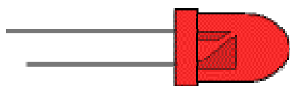
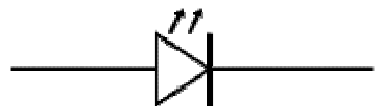
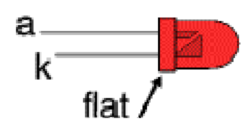
Working With
Light Emitting Diodes (LEDs)

By: George Mustafa IPMS-PR, August 2009

Example:  Circuit symbol: 

Function: LEDs emit light when an electric current passes through them.

Connecting and soldering: LEDs must be connected the correct way round, the diagram may be labeled a or + for anode and k or - for cathode (yes, it really is k, not c, for cathode!). The cathode is the short lead and there may be a slight flat on the body of round LEDs. If you can see inside the LED the cathode is the larger electrode (but this is not an official identification method).



LEDs can be damaged by heat when soldering, but the risk is small unless you are very slow. No special precautions are needed for soldering most LEDs

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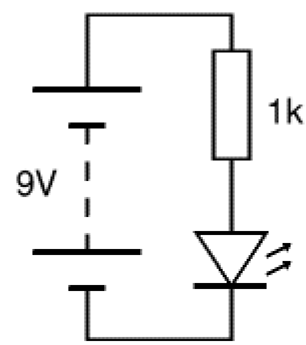
Testing an LED

Never connect an LED directly to a battery or power supply without a resistor! It will be destroyed almost instantly because too much current will pass through and burn it out.

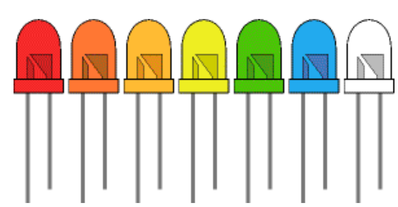
LEDs must have a resistor in series to limit the current to a safe value, for quick testing purposes a 1kΩ resistor is suitable for most LEDs if your supply voltage is 12V or less. **Remember to connect the LED the correct way round!**



Colors of LEDs

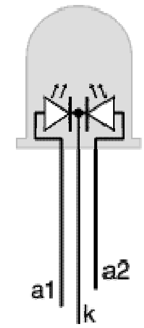
LEDs are available in red, orange, amber, yellow, green, blue and white. Blue and white LEDs are much more expensive than the other colors.

The color of an LED is determined by the semiconductor material, not by the coloring of the 'package' (the plastic body). LEDs of all colors are available in uncolored packages which may be diffused (milky) or clear (often described as 'water clear'). The colored packages are also available as diffused (the standard type) or transparent.



Tri-color LEDs

The most popular type of tri-color LED has a red and a green LED combined in one package with three leads. They are called tri-color because mixed red and green light appears to be yellow and this is produced when both the red and green LEDs are on.



The diagram shows the construction of a tri-color LED. Note the different lengths of the three leads. The centre lead (k) is the common cathode for both LEDs, the outer leads (a1 and a2) are the anodes to the LEDs allowing each one to be lit separately, or both together to give the third color.

Bi-color LEDs

A bi-color LED has two LEDs wired in 'inverse parallel' (one forwards, one backwards) combined in one package with two leads. Only one of the LEDs can be lit at one time and they are less useful than the tri-color LEDs described above.

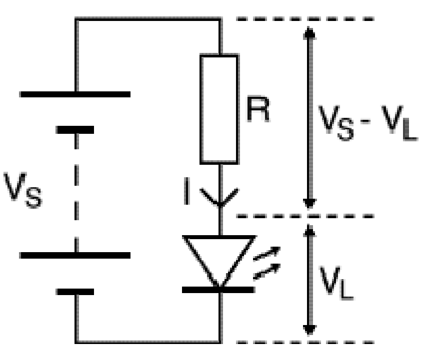
Sizes, Shapes and Viewing angles of LEDs

LEDs are available in a wide variety of sizes and shapes. The 'standard' LED has a round cross-section of 5mm diameter and this is probably the best type for general use, but 3mm round LEDs are also popular.

Round cross-section LEDs are frequently used and they are very easy to install on boxes by drilling a hole of the LED diameter, adding a spot of glue will help to hold the LED if necessary. LED clips are also available to secure LEDs in holes. Other cross-section shapes include square, rectangular and triangular.

As well as a variety of colors, sizes and shapes, LEDs also vary in their viewing angle. This tells you how much the beam of light spreads out. Standard LEDs have a viewing angle of 60° but others have a narrow beam of 30° or less.

Calculating an LED resistor value



An LED must have a resistor connected in series to limit the current through the LED; otherwise it will burn out almost instantly.

The resistor value, R is given by:

$$\mathbf{R = (V_S - V_d) / I}$$

V_S = supply voltage
V_d = Device (LED) voltage (usually 3V)
I = LED current (e.g. 20mA), this must be less than the maximum permitted

If the calculated value is not available choose the nearest standard resistor value which is **greater**, so that the current will be a little less than you chose. In fact you may wish to choose a greater resistor value to reduce the current (to increase battery life for example) but this will make the LED less bright.

For example

Supply voltage V_S = 9V, an LED (V_d = 3V), requiring a current I = 20mA = 0.020A,
R = (9V - 3V) / 0.02A = 300Ω, so choose 330Ω (the nearest standard value which is greater).

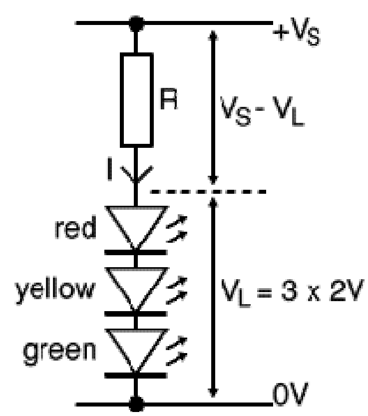
Working out the LED resistor formula using Ohm's law

Ohm's law says that the resistance of the resistor, R = V/I, where:
V = voltage across the resistor (= V_S - V_L in this case)
I = the current through the resistor

So $R = (V_S – V_d) / I$

For more information on the calculations please see the Ohm's Law page.

Connecting LEDs in series

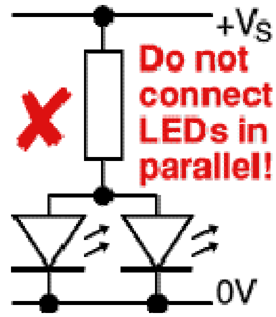


If you wish to have several LEDs on at the same time it may be possible to connect them in series. This prolongs battery life by lighting several LEDs with the same current as just one LED.

All the LEDs connected in series pass the **same current** so it is best if they are all the same type. The power supply must have sufficient voltage to provide about 2V for each LED (4V for blue and white) plus at least another 2V for the resistor. To work out a value for the resistor you must add up all the LED voltages and use this for V_L.

Example calculations:
A red, a yellow and a green LED in series need a supply voltage of at least 3 × 2V + 2V = 8V, so a **9V battery** would be ideal.
V_L = 2V + 2V + 2V = 6V (the three LED voltages added up).
If the supply voltage V_S is 9V and the current I must be 15mA = 0.015A,
Resistor R = (V_S - V_L) / I = (9 - 6) / 0.015 = 3 / 0.015 = 200Ω,
so choose R = 220Ω (the nearest standard value which is greater).

Avoid connecting LEDs in parallel with one resistor!



Connecting several LEDs in parallel with just one resistor shared between them is generally not a good idea.

If the LEDs require slightly different voltages only the lowest voltage LED will light and it may be destroyed by the larger current flowing through it. Although identical LEDs can be successfully connected in parallel with one resistor this rarely offers any useful benefit because resistors are very cheap and the current used is the same as connecting the LEDs individually. **If LEDs are in parallel each one should have its own resistor.**

Reading a table of technical data for LEDs

Suppliers' catalogues usually include tables of technical data for components such as LEDs. These tables contain a good deal of useful information in a compact form but they can be difficult to understand if you are not familiar with the abbreviations used.

The table below shows typical technical data for some 5mm diameter round LEDs with diffused packages (plastic bodies). Only three columns are important and these are shown in bold. Please see below for explanations of the quantities.

Type	Color	I_F max.	V_F typ.	V_F max.	V_R max.	Luminous intensity	Viewing angle	Wavelength
Standard	**Red**	**30mA**	**1.7V**	2.1V	5V	5mcd @ 10mA	60°	660nm
Standard	**Bright red**	**30mA**	**2.0V**	2.5V	5V	80mcd @ 10mA	60°	625nm
Standard	**Yellow**	**30mA**	**2.1V**	2.5V	5V	32mcd @ 10mA	60°	590nm
Standard	**Green**	**25mA**	**2.2V**	2.5V	5V	32mcd @ 10mA	60°	565nm
High intensity	**Blue**	**30mA**	**4.5V**	5.5V	5V	60mcd @ 20mA	50°	430nm
Super bright	**Red**	**30mA**	**1.85V**	2.5V	5V	500mcd @ 20mA	60°	660nm
Low current	**Red**	**30mA**	**1.7V**	2.0V	5V	5mcd @ 2mA	60°	625nm

I_F max.	Maximum forward current, forward just means with the LED connected correctly.
V_F typ.	Typical forward voltage, V_L in the LED resistor calculation. This is about 2V, except for blue and white LEDs for which it is about 4V.
V_F max.	Maximum forward voltage.
V_R max.	Maximum reverse voltage You can ignore this for LEDs connected the correct way round.
Luminous intensity	Brightness of the LED at the given current, mcd = millicandela.
Viewing angle	Standard LEDs have a viewing angle of 60°, others emit a narrower beam of about 30°.
Wavelength	The peak wavelength of the light emitted, this determines the color of the LED. nm = nanometer.

Flashing LEDs

Flashing LEDs look like ordinary LEDs but they contain an integrated circuit (IC) as well as the LED itself. The IC flashes the LED at a low frequency, typically 3Hz (3 flashes per second). They are designed to be connected directly to a supply, usually 9 - 12V, and no series resistor is required. Their flash frequency is fixed so their use is limited and you may prefer to build your own circuit to flash an ordinary LED, for example our Flashing LED project which uses a 555 astable circuit.

Specialized LED's

www.ngineering.com sells very specialized micro LED's. These LED's are in sizes ranging from 2x3 mm, micro and Nano LED's. The Nano LED is as big as the size of the ear of the Lincoln in the penny, that's how small it is! These LED's require some very specialized wiring, as thick as a human hair and soldering iron, all sold by them. Also, these LED's require experience in soldering and basic electronics.

2x3mm LED size comparison.

Micro LED size comparison.

Nano LED size comparison.

How to Connect LED's

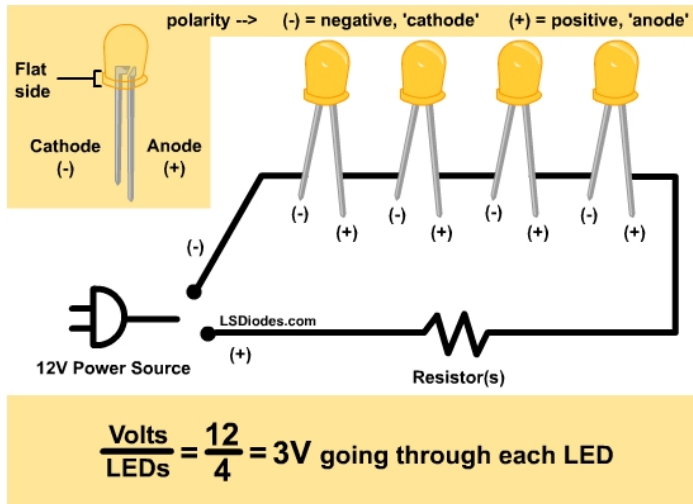
This is a **very** basic guide to help people unfamiliar with circuits get their LEDs up and running without blowing them out and wasting all their money. IT IS VERY BASIC!! Current is hardly ever mentioned, not because it's not important, but because we've found it makes things confusing when trying to teach people about this sort of thing.

There are two basic types of circuits: **Series** and **Parallel.**

Series or powering lots of LEDs off a higher voltage source

When LEDs are placed in a series, the voltage is dispersed between the LEDs, meaning less voltage goes to each LED. This can be very useful. For example, if a 12 volt adapter were powering one LED, there'd be 12V going through that LED which is way too much for any LED to handle and would result in a rather unpleasant burning smell.

However, if you take that same 12V power source and put 4 LEDs in series, there would be 3V going to each LED and (assuming the LEDs are made to run off 3V) each would be powered and just dandy. Check out this illustration:



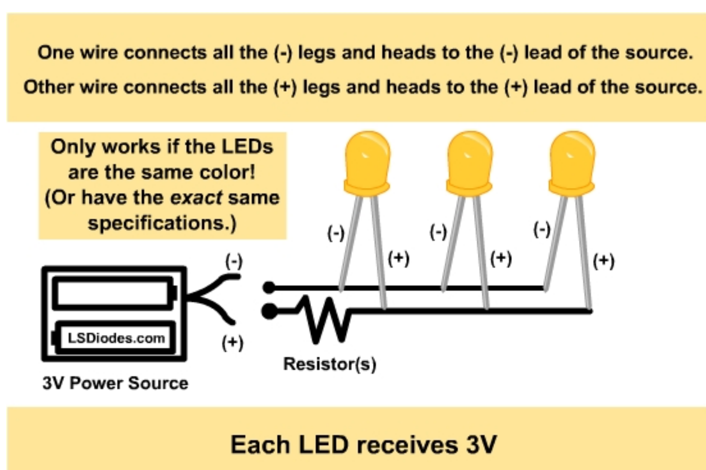
It's important to notice how the LEDs are positioned: (-) (+), (-) (+), etc. making sure that the end (-) connects to the (-) wire and the end (+) connects to the (+) wire, if any LEDs are backwards nothing bad will happen, they just won't turn on.

If three LEDs were in series with a 12V source, each would receive 4V, if six were in series, each would receive 2V, etc.

If I have four LEDs powered from a 12V source and I want each to receive less than 3V/ea?"
This is where the little 'Resistor(s)' squiggly comes in. By adding a resistor it's possible to tone down the amount of voltage each receives. To find out what value resistor you should use, use an led calculator such as this one. Go to the middle form where it says 'LEDs in series' and simply type in your power sources' voltage, the LEDs' voltage you'd like and the LEDs current capability (use 20mA.) It then tells you what ohms value the resistor needs to be to stick in the circuit.

Parallel or powering lots of LEDs from a lower voltage source

Let's say you wanted to power three of your brand new LEDs off a 3V battery pack (two 1.5V AA's in series, make sense?) you found lying around. If you were to series the three LEDs there'd be 1V going to each (3 Volts / 3 LEDs = 1V for each LED). That's not enough to power your LEDs! You want them to have the full 3V going to each. Here's how:

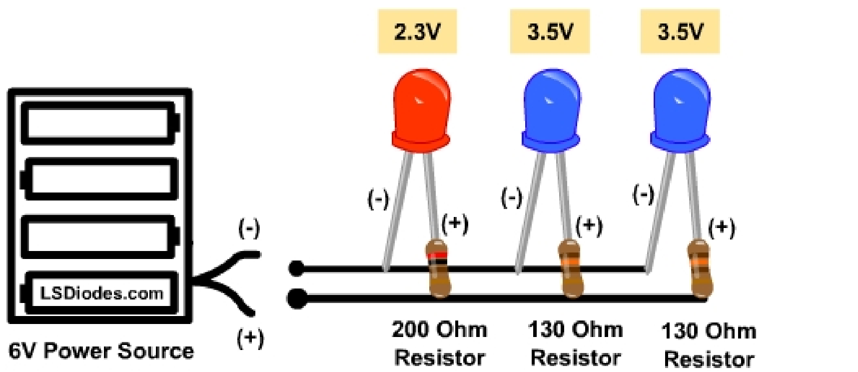


How this works is that while every LED receives the same amount of voltage, the current of the source is dispersed between the LEDs. What this means for you is that you have 20 LEDs paralleled off a battery, it's going to drain the battery a lot quicker than if you only had 2 LEDs in parallel. If you're paralleling off a wall adapter, for instance though, the source can constantly renew itself so you can essentially parallel as many as you'd like without fear of draining the batteries.

To use resistors in a parallel circuit, say if you'd like each LED above to receive 2.5V instead of 3V, use an LED calculator (make sure you're in the parallel section) to find the right ohms and then stick it somewhere in the circuit!

Reasons why LEDs have to be the same color. If you mix colors, say if you paralleled a red (~2.3V) and two blue (~3.5V), the blue LEDs would not light. Why's this? Because the electricity is going to take the easiest path it can to complete the circuit and in this scenario the red LED requires less energy, leaving the two blue unpowered and lonely. To fix this you would need to stick a resistor onto the leg of each LED to 'equalize' all of the LEDs. Note illustration:

To find the resistor you'd need for each LED, use the 'Single LED' portion of an LED calculator, type in the supply voltage, LED's voltage and 20mA for each LED and there you go. Now each LED will turn on and each will receive its desired amount of power. The resistors act like 'shocks' in a car, they give the power source some 'squish' and let each LED find its happy place (forward voltage).



Each LED receives its necessary voltage and the circuit treats each LED equally.

Resistance Formula for LED's $R = (V_S - V_d) / I$

V_S = supply voltage V_d = Device (LED) voltage (usually 3V) I = LED current (e.g. 20mA), this must be less than the maximum permitted

Reference: Websites to buy LED's and other components

http://www.superbrightleds.com/, for normal 30 degree 8, 5, 3 mm LEDs and 360 degree 8 and 5 mm LED's
www.miniatronics.com, for mini 1.5 mm red, green and amber LED's, micro connecting wires, specialized micro circuitry (flashers, strobe simulators, emergency vehicle light simulators, etc.
www.ngineering.com, for very specialized micro, nano, and 2x3 mini LED's, highly specialized micro circuitry: flashers, strobes, beacons, etc.
https://e-luminates.com/osc/index.php, for EL (Electroluminescent) sheets (light sheet) and power supplies.