

All About Batteries

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Overview



This tutorial is about **batteries** (if you couldn't tell) - and how to decide which batteries will run your project best! I'll cover both rechargeable and "one shot" batteries, trying to cover everything I've learned about these surprisingly-complex electronic components!

How Batteries Are Measured

There are a few different ways to 'measure' batteries, here are the ones I will be comparing

- **Size**

This is pretty straight forward, how big are the batteries? Lead acid batteries don't get much smaller than C-cell batteries. Coin cells don't get much larger than a quarter. There are also standard sizes, such as AA and 9V which may be desirable.

- **Weight and power density**

This is a performance issue: higher quality (and more expensive) batteries will have a higher power density. If weight is an important part of your project, you will want to go with a lighter, high-density battery. Often this is expressed in Watts-hours per Kilogram.

- **Price**

Price is pretty much proportional to power-density (you pay more for higher density) and proportional to power capacity (you pay more for more capacity). The more power you want in a smaller, lighter package the more you will have to pay.

- **Voltage**

The voltage of a battery cell is determined by the chemistry used inside. For example, all Alkaline cells are 1.5V, all lead-acid's are 2V, and lithiums are 3V. Batteries can be made of multiple cells, so for example, you'll rarely see a 2V lead-acid battery. Usually they are connected together inside to make a 6V, 12V or 24V battery. Likewise, most electronics use multiple alkalines to generate the voltage they need to run.

Don't forget that voltage is a 'nominal' measurement, a "1.5V" AA battery actually starts out at 1.6V and then quickly drops down to 1.5 and then slowly drifts down to 1.0V at which point the battery is considered 'dead'.

- **Re-usability**

Some batteries are rechargeable, usually they can be recharged 100's of times.

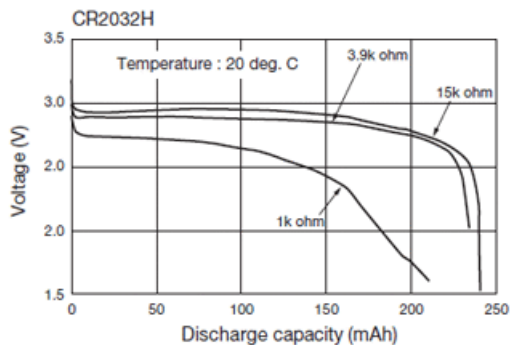
Power Capacity and Power Capability

Since this is a particularly confusing part of measuring batteries, I'm going to discuss it more in detail.

Power capacity is how much energy is stored in the battery. This power is often expressed in Watt-hours (the symbol **Wh**). A Watt-hour is the *voltage* (V) that the battery provides multiplied by how much *current* (Amps) the battery can provide for some amount of time (generally in hours). $\text{Voltage} * \text{Amps} * \text{hours} = \text{Wh}$. Since voltage is pretty much fixed for a battery type due to its internal chemistry (alkaline, lithium, lead acid, etc), often only the Amps*hour measurement is printed on the side, expressed in Ah or mAh (1000mAh = 1Ah). To get Wh, multiply the Ah by the nominal voltage. For example, lets say we have a 3V nominal battery with 1Amp-hour capacity, therefore it has 3 Wh of capacity. 1 Ah means that in theory we can draw 1 Amp of current for one hour, or 0.1A for 10 hours, or 0.01A (also known as 10 mA) for 100 hours.

However, the amount of current we can really draw (the power *capability*) from a battery is often limited. For example, a coin cell that is rated for 1 Ah can't actually provide 1 Amp of current for an hour, in fact it cant even provide 0.1 Amp without overextending itself. Its like saying a human has the capability to travel up to 30 miles: of course running 30 miles is a lot different than walking! Likewise, a 1Ah coin cell has no problem providing a 1mA for 1000 hours but if you try to draw 100mA from it, it'll last a lot less than 10 hours.

For example, in this image, a coin cell can drive a 3.9Kohm resistor and provide 230mAh (which is what its rated for) before dropping to 2V, but if its a 1Kohm resistor, it will only provide 125mAh (image from http://biz.maxell.com/en/product_primary/?pci=9&pn=pb0002 (<https://adafru.it/aYC>))



The way the power *capability* is measured is in C's. A C is the Amp-hour capacity divided by 1 hour. So the C of a 2Ah battery is 2A. The amount of current a battery 'likes' to have drawn from it is measured in C. The higher the C the more current you can draw from the battery without exhausting it prematurely. Lead acid batteries can have very high C values (10C or higher) , and lithium coin cells have very low ones (0.01C)

Lead Acid Batteries



Lead Acid batteries ([image above \(https://adafruit.it/aYD\)](https://adafruit.it/aYD)) are the workhorse batteries of industry. They are incredibly cheap, rechargeable, and easily available. Lead acid batteries are used in machinery, UPS's (uninterruptable power supply), robotics, and other systems where a lot of power is needed and weight is not as important. Lead acid batteries come in 2V cells, that means you can have a battery with an even number of volts. The most common voltages are 2V, 6V, 12V and 24V.

Pros: Cheap, powerful, easily rechargeable, high power output capability.

Cons: Very heavy, batteries tend to be very large bricks because power density is very low.

Prices: A 12V lead acid battery with 7Ah of charge should run about \$25.

Power Density: 7 Wh/kg.

Alkaline



Alkaline batteries are the most common batteries you will come across. They are the ones sold in every store, so they're great for projects that need to be 'user serviceable.' They have higher power density than NiCads and slightly better power density than NiMH. However, they are one-time use. Cells are 1.5V, and available in sizes from coin cells to AAAA to D cell. One nice thing about having multiple sizes with a standard voltage is that you can always just specify the next size up when you need more capacity and capability. You'll get the published capacity rate if they are discharged at about 0.1C.



6V lantern batteries (image above) are very large alkalines made of a couple large cells, they're rather convenient in that they're available in many stores, have massive capacity and capability and you can clip/solder onto their tabs pretty easily.

9V batteries are a strange case: they're actually made of 6 very small 1.5V batteries, pretty much the size of coin cells. As a result they have very low capacity and capability and are very expensive. If you are drawing more than 20mA then they are probably not a good idea to use.

Prices: AA size battery costs about \$1 and has up to 3000 mAh of charge capacity.

Power density: 100 Wh/kg

Pros: Popular, well known, safe, long shelf life

Cons: Non-rechargeable, low-capability

Ni-Cad Batteries (Nickel Cadmium)



These are the older rechargeables that were popular for a long time. They come in 'standard small' battery sizes like AA, AAA, C as well as rectangular shapes that make them easier to embed in an enclosure ([see image above \(https://adafruit.it/aYE\)](https://adafruit.it/aYE)). They are not used as much these days because NiMH batteries have much higher power density. However, they are cheaper and are still used in many cordless phones, solar lights and RC cars where performance is not as important as price. Another nice thing is they discharge slower than NiMHs. (That is, left alone, they will retain their charge longer.) Battery cells are 1.2V, often bundled in "packs" of 3 to make 3.6V.

Pros: Inexpensive, rugged, come in "standard" sizes, easy to recharge.

Cons: Lower power density, requires "full discharge/recharge" cycles every once in a while to reduce 'memory effect' (the growth of crystals on the battery plates), contains toxic metal.

Prices: AA size battery costs around \$1 and has up to 1000mAh of charge capacity.

Power Density: 60 Wh/kg

Ni-MH Batteries (Nickel Metal Hydride)



These are more popular rechargables, they also come in 'standard' sizes. These are a good replacement for standard alkaline batteries in many cases. The battery cell voltage is 1.25V per cell, that's less than the 1.5V of alkalines but more than the 1.2V of NiCads. The most annoying thing about them is their high self-discharge although battery technology has improved and there are a few low-self-discharge batteries on the market. They like to be charged at about 0.1C but can be discharged at 0.2C

Pros: Good alternative to Alkalines in most situations, high power density, "standard" size, better capability than alkalines, pretty easy to recharge but not as rugged.

Cons: More expensive than Ni-Cads, service life isn't as long, self-discharges quickly.

Prices: AA size battery costs around \$2 and has up to 2500mAh of charge capacity.

Power Density: 100 Wh/kg

Li-Ion (Lithium-Ion) and LiPoly (Lithium Polymer)

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These are the latest in rechargeable battery technology, and are quickly becoming the most common batteries for consumer electronics like camcorders, cell phones, laptops etc. They are very lightweight, don't mind high discharge rates, and have very high power density. However, they are very delicate and require special circuitry to keep them from exploding! This means that raw Lilon cells are very rare and very dangerous. Most li-ion batteries come with protection circuitry that keeps the battery operating safely. If you want to use Lillons, your best bet is to use camcorder or cell phone batteries and use the charger that matches up with it. Lilon cels are around 3.6V so 3.6V and 7.2V are the most common battery voltages you'll see. They can easily provide up to 1C of current, some can go up to 10C!

Pros: Ultra-light, high power, high capability, high cell voltage.

Cons: Expensive, delicate, can explode if misused!

Prices: replacement "cell phone" batteries cost around \$10 and have ~750mAh charge capacity.

Power Density: 126 Wh/kg for lithium ion, 185 Wh/kg for lithium polymer

Lithium Batteries & Coin Cells



Most of the lithium batteries you'll see are in coin/button cell form. Coin cells are small discs ([see above \(https://adafru.it/aYF\)](https://adafru.it/aYF)), often Lithium cells are used (3V) but Alkaline, zinc air, and manganese are also used (1.5V).

They are very small and very light, great for small, low-power devices. They're also fairly safe, have a long shelf life and fairly inexpensive per unit. However, they are not rechargeable and have high internal resistance (which is what makes them fairly safe if there's only one or two in use) so they can't provide a lot of continuous current: 0.005C is about as high as you can go before the capacity is seriously degraded. However, they can provide higher current as long as its 'pulsed' (usually about 10% rate).

One of the most popular coin cells in use right now is the CR2032 which is 20mm diameter x 3.2mm thick, provides 220mAh at 3V. Lithium coin cells can get as large as the CR2477 (24mm x 8mm) with a capacity of 1000mAh for \$3.50

The only other lithium cell you'll see around is the CR123, which is a 3V cell thats a bit thicker than a AA battery and a bit shorter too.

Pros: Light, high-density, small, inexpensive, high cell voltage, easy to stack for higher voltages, long shelf-life.

Cons: Non-reusable, low current draw capability, needs a special holder.

Prices: CR2032 are around \$0.35 (220mAh) CR123's are \$1.50 (1300Ah).

Power density: 270 Wh/kg

How to Pick the Right Battery For Your Project

OK, so you have a project and now you want to power it off of a battery, how do you choose the best setup?

The two easiest cases are the extremes:

- **Is your project very power-hungry?** Projectors, large sound systems, and motorized projects all draw on the order of amps of current! You'll want to go with lantern cells (one-time use) or lead acid batteries (rechargeable). If you are planning to be somewhat 'abusive' to the battery (heavy-usage, running it down all the way) you may want to look at "marine deep cycle" batteries.
- **Is your project super-small, like an inch on each side?** You're going to have to go with a lithium coin cell (one time use) or little lithium-polymer cells like the ones used for tiny RC planes.

Here are some other very popular cases:

- **Do you need to make a lot of these things?** Go with inexpensive alkaline batteries in popular sizes.
- **Need to be user-servicable?** 9V or AA size batteries are universal!
- **~5V input necessary?** 3 Alkaline (4.5V) or 4 NiMH cells (4.8V) will get you pretty close - check your circuit to see if it'll run at these slightly lower voltages
- **Making a 'rechargeable battery pack'?** Use a battery holder from your local hobby/electronics/repair shop and stick with NiMH batteries, then recharge them with a high quality charger.
- **Want to replace alkalines with rechargeables?** Test to make sure that the lower voltage won't make the device unhappy.
- **Need to stack batteries?** Remember to stack batteries only if they have matching C and Ah capability, if you stack a 9V and a AA to make 10.5V the 9V will drain in 1/10th the time leaving you with 1.5V.
- **Want your rechargeable batteries to last a long time?** Use a high-quality charger that has sensors to maintain proper charging and trickle charging. A cheap charger will kill off your cells.