Let's Put LEDs in Things!

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https://learn.adafruit.com/lets-put-leds-in-things

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Introduction

Gotta love cosplayers. That mix of fanatical passion and hand-craftedness. These are makers. These are my people.

Walking around fannish events and conventions, the variety of costume- and prop-making techniques is astounding: sewing, leatherwork, casting, chain mail, makeup, foam sculpting, thermoplastic armor, to name a few. But I'm surprised electronics isn't more prevalent…a simple thing can add so much punch!

Remember those little red LEDs on Deckard's pistol in Blade Runner, how that one detail upped the badass factor tenfold? Or the glowing eyes in the photo above… fantastic costuming to begin with, but the luminous elements put it over the top.

We're seeing more of this in cosplay (https://adafru.it/b128897), but it's still relatively scarce. Is it too heady? "It's engineer stuff and must be hard!" Nonsense. Patterning trousers is hard. LEDs are a piece of cake!

We'll start simple and work up. You can step off the bus at whatever level suits your interest.

No-Brainer Method

Some folks think I'm joking, but no: if you can find a "dollar store" item with the effect you're after, use it! LED tea lights, kids toys like zap guns and magic wands, those battery-operated Christmas light strings by the checkout line...pop in a battery, flick a switch and it's done. The challenge then is disguising the item to hide its obvious toy store origin.

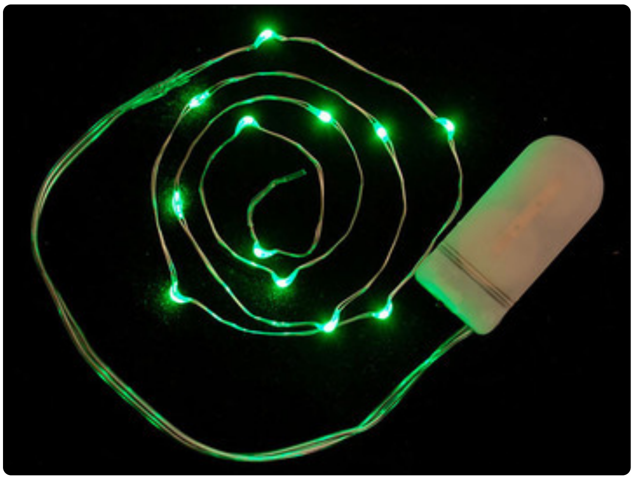
Important points to keep in mind:

- If you dismantle a toy to work it into your design, never defeat safety measures like interlocks (e.g. shutting off automatically when a hatch is opened) or covers (like the zap gun above...the spinning LEDs are inside a clear capsule, no pinched fingers or tangled hair!). Also be mindful of metal parts inside both the toy and your prop; there's a potential for electrical shorts.
- Even "flexible" items, like a string of LED lights, don't take well to repeated bending and will eventually fail. This is the downfall of every would-be TRON cosplayer! Steer clear of elbow and knee joints.

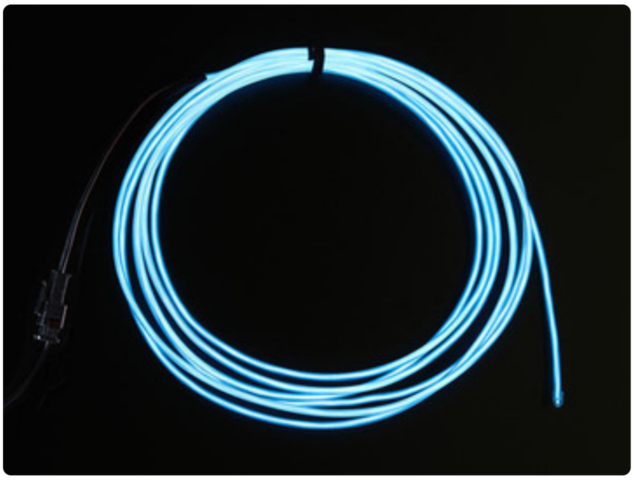
We sell a few such ready-to-go items:

These Litex white LED ribbons (https://adafru.it/dV7) can be sewn or glued into garments and props. A tiny button cell provides power, and several modes (on, fade, blink) are selectable.

Project: LED Ribbon Shoes **(https://adafru.it/CdG)**



These 12-LED strands are similar, with wires instead of ribbon, no modes (just an on/off switch) and come in several colors: cool white (http://adafru.it/894), warm white (http://adafru.it/893), red (http://adafru.it/897), green (http://adafru.it/896) and blue (http://adafru.it/895).



Very different from
LEDs, electroluminescent (EL) wire is amazing stuff, and pretty easy to use if you stay with the 2.5 meter length of the starter packs (http://adafru.it/320). Trimming, extending or splitting EL wire requires advanced techniques best left to other tutorials (https://adafru.it/CdH).

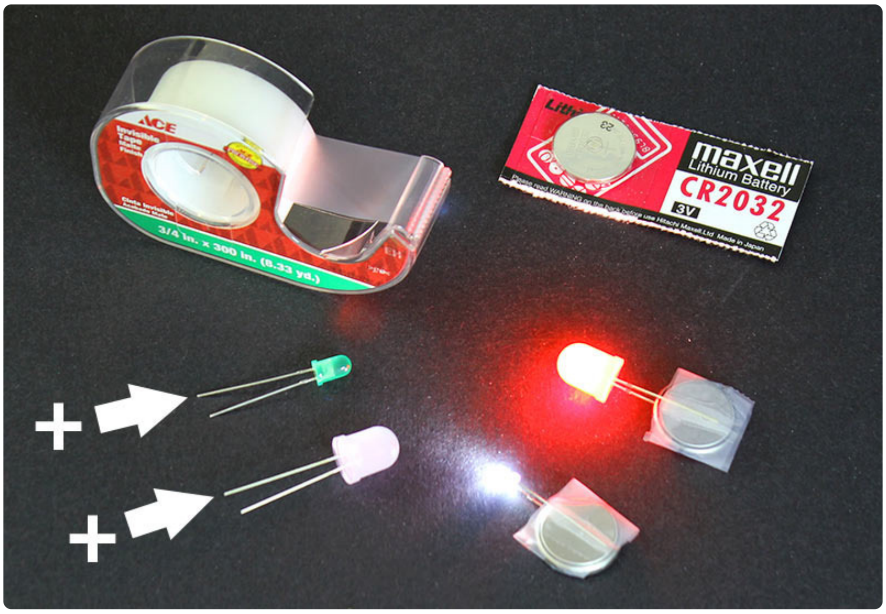
Project: EL Wire Animal Masks **(https://adafru.it/CdI)**

The same rule about frequent bending applies to these. Minimize movement or they'll soon break.

Another easy method uses a coin cell battery (http://adafru.it/654), a single LED and some tape. Sometimes called "LED throwies" because people used to add a magnet

and toss them at metal bridges (please don't do this…it's littering, and e-waste materials don't belong in landfills or the street).

LED is short for light-emitting diode. **A diode is a one-way valve for electricity.** Just like a battery has a + and – side, diodes also have polarity — they go a certain way. Look at the legs of an LED and you'll see one is **longer**: that's the + side. Connect this to the + side of the coin cell, and the shorter leg to the – side, wrap with some tape and you're done. It'll run for a day or so, gradually getting dimmer.



Most two-legged LED varieties (https://adafru.it/dLA) (except for infrared) should work this way. Some even have special color flashing (http://adafru.it/680) or fading (http://adafru.it/679) modes.

This fantasy armor has glowing jewels using this technique…each backed with a single LED and coin cell battery.

This works for small numbers of LEDs at one-time appearances like a Halloween party, but is **not recommended for frequent use.** The connections aren't durable and the batteries don't last as long as other types…there's the potential for a lot of waste. **Spent batteries need to be properly disposed of with other e-waste.**

Serious Engineers™ may scoff at such approaches, that you're not doing real electronics. Technically they may be right, but we're not all looking to go pro. And for crying out loud, we're grown adults playing dress-up! How serious can you be?

That said, if you're ready to step your game up, I'd be happy to oblige…

A Basic Recipe

Let's look at a simple electronic "LED recipe" without a lot of theory. Later we'll show the "why," working from scratch to expand one's repertoire.

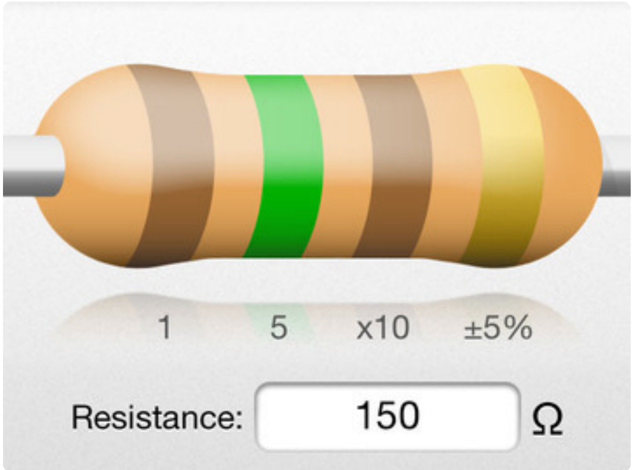
Start with one of these 3-cell battery holders with switch: AAA will usually suffice (http://adafru.it/727)...but if you have a lot of LEDs or want extended run time, AA provides about three times the capacity (http://adafru.it/771). The switch is handy, one less part to add ourselves.

Our recipe **requires 3 cells.** Do not start out with a 4-cell (or larger) pack!

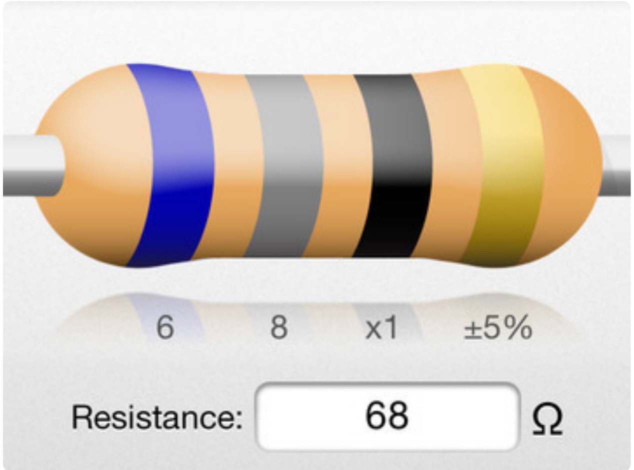
We'll use common alkaline (single-use) batteries (http://adafru.it/617). There are "better" batteries, but for cosplay stuff I really like alkalines...traveling to conventions afar, you can get spares anywhere, just visit the nearest drugstore or the hotel's traveler shop.

This battery pack is much bigger than the coin cell in the LED throwie, so **never connect the LED directly**. That's like drinking from a firehose...the LED will quickly burn out, even pop! **Adding a resistor pinches off some of the electrical current** to keep things in check.

The resistor must be matched to the LED type and battery. Resistance, measured in Ohms (Ω), is marked with colored stripes. (Way back when, there was no way to print tiny numbers on them, and this system stuck around.)



For **red, orange, yellow** and older **green LEDs**: use a **150 Ohm** resistor. Not 150K, just **150**. The colored bands will be brown, green brown and gold.

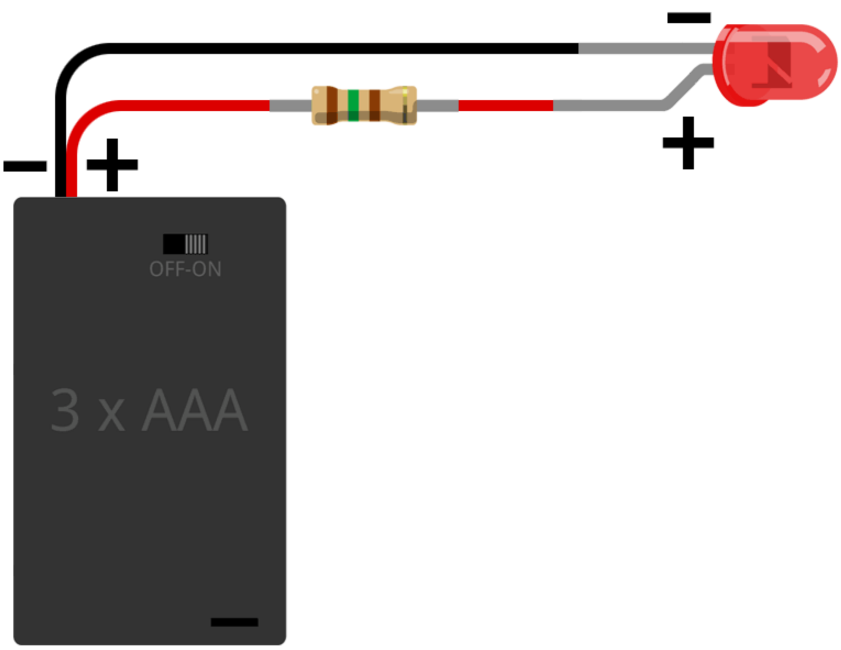


For **blue, white, ultraviolet** and newer **“true green” LEDs**: use a **68 Ohm** resistor (blue, gray, black, gold).

Adafruit doesn’t sell these resistors. They can be found at Radio Shack (if they still exist when you’re reading this), or places like Fry’s or Micro Center if you have one locally. Otherwise, search online.

If you can’t locate these exact values, that’s okay! Use the next available size up. The LED will be slightly dimmer, but still totally usable. 1/4 Watt reistors are ideal, but 1/2 Watt is fine too.

The goal then is to create a circuit - a loop linking the battery, led and resistor in series (one following the other around the loop):

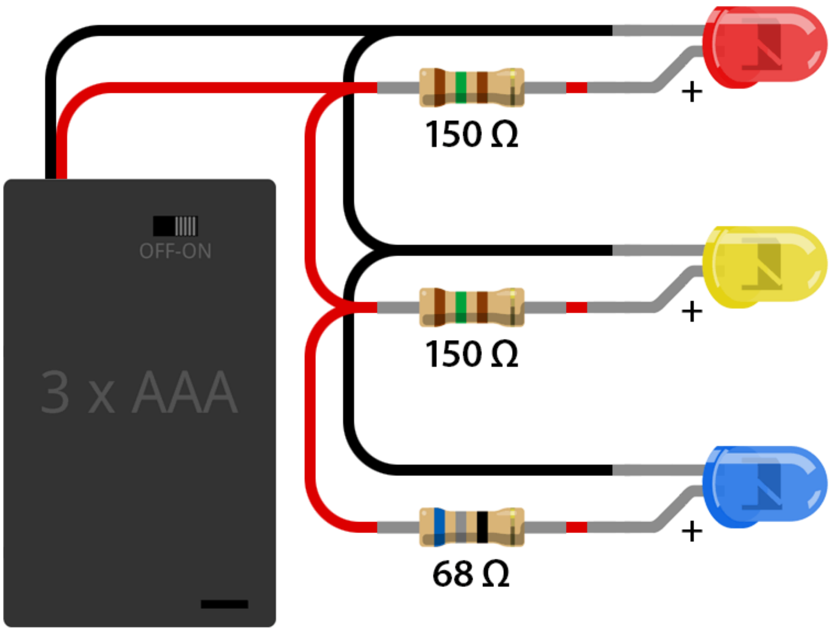


Recall from the throwie discussion that **LEDs have polarity**; the “+” (longer) leg goes to + on the battery pack.

Resistors don’t have polarity. It’s shown on the + wire, but they’re not picky and can go on either side of the LED, + or –. It can be inserted anywhere along that wire, but usually easiest to install close to the LED (or even joined directly).

The wires can be as long as needed…even several feet, say if battery and lights are at opposite ends of a staff. There’s a convention of using **red** wire for + and **black** for –, but this is totally for human convenience and doesn’t affect the circuit (a very common misconception, so don’t feel silly for asking). If you only have one color of wire (or want to use all black because it hides well), that’s fine, just keep track of your connections.

For multiple LEDs (such as glowing eyes), connect + and – to each one, with a **separate resistor for each LED.** You can mix and match LED colors in the same circuit, just make sure each has the correct value of resistor (e.g. red and blue will be different).



That's the basic idea. Now…how to build it?

Tools & Supplies

Soldering is a foundational skill for electronics. Trying to get by without it is like trying to make costumes without sewing. Possible, but limiting, and more frustrating than simply acquiring the tools and skills needed.

Tool up right. “Cold heat” soldering irons are terrible and can actually damage electronics! Avoid $5 disposable crap from that big discount importer. And graddad's hand-me-down 100 Watt soldering gun won’t do...it’s a bazooka by modern standards.

You can pick up a good hobbyist **soldering iron** for under $25 (http://adafru.it/180). Around $100 and up are professional tools that will last a lifetime (http://adafru.it/1204).

If your iron doesn’t come with a proper stand (http://adafru.it/150), **get one! I** cannot emphasize this enough. Just a few bucks, you’ll stop burning your fingers and melting other things on your desk.

A wire stripper/cutter (http://adafru.it/147) trims insulation away to reveal the conductive wire inside.

Use this. Never ever use your teeth!

Optionally, flush cutters (http://adafru.it/152) provide a cleaner cut for wires, and are the perfect tool for shortening the legs of LEDs and resistors.

Use tools for their intended task. The iron is for soldering, never melting holes in things. Some people keep an old “beater” iron around for dirty jobs.

There are additional tools that may be helpful, but aren’t absolutely essential. We’ll stop here so as not to overwhelm. In the future, you might add others as you need them.

Next, there’s the consumables of any project:

Solder is the glue of electronics, a blend of metals with a relatively low melting point. Get the **rosin core 60/40 type** (http://adafru.it/145). Rosin is a flux, cleaning the underlying surface to help molten solder flow smoothly onto wires. 60/40 means it's 40% lead…much easier to work with than lead-free solder. Not to worry…wash hands afterward, store it away from kids, everything's good.

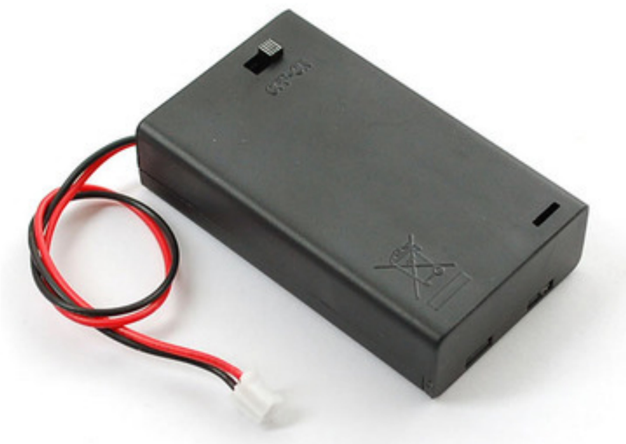
Some places only have the lead-free kind now. We'll cope, just be aware it's like learning to drive a stick.

Wire is the scaffolding, joining components of the circuit. There are a zillion kinds…a useful all-around type is **solid-core 22 gauge insulated wire.** Different colors (black (http://adafru.it/290), red (http://adafru.it/288), yellow (http://adafru.it/289), assortment (http://adafru.it/1311)) help organize a circuit; they don't change the wire's properties. Gauge (or AWG) is the thickness…higher number = thinner wire.

Solid-core wire is stiff and springy. For wearable projects that need to move, I much prefer **stranded wire**…it flexes better. We don't stock this type on spools. Like resistors, you'd need to seek it elsewhere.

[Heat-shrink tubing (http://adafru.it/1649)](http://adafru.it/1649) insulates connections to prevent a short circuit (unwanted contact).

Electrical tape is a poor choice. It's seldom permanent and leaves a sticky gross residue.



From the "Recipe" page: add some **LEDs**, suitable **resistors** (68 or 150 Ohm) and a **battery holder**.

[Most of the two-legged "gumdrop" style LEDs here will work (https://adafru.it/dLA)](https://adafru.it/dLA) (except infrared).

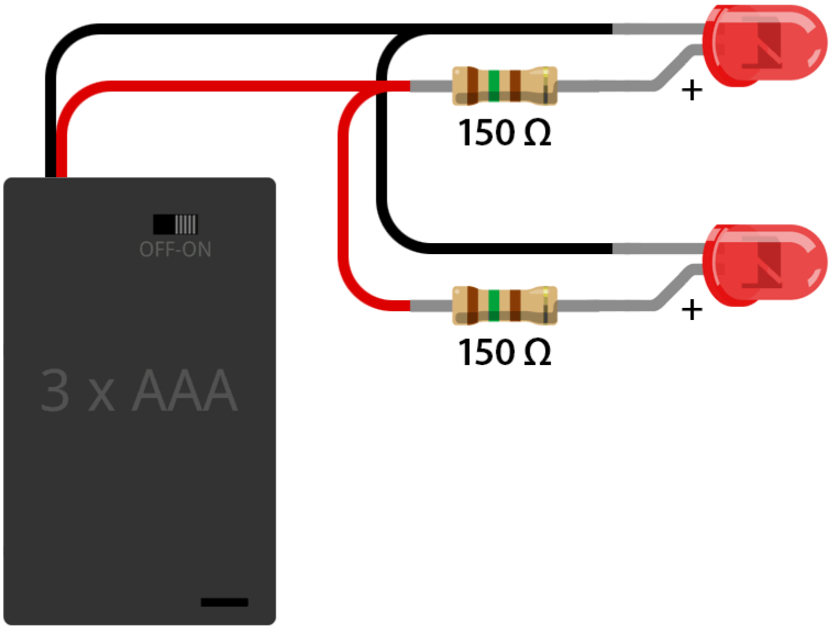
Have some spares. Mistakes happen!

Now let's get **soldering!**

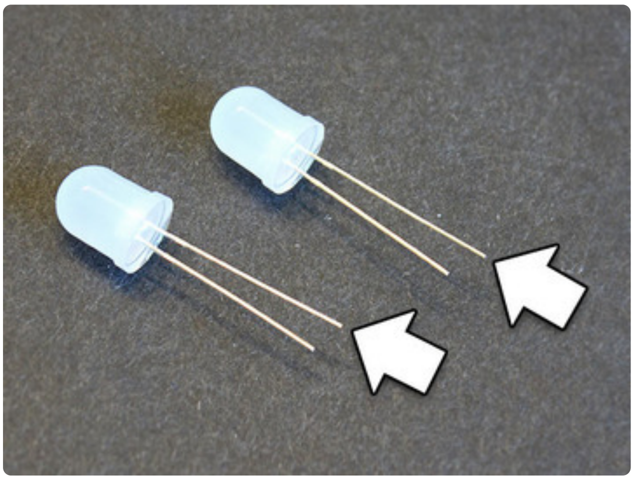
Soldering 101

Proper soldering technique is actually quite easy, but many folks just don't get a good explanation or a shoulder to watch over. **It's this construction phase, not the electronics theory, that's the biggest barrier for newcomers.** Their project falls apart, they're discouraged and quit.

Using the recipe and materials previously shown, we'll demonstrate how to best construct a set of battery-powered glowing eyes — two LEDs — suitable for a Halloween jack-o'-lantern or a mask.

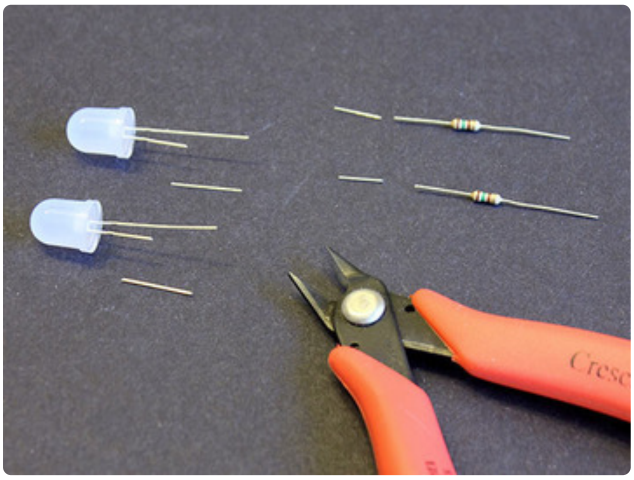


Plug in and switch on your soldering iron, it **needs a few minutes to fully heat up.** While waiting, gather your parts: battery pack, wire, resistors, LEDs and heat-shrink tubing (you'll also need a lighter, matches or heat gun for the tubing). If you have the kind of iron stand with a sponge, take a moment to **wet and wring it out** (in a bathroom or utility sink — don't do this over a kitchen sink full of dishes).

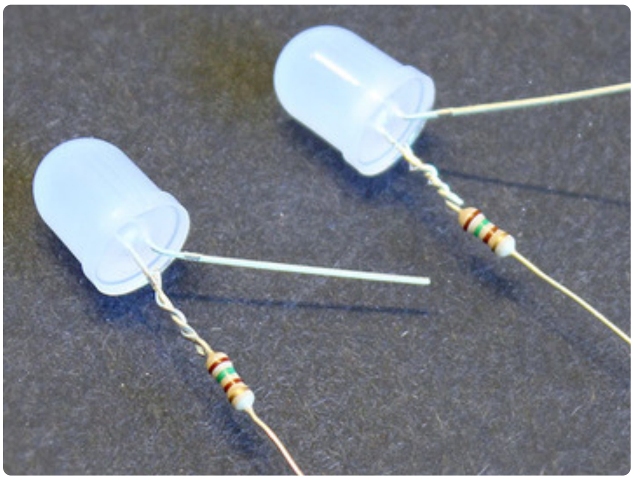


Identify the "+" leg on both LEDs. It's the longer one.

I’m using **red LEDs**, hence the **150 Ohm** resistor value from the **Recipe** page (other colors might need different resistors). Luckily I had some 150 Ohm resistors in my parts collection. If not, I’d just step up a slightly higher value…180 or 220 Ohm…close enough, it’ll still work if that’s all you can find.



Clip the “+” leg down to about 1/2 inch long, on both LEDs. Do the same on the resistors, clipping one end to the same length. Resistors don’t have a + or – side, either end will do.

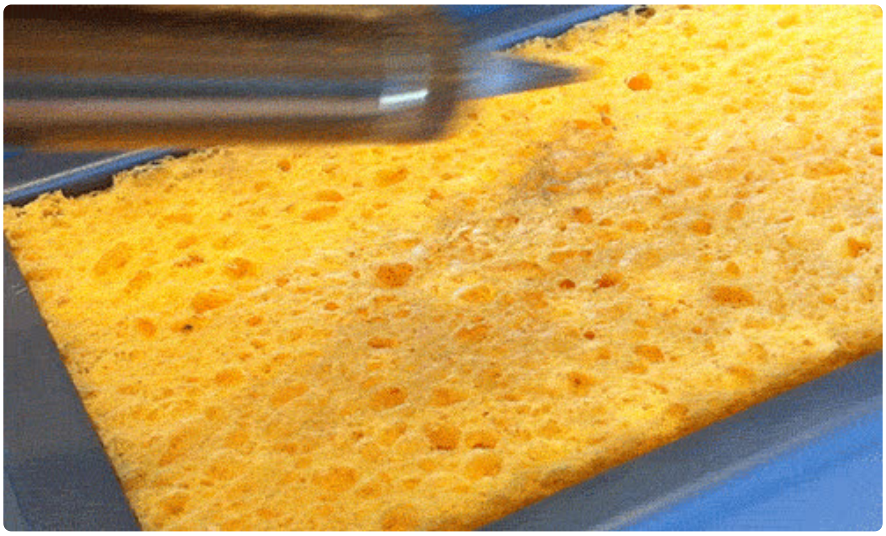


Twist the clipped leg of the LED and resistor around each other. Needlenose pliers can help.

The iron is probably ready by now.

Wipe both sides of the tip against the damp sponge to clean off any old sooty residue. Or if you have the brass “Brillo Pad” style sponge, just stab it with the iron a couple times.

Add just a **small amount** of solder to the tip of the iron…



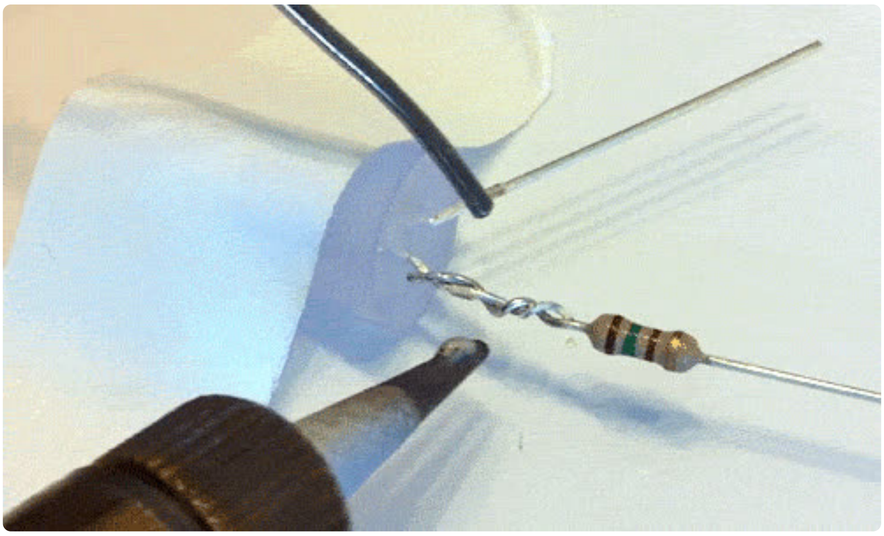
...this is called **tinning** the iron.

The #1 Novice Soldering Mistake

That dab of solder on the tip is **not for joining parts.** It helps with **heat transfer.** Same principle as licking your finger to test the wind (don't try this right now, you've been handling solder).

The idea is to **transfer heat to the parts**, then apply more solder to make the connection.

Touch the "tinned" iron to one side of the connection and wait about a second. After heating, you can then add more solder from the other side, waiting another second for it to spread out. **Don't** melt solder on the tip and then wipe it on the parts... that makes a really poor connection!



Notice how the molten solder flows all throughout the connection via capillary action. No blobs, it's smooth and shiny. **That's a good solder joint.**

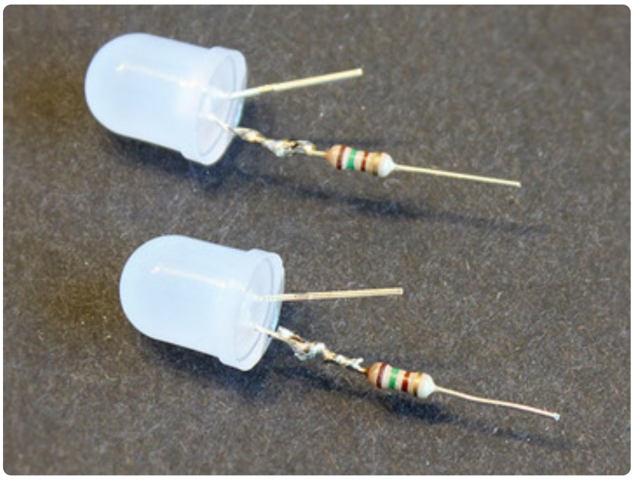
Don't blow. Let the solder cool at its own pace. Blowing makes it brittle.

This is the essence of a strong bond. Don't just tack the parts together; solder alone isn't good for load-bearing. Twisting + solder makes the toughest connections...NASA requires it! (https://adafru.it/dW4) **Costumes are hard on electronics**...pulling, flexing, perspiration, cleaning. This is why we go to these extra lengths.

"BUT...OMG...LEAD FUMES!"

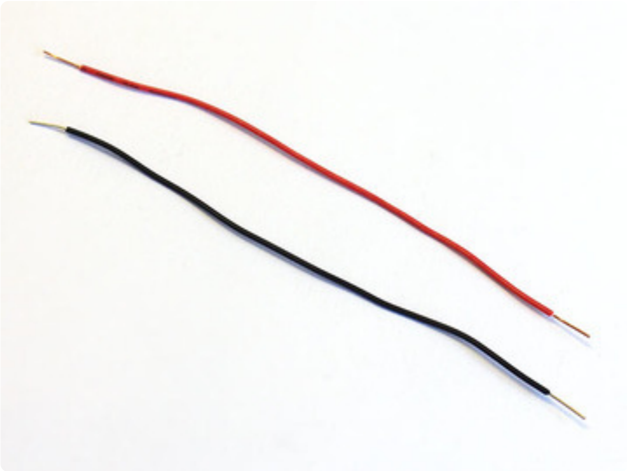
> **Solder smoke does not contain "lead fumes."** Lead boils at thousands of degrees, many times hotter than our soldering iron. The fumes are the flux boiling off...tree sap, basically. Still, that's no reason to breathe it...smoke is smelly and irritating. If you start doing lots more soldering, invest in a desktop fume extractor, a small filter fan that pulls away the smoke. For infrequent soldering, just keeping your face away from the smoke is usually sufficient.

As you pull the iron away, a little solder comes with it. This provides tinning for the next connection, and so forth. Every few connections, or once a minute or so, **clean the tip on the sponge and re-tin it.** Otherwise the flux all boils away, the solder gets gummy and doesn't flow well.

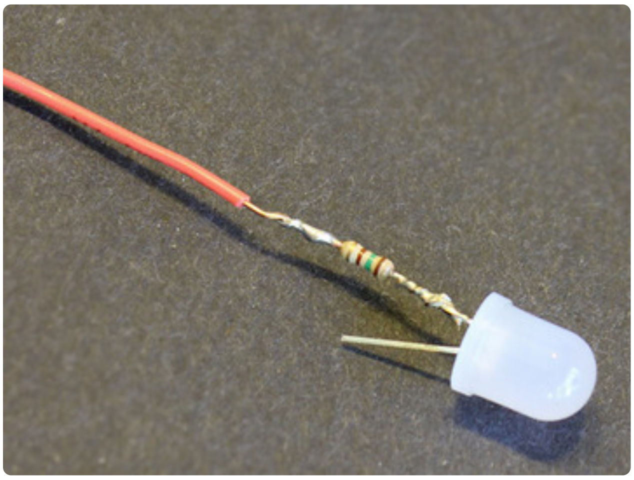


Repeat the soldering for the second LED.

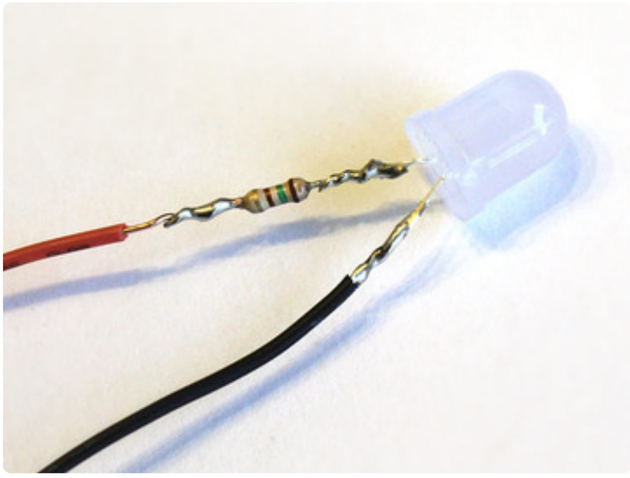
After soldering and cooling off, trim the other leg of the resistors and the LEDs to about 1/2 inch.



Cut two wires about 6 inches long…use different colors if you have them. Strip about 1/2" of insulation from both ends.



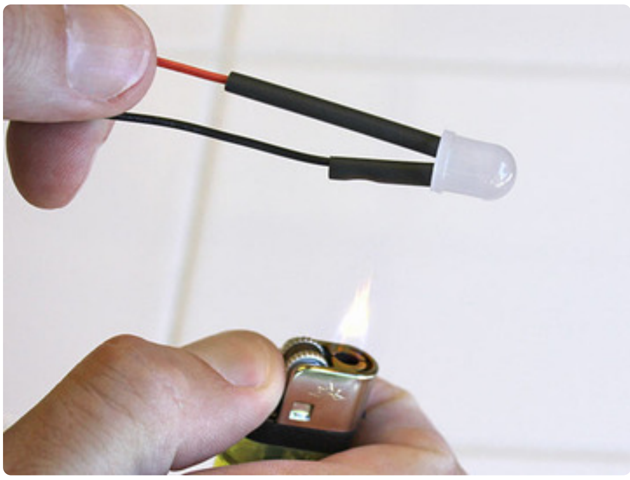
Take one of the wires (red, if you’re color-coding) and do the same twist-and-solder procedure to the free end of the resistor.



Then repeat with the other wire on the other leg.

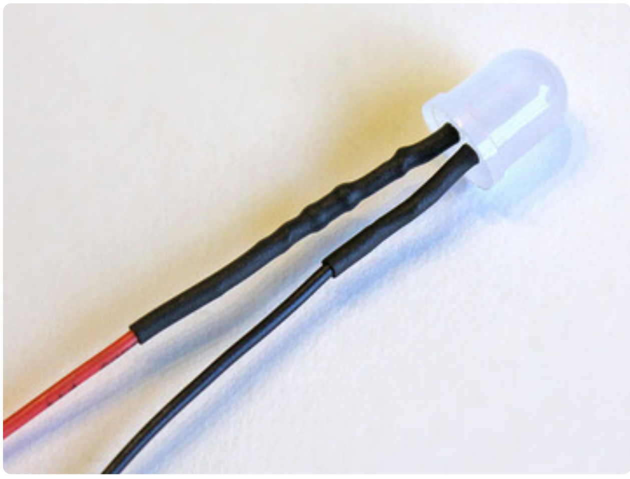
Do this with just **one** of the LEDs.

Cut a couple pieces of heat-shrink tubing, a bit longer than the exposed wiring parts.

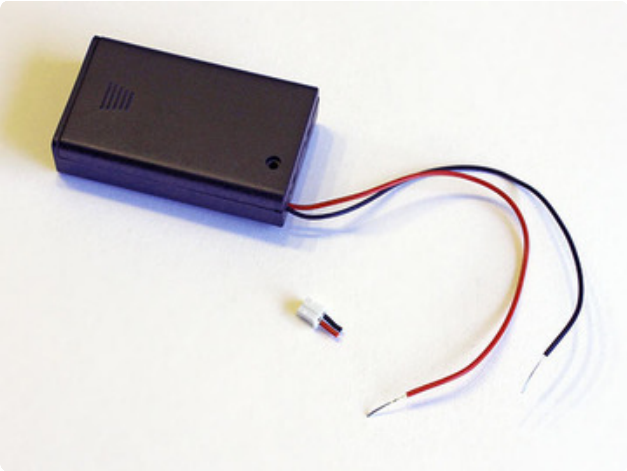


Slide these down the wires, butting them right up against the LED.

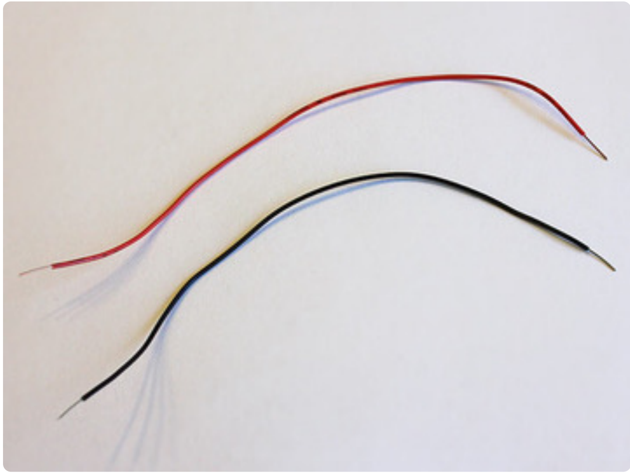
Heat with a match or lighter (or heat gun if you have one), turning the parts over to get all sides. Done right, the tubing will hug the wires.



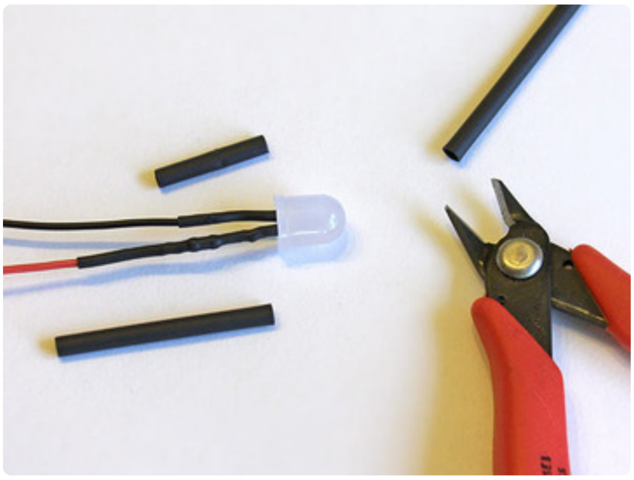
A very common novice mistake is holding the flame too close, charring the plastic. You just want to catch the heat rising off the flame.

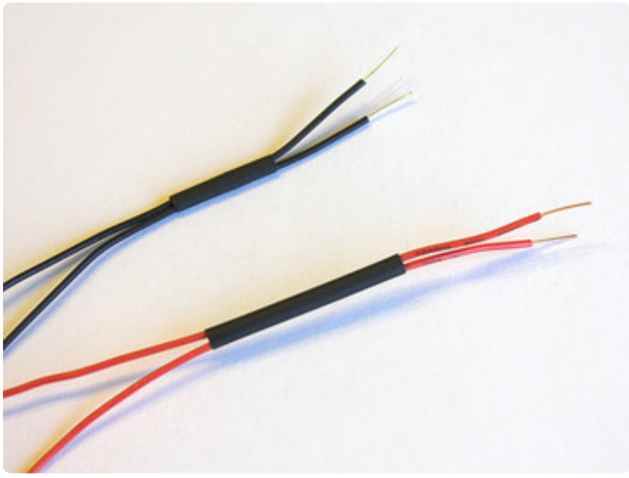


Cut two more pieces of wire, about 12 inches long this time, and strip both ends.



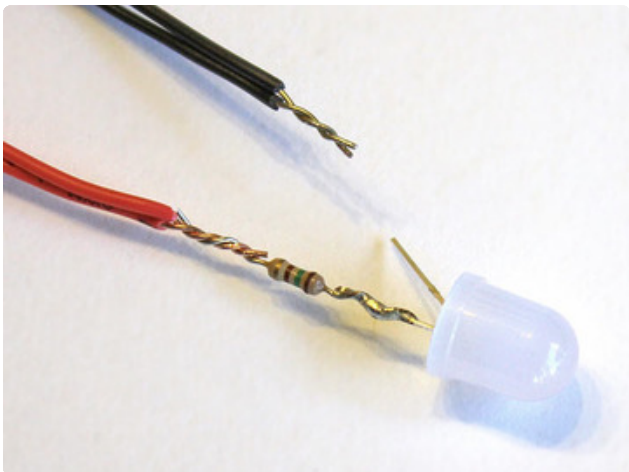
Clip the connector off the battery pack (if it has one) and strip about 1/2 inch of insulation from the wires. These will usually be stranded wire...twist it a bit to keep it from fraying.





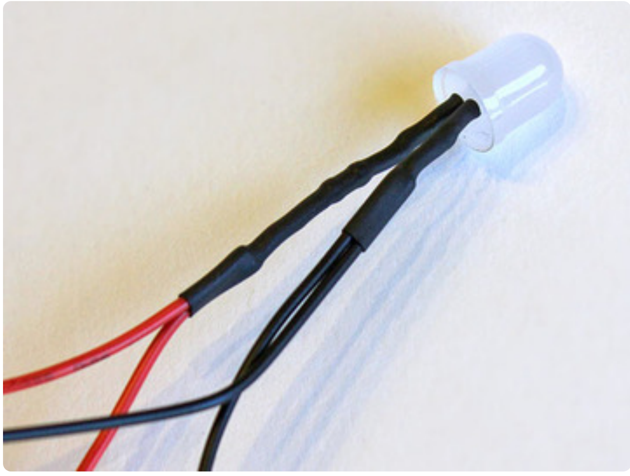
Using the first LED for reference, cut two more pieces of heat-shrink tubing to the same lengths as before.

Now pair up the wires from the first LED side-by-side with the newly-cut ones, and slide the heat-shrink over these (the longer piece goes on the wire with the resistor). This time the heat-shrink goes over the wires before soldering. Push it down a ways, so it’s not too close to the stripped wire ends.



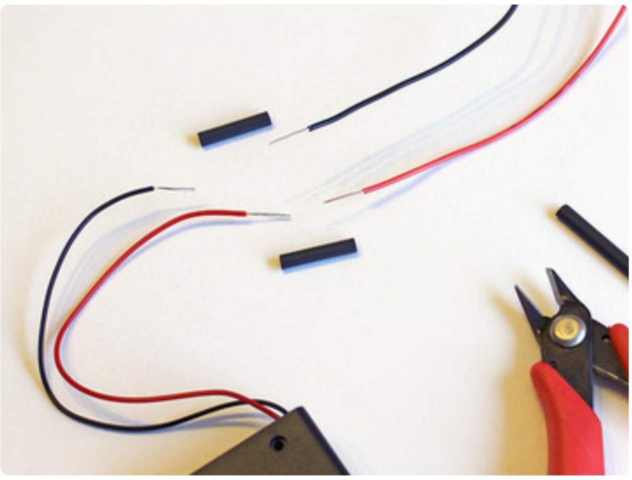
Twist the wire pairs together, twist these pairs to the corresponding legs of the LED, then solder the connections (clean and re-tin your solder tip first, it’s been a minute).

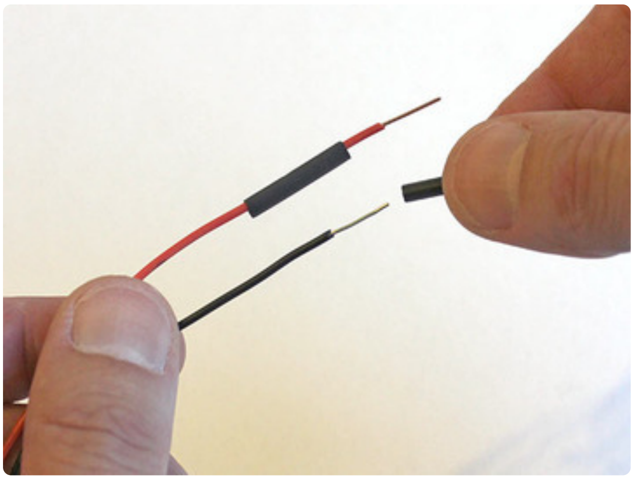
These three-way inline splices are tricky. If you can master this, electronics is your oyster.



After both connections are soldered and cooled, slide the heat-shrink tubes to butt against the LED, and apply heat as before.

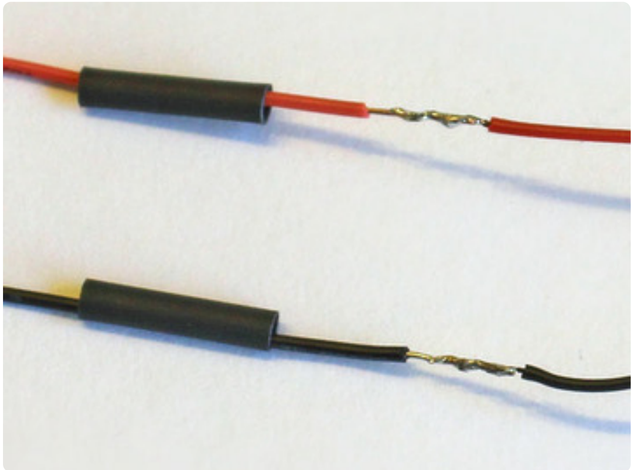
Another common heat-shrink error is forgetting to put the tube on the wire before soldering. I've been soldering since dinosaurs roamed the Earth and still make this mistake.



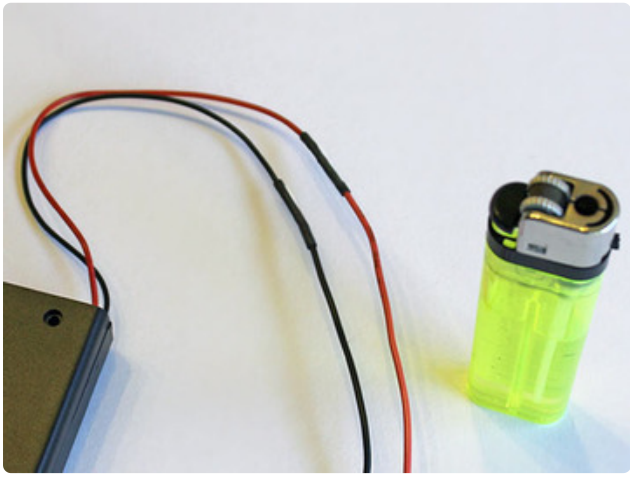


Cut a couple more pieces of heat-shrink tubing, about 3/4" to 1" long. Slide these over one pair of wires (either the battery pack wires or the wires leading to the LEDs).

Twist the wires, solder the connections, and shrink the tubing as before.

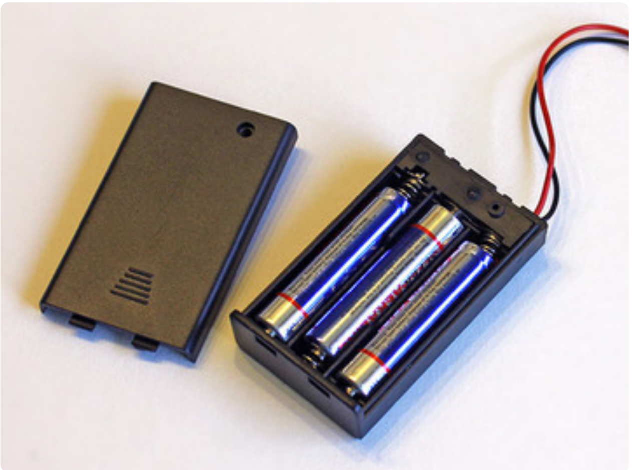


One more heat shrink tip: keep the un-shrunk tube away from the connections while soldering; the hot wires will shrink the tubes prematurely. This stuff is just fraught with peril, isn't it? But it's so much nicer than electrical tape!



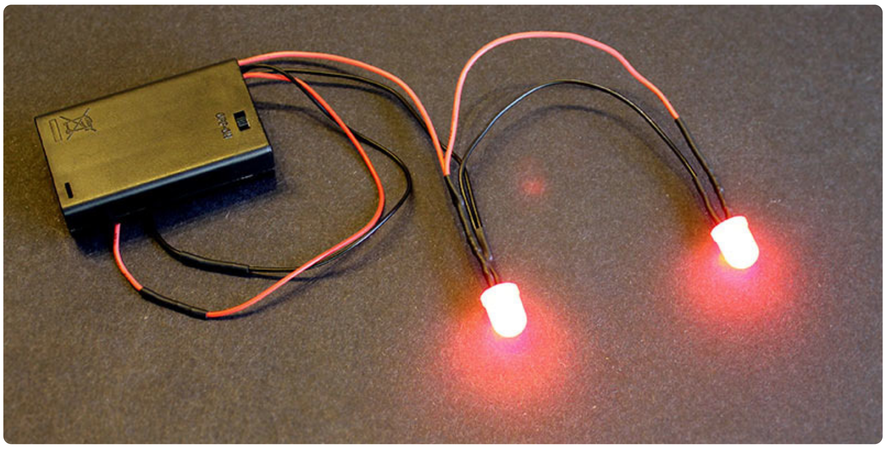
Notice most of our connections (except the 3-way) are inline splices…the wires join in a straight line.

A pigtail splice, wires side-by-side, isn't recommended for wearable projects…it's weaker if wires get pulled. Pigtails work fine for house wiring because nothing moves.



Pop in some batteries, close the lid, flick the switch…

Et voila! Lights!



If everything works, you can switch off the iron, put away your tools and solder and go wash your hands.

Troubleshooting

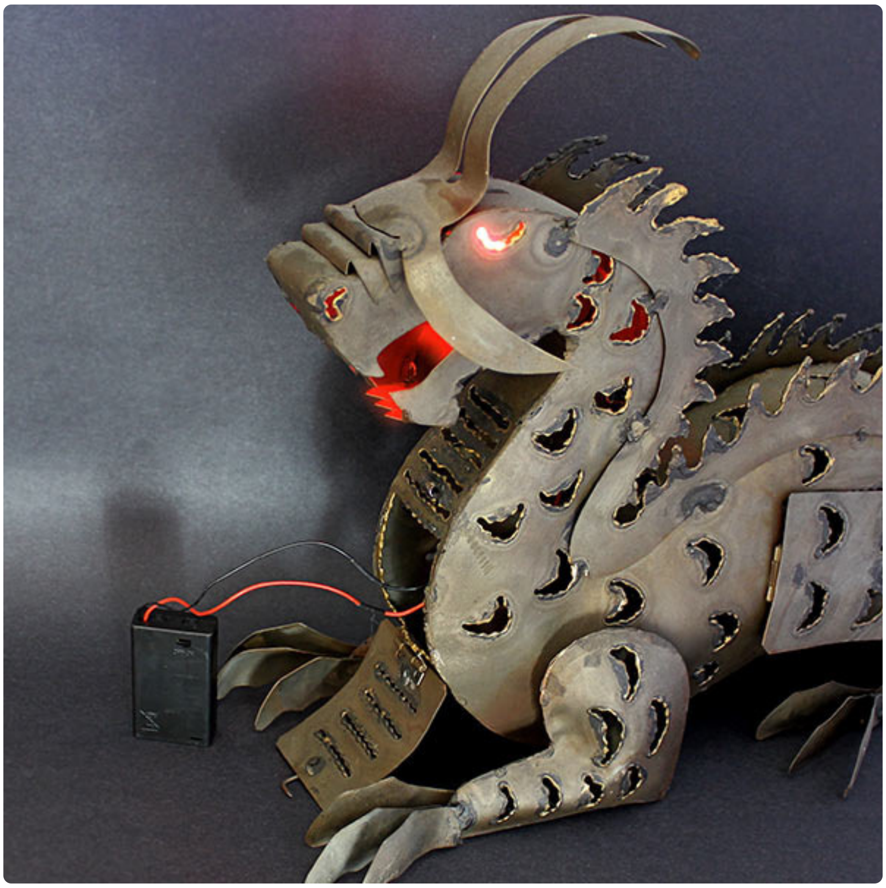
If nothing lights up, check the most obvious: are the batteries installed the correct way in the holder? Are the batteries fresh? Do they work in another device?

If your solder didn't flow well into connections, this is a cold solder joint. Try wiggling the wires. If the LEDs flicker, that's probably a cold joint. Clip it off and try again. This is why having a few spare parts is a good idea.

Keep in mind that LEDs are "one way" — a specific side must connect to + vs –. If only one LED is lighting, the other might be backwards. Try clipping the wires, swap and re-solder them. If neither lights, both might be reversed, in which case you'd swap the wires from the battery pack.

Occasionally an LED is damaged by heat from soldering. This can happen if you linger too long. Solder connections should be made quickly.

If nothing seems to work right, sometimes test-building with alligator clips (http://adafru.it/1008) first can be insightful.



I put mine inside this metal dragon. When installing the LED eyes somewhere, be careful not to bend too sharply close to the LEDs, or you'll break off the legs.

With a fresh set of AAA batteries, this is probably good for at least a full 24 hours (probably a whole year's worth of convention outings), or a bit shorter as additional LEDs are added. AA batteries have about three times the capacity, but are somewhat larger and heavier, making them less comfortable for wearable projects.

The Adafruit Guide to Excellent Soldering (https://adafru.it/dxy) discusses soldering tools and techniques in greater detail, while Collin's Lab (https://adafru.it/dyT) shows video of these methods in action. Both show circuit board soldering (rather than wire-to-wire as we're doing here), but the essential concepts still apply.

Sewable Circuits

Sewable electronics? Yes, this is a thing! If you have more experience with needlework than with hand tools, it might be just the trick for certain situations.

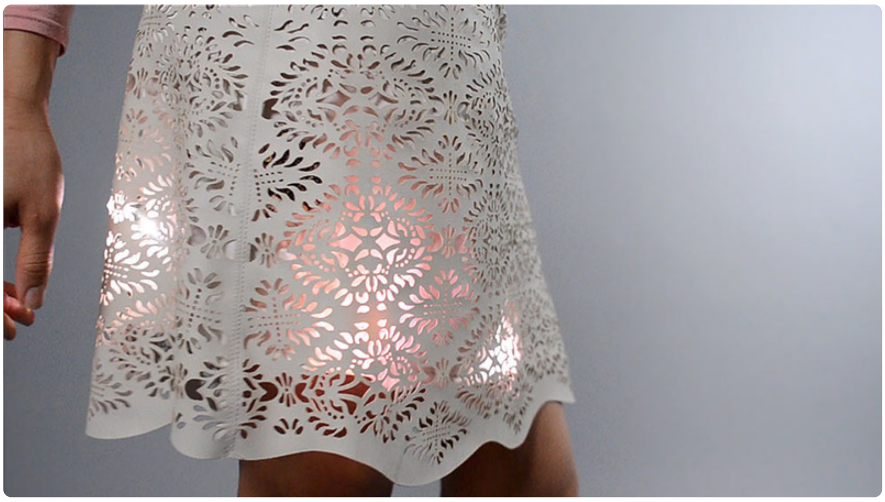
These "soft circuits" rely on a **special conductive thread** (http://adafru.it/640). Ladyada scoured the planet in search of the perfect kind of stainless steel.

Sewable LED Sequins (https://adafru.it/dVe) already have a resistor built in…they can stitch to a battery holder (http://adafru.it/653). Just don't cross the tracks, and you're golden.

The metallic thread isn't insulated, so this is best for outerwear, not against the skin. The cool part is…with the battery removed, these garments can safely be washed (https://adafru.it/tfM).

Conceptually, these circuits are identical to their wire-and-solder counterparts, observing the same principles of polarity and resistance and such. Only the materials, methods and sometimes scale are different.

There's a lot more than just LEDs, too. Sewn circuits are a whole medium in itself. This guide will lead you down the rabbit hole. **(https://adafru.it/dn3)**



Circuits From Scratch

Up to this point, we've focused on the mechanics of electronics — wiring and soldering — skirting around the theory by following some shortcuts and recipes. It's sufficient for many folks' needs.

Learning the underlying principles creates opportunities for using other battery types (including rechargeables) and achieving longer run times. Or maybe you're just curious! There's some reading, new terms and a little bit of math involved, but nothing onerous.

Science!

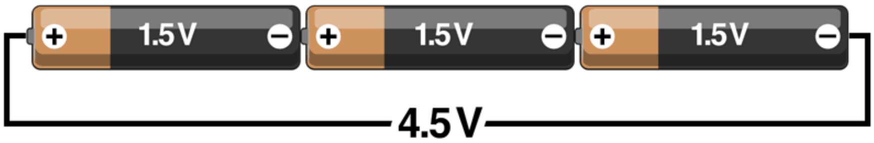
Electricity is the transfer of electrons — negatively charged particles in every atom. It's an invisible force of nature, but we can picture it like water. As electricity flows from place to place, things can be inserted in that flow to extract useful work, just as a water wheel uses a flowing stream to mill grain. Electronics, then, is creative plumbing.

Batteries

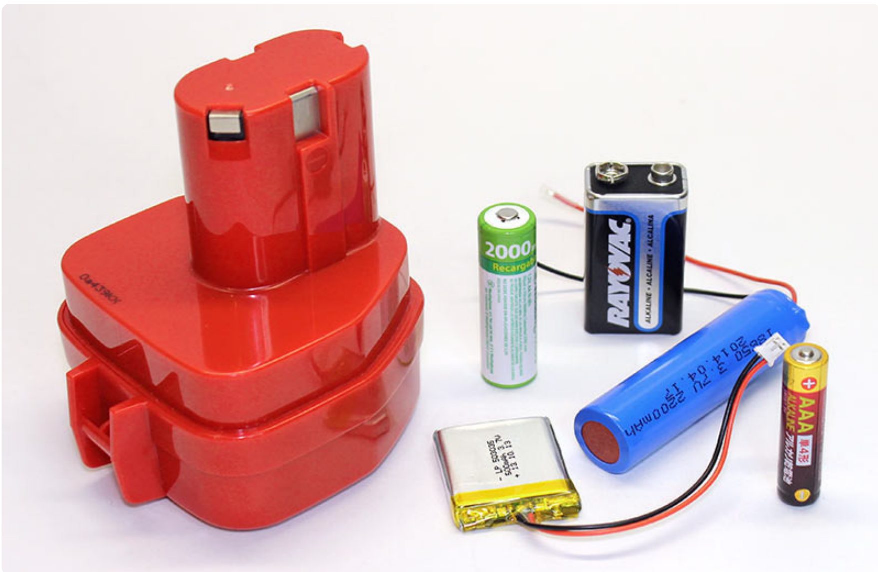
A battery houses two complimentary chemical reactions; one producing a surplus of electrons, the other a deficit. The two reactions are kept apart within the battery, but the attraction is strong enough that adding an external conductor — a path for electrons — consummates those reactions. This is why batteries have a "+" and a "–" end, and why electronics is all about circuits — a loop between the two. When that loop is closed, electrons flow, things happen. (This is what a switch does — it opens or closes the circuit.)

Different battery chemistries use different combinations of reactions. That mix determines the Voltage, sort of the “urgency” of the reaction. Using our plumbing analogy, Voltage is like water pressure.

Our standard recipe called for three AAA or AA alkaline (single-use disposable) batteries. The chemistry of these batteries produces about 1.5 Volts. Linked end-to-end in the case (“in series” in electronics jargon), voltages are added to get a total: 1.5 + 1.5 + 1.5 = 4.5 Volts. Our recipe was built around this number; it’s why there’s a simple choice of two resistors depending on LED color. Change that, and something else has to change with it.



(In electronics, the technical term for a single battery is a cell. “Battery” then refers to a group of cells. Going forward, we’ll use these terms.)



The chemistry of rechargeable Nickel Cadmium (NiCd) or Nickel Metal Hydride (NiMH) cells produces about 1.2 Volts each. Lithium Ion or Lithium Polymer cells are 3.7 to 4.2 Volts (depending on the exact chemistry used). The battery packs for cordless tools and radio-control vehicles often link a number of cells in series for higher voltages. And inside a 9V alkaline battery there’s really several small 1.5V cells in series. We can work with any of these with a little more knowledge…

Current, Resistance and Ohm's Law

Current is a head count of the flow of electrons, in units called Amperes (A). One Ampere = 6.2 quintillion electrons passing a given point in one second!

What regulates current? In plumbing, the width of the pipe. In electronics, it's resistance, measured in Ohms (Ω). As alluded to in our recipe, resistance in a circuit is a throttle on the cells' chemical reaction, keeping it from going off too quickly.

Voltage, current and resistance are directly interrelated; knowing any two of those values, the third can be derived. This relationship is called Ohm's Law:

V = IR

Voltage (Volts) = Current (Amperes) × Resistance (Ohms). ("I" is from the French word intensité…C was already taken.) Or, through algebraic substitution:

R = V÷I (Resistance = Voltage ÷ Current)

I = V÷R (Current = Voltage ÷ Resistance)

This relationship is the bedrock of all electronics, as fundamental as F=ma in physics.

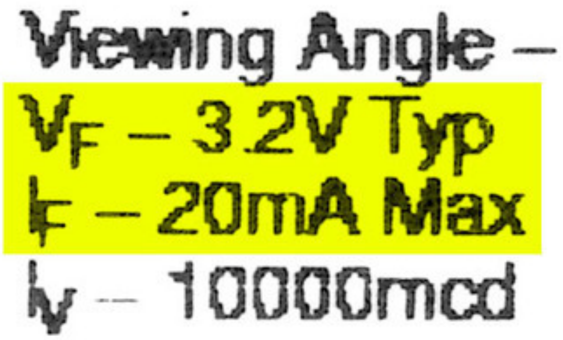
LEDs

LEDs trade electrons for photons — light! And just as batteries have different chemistries and voltages, LEDs too have a unique forward voltage (abbreviated V_F) at which they operate, a function of their chemical composition.

Color	Typical Forward Voltage (V_F)
Red, orange	2.0
Yellow	2.1

Green (older yellow-green variety)	2.2
Blue, white, ultraviolet and newer “true” green	3.3

These numbers are just rough guidelines, they’ll do for most situations. For more precise values, and for other colors not listed here, the exact voltage can be found on the package, product page or in the datasheet (documents published by electronic parts manufacturers listing every minute detail of a device). Here’s the back of of turquoise LED package:



There’s the number we’re after, V_F: 3.2 Volts.

That next value — I_F — will also be useful in a moment. Remember “I” represents current in our equations. I_F is forward current.

Current determines the brightness of an LED…up to a point. **Too much current will destroy it!**

The LED above shows a maximum current of 20 milliamps (1mA = 0.001 Amperes, so 20mA = 0.020A). This value is typical of most LEDs, but some work higher or lower… again, check the packaging, product page or datasheet.

Notice that’s a maximum. I like to back off a little, 10–15%, to ensure longer life. So that’s 17–18 mA.

The LED voltage (let's call it V_{LED} instead) must be lower than the battery voltage (V_{BAT}), or it won't light. Taking the difference of the two voltages then, and applying Ohm's Law, tells us exactly how much resistance is needed in that gap to produce the desired current:

$R = (V_{BAT} - V_{LED}) \div I$

Assuming a 4.5V battery from the recipe, and a 3.3V blue LED, aiming for 18mA current:

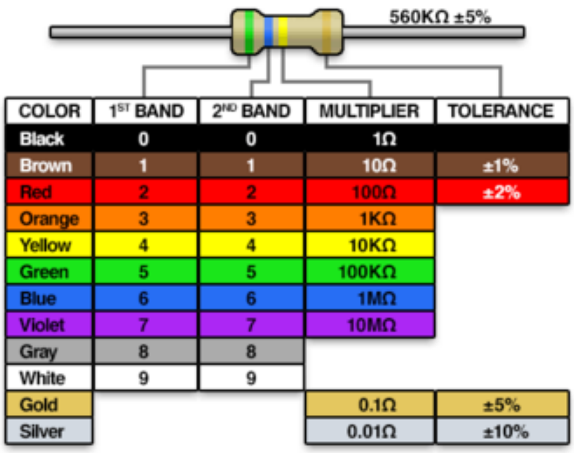
$R = (4.5 - 3.3) \div 0.018 = 66.67$ Ohms

But **resistors generally come in a limited set of values,** so we round up to the next common size...**68 Ohms** (as shown in the recipe), or perhaps 100 Ohms if that's all you can find.

How about a 3.7V lithium-polymer battery and a 2 Volt red LED?

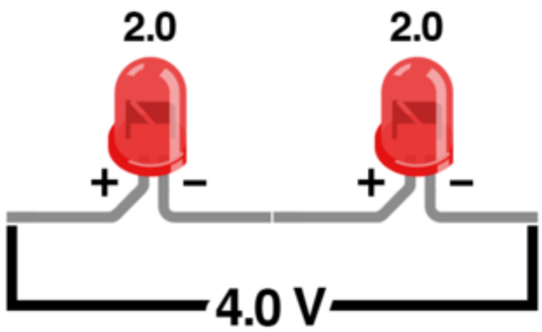
$R = (3.7 - 2.0) \div 0.018 = 94.44$ Ohms

Step up to the nearest standard size, **100Ω.** And that's all there is to it! Nobody can give you crap for not doing "real electronics" anymore.



COLOR	1ST BAND	2ND BAND	MULTIPLIER	TOLERANCE
Black	0	0	1Ω	
Brown	1	1	10Ω	±1%
Red	2	2	100Ω	±2%
Orange	3	3	1KΩ	
Yellow	4	4	10KΩ	
Green	5	5	100KΩ	
Blue	6	6	1MΩ	
Violet	7	7	10MΩ	
Gray	8	8		
White	9	9		
Gold			0.1Ω	±5%
Silver			0.01Ω	±10%

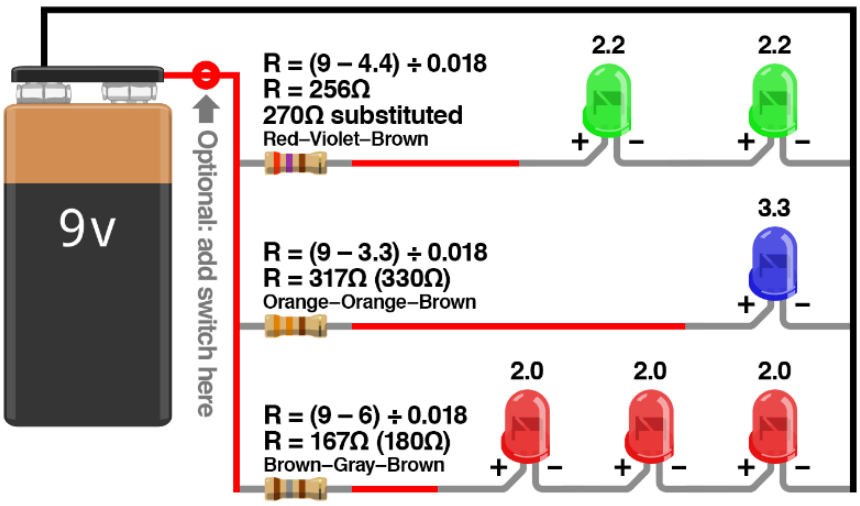
Resistors are easy when they're labeled on the package. Not so much once they're jumbled with other parts. Resistor color charts like this one help in deciphering the codes.



Recall that batteries in series produce a higher supply voltage. LEDs connected in series likewise have a higher forward voltage.

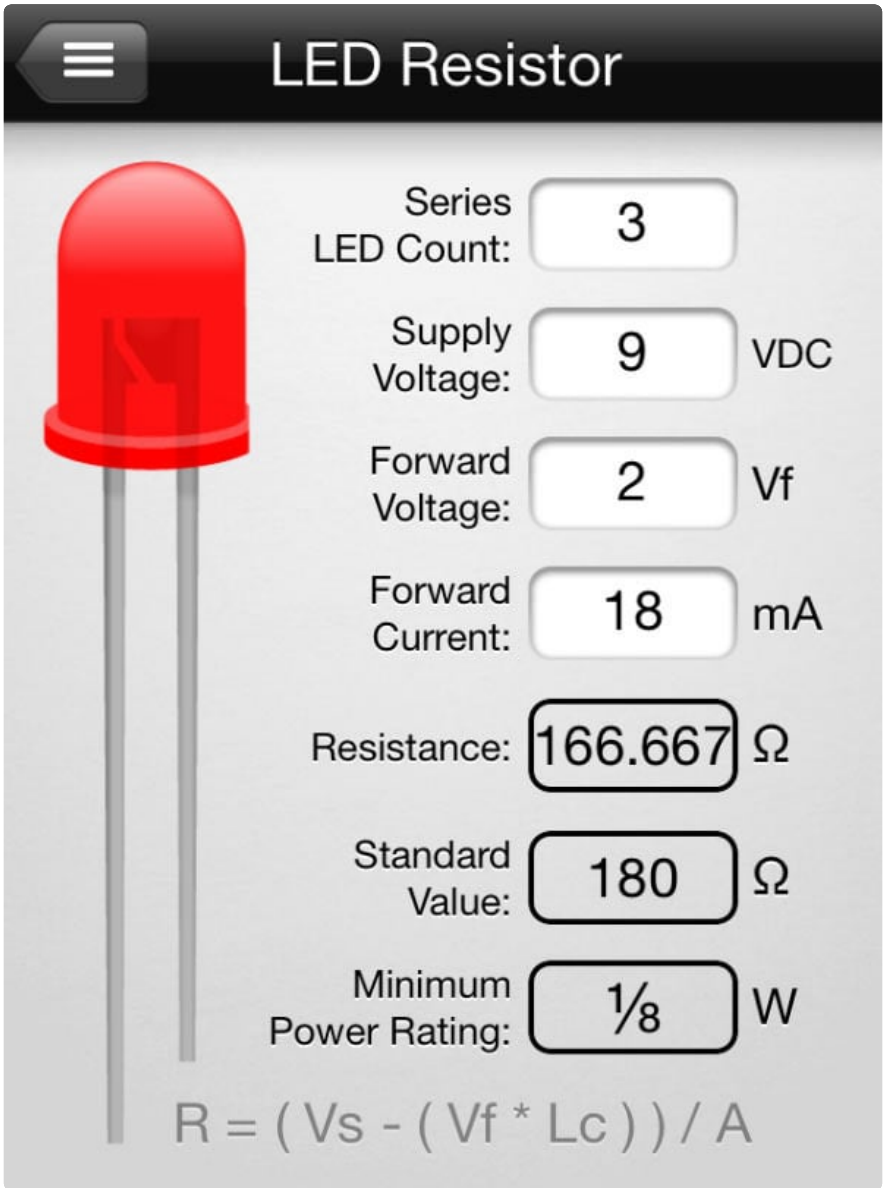
If your design uses multiple LEDs, and if the battery and LED voltages allow it, connecting in series like this is slightly more efficient, helping the battery run longer.

LEDs in series (like above) can share one resistor for the chain. LEDs in parallel (as originally shown in the recipe) require separate resistors for each, even if the LEDs are the same kind. A combination of these — a series-parallel circuit — has one resistor per string. This combines everything learned so far, and it's an opportunity to practice the math:

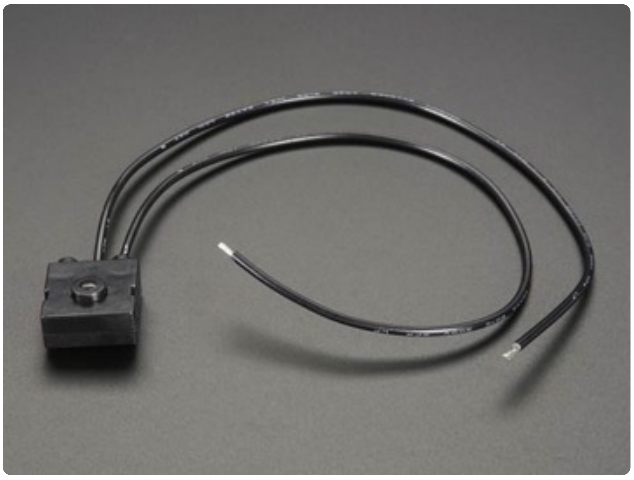


LEDs and the associated formulas are explained in even greater depth in our All About LEDs (https://adafru.it/rRD) tutorial. This includes quizzes to make sure you're on the right track.

Practicing a few times manually helps to reinforce the concepts. When you just need quick answers, there are LED resistor calculators online, and an excellent one included in Adafruit's Circuit Playground app for iOS (https://adafru.it/dXr):



If the supply and forward voltages are very close, you might get a resistor value near zero. As insurance, always include at least a little resistance — perhaps 50 Ohms — to allow for differences between “typical” and actual voltages. For example, a fresh battery has a slightly higher voltage than one nearly depleted.



If using a battery or case without its own switch, consider adding one of these Tactile On/Off Switches with Leads (http://adafru.it/1092). The positive clicky action and low profile make this one great for wearable projects.

The LED “throwie” doesn’t include a resistor. What’s up?

Coin cells exhibit internal resistance — they can only push so much current, it’s the inherent nature of their size and chemistry.

So yes, they can run an LED directly…**but**…this puts stress on the cell and shortens the run time. You can get away with it for quick results, but doing the math and adding a resistor improves longevity.

Ultimate LEDology

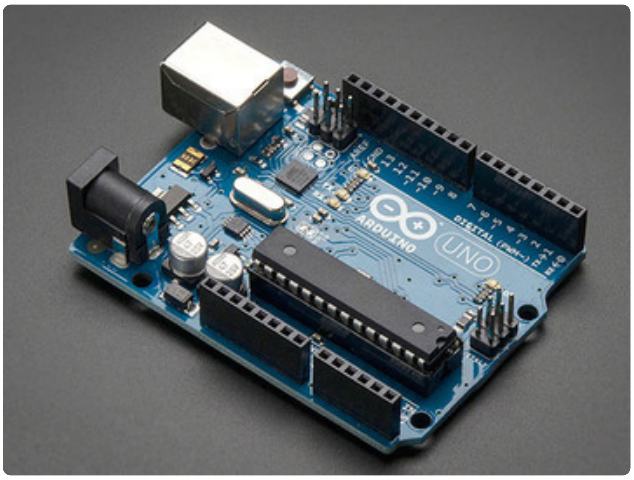
Everything shown so far is “steady on.” Bang for buck, it can’t be beat. Just as important, you’ve gained the necessary foundation for planning and assembling robust electronic circuits.

The next level up…the final boss…is LEDs that blink, pulsate, animate and even change color.

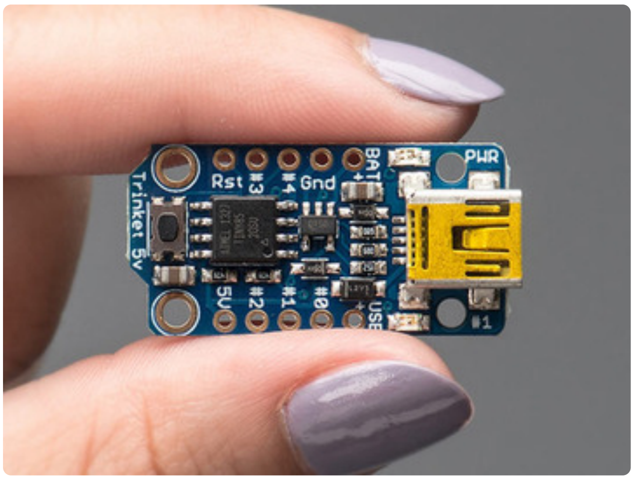
Such effects require a microcontroller, a tiny computer running tiny software. This is a tremendous topic in itself, far beyond what this single guide can offer, but we’ll leave you with some pointers…

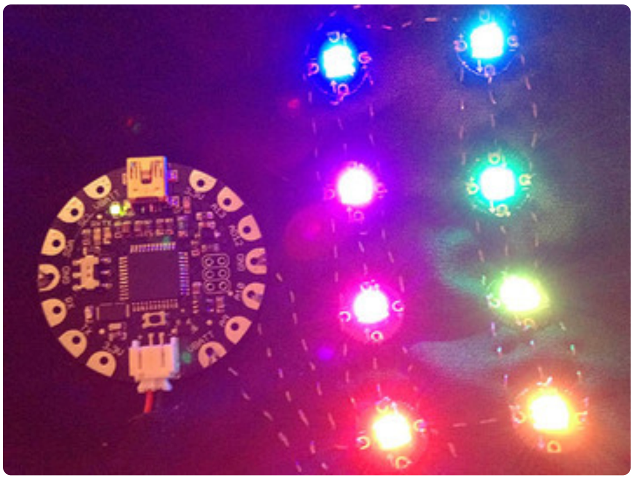
A microcontroller gives you unparalleled control over time and interactivity. LEDs can run in a sequence, or can respond to buttons, switches, even sound levels!

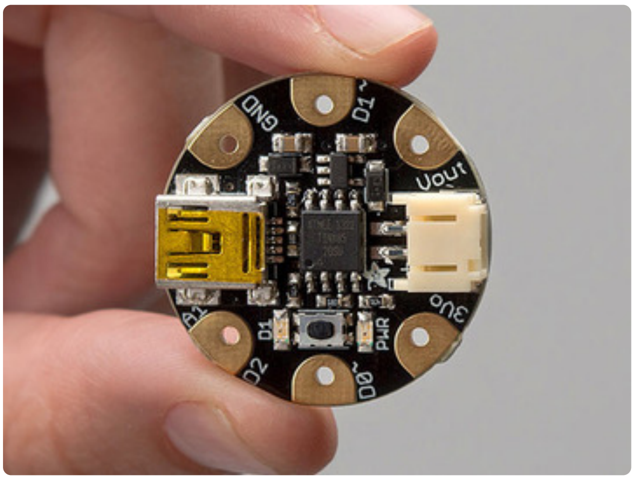
The best-known brand of microcontroller board is called **Arduino**. Though not the cheapest, nor most powerful, where Arduino reigns supreme is an **enormous community of learning resource and shared code.** Entire volumes are written on the subject, and thousands of free tutorials online, many right here in the **Adafruit Learning System**. (https://adafru.it/BQZ)



If you want to start down this path, we strongly suggest starting out with an Arduino Uno **(http://adafru.it/50)**. Not “Mega” or “Pro” anything…you can’t go wrong learning with the Uno.



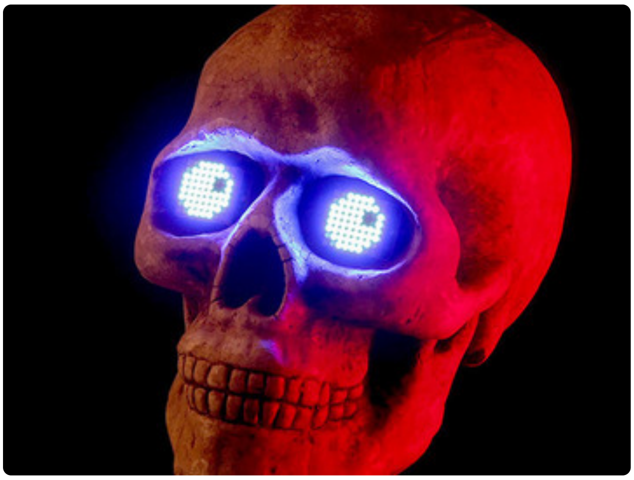




Once you understand the principles, you can then carry that knowledge over to more specialized microcontroller boards. Trinket (http://adafru.it/1501) is very small and basic…just a fraction of an Arduino…but it's often all you need, and can fit into the smallest of projects. FLORA (http://adafru.it/659) and GEMMA (http://adafru.it/1222) are specifically designed for wearable electronics.

Programming…writing in the computer's native tongue…is an abstract thing, a different way of thinking. Newcomers face the dual challenges of logic — breaking problems down into a sequence of very short, simple steps — and syntax — accurately conveying this in the proper combination of words and symbols. The good news is, once you crack that nut, code and ideas can be carried over to new projects. And there's lots of ready-made examples out there.

NeoPixels (https://adafru.it/dVm) may be the ultimate expression of the LED. They chain together almost like Christmas lights, each with an independent color and brightness controlled by your own program. If you see some really whizbang LED effects, chances are there’s NeoPixels involved.



There are LED strips, grids, even tiny bitmapped graphical displays. **Microcontrollers open other doors too…** sound, motion, sensors that respond to the environment…it’s practically boundless.

But it all starts with an LED.