows the construction of a typical lithium "button" cell; Fig. 7-*b* shows how Kodak combines three manganese-dioxide-type lithium cells in one package to produce a nine-volt, "transistor-type" battery.

The output of a lithium/MnO_2 cell is nominally three volts; in some applications it may be possible to replace two 1.5-volt carbon-zinc or alkaline cells with one lithium one. By using a lithium/ferric-sulphide (FeS_2) combination, a lightweight and powerful 1.5-volt cell can be produced. One of the great benefits of using lithium cells is their extremely long shelf life; five years or even ten. Under conditions of low drain, their useful working life may almost equal that figure.

A rechargeable lithium/MnO_2 button cell has recently been introduced by Sanyo (see Fig. 8). It is intended primarily as a replacement for the Ni-Cd cells and large-value capacitors used in keeping memory circuits alive.

Other types

While the types of energy cells already described can fill most electronics needs, actual and anticipated, there are a few additional kinds that bear mentioning.

Mercury cells have long been used as a compact power source in devices such as hearing aids and cameras. They use a mercuric-oxide cathode, powdered-zinc anode, and a potassium hydroxide (KOH) or sodium hydroxide (NaOH) electrolyte. The output voltage is 1.3 volts, and remains stable over a long life of storage or use. Silver-oxide cells are also used for similar applications (see Fig. 9).

FIG.9—THIS SILVER OXIDE battery is often used in cameras.

Another type of energy cell found in hearing aids and watches is the zinc-air, or just plain "air," cell. It uses atmospheric oxygen to produce electrochemical energy. Zinc-air button cells use a powdered-zinc-with-potassium-hydroxide-electrolyte anode and have a very thin cathode region incorporating a catalyst. Oxygen in the air provides the cathode material. Although they are not able to output large amounts of current, zinc-air cells have very high energy densities. Because air is kept out by a pull tab until a zinc-air cell is ready to be used, its shelf life is extremely long. A zinc-air cells's output voltage of about 1.4 volts remains stable over a working life of several hundred hours before falling rapidly to an unusable level.

There are, of course, still many more types of energy-producing cells, primary and secondary. Some are being produced today, some are still in the experimental stage, and others have been abandoned either for practical reasons or because they have been rendered obsolete by newer battery designs. **R-E**