

Batteries and Cells

The electro-chemical — primary and secondary cells — the Le Clanche cell — construction and operation — series and parallel combinations — the alkaline cell — the "mercury" cell — the lead-acid accumulator — the Ni-Fe cell — the nickel-cadmium cell.

A battery may be defined as a device which, by chemical action, produces an excess of free electrons at one terminal and a large number of positive ions at the other. The first terminal is negative; the second is said to have a positive charge, because it is deficient in free electrons.

When the two terminals are joined by an external conducting path, the electron pressure or EMF of the battery causes a movement of electrons along this path. In other words, the battery initiates the flow of an electric current through the external conductor.

To be precise, a single electro-chemical unit should be referred to as a cell; it is an interconnected group of cells which makes up a battery.

Investigators have produced quite a variety of electric cells, and a lot of space could be devoted to a discussion of their chemical action and their characteristics. However, for the purpose of this chapter, it seems more appropriate to devote the necessary mental energy to a study of the types normally used with electronic equipment.

Cells fall into two broad classifications; **primary** and **secondary**. Primary cells are relatively inexpensive, and designed for use once only. When discharged they are simply discarded. Secondary cells are a lot more expensive, but, when exhausted, they may be recharged and used again. Most such cells may be cycled several hundred times, and this alone fully justifies their higher first cost. In addition, they have many other advantages.

More recently, there has been developed a cell which is not strictly either a primary or secondary cell, but falls midway between. This is the manganese-alkaline cell which, although normally sold as a primary cell, is also available in a modified form which can be recharged — within limits.

Most primary or secondary cells may be further classified as "wet" or "dry".

These terms are not strictly accurate, but are used to differentiate between those types in which the electrolyte is a free liquid and the container is not completely sealed, and those in which the electrolyte is a jelly or paste and the cell is effectively sealed.

The first really practical primary cell was produced by Georges Le Clanche in 1868. His cells used a zinc rod for the negative pole and a carbon rod, surrounded by a mixture of manganese dioxide and powdered carbon in a porous container, as the positive pole. The whole lot was housed in a glass jar containing a solution of sal-ammoniac (ammonium chloride).

The Le Clanche cell in this form, though an entirely practical arrangement, suffered from the disadvantage of having a liquid electrolyte, subject to spilling and "creeping". These problems were largely overcome when, in 1888, a "dry" cell was produced by Dr

Gassner, using the basic Le Clanche principle but in a more convenient form.

The modern "dry" cell is essentially similar to that produced by Gassner. The glass jar is eliminated and the negative zinc electrode becomes the container for the chemicals. The carbon rod and manganese dioxide is retained as the positive electrode, but the sal-ammoniac is thickened to a non-spillable paste. A coat of wax over the top serves to seal the whole unit.

Such a cell is not truly dry and, indeed, could not be so. However, the cell may be used in any position without danger of the electrolyte spilling or doing damage to other apparatus. Although dry cells have changed little in appearance for many years, various chemical refinements have trebled and even quadrupled their service life.

When first manufactured, the cell builds up a certain potential across its terminals and, thereafter, the chemical action becomes very slight. However, there is always a slow chemical action going on and a drying-out process, so that a cell will not remain fresh indefinitely. After a few months, its terminal voltage begins to diminish and the amount of electrical energy it can supply becomes very limited.

The ability of a cell to remain "fresh" for a long period of idleness after manufacture is expressed in terms of its shelf life. Generally speaking, large cells have a much longer shelf life than small ones.

The main factor controlling shelf life is the

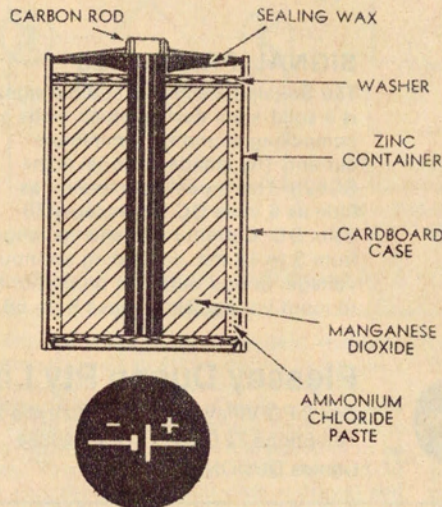


Figure 1: A cutaway view of the "dry" Le Clanche cell, showing the details of its construction; note the paste form of the electrolyte.



A collection of modern cells and batteries. At the rear are large Le Clanche "dry" batteries used for lanterns and higher-power electronic equipment, while in front of these are smaller batteries and cells used for low power applications. The two disc-type cells are of the nickel-cadmium type.

purity of the materials employed, particularly the zinc. If these were all 100 per cent pure, most of the shelf life problems would be solved. Unfortunately, this level of purity is impractical on a commercial basis and the battery manufacturer has to be content with something less. However, against this background battery manufacturers have improved shelf life significantly over the years. In addition, they can design a battery to have either a long shelf life — at the expense of some other characteristic — or minimum shelf life where other characteristics are more important and can be improved by so doing.

Again, for any one design, the temperature at which the battery is stored will have a significant effect on shelf life. High temperatures shorten it, low temperatures prolong it, so that it is customary to keep batteries in cold storage where the type of battery, kind of usage, and climatic conditions would otherwise create problems.

When, in actual service, a conducting path is provided between the terminals there is an evident electron movement from negative to positive along the path, which tends to relieve the electron pressure within the cell. However, the cell automatically tries to maintain the initial potential between its terminals, so the flow of electric current is invariably accompanied by increased chemical activity.

It is only comparatively recently that there has been general agreement on the chemical reactions in zinc-carbon cell, due to its extreme complexity. A popular concept for many years was that of a main energy producing reaction between the zinc and the ammonium chloride, with hydrogen liberated as a by-product. The formation of hydrogen bubbles on the carbon rod is responsible for a very undesirable cell characteristic called polarisation. Previously, it was assumed that the manganese dioxide overcame this by combining with the hydrogen to form water. More recently, it has been shown that the role of the manganese dioxide is much more direct, in that it prevents the formation of gas, rather than simply reducing any already formed. In addition, it is now known that the manganese dioxide is not simply a depolariser, but an active electrode which contributes more than half the energy which the cell delivers.

All dry cells which correspond to the foregoing description have an initial EMF of 1.5 volts or thereabouts between their terminals, irrespective of their physical size. However, large cells have a much longer shelf life than small cells, and, in service, can supply much heavier currents without running down.

Because of this, some care should be exercised in selecting the best size cell for a particular application. In general, larger cells are more economical than smaller ones, even though the latter have the advantage of low initial cost and, possibly, greater convenience. On the other hand, it is unwise to use a cell which is so large, relative to the current drain, that its theoretical discharge life far exceeds its shelf life. There is, therefore, an optimum size for any application.

The larger a cell, the greater is the surface area over which chemical activity can be evident. Therefore, such a cell is better able to maintain its electron pressure — or EMF — when called upon to deliver relatively high current.

The loss of EMF due to output current may be regarded very conveniently as an effective internal resistance of the cell itself. This internal resistance is small with large cells, and increases as the size of the cell is diminished.

The largest dry cell in common usage measures about 6in in height and 2in in diameter, and has a shelf life of two or three years — sometimes much longer. It is designed for a normal intermittent load of between 200 and 300 milliamps and is frequently used in telephone circuits.

The cells used in the larger type of "radio battery", used in the valve-type portable radios of a few years back, were designed to handle normal loads up to only 15 milliamps or so, but gave a useful life on intermittent service of 500 to 700 hours.

The cells in the "energiser" type of batteries used in transistor equipment are designed along somewhat different lines to the usual type of cell, to suit them to the type of loading conditions imposed by transistor circuitry. When used with a piece of equipment which draws the current values for

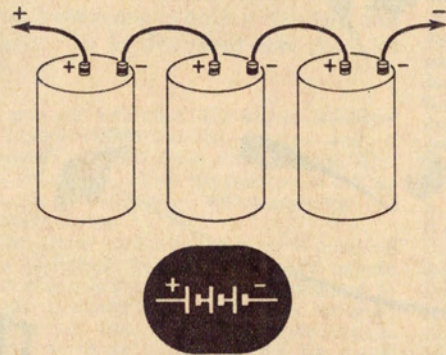


Figure 2: Series connection of cells, to deliver a higher voltage. The total voltage is equal to the number of cells times the single cell voltage.

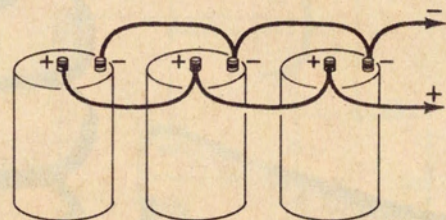


Figure 3: Cells connected in parallel, to deliver greater current without serious loss of terminal voltage.

which they are intended, such batteries have about the same useful life as the "B" batteries mentioned above.

Small single cells of the "penlight" variety will deliver only 8 or 10 milliamps comfortably and would give only a small fraction of their service life if asked to supply such currents for any length of time.

A sectional drawing of a typical dry cell is shown in figure 1, together with the usual schematic symbol. As may be seen, a single cell is represented by two parallel lines of unequal length. As a rule the longer stroke signifies the positive side of the cell, but it is occasionally found the other way round. To be on the safe side, most circuit draughtsmen clearly mark the polarity with a plus and a minus sign, as shown.

For many purposes the EMF or voltage available from a single dry cell is often inadequate and a higher voltage is obtained by connecting two or more cells in series. That is to say, they are linked together with the positive terminal of one cell going to the

negative terminal of the next, and so on. Any number of cells may be connected in this way, and the two terminals left over are the positive and negative connections to the bank of cells — or the battery, as it is generally called.

The most familiar illustration of this principle is that afforded by the ordinary two or three-cell torch or "flashlight".

In ordinary torch cells the tip of the positive carbon rod protrudes through the wax and is fitted with a brass contact cap. The negative connection is actually the bottom of the zinc can. When the cells are pushed into the torch case they are automatically connected in series and the resultant EMF is equal to the sum of their individual voltages. For two cells it is approximately 3.0 volts, for three cells about 4.5 volts, and so on. The connection is illustrated graphically and schematically in figure 2.

For the sake of convenience, battery manufacturers often assemble a number of cells in a single package or carton, connecting the cells together internally and bringing out just the one negative and the one positive lead. The actual voltage depends mainly on the number of cells contained.

The method of representing such batteries schematically is worth noting. There is an obvious objection to drawing a large number of individual cells, so that circuit draughtsmen normally show a couple of cells at each end, with a dashed line between them and a figure signifying the total terminal voltage.

For certain applications, voltages may be required intermediate between the negative and the full positive EMF. Standard procedure, in this case, is to provide the battery with one or more intermediate terminals, connected to the appropriate point in the series network of cells.

In the days when valves were widely used in battery-operated equipment, multiple-cell batteries were produced which gave quite high terminal voltages — typically 45V and 90V. These were commonly known as "radio B batteries". There were also smaller batteries with intermediate terminals used for grid biasing, and known as "C batteries". Both types were often made up using a "layer building" form of construction, in which the cells were formed by successive flat layers of zinc, carbon, electrolyte-soaked cardboard, and manganese dioxide.

It is well to note in passing that two or more cells may alternatively be connected in parallel, the positive and negative terminals being joined together as shown in figure 3.

With this arrangement, the EMF between the terminals remains at 1.5 volts (approx), but the load current is shared between the total number of cells. Because each cell is then called upon to deliver only one half, one third, one quarter, etc., of the total load, the bank of cells can handle a proportionately higher current than any one of the cells singly. A similar current capacity, with possibly longer shelf life, could be obtained from a single very large cell, but the parallel arrangement is sometimes used for convenience or expedience.

A modified version of the Le Clanche cell is the alkaline cell, which uses an alkaline electrolyte instead of the acidic ammonium chloride. This gives a better high-rate performance and a cell which can be more readily manufactured in smaller sizes. The smaller sizes are generally for low current drain applications only, although an "inside out" construction (ie, with the positive plate connected to the outer case) has been designed, with potassium hydroxide as the electrolyte, for higher current drains.

The energy volume ratio of alkaline

manganese cells is higher than the acidic Le Clanche cell and they have a longer shelf life. They may well eventually replace the Le Clanche for general commercial use but, at present, are slightly more costly to produce.

Another type of primary cell is the so-called "mercury" cell, which has been used for some years now in hearing-aids and other continuous-use devices, and is finding use in some of the newer transistor equipment (figure 4).

The mercury cell uses zinc as the negative electrode, as before, but the positive electrode is of mercury. Mercuric oxide is used both as a source of the mercury and as a depolariser. The electrolyte is a strong solution of potassium hydroxide and zinc oxide in water.

Mercury cells are commonly made "inside out" — that is, with the negative (zinc) electrode brought to the top as a cap. This enables a steel case to be used, both to connect to the positive mercury electrode and to act as a container.

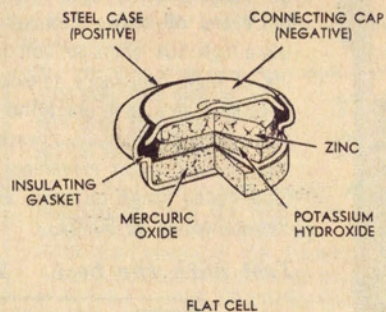
They may also be made in the "flat" variety, for stacking in series to produce voltages higher than that of a single cell. The voltage of a single mercury cell is approximately 1.35 volts, slightly lower than the Le Clanche type, but the internal resistance is generally very low in comparison, and mercury cells have a very high capacity. This makes them more suited to applications where the battery cannot be replaced very often, and to circuits which draw high currents for short periods.

In all the cells we have described so far, the electro-chemical action necessarily ceases when the chemicals have been used up, and the cells are then of no further use.

mixture to be decomposed, releasing atoms of hydrogen and oxygen at the respective plates. The hydrogen mostly escapes, but the oxygen liberated at the positive plate combines with the plate to form the dark brown peroxide of lead.

When the charging has proceeded for an adequate length of time, the battery may be removed from the charging circuit.

If a conductor is then connected between the two plates, a current is found to flow, and, as it does so, a chemical change becomes evident in both plates. The positive plate, coated with lead peroxide begins to take a coating of greyish lead sulphate, and much the same thing happens to the lead negative plate. The "sulphate" molecule comes from the acid, which is therefore progressively weakened as the discharge continues.



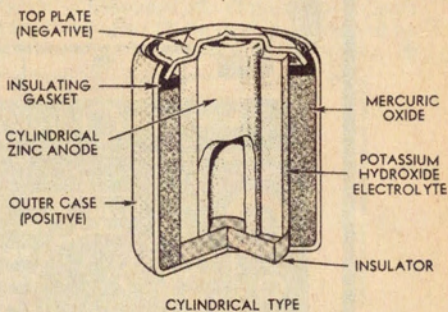
FLAT CELL

mount several cells, side by side, in the one large subdivided container. The cells are sealed across the top to prevent spilling of the acid and then connected permanently in a series arrangement, as already described for dry cells.

The current capacity of an accumulator is summed up in its AMPERE-HOUR rating, which gives a rough idea of the number of hours it will continue to deliver a specified amount of current after a full charge.

As well as the lead-acid accumulator, there are a number of other secondary cells used for special applications. One of these is the Nickel-Iron (Ni-Fe) cell, sometimes called the Edison cell, after Thomas Edison, who is credited with its invention.

The Ni-Fe cell is a complex structure, the positive electrodes being rows of perforated nickled-steel tubes filled with alternate layers



CYLINDRICAL TYPE

Figure 4: Basic construction of the two forms of Ruben-Mallory mercury cell, a primary cell which has a very high capacity and low internal resistance. Note the "inside out" construction, compared with the familiar Le Clanche cell. The steel outer case is the positive terminal.

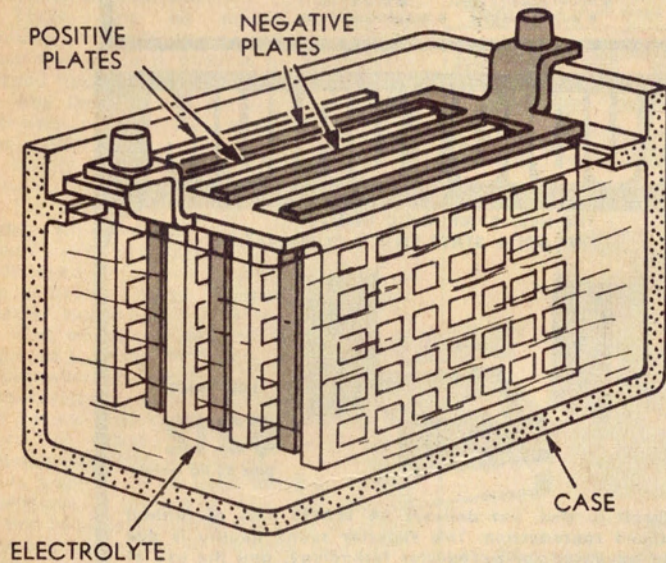


Figure 5: A single lead-acid secondary cell, showing the alternate lead plates supported in the acid electrolyte. Three or six such cells are used in the familiar automotive battery, to obtain 6 or 12 volts.

These so-called primary cells are distinguished from secondary cells by the fact that the latter can be made to deliver current afresh by a process called recharging.

The most common type of secondary cell or battery is the lead-acid accumulator used in motor vehicles. These were also used as filament of "A" batteries in the earliest battery radio sets.

In the lead-acid accumulator, two sets of lead plates are immersed in a mixture of sulphuric acid and water. To "charge" this type of cell the plates are connected to an external EMF in such a way that a current of up to several amperes flows through the acid via the plates.

The flow of current causes the acid-water

When next the cell is recharged, the lead sulphate on the negative plate is reduced to pure spongy lead, and the coating on the positive plate reverts to the dark coloured lead peroxide. At the same time, the strength of the acid is built up again, so that the cell is ready once more for a period of discharge. This charge and discharge cycle can be repeated hundreds of times until, after a period of perhaps several years, the active electrodes begin to disintegrate.

The EMF of a lead-acid secondary cell is normally reckoned at 2.0 volts, irrespective of its size. The actual current handling capacity is governed largely by the number, the size, the spacing and the nature of the plates.

For voltages greater than 2.0, it is usual to

of nickel hydroxide and thin flakes of pure nickel. The negative electrode is a grid made from nickeled sheet steel containing pockets filled with iron oxide. The electrolyte is a 21 per cent solution of potassium hydroxide in distilled water, plus a small percentage of lithium hydrate.

The voltage of this cell is 1.37 when fully charged, dropping to 1 volt when discharged. A greater number of cells are therefore required for a given battery voltage. The cells are a good deal more costly than the lead-acid type, but offer a number of advantages in certain applications, particularly for electric traction vehicles and similar heavy-duty service. They are a very robust cell, not easily damaged by other than optimum charging conditions — even including accidental reverse charge — which would quickly ruin a lead-acid cell. The working life may be 20 years or longer.

A more recently developed secondary cell is the nickel cadmium type. Although initially dearer than the lead-acid cell, it has many advantages which make it attractive for modern, compact, electronic equipment.

Among its advantages are a very favourable power to weight ratio, and a far greater tolerance to neglect than the lead-acid cell. Also, it is designed to provide a completely closed chemical cycle, whereby gas evolved during charging is re-absorbed within the cell. Thus the cell can be completely sealed. It is finding increasing use in portable equipment, such as electronic photo-flash, transceivers, portable radio, etc.

Another application is in self-contained electrical appliances. Electric shavers and electric drills are two examples of this, in which these cells make possible a compact, convenient device which can be used anywhere, independently of power lines, or where the use of high voltage equipment may be dangerous.