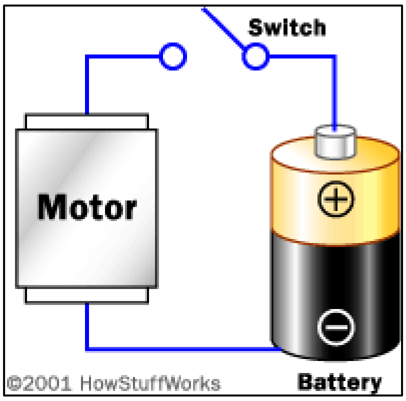
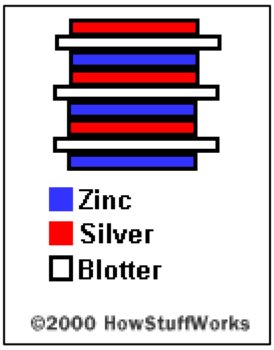
Battery Basics



If you look at any battery, you'll notice that it has two terminals. One terminal is marked (+), or positive, while the other is marked (-), or negative. In an AA, C or D cell (normal flashlight batteries), the ends of the battery are the terminals. In a large car battery, there are two heavy lead posts that act as the terminals.

Electrons collect on the negative terminal of the battery. If you connect a wire between the negative and positive terminals, the electrons will flow from the negative to the positive terminal as fast as they can (and wear out the battery very quickly -- this also tends to be dangerous, especially with large batteries, so it is not something you want to be doing). Normally, you connect some type of load to the battery using the wire. The load might be something like a light bulb, a motor or an electronic circuit like a radio.

Inside the battery itself, a chemical reaction produces the electrons. The speed of electron production by this chemical reaction (the battery's internal resistance) controls how many electrons can flow between the terminals. Electrons flow from the battery into a wire, and must travel from the negative to the positive terminal for the chemical reaction to take place. That is why a battery can sit on a shelf for a year and still have plenty of power -- unless electrons are flowing from the negative to the positive terminal, the chemical reaction does not take place. Once you connect a wire, the reaction starts.



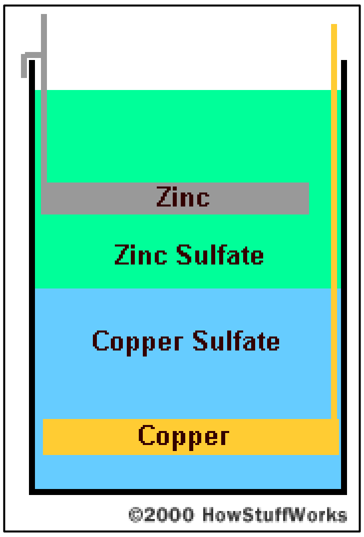
The first battery was created by Alessandro Volta in 1800. To create his battery, he made a stack by alternating layers of zinc, blotting paper soaked in salt water, and silver, like this:

This arrangement was known as a voltaic pile. The top and bottom layers of the pile must be different metals, as shown. If you attach a wire to the top and bottom of the pile, you can measure a voltage and a current from the pile. The pile can be stacked as high as you like, and each layer will increase the voltage by a fixed amount.

In the 1800s, before the invention of the electrical generator (the generator was not invented and perfected until the 1870s), the Daniell cell (which is also known by three other names -- the "Crowfoot cell" because of the typical shape of the zinc electrode, the "gravity cell" because gravity keeps the two sulphates separated, and a "wet cell," as opposed to the modern "dry cell," because it uses liquids for the electrolytes), was extremely common for operating telegraphs and doorbells. The Daniell cell is a wet cell consisting of copper and zinc plates and copper and zinc sulphates.

To make the cell, the copper plate is placed at the bottom of a glass jar. Copper sulphate solution is poured over the plate to half-fill the jar. Then a zinc plate is hung in the jar as shown and a zinc sulphate solution poured very carefully into the jar. Copper sulphate is denser than zinc sulphate, so the zinc sulphate "floats" on top of the copper sulphate. Obviously, this arrangement does not work very well in a flashlight, but it works fine for stationary applications.

Battery Reactions



Probably the simplest battery you can create is called a zinc/carbon battery. By understanding the chemical reaction going on inside this battery, you can understand how batteries work in general.

Imagine that you have a jar of sulphuric acid (H2SO4). Stick a zinc rod in it, and the acid will immediately start to eat away at the zinc. You will see hydrogen gas bubbles forming on the zinc, and the rod and acid will start to heat up. Here's what is happening:

The acid molecules break up into three ions: two H^+ ions and one $SO4^{--}$ ion.

The zinc atoms on the surface of the zinc rod lose two electrons ($2e^-$) to become Zn^{++} ions.

The Zn^{++} ions combine with the $SO4^{--}$ ion to create ZnSO4, which dissolves in the acid.

The electrons from the zinc atoms combine with the hydrogen ions in the acid to create H2 molecules (hydrogen gas). We see the hydrogen gas as bubbles forming on the zinc rod.

If you now stick a carbon rod in the acid, the acid does nothing to it. But if you connect a wire between the zinc rod and the carbon rod, two things change:

The electrons flow through the wire and combine with hydrogen on the carbon rod, so hydrogen gas begins bubbling off the carbon rod.

There is less heat. You can power a light bulb or similar load using the electrons flowing through the wire, and you can measure a voltage and current in the wire. Some of the heat energy is turned into electron motion.

The electrons go to the trouble to move to the carbon rod because they find it easier to combine with hydrogen there. There is a characteristic voltage in the cell of 0.76 volts. Eventually, the zinc rod dissolves completely or the hydrogen ions in the acid get used up and the battery "dies."

In any battery, the same sort of electrochemical reaction occurs so that electrons move from one pole to the other. The actual metals and electrolytes used control the voltage of the battery -- each different reaction has a characteristic voltage. For example, here's what happens in one cell of a car's lead-acid battery:

The cell has one plate made of lead and another plate made of lead dioxide, with a strong sulphuric acid electrolyte that the plates are immersed in.

Lead combines with SO4 to create PbSO4 plus one electron.

Lead dioxide, hydrogen ions and SO4 ions, plus electrons from the lead plate, create PbSO4 and water on the lead dioxide plate.

As the battery discharges, both plates build up PbSO4 (lead sulphate), and water builds up in the acid. The characteristic voltage is about 2 volts per cell, so by combining six cells you get a 12-volt battery.

A lead-acid battery has a nice feature -- the reaction is completely reversible. If you apply current to the battery at the right voltage, lead and lead dioxide form again on the plates so you can reuse the battery over and over. In a zinc-carbon battery, there is no easy way to reverse the reaction because there is no easy way to get hydrogen gas back into the electrolyte.

Modern batteries use a variety of chemicals to power their reactions. Typical battery chemistries include:

Zinc-carbon battery - Also known as a standard carbon battery, zinc-carbon chemistry is used in all inexpensive AA, C and D dry-cell batteries. The electrodes are zinc and carbon, with an acidic paste between them that serves as the electrolyte.

Alkaline battery - Used in common Duracell and Energizer batteries, the electrodes are zinc and manganese-oxide, with an alkaline electrolyte.

Lithium photo battery - Lithium, lithium-iodide and lead-iodide are used in cameras because of their ability to supply power surges.

Lead-acid battery - Used in automobiles, the electrodes are made of lead and lead-oxide with a strong acidic electrolyte (rechargeable).

Nickel-cadmium battery - The electrodes are nickel-hydroxide and cadmium, with potassium hydroxide as the electrolyte (rechargeable).

Nickel-metal hydride battery - This battery is rapidly replacing nickel-cadmium because it does not suffer from the memory effect that nickel-cadmiums do (rechargeable).

Lithium-ion battery - With a very good power-to-weight ratio, this is often found in high-end laptop computers and cell phones (rechargeable).

Zinc-air battery - This battery is lightweight and rechargeable.

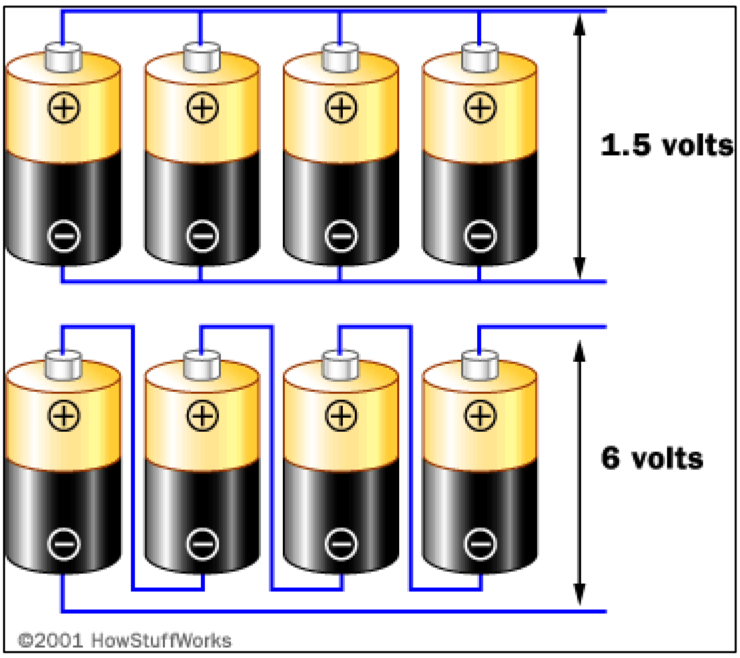
Zinc-mercury oxide battery - This is often used in hearing aids.

Silver-zinc battery - This is used in aeronautical applications because the power-to-weight ratio is good.

Metal-chloride battery - This is used in electric vehicles.

Battery Arrangements

In almost any device that uses batteries, you do not use just one cell at a time. You normally group them together serially to form higher voltages, or in parallel to form higher currents. In a serial arrangement, the voltages add up. In a parallel arrangement, the currents add up. The following diagram shows these two arrangements:



The upper arrangement is called a parallel arrangement. If you assume that each cell produces 1.5 volts, then four batteries in parallel will also produce 1.5 volts, but the current supplied will be four times that of a single cell. The lower arrangement is called a serial arrangement. The four voltages add together to produce 6 volts.

Normally, when you buy a pack of batteries, the package will tell you the voltage and current rating for the battery. For example, my digital camera uses four nickel-cadmium batteries that are rated at 1.25 volts and 500 milliamp-hours for each cell. The milliamp-hour rating means, theoretically, that the cell can produce 500 milliamps for one hour. You can slice and dice the milliamp-hour rating in lots of different ways. A 500 milliamp-hour battery could produce 5 milliamps for 100 hours, or 10 milliamps for 50 hours, or 25 milliamps for 20 hours, or (theoretically) 500 milliamps for 1 hour, or even 1,000 milliamps for 30 minutes.

However, batteries are not quite that linear. For one thing, all batteries have a maximum current they can produce -- a 500 milliamp-hour battery cannot produce 30,000 milliamps for 1 second, because there is no way for the battery's chemical reactions to happen that quickly. And at higher current levels, batteries can produce a lot of heat, which wastes some of their power. Also, many battery chemistries have longer or shorter than expected lives at very low current levels. But milliamp-hour ratings are somewhat linear over a normal range of use. Using the amp-hour rating, you can roughly estimate how long the battery will last under a given load.

If you arrange four of these 1.25-volt, 500 milliamp-hour batteries in a serial arrangement, you get 5 volts (1.25 x 4) at 500 milliamp-hours. If you arrange them in parallel, you get 1.25 volts at 2,000 (500 x 4) milliamp-hours.

Have you ever looked inside a normal 9-volt battery? It contains six, very small batteries producing 1.5 volts each in a serial arrangement!

Memory Effect

Yes, it does exist. And, yes, your batteries could possibly have the effects of it. It's the memory effect. The term "memory" basically is described as the battery "remembers" its usual discharge point and superficially "needs" a charge whenever it hits that point. In other words, if you have a Nicad that always gets discharged to only 50% of its capacity, it will eventually not run below that 50% mark if you ever wanted to discharge it to a lower point. Many people who do not know about this effect just throw away the battery because they think it is dead. More than likely, the battery can revived providing that the battery isn't completely damaged (i.e. from years of memory build up). The simplest way to get rid of memory is to discharge the battery to 1.0 volt per cell (VPC) on a minimal load, and then charge it fully. Repeat this procedure until you notice the battery lasting longer and longer on the drain, until it holds its correct capacity and not the "memorized" one. Unfortunately, unless you have good equipment, it is hard to discharge to 1.0 VPC without accidentally "reversing" a cell. Now, if you were only working on one cell at a time, discharging to 1.0 VPC would be easy, but most batteries nowadays for cellular phones and such are multiple cells in a plastic case. This makes it hard to get every cell to 1.0 VPC. No batteries are created equal, and what will most likely happen in a multi-cell battery is that one or more of the cells will "reverse" because they are weaker than the other cells. The reversed cell begins to accept a "backwards" charge from the other better-charged cells around it. This is really bad for a battery if you don't catch it, because chances are it won't charge again while in the pack. If you are going to discharge a pack and you cannot open it to test individual cell voltages, please discharge to approximately 1.2 VPC. This will help prevent reversing cells. If you do reverse a cell and can access each individual cell, I have found that giving that cell about 4.5 volts (up to 1 A current) in the right direction, it will probably set itself straight. Measure the voltage of the cell after the "shock" charge. If it doesn't improve, try again. If you are still unsuccessful, try a higher voltage. I've needed 9 volts in some cases to get a cell working again. Once you get the cell at > 1.2 volts, immediately put the pack on charge now so that battery won't have time to reverse again. Charge the pack fully for 24 hours on a trickle charge to make sure that the reversed cell(s) have recovered fully. Also note that the once-reversed cell will never be the same. It will now always be the first one to reverse in the pack, so you might want to be aware of that when you try to discharge/cycle it in the future. Remember this: if you treat your battery well from the beginning by never letting it acquire memory, you won't have to worry about these weird procedures. Also, remember that all batteries have an expected life. Nicads have a life of approximately 1000 cycles as long as they are treated very well. So, if your battery is really old and doesn't hold a charge anymore, chances are it's not memory, but a tired battery. Let it retire at a recycling centre.

Keith Appleford.