REFERENCE GUIDE FOR BATTERIES

Terence O'Kelly

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Is it live or is it Memorex?®

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Memorex has long been one of the world's foremost suppliers of media for memory storage. The very name of the company is a shortened form of "**MEMOR**y **EX**cellence" that started in 1961 with the manufacture of half-inch 9-track computer tape and progressed to audio and video cassettes, digital audio cassettes, and computer diskettes. As storage technology developed, Memorex expanded to optical storage media such as recordable and rewritable CDs and DVDs and to solid-state storage in the form of flash memory. As memory devices have grown smaller and more sophisticated, Memorex has continued to expand to include another storage medium—power storage in the form of batteries.

People often associate batteries with an energized bunny and a charged duck, but it was an unnamed frog who contributed most to the development of the battery by giving his leg and his life to science. At the end of the eighteenth century Luigi Galvani, Professor of Anatomy at Bologna University in Italy, described in his recently published treatise how he had discovered that connecting two lengths of copper wire and iron wire together so that they touched the frog's leg on one end and the exposed nerve endings on the other end would make the leg convulse. He attributed the phenomenon to "animal electricity." He believed that the leg stored electrical energy. Alessandro Volta disagreed. He was convinced that the source of power lay in the two different metals used for the wire because a single metal wire would not produce the same convulsions. His experiments proved that the electrical energy came from the two metals separated by various liquids, and he built a "voltaic pile" that could produce a shock when the ends were touched.

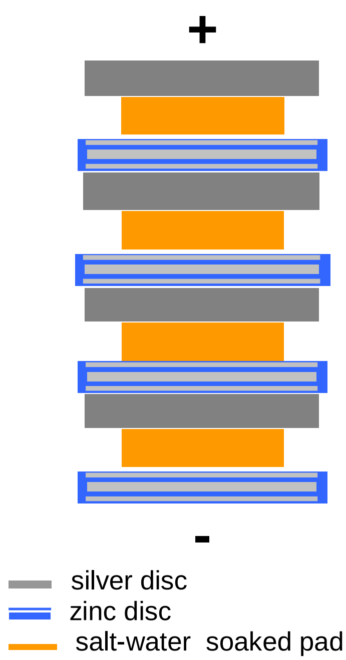


Figure 1

Volta's "Crown of Cups"
Battery of Simple Cells

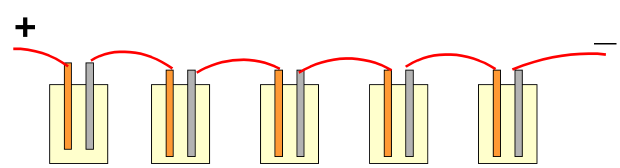


Figure 2

The voltaic pile was a stack of pairs of silver and zinc discs separated by cloth pads soaked in brine (Figure 1). When someone touched the top silver disc and the bottom zinc disc at the same time, he felt an electrical shock. There was a problem in the design in that the weight of the metal discs squeezed the brine out of the pads and down the stack; so in 1800 Volta came up with a different solution in the form of a series of small cells holding strips of silver or copper and strips of zinc dipped into dilute sulfuric acid. A copper wire ran from the top of one metal strip to the next in what Volta called "a crown of cups" (Figure 2). If the series or "battery" of simple cells contained a hundred or more cells, a person holding the wires at the end of the first and last cells received a tingling sensation indicating that electricity was flowing through the wires. Volta's battery differs from today's batteries only in the materials and chemicals used and the amount of surface area on the metal strips. Volta's design is the grandfather of today's wildly varying battery types and styles.

Volta experimented with different metals and salt or acid solutions with varying results. His battery produced electrical energy instead of heat in an electrochemical reaction in a manner explained later by chemists who understood the process better. If just the zinc is placed in the acid, it begins to dissolve and create heat. But when the wire connects the copper and zinc strips, the zinc no longer gives off the heat. As it begins to dissolve in the diluted sulfuric acid, bubbles of hydrogen form on the copper. As this chemical process takes place, a current of electrons flows through the wire from the zinc to the copper. The electrical power develops in the following way:

1. Pure sulfuric acid is described by the chemical formula H_2SO_4.
2. Adding water to the pure acid causes the SO_4 atoms to separate from the two H (hydrogen) atoms and at the same time take away two electrons, one from each H atom. (This is the reason that some car batteries have to have distilled water added every now and then if some water has evaporated.)
3. The H atoms now have a positive charge because each lacks a negative electron. Charged atoms or groups of atoms are called "ions." The SO_4 molecules are now negatively charged ions.
4. The negative SO_4 ions in the solution encourage the dissolution of the zinc into the acid to form zinc sulfate.
5. The acid dissolves the zinc strip, and the dissolved zinc atoms go into the solution as Zn^{2+} ions. Each dissolved zinc ion is positively charged because it leaves two electrons on the zinc strip.
6. When zinc dissolves in sulfuric acid, the chemical reaction usually produces heat; but in this case, the excess electron charges on the remaining zinc strip create an electron current through the wire from the zinc strip to the copper strip.
7. The positively charged H atoms have been busy, too. As they are being abandoned by the fickle SO_4 ions, they deposit themselves on the copper strip.
8. The copper offers each H ion one of its electrons and turns each back to a neutral hydrogen atom, transformed into a bubble of hydrogen on the copper strip.
9. The copper atoms now turn into positively charged copper ions after yielding their electrons to the hydrogen.

The zinc strips have extra electrons from the Zn^{2+} ions, and the copper strips are short on electrons since they have given them to the hydrogen. To balance things again, the electrons flow from the zinc through the wire to the copper and create electrical current.

These chemical reactions are the principle behind all batteries. The materials have changed over the years to increase efficiency and practicality. The first problem with Volta's crown of cups was that the accumulation of hydrogen bubbles on the copper strip would eventually insulate it from further chemical reaction. Adding a small amount of potassium dichromate solution to the diluted sulfuric acid allowed it to place oxygen atoms on the hydrogen bubbles, turning them into water and clearing the copper plate. (This is why a battery that appears to have given up all its energy can "recover" after an hour or so. The hydrogen insulation dissipates in time.) This chemical fix decreased the "internal resistance" of Volta's original design and made this simple cell arrangement more efficient. Over the years battery engineers have introduced many new materials and designs to overcome one deficiency or another or to enhance a particular characteristic. The many different designs account for the differences in battery types, their electrical characteristics, and their uses.

BATTERY TYPES

Batteries not only come in all different sizes, they also use very different designs based on the applications for their use. Some are meant to supply large amounts of current in bursts of energy (high-drain use) while others are used to supply long-lasting supplies of low current power. The most common types are:

Lead-Acid Battery—the Standard Car Battery

The cells of a car battery use large flat plates of lead and lead dioxide instead of strips of copper and zinc. The plates have tips on their upper ends that are the "electrodes" to which the car's electrical wires are attached. The lead plate has the negative electrode and the lead dioxide plate sports the positive electrode. The exchange solution or "electrolyte" is the same dilute sulfuric acid that Volta used. The chemical reaction is similar to the crown of cups:

1. The lead plate sitting in the acid combines with the acid to form $PbSO_4$ plus one free electron. (Pb stands for "plumbum," Latin for "lead." It is a heavy, malleable metal used by the original plumbers to make pipes in the Roman days.)
2. The flow of current from the negative lead plate through the car's starter to the positive lead dioxide plate creates water on the lead dioxide plate and builds lead sulfate on both plates.
3. As the battery sends more current from the negative pole of the battery through the starter to the positive pole, the acid solution becomes more diluted with water and the lead sulfate increases, weakening the battery.
4. However, when the car starts running and the generator now charges the battery, the current flowing to the battery's poles returns the plates to their original lead and lead dioxide states, making the battery reusable.

Each of the cells in a car battery can provide about 2 volts. The typical 12-volt battery has six cells, each with its own chamber. Looking at the top of a typical battery, one can see the six inlets for those batteries that require the addition of distilled water to keep the electrolyte solution at the proper acid/water ratio. The very large, flat lead negative plate sits very close to the lead dioxide plate shaped in a grid pattern in order to provide the largest amount of surface area possible. This design is to allow the maximum transfer of current needed to turn over an internal combustion engine, even on the coldest days when the lubricating oil is thick. Batteries such as car batteries designed to supply short, intense bursts of electrical energy are know as '"high-drain" batteries.

Alkaline Battery

These batteries use zinc and manganese-oxide as the electrodes, and an alkaline formulation acts as the electrolyte. These batteries are excellent for electrical devices that require a steady, uninterrupted flow of current such as wall clocks, flashlights, and portable music players. There are also high-drain versions of alkaline batteries available, and they do outlast conventional alkaline types; but since the high-drain design costs twice as much, it is more economical to invest in two standard alkaline types for the longer power supply. The alkaline battery is increasingly common since it outlasts the older zinc-carbon "heavy-duty" batteries with little cost penalty and is easily disposable after it has expired.

There are also rechargeable alkaline batteries on the market that are cheaper than rechargeable nickel-metal hydride batteries (see below) and do not suffer the power losses in storage that NiMH batteries do. Unfortunately, they can only be recharged about 25 times, and the amount of charge life decreases after each recycle.

Lithium-Ion Battery
These rechargeable batteries are long lasting but not as heavy as other designs. The typical electrode is based on cobalt chemistry, but researchers are developing electrodes based on phosphates or manganese that may offer better characteristics for the future. The favorable power-to-weight ratio of the lithium-ion battery makes it popular in cell phones and in the more expensive laptop computers. Lithium-Ion batteries are generally far more expensive than other battery types.

Lithium Photo Battery
Battery designs based on lithium, lithium iodide, and lead iodide are high-drain designs capable of sudden power surges such as those required by the flash devices on cameras. This is the common type of battery used in photographic equipment. They are long lasting batteries, lasting about twice as long as alkaline versions both in use and in storage; but they tend to be rather expensive, typically about four times more expensive than the alkaline versions.

Metal-Chloride Battery
These are heavy rechargeable batteries capable of supplying current for long periods. These characteristics have made them the choice for use in battery-powered automobiles.

Nickel-Cadmium Battery (NiCad)
This rechargeable design uses nickel-hydroxide and cadmium as the electrodes in an electrolyte of potassium hydroxide. The battery chemistry works best when the battery is drained nearly to its limit and immediately fully recharged because it has a "memory effect" that leaves it last charged state as its maximum capacity for the future. Although NiCad batteries are relatively low in energy density compared to NiMH batteries, their long life and capability of high discharge rates offer considerable advantages. The cadmium in the battery is a hazardous waste material; so these batteries cannot simply be tossed into the garbage when they have expired. They need to be properly recycled.

Nickel-Metal Hydride Battery (NiMH)
The NiMH battery is renowned for its ability to last through 300 to 600 recharge cycles and keep on delivering power. That strong point is balanced by the fact that NiMH batteries drain faster than alkaline batteries, and that drain continues even when the batteries are not being used. Electrical devices that sit in wait for sporadic use, such as flashlights and remote controls, are the wrong type for NiMH batteries.

Silver-Zinc Battery
This is another battery with a good power-to-weight ratio in its design. That makes it more common in airplanes and other equipment where weight is a critical factor.

Zinc-Air Battery
Like the silver-zinc battery, this design is also lightweight and rechargeable.

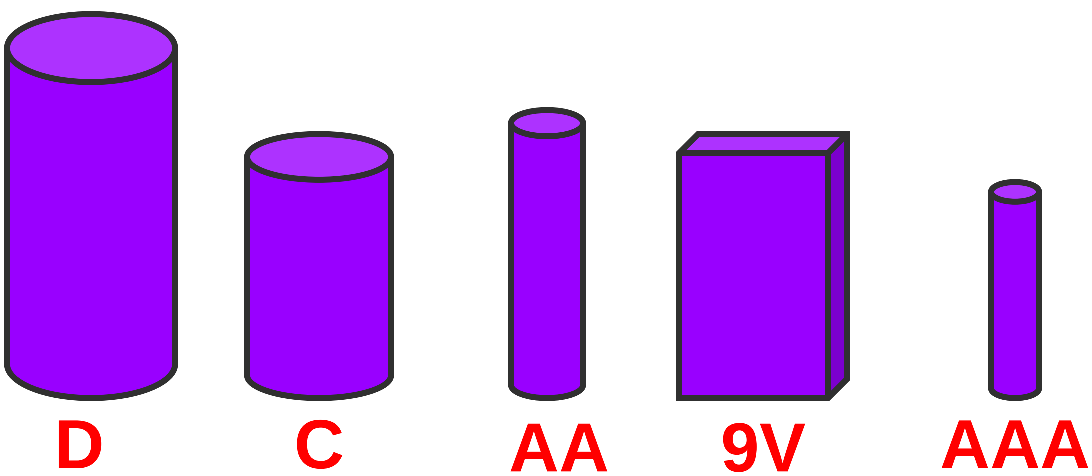
Zinc-Carbon Battery
This design is a very common, inexpensive design available in the typical AA, C, and D sizes. The electrodes are zinc and carbon with an acidic paste pressure squeezed into the casing that acts as the electrolyte. The paste is what made this design one of the first "dry cell" batteries that did not rely on a corrosive liquid electrolyte that could leak or spill. The "heavy-duty" moniker is often used to describe this particular design.

Zinc-Mercury Battery
The zinc-mercury battery is a lightweight, low-drain design common in hearing aids.

BATTERY SIZES

Batteries can take all sorts of shapes and sizes, as anyone who has ever tried to change a watch battery has discovered. Since all that is required is the two electrodes (the anode for the negative pole and the cathode for the positive pole and the chemical material creates the energy), those materials can take any shape required. The most common types of batteries, however, take a few specific shapes that are designated by an old combination of letters established years ago by ANSI, the American National Standards Institute. The IEC, the International Electrotechnical Commission, has set new, voluntary designations on batteries; but in the American market people still refer to the old letter code.

	ANSI Designation[1]	IEC Designation
1.5 volts	D	R20
1.5 volts	C	R14
1.5 volts	AA	R6
9.0 volts	9V	6F22
1.5 volts	AAA	R03



[1] The sizes ranged from A to D. The missing "B" size was a battery used in vacuum tube radios up until the 1960's when both the radios and the B batteries disappeared as transistor radios displaced the older tube versions. The B battery was taller than the C type and not quite as thick.

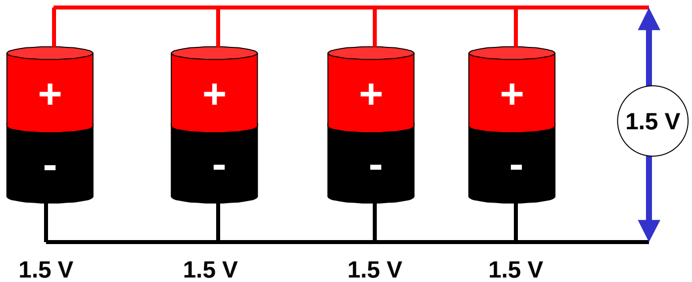
CELL ARRANGMENTS

Batteries differ not only in their composition, size, and shape but also in their voltage and current flow. Voltage is the amount of electrical force or potential across the two electrodes of the battery. Current describes the flow of electricity across the electrodes if they are connected to each other through a form of resistance, which could be a filament in a light bulb, an electrical motor, or some other electrical device. (If the two electrodes are directly connected with a wire and no resistance at all, the circuit is known as a "short circuit" with all that implies—sparks, heat, and potential fire as well as damage to the battery.) Current describes the flow of electricity; voltage describes the power pushing it. If electricity were water, a rain shower would be high current (fast moving) but with low voltage (not a lot of force in each drop). A pinhole leak in Boulder Dam, on the other hand, would be similar to low current, high voltage—not much flow, but a lot of force behind it. A shock of 50,000 volts is about the same as a static spark resulting from walking on a rug in a dry room in winter—lots of voltage, very little current. A bolt of lightning has about the same voltage as the static spark—but it is the tremendous current of the lightning bolt that lights up the sky and does the damage.

Batteries are most often just what the word originally meant: a series or battery of cells connected together to produce electricity. The way the cells are arranged determines the voltage of the battery and its ability to deliver current. There are two basic arrangements: parallel and serial.

Parallel Cells

Just as in a parallel circuit, a parallel design of cells allows the voltage to remain the same while current flow increases depending on the number of cells. In Figure 3 below, the number of 1.5-volt cells is four, each capable of supplying a particular amount of current. In the parallel arrangement, the voltage of the total cells connected together remains 1.5 volts; but the cells together can deliver four times the current flow of just one of the four cells. A device requiring low voltage in a large burst of energy would use a battery with the parallel cell design.



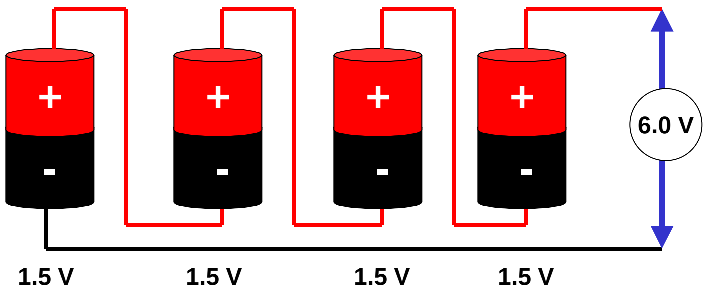
Parallel Arrangement

Total Voltage = Voltage of 1 cell X 1

Total Current = Current of 1 cell X number of cells

Figure 3

Serial Cells
Cells arranged in a serial design will increase their voltage potential by the number of cells connected in the series. The current capability remains the same as that of each single cell in the series. In the example in Figure 4 below, the total potential of the four 1.5-volt cells is 6 volts. The current is no different from that of a single cell in the series.



Serial Arrangement

Total Voltage = Voltage of 1 cell X number of cells

Total Current = Current of 1 cell X 1

Figure 4

The individual cells of a battery often produce little voltage. The arrangement of the cells within the battery determines its total voltage. The typical 12-volt car battery has 6 cells in it, each capable of 2 volts. The serial arrangement brings the total voltage to 12 volts, and the large plates inside increase the amperage to what is required. A nine-volt battery typically has six 1.5-volt cells arranged in series inside its case.

Devices that require a particular current flow or voltage generally rely on existing battery types to deliver the power the correct way. The batteries themselves can be arranged in parallel or in series, depending on the requirements. This makes it much easier for the consumer to get the devices working without having to get involved in calculations of electrical circuitry. The only important requirement is to put the batteries in the device properly so that the positive electrodes and negative electrodes are facing the correct directions.

BATTERY TERMINOLOGY

Battery data sheets and sales literature use a lot of electrical terms to describe the performance and operation of the batteries. Many of the terms are only vaguely familiar to users, and it helps to understand what the terms mean in order to understand the claims made for battery performance.

Active Material: the material at the positive or negative electrode that reacts chemically to move the electrons to store an electrical charge. The battery type usually takes its name from the type of active material used in the battery.

Ampere: a measure of the flow of current through a circuit.

Ampere-hours: a measure of the electrical charge passing through a circuit at a rate of one ampere per hour. The measure is taken by multiplying the amount of current in amperes time the number of hours. Of course a small battery is incapable of sustaining that amount current flow, so the figure is generally measured in thousands of an ampere or milli-amperes.

Anode: the negative electrode that **loses** the electrons in a chemical reaction.

Cathode: the positive electrode that **accumulates** the electrons from the anode.

Capacitance: a ratio of an increased charge on a conductor to the corresponding change in voltage.

Capacity: the amount of electrical output a battery can sustain over a period of time, generally expressed in mAh, or milliamps per hour. The measurement is taken on a specific load at a specific temperature until the voltage drops to a specified point. The load represents a resistance typical of the application in which the battery is used.

CCV: Closed Circuit Voltage. The voltage of a battery measured under a specific load or resistance and time interval. An open circuit is one in which there is no connection between the electrode or anode and no current flow. A short circuit is one in which there is a direct connection between the anode and cathode and no resistance at all! Short circuits are what lead to uncontrolled chemical reactions and the danger of fire.

Constant Resistance: resistance that does not vary over the life of the battery as the battery's voltage and current decline.

Discharge: the withdrawal of electrical energy from a battery, usually during its operation.

Drain: the withdrawal of current from a battery whether or not it is connected to a circuit.

e.v.: ending voltage. This is the lowest level of voltage in the battery at which either the battery can still operate any devices connected to it or below which it should not operate.

Impedance: opposition to the flow of alternating current that is a combination of resistance, inductance, and capacitance.

Inductance: the property of a circuit by which the flow of current through a conductor produces an electro-magnetic field and the corresponding electro-motive force.

Internal Resistance: (Ri)—the opposition of direct current flow within the battery itself that results in a drop in closed circuit voltage.

Ω: Ohm--the standard unit of electrical resistance that is equal to a conductor in which a current of one ampere is produced by a potential of one volt across the conductor's terminals.

Power: the amount of work an energy source can perform, expressed in watts. Watts are the product of the voltage times the current.

Shelf Life: The amount of time a cell or battery will retain a specified percent of its rated capacity, typically under ambient storage conditions.

Voltage: the measurement of electro-motive force or electric potential. One volt is defined as the amount of potential between two points of a conductor with a constant current flow of 1 ampere producing 1 watt of power.

Watt: a unit of electrical power.