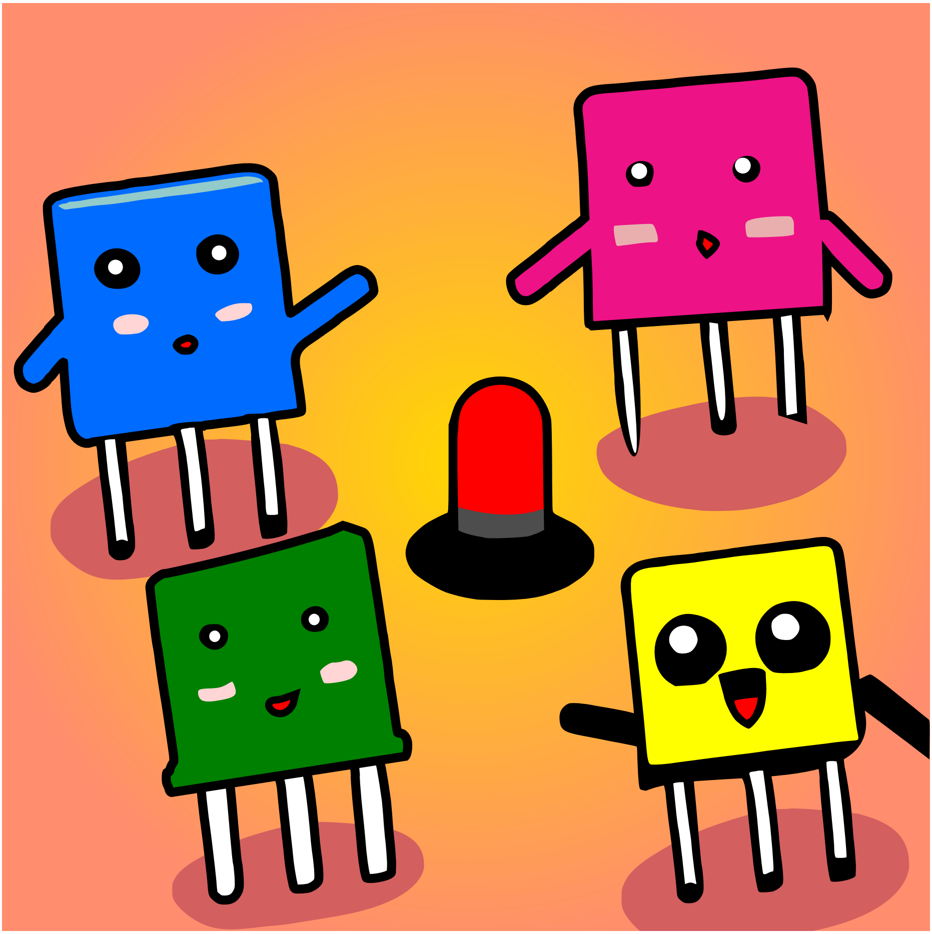
XYZ-01 Electronics Starter Kit

Instruction Manual



Safety precautions

You are probably aware of the fact that electricity can be dangerous. Wall power is indeed **very** powerful and dangerous. Never stick things into power outlets! The experiments in this booklet all use batteries instead of wall power, but even batteries can be dangerous. Batteries have low voltages that cannot penetrate the human skin, but if your skin is wet, even low voltages can penetrate the skin and give you a shock! So make sure that your hands are dry before handling batteries or things connected to batteries. This is true for all electronics, not just the electronics in this kit!

Note: most experiments in this booklet use tiny coin batteries and other small components. Keep these things away from babies because babies always like to put all kinds of things in their mouth. These things are not edible!
If something doesn’t work, don’t be afraid to ask an adult for help.

Introduction

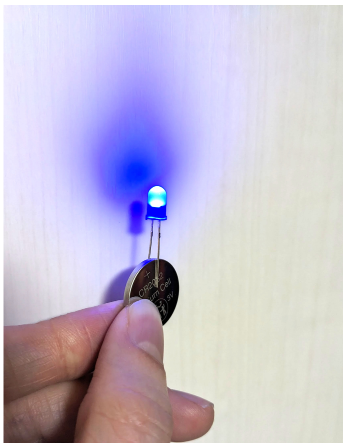
Did you know that many electronic appliances aren't that complex, actually?

Electronic devices are made of just a couple different parts, and we'll look at some of the most fundamental parts in the following experiments.

In the first experiment, we light up a single LED (light-emitting diode). An LED, as the name suggests, produces (“emits”) light. I bet lights on most appliances in your house, and even the ceiling lights in your house, contain LEDs too! Don't worry too much about the meaning of the D (diode) part for now! (By the way, the use of LEDs in ceiling lights is a relatively recent development.)

In order to light up LEDs, we need a power source. The power source we'll use today is... a single non-rechargeable coin battery. It’s called a coin battery because it looks somewhat like a coin. Here’s an example:

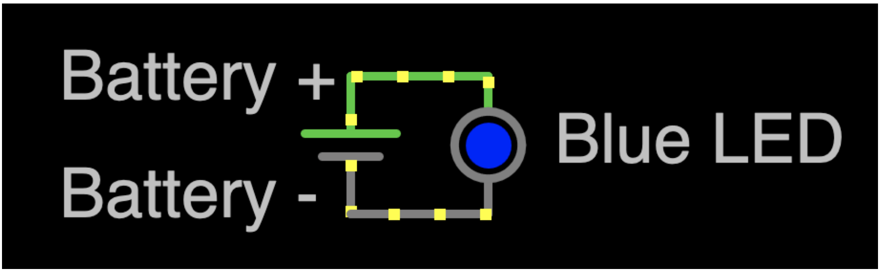
This is a battery and its full name is CR2032; 20 because it’s 20 mm across and 32 because it’s 3.2 mm thick. It's a standard battery that you will find in all kinds of small devices, such as remote controls or perhaps even the multimeter you will be using in some of these experiments!



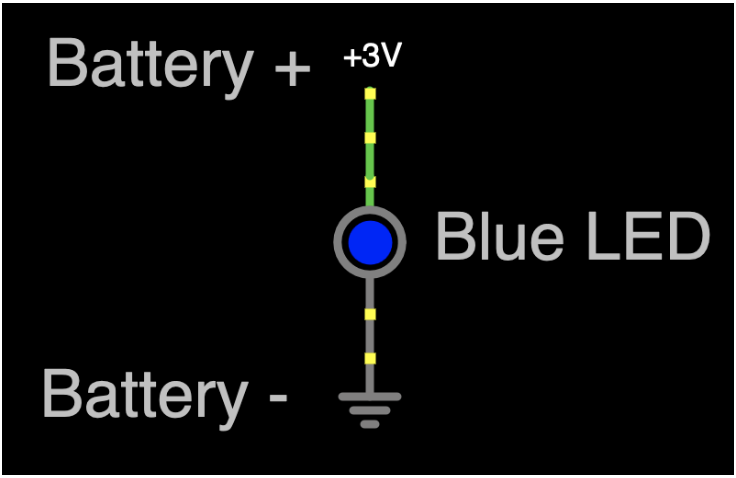
Why this battery? Because it’s 3V, which just happens to be a suitable voltage to power a single blue or white LED without using any other components! (It would be better not to attempt to wedge a red LED (or other component included in this set) on the battery; it could potentially damage the LED. It should be okay if you do it for just 1 second or so.) It’s also quite safe because it doesn’t get too hot when used incorrectly, and never leaks, unlike other common batteries. (This kit also contains four AA batteries. These batteries can leak! To prevent leakage, take them out of the battery holder and store them in small plastic bags.)

All we have to do is connect either end of the LED to either end of the battery. This is very easy to do: just wedge the coin battery between the LED’s two legs. There's a certain thing about LEDs though: if you look closely, you'll see that one "leg" of the LED is longer than the other one. Connect that leg to the + side of the battery, and the other leg to the - side. Otherwise nothing will happen! (Nothing bad will happen, either. There just won't be any light. Feel free to try it!)

In this booklet, we will sometimes show diagrams of circuits. The above experiment can also be shown as a diagram. Here it is:



And here is an alternative way to draw the same circuit:



The second way is usually more convenient for the person drawing the diagram; they are exactly the same functionally.

Grats on completing your first circuit!

The D in LED is short for “diode”. Diodes are common electronic components that only let electricity pass one way, but not the other. LEDs only work when the long leg is connected to the + side because LEDs are diodes! If **you** connect the long leg to the – side, the diode won’t let any electricity pass through, and thus there won’t be any light either.

Be sure to never connect the battery's two sides to each other without any power-consuming component in between! That will “short-circuit” the battery. The battery and the wires will get hot fast! (This is generally true for all batteries and other power supplies. The CR2032 isn’t that bad in this regard, however.)

What could happen if a huge battery got short-circuited? Or if power lines got short-circuited? There could be sparks, a bang, or even an explosion!

So why would the battery get hot if we were to connect a piece of metal between the two sides, but not if we have an LED in between?!

Well, when electricity flows, there are two properties that matter. One is **voltage**, and the voltage supplied by the battery is printed right on it. 3V is not a lot, in the grand scheme of things. The other property is the **current**. Current is measured in A (amperes, pronounced "am-pair(z)", or “amps” for short), and the scales are very different from volts: 3A would be quite a lot of current! That's why, more commonly, current is measured in thousandths of an ampere. Just like with millimeters and meters, a thousandth of an ampere is called a milliampere (or “milliamp” for short).

Simply put, the number indicating the voltage is dictated by the battery (or other power supply). The number indicating **the current, however, is dictated by the devices/components connected to the battery**! If you didn't add a device and just used a piece of metal, the flow of current wouldn't be hindered at all, and the current would be very strong. Like, for the CR2032 it’s just

100-200 milliamps max, possibly less for the CR2032s included in this set, but for a standard AA battery it could be up to 10A! 10 isn't a high number, but 10 amperes is a **very** high current. Same as 10 apples vs. 10 elephants. 10 apples probably fit on a plate, 10 elephants do not.

Well, let's get back to the LED. How much current will flow if we connect an LED between the battery's poles? Well, the current will depend on the voltage and the type of LED used. (Yes, the more voltage you give, the higher the current will be! There is a relationship between voltage and current; they aren't completely separate.) The proper voltage for an LED is mostly determined by its color. The below examples are for common blue LEDs, but there is some variation between LEDs from different manufacturers.

The following values are just representative values and may not match your LEDs:
If we supply 2.4V or even less, the blue LED won't glow at all.
If we supply 2.5-2.9V, the blue LED will glow faintly, and the current will be less than 10 mA.
If we supply around 3V, the current will be around 10 mA, and the LED will glow nicely.
If we supply around 3.1V, the current will be 20 mA and the LED will glow quite bright
If we supply around 3.2V, the current will go up to 40 mA and the LED will be yet brighter. It will also slowly get a little warm to the touch.
If we supply more, the current will go up even higher. Even if we just go up in 0.1V steps, the current will go up much more. The higher the current, the hotter the LED will be.

If we supply 4V or even more, the LED will glow very bright, but more importantly, get very hot! If the LED gets too hot, it will break.

Why does the LED break from getting hot? Very simply put, it will be so hot inside the LED that a tiny but important part inside the LED will burn or melt (this may happen in a split second – once the LED is broken there will be a tiny gap in the circuit and the LED will cool off again).

Changing the voltage just a little bit (beyond a certain point) has a large effect on the current. Even small deviations from the recommended voltage can be enough to shorten the lifespan of the LED. (Don’t worry too much though, the normal lifespan of an LED is very long.)

We are a bit lucky to have a coin battery that works perfectly with blue LEDs. (It also works quite well with white LEDs by the way!) If its voltage were just a little higher, we wouldn’t have been able to conduct this experiment. But what about other LED colors? Or other batteries?

Red, yellow, and green LEDs

Red LEDs have a voltage of around 1.7 to 2V. It depends on the make. The red LEDs included with this set are 1.7V. (That’s much lower than the voltage for blue LEDs!) If the voltage is lower than that, the red LED won’t light up. If it’s higher, it will draw more current and the LED will get hot and break. Many batteries are 1.5V, which is not enough to power a 1.7V red LED. However, very

new batteries often are 1.6V or thereabouts, and will make the red LEDs included with this set glow faintly.
Yellow and green LEDs require an even higher voltage of e.g. 2V or 2.1V.

So we do not have a power source that directly works with red LEDs. But well, it turns out that there is a very basic electronic component that helps us here, and it's included! Probably the most basic component there is: if you haven't heard of the **resistor**, you can't say you're an expert in electronics!

The resistor **resists** the flow of current. It hinders the flow of electricity. It limits the current. All different ways to say the same thing. All we have to do is put a resistor between the battery and the LED, and tada! The current will be limited to a value that doesn't damage the LED.

So how many milliamps does the resistor limit the current to? Ideally, we would want the current to be between 5 mA and 20 mA. Go any lower and the LED will probably be too dark. If we go higher, it'll be too bright and get warm. Much higher and it'll get hot and break.

Let's try this

Imagine we wanted to power a red LED with our 3V battery. Well, as already mentioned, if we supply much more than 1.7V, the red LED will be damaged. In fact, 3V could be enough to damage a red LED. So what do we do in this case?

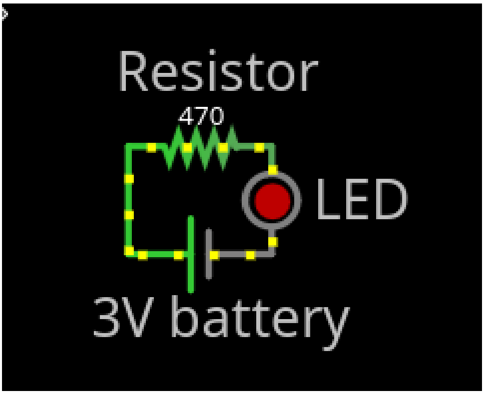
Let's remind ourselves what causes the red LED to be damaged when the voltage is higher than expected: the current will be high. Lots of milliamperes.

Well, it turns out that the aforementioned component, the resistor, can be used to limit the amount of current. They are used, in large quantities even, in virtually every electronic device that you have ever used. This experiment only shows one of the resistor's many use cases. There are more!

There are different types of resistors, but the most important property of any resistor is its resistance value. The resistance value determines the current limit. All you have to do is **take the voltage and divide it by the resistance value, there you have your current limit!** Got 3V and a 510 “ohm” resistor? (Which you do, it’s included in this set!) Work out 3÷510 and the answer is 0.005882352941176… amps! That's about 5.88 mA. And there’s usually no need to be this precise, so saying “about 6 mA” is fine too! (To convert between amps and milliamps you just have to shift the digits to the left or to the right). 6 mA is a bit on the low side but still a suitable current for a red LED!

Don’t worry too much about this weird number; a zero followed by a dot and a bunch of digits that seem to go on forever? Well, it’s not that weird really. Just remember that we’re performing just a normal division here, but with numbers that yield results that don’t look all that pretty when you print them on paper.
If you have 3 apples and divide them between 510 people, how much apple will everyone get? 0.005882352941176… apples. Not much, eh!

So let's try to do the connections! It's kind of hard with just two hands. Here is a diagram of our experiment. The bottom symbol is the battery. The green "plate" is the plus side. The resistor is directly connected to the battery's plus side. The resistor has two legs, just most other components. The zig-zag symbol is a standard symbol for resistors. Unlike the LED, it's not possible to place the LED the wrong way round. It works both ways exactly the same. On the resistor's other leg we connect the LED (the long leg). The LED's other leg goes to the battery's minus side.



Before heading over to the next experiment, let's check out some other examples. If you want to and know how to, feel free to verify these calculations.

If we had 5V and a 510 ohm resistor? 5÷510=0.009803921568627... amps. That's about 10 mA! Good current for an LED.

If we had 9V and a 510 ohm resistor? 9÷510=0.017647058823529... amps. That's about 17 to 18 mA! A bit on the high side, but a permissible current for the LEDs like the ones included with this kit.

All of this is using calculations that were discovered by a smart guy called Ohm; he lived a very long time ago. He’s the one who discovered this principle, but he didn’t use LEDs in his experiments. LEDs were invented much later!

“Voltage consumption”

In the first few experiments, we connected LEDs directly to a battery. That means that the battery’s voltage will be directly applied to the LED, and the LED “consumes” all this voltage.

So when we’re using a 3V battery with the resistor and a red LED, does this mean that the red LED will be “consuming” 3V at 10 mA? No, the **resistor** will “consume” about 1V at 10 mA, and the LED the remaining 2V at 10 mA.
Why?
We already know that the amount of current “pulled” by an LED is determined by the voltage going through it.
It works the other way as well! The amount of voltage “consumed” or “dropped” by an LED is also determined by the current going through it, i.e., around 1.7-2V in the case of a red LED. Maybe 2.2V or so for a green LED. (I didn’t measure it, it’s just a guess!) And if there is any voltage left, it will be “consumed” or “dropped” by the resistor.

(Someone who already knows their stuff will agree with this explanation. Someone who doesn’t know yet will read it a bunch of times over and over again, and maybe not quite get it. Sorry for the bad explanation. You can try asking an adult, or try to consult an alternative source. Or think about it for a while.)

Conclusion: if you know the voltage going into an LED, you can calculate the current. That’s what we did above. If you know the current going through the LED and a resistor, you can calculate the voltage going through the LED and through the resistor. (And of course if you take the LED’s voltage and calculate the current again, you get the same current again.)

So, what does it mean if a resistor “consumes” 1V at 10 mA? Unlike the LED, it doesn’t produce any light, does it?
That’s right. But you may find that it gets very slightly warm after a while, however.
But we didn’t want to produce any heat, did we? We just want to light an LED. The heat is a bit of a waste of energy.
There are ways to waste less energy when adjusting a given voltage to an LED, but they aren’t very easy. Using a resistor is the easiest way!

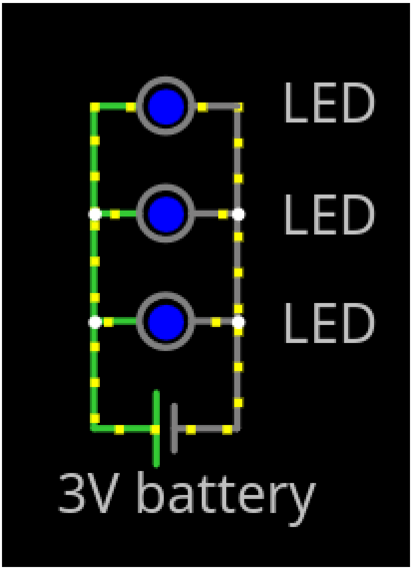
We went through a lot of stuff already! Here’s a short recap!

Voltage: determined by the power source. Our coin battery is 3V. A bit more when it’s new. Less once it gets old.
Current: determined by the combination of devices attached to the power source
Resistor: limits the current, but wastes some power

In-series connections vs. parallel connections

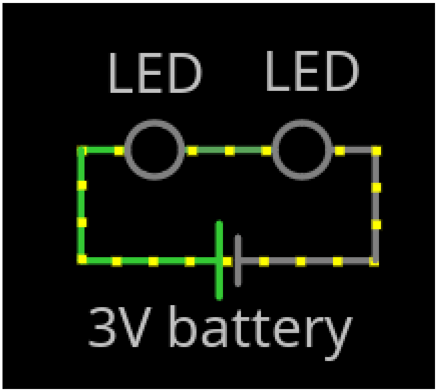
The following experiments demonstrate that there are two ways you can connect things. In the above experiments, we connected just a single LED to our battery. In the next experiment, we will use two or more LEDs.

First of all, let’s do a parallel connection. A diagram would look like this:



With the coin battery, we just attach a couple extra LEDs to the battery, in exactly the same way as the first LED. If you don’t understand why that is equal to the above diagram, try asking your dad or uncle! Basically: it all boils down to whether there is some metal (anything conductive) between certain points or not. This is very important to remember.

Let's think about series connections next.



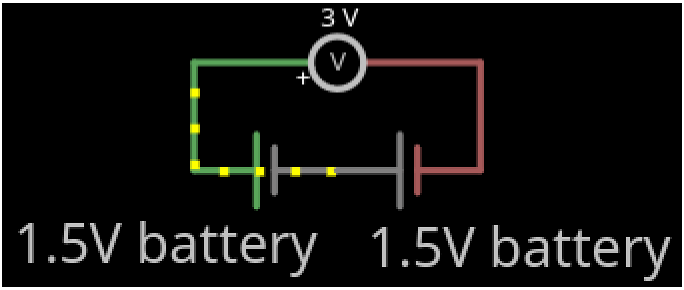
We've already seen a series connection actually – when we used a resistor with the LED in the previous chapter. Let's look at a few more examples of series connections.

First of all, let's think about connecting LEDs in series. Long leg to battery plus. Short leg to long leg of next LED. Short leg of that LED to battery minus. There's a diagram on the right, and as you can see both LEDs are off. Why? Because in a series connection, the available voltage is split between the connected devices. In this example, both LEDs are the same and have the same electrical properties, so they both get an equal share of the available 3 volts: both get exactly 1.5 volts. 1.5 volts isn't enough to light up a red LED, let alone a blue LED!

So, what is going on here? In the parallel circuit, the battery's full 3 volts reach every LED, so every LED lights up. In the series circuit, the 1.5V of the battery is shared equally between the two LEDs. Both get about 0.75V, which is not enough voltage to light up an LED.

There is a very common but different type of series connection that you have most likely seen before: the use of multiple batteries, connected in series, inside a device such as a remote control. For example, two AA/AAA batteries that are each 1.5V.

We have already learned that 1.5V isn't a lot – we can't even power a red LED with that. Therefore, most (but not all) devices that use AA or AAA batteries use two or more of them, which gets us the 3V we could get from a single coin battery. (AA/AAA batteries have other advantages, so it does make sense to do this!) Similarly, we could stack two coin cells and effectively get a 6V battery.



Just some food for though: could we stack two of our 3V batteries to get 6V, and use that to power 3 red or green (roughly 2V) LEDs in series? Yes, we could! It would work beautifully! Feel free to try. But without using something to hold the batteries and components in place, it might be difficult to do experiments like this. This kit includes some simple things to hold components in place, such as a breadboard and coin battery holders that can be hooked into the breadboard. There's a chapter on breadboards a little further in!

Capacitors

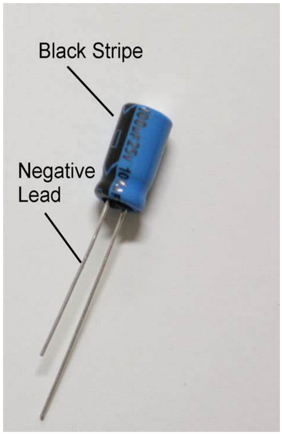
So far, we've introduced batteries, LEDs, and resistors, and I will not beat around the bush, that was a lot to digest.
Capacitors have a weird name that is unfortunately less illustrative

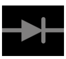
than for example “resistor” or “light-emitting diode”. (Well, we haven’t talked about the “diode” part, but still.)

What do capacitors do? They work like a tiny, tiny battery. You can charge them and use energy stored in them. But while you can power LEDs for many, many hours using a single battery, a single capacitor can only power an LED for a couple seconds, or even just a split second. The name derives from “capacity”.

In this experiment, we will charge a somewhat large capacitor, and then hold a red LED against it.

We will use our multimeter to charge up the capacitor. In the real world, this would be an unusual way to charge a capacitor, but it’s very safe, because we won’t charge the capacitor too much, and the multimeter will even show us the charge level up to a certain point! You do not have to fully understand the process right now, the multimeter works its magic here.



1. Put the multimeter in diode mode. This is the diode symbol:
   
2. Locate the negative side of the capacitor. There is a mark on the side of the capacitor. This mark may be black or white. The capacitor leg close to this marked side is the negative side!

3. Hold the black multimeter probe against this leg, and the red multimeter probe against the non-marked leg. You should see a number on the multimeter, and this number gets higher and higher until it's "out of range" and the multimeter just displays a 1. (Note 1: ranges differ between different multimeter brands. Note 2: if the capacitor is already charged, no number will appear. Note 3: small capacitors charge quickly, so the number may disappear quickly.)
4. You can now remove the multimeter probes. Be careful not to "bridge" the capacitor's legs with the multimeter probes, otherwise you will short-circuit the capacitor. As the charge is very small, nothing bad will happen, but you will have to re-charge the capacitor.
5. Next, connect the short leg of a red LED to the leg on the marked side of the capacitor, and the long leg of the red LED to the leg on the unmarked side.

You will see that the LED will light up and then gradually fade! Most capacitors are so small that they could only light up an LED for a split second, but here we're using a relatively large capacitor, and the LED will stay on for up to a few seconds. There are even larger capacitors. Capacitors, especially large capacitors, can be a bit dangerous. Do not use them (except in these experiments) until you know enough to teach someone how to use them!

Capacitors are a bit interesting. Unlike (chargeable) batteries, they can be charged almost instantly. Charging a smartphone's battery takes at least an hour. Capacitors can be charged and discharged in a split second!

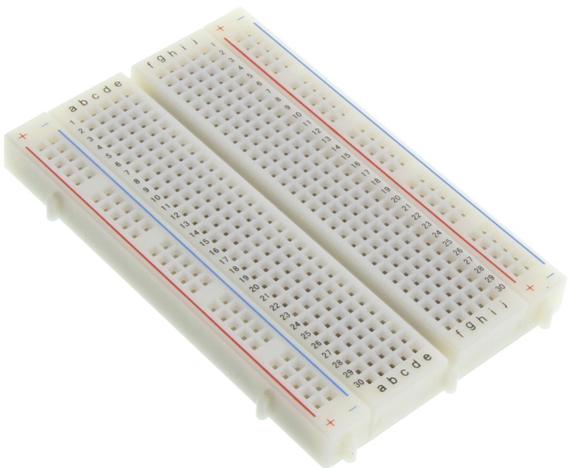
There are experimental electric buses that use huge capacitors instead of batteries. This allows them to charge very fast – think 10-30 seconds. However, the charge only lasts up to the next bus stop.

In the above experiment, we used our multimeter to charge the capacitor, and the multimeter has a builtin current limiter (probably just a resistor!) which prevents the capacitor from being charged instantly.

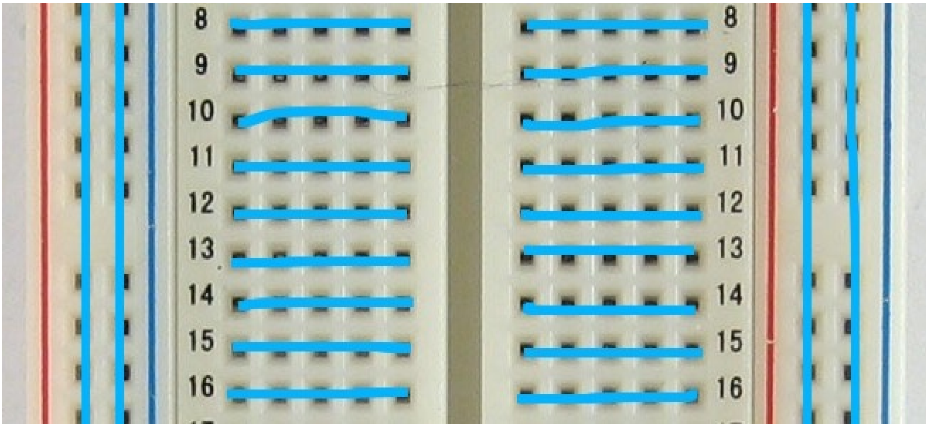
If we were to connect the capacitor directly to a battery, it would charge instantly. You shouldn’t do this with large capacitors. For the capacitors included in this kit, it’s okay, as long as you use a battery.

Breadboards

Breadboards look like this:



Breadboards are very useful for electronic experiments because you can just stick components’ legs into the holes and connect components together without holding them together using your hands. How? Breadboards already have things connected together inside! The following picture shows the breadboard's inside connections in blue:



In some of the following experiments, we'll be using breadboards.

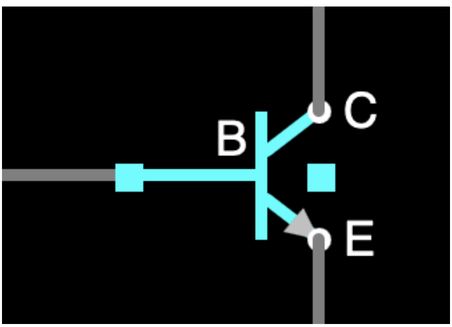
Transistors

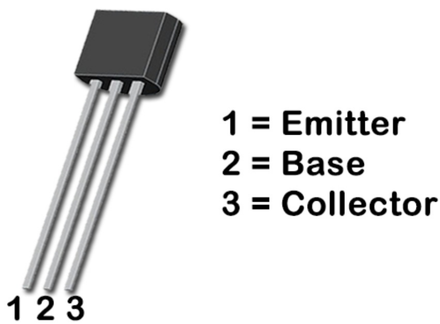
In the next experiment, we will be using a transistor! Transistors are even more complicated than the previous parts; they have three legs!
There are many different ways to use a transistor, but we'll use our transistor in a very fundamental way.

We will connect one leg to the plus side of the battery, and another leg to the minus side of the battery. What about the remaining third leg?
The third leg in a transistor controls whether to allow electricity to pass between the other two legs! If we leave the third leg unconnected or connect it to the minus side of the battery, there

will be something like a microscopic “gap” inside the transistor, which will mean that current cannot flow between the other two legs. It’s the same as if you hadn’t connected the two legs to the battery at all!
However, if we connect the third leg to the plus side of the battery, the gap in the transistor will close and it will be as if we had directly connected the plus side of the battery to the minus side of the battery (though the current will flow through the other two legs of the transistor). Do not attempt this! Because, if you remember, directly connecting the plus side of the battery to the minus side of the battery is a big no-no, because that is a “short circuit”. The battery and the wire will get hot. In this case, the transistor will get hot too! And the transistor will break, just like an LED connected to a too-high voltage, because a microscopic thing inside the transistor will burn or melt.

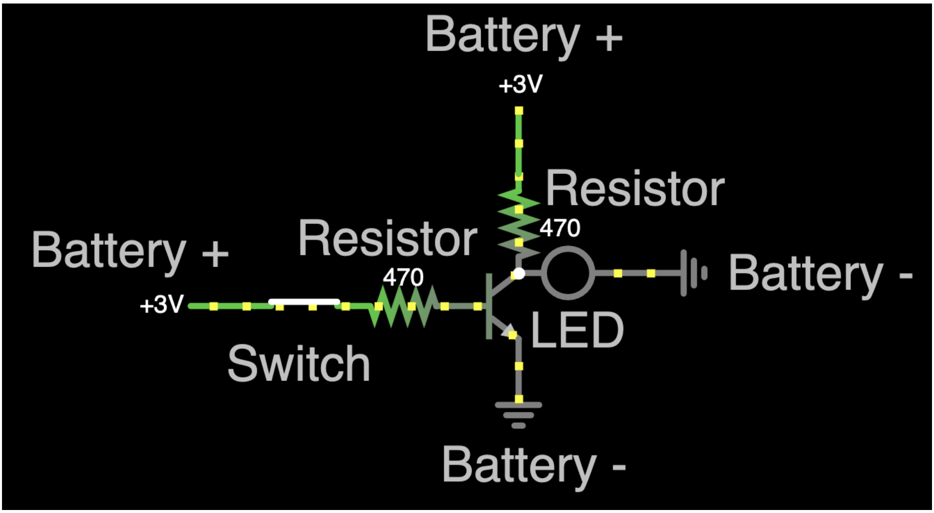
This is the symbol for a transistor. The B is the aforementioned leg that controls whether the transistor is on or off. B is short for base. When the transistor is turned on, electricity can pass from C to E. C is short for “collector” and E is short for “emitter”. These words are just words. There is of course a reason these words were chosen, but maybe it isn’t a very good reason; best not to worry about it for now!





It’s usually necessary to add resistors when using a transistor. We will have one on the plus side, and on the side that acts as the switch. (But there are other ways!) Now we can turn the transistor on and off without creating a short circuit, and can do further experiments.

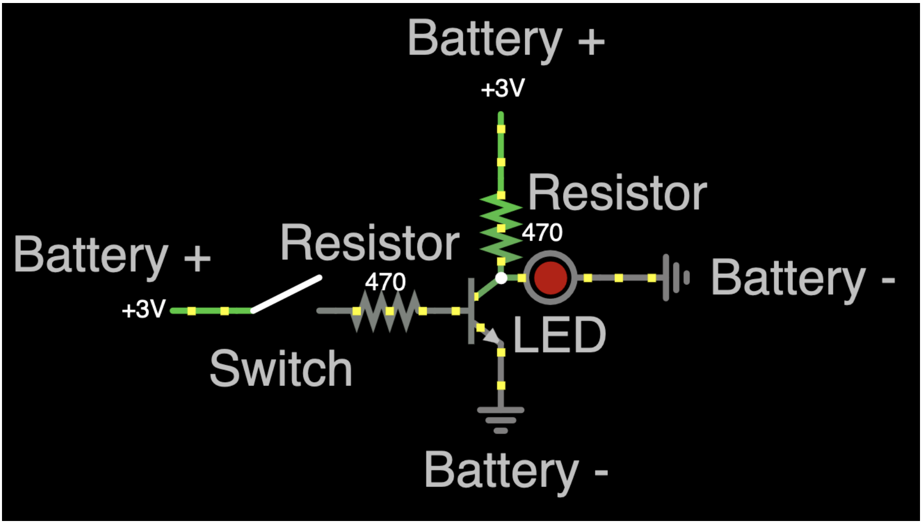
Here is a very complicated circuit. This circuit contains a “switch”, which is just a button that connects the left and right side with some metal. It’s the same as manually removing or attaching a piece of wire! (In fact, this kit doesn’t include a switch, so you will have to emulate this circuit by (for example) unplugging the resistor and plugging it in again.)



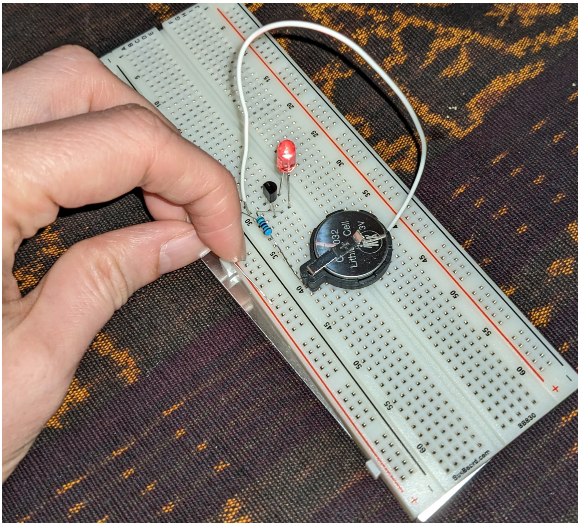
We will go through this circuit component by component, until we understand what it does and how it does it.
So the circuit contains a switch, and the switch is currently touching the wires on its left and right side. This means that the switch is currently pressed.

The circuit also contains an LED, which is currently **off**.
The circuit also contains a transistor.
The transistor has resistors on the base and on the collector. The emitter is directly connected to the battery's minus side. (Note: the resistors used in this image are 470 ohm, but 510 ohm is almost the same.)

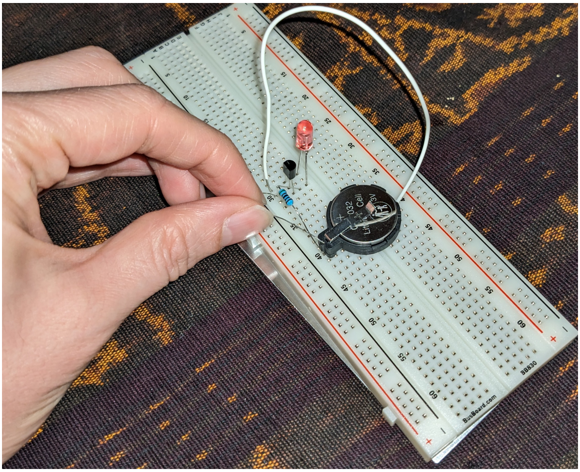
Here is the same circuit again, but with an inactive switch. We can see that the LED is **on**!



This is what this circuit could look like on a breadboard:

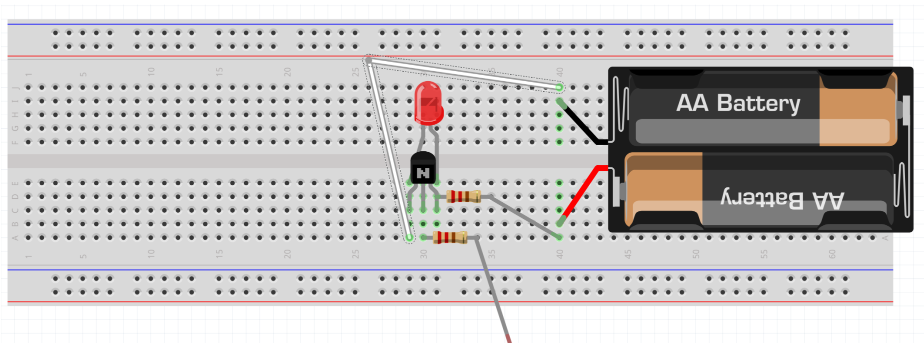


In this picture, we're holding the base-side resistor in the mid-air. The LED is on.

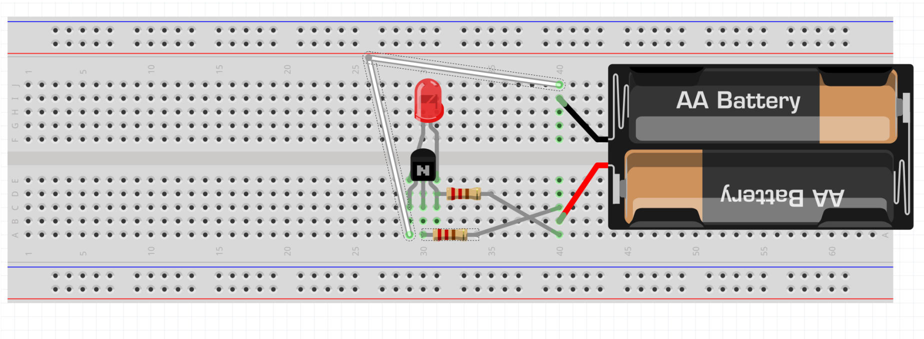


In this picture, we're holding the base-side resistor against the plus side of the battery. The LED is off.

Here are clearer pictures of what's going on on the breadboard. (Battery's different but don't worry about that – two AA batteries are 3V just like the coin battery.)



Resistor on transistor base (middle pin) is dangling in mid-air.



Resistor on transistor base (middle pin) is connected to battery plus side

In this circuit, the LED is on when the switch is off, and the LED is off when the switch is on! That's all the circuit does. This type of circuit is called an **inverter** circuit.

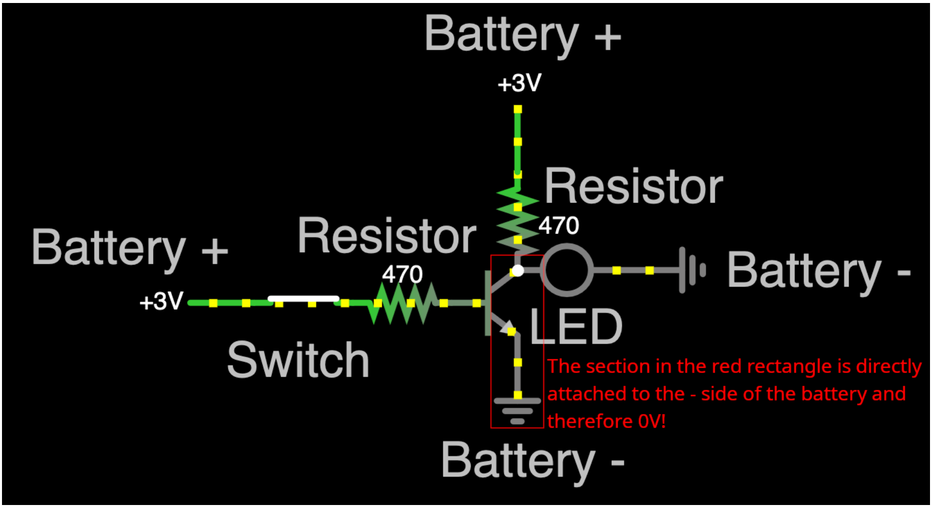
Now let's go through the circuit, little by little. We usually start reading circuits on the plus side. When reading circuits, you should imagine that the electricity flows from + to -. (You may sometimes hear that this is wrong, but while it's not 100% correct, it's more correct than wrong!)
In this circuit, there are two plus connections.
Let's look at the one with the switch first, just because it looks a bit easier.

Electricity flows from the battery plus. If the switch isn't pressed, the electricity cannot flow into the transistor's base, so the transistor is **off**. If the switch is pressed, the electricity can flow into the transistor's base, so the transistor is **on**. It is necessary to have a resistor on the base of the transistor, otherwise the transistor will pull too much current and break!

Just like with LEDs, there is a voltage that would be safe to use without resistors. But unlike LEDs that is just theoretical. The current will be exceptionally high even with just a slight deviation from the correct voltage. In practice it is extremely important that a resistor be used, otherwise the transistor will be toast!

Now let’s look at the other plus connection at the top of the circuit diagram. Remember, we need a resistor on the transistor’s collector or emitter, otherwise the current won’t be limited from the battery plus side at the top and the battery minus side at the bottom of the circuit diagram.

If the transistor is off, electricity will not be able to flow through the transistor, so it’ll only flow into the LED, and the LED lights up.
If the transistor is on, electricity will be able to flow through the transistor. But there is still a path to the LED, right? Why does the LED turn off if the transistor is on? Well, if the transistor is on, not only will electricity be able to flow through the transistor, it actually will be like there is a straight metal connection from the top of the transistor to the minus side of the battery:



We can do cool things with inverter circuits, such as building a circuit with blinking LEDs!

One important thing to note is that it doesn't take much electricity to turn a transistor on or off! You can control the base with very little current. That means you can use a high-ohm resistor to limit the current to the base much more, and it will work just fine! When we draw a lot of current from the battery, the battery will be empty much sooner. So in real products it is important to use resistors with an appropriate resistance value.

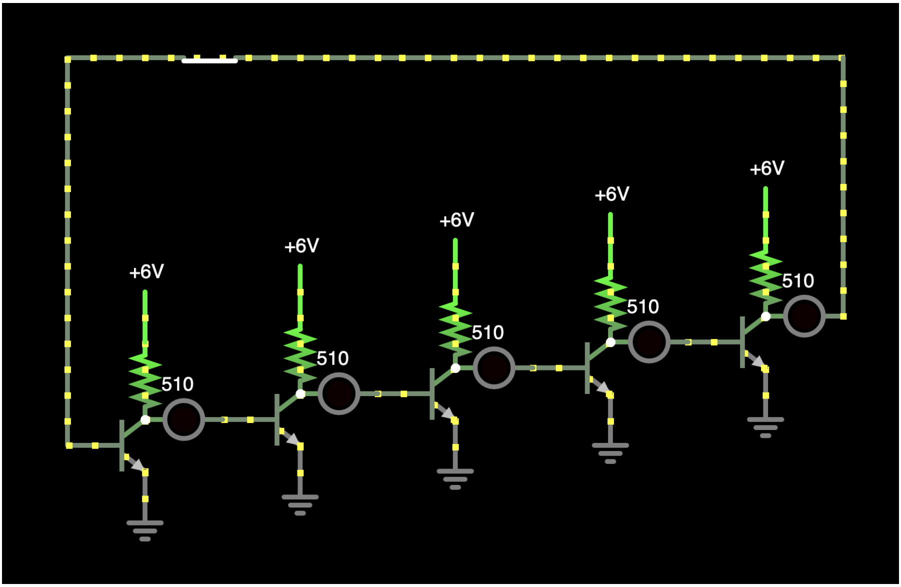
So the base resistor can be quite high, meaning we sharply limit the current to the base. On the other hand, we can use a low-value resistor on the path with the collector and emitter, meaning we

don’t have to limit the current that much. We still have to limit the current somewhat though!
It depends on the type of transistor how much we have to limit the current to. There are many types of transistors for different purposes! This set includes a very common type of transistor, called “2n2222”. The current shouldn’t exceed 200 milliamps. For a 3V power supply, a 15 ohm resistor would be the lowest acceptable resistor. For a 6V power supply, it would be 30 ohms.

Blinking LEDs

The above circuit turns an LED on if the transistor is off, and off if the transistor is on.
Imagine a chain of 5 inverters with LEDs: if the LED on the first inverter is on, if we add a connection from the first LED to the base of the next inverter, there won’t be any electricity reaching the base: this means that the second LED will be off! If we do the same for the next inverters/LEDs, the third LED will be on, the fourth LED will be off, and the fifth LED will be on. (Yes, you can chain things together like that in many cases.)

Now imagine we did something very cheeky and connected the fifth inverter in the chain back to the first inverter in the chain!
This is the circuit:



Note that we do not have a resistor on the base of the transistor because we already have a resistor in the path from +6V to the base of the transistor.

The **first** LED would have no choice but to switch **off**, the **second** LED would switch **on**, the **third** LED would switch **off**, the **fourth** LED would switch **on**, the **fifth** LED would switch **off**, and back: the **first** LED would switch **on** again, etc.

So we’d have:

1	2	3	4	5
OFF	ON	OFF	ON	OFF
1	2	3	4	5
ON	OFF	ON	OFF	ON
1	2	3	4	5
OFF	ON	OFF	ON	OFF
1	2	3	4	5
ON	OFF	ON	OFF	ON

...

Cool, so we’d have blinking LEDs, right? No, unfortunately we wouldn’t, because transistors react extremely fast. We wouldn’t even notice that the LEDs switch on and off, to be honest. The signal would be so fast that it could probably only be measured with sensitive laboratory equipment!

Slowing down the transistors

Is there something we can do to slow down this cascade? Yes!
Currently, we feed the output of each inverter directly into the next inverter.
But there is a way to delay electric signals. And it’s done very often in real-world devices.
If we add a capacitor as an additional path the electricity can take, it will take some time to charge/discharge the capacitor. While the capacitor is charging, it reduces the electricity reaching the transistor’s base, and the transistor doesn’t turn on until the capacitor has charged up a bit. Similarly, once the capacitor is charged, it’ll provide some electricity to the transistor’s base, and

the transistor will stay on a little longer.

That's all there is to it really! We can delay the cascade quite a bit as capacitors come in many sizes. We could even use two or more capacitors to make the delay even longer.

Remember how resistors have their resistance measured in Ohms, named after someone who lived a long time ago? Capacitors also have their own unit, and it's called Farad!

There's a strange thing about Farads: 1 Farad is a *lot*. 1 Farad is so much that capacitors that have this kind of value are called *super*capacitors.

Okay, one thousandth of a meter is called a millimeter, right?

Do you know what's a thousandth of a millimeter? It's a micrometer.

And one thousandth of that? Nanometer.

And one thousandth of that? Picometer.

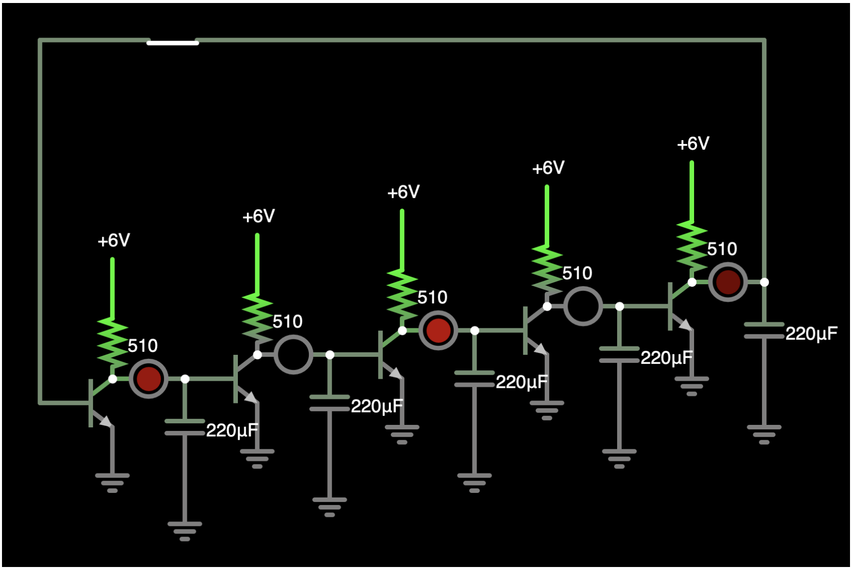
The same prefixes are used with Farads!

However – I kid you not – most capacitors are measured in pico-Farads, nano-Farads, and micro-Farads.

The capacitors enclosed with this kit are 220 and 470 micro-Farad. They are labeled 220 µF / 470 µF. That weird µ character means "micro", and is also often used for micrometers (µm) or micrograms (µg). Maybe you've seen it before on a nutrition facts label? The amount of vitamin A needed by an adults is just 900 µg, so "µg" often makes an appearance on these labels. (Note: the daily allowance for 8-year-olds is 400 µg.)

Capacitors larger than 470 micro-Farad aren't used very often in normal electronics.

The circuit, with added capacitors



So why does the capacitor take all the electricity, reducing the electricity that makes it to the transistor's base, and thus cause a delay? This is due to a well-known concept: electricity takes the path of least resistance. (This is actually not entirely true: electricity actually goes down all available paths, but more electricity will go down paths with less resistance.)

So, why does the capacitor have the least resistance? Uncharged capacitors have almost no resistance, and the resistance goes up the more charged they are.

The words "path of least resistance" appear in other contexts too! For example, if many people say that you should do something, it may take more effort to convince everyone that you shouldn't do it, than just doing the task. Even if you don't like the task. So taking the "path of least resistance" would be to just do the task and get it

over with.
Of course, if you are asked to do something bad, you shouldn’t do it, even if you have to convince people that the thing is bad.
So for humans, choosing the path of least resistance can be good, and it can be bad. Life can get pretty complicated here.
But for electricity, it’s just the way things go. Electricity doesn’t think about which path to take, it’s just forced to take a certain path.
Water flows in a similar way. If you open a small hole and a big hole in a plastic bottle filled with water, much more water will flow out of the big hole.
There will still be some water flowing out of the small hole – and it’s the same with electricity.

Appendix

Circuit simulation

Here is a site that allows you to simulate circuits:
https://www.falstad.com/circuit/circuitjs.html
Using this site, you can build and try out circuits without having to build them out of real components! Once you have determined that the circuit works correctly you can build it on a breadboard.

Summary

Voltage: determined by the power supply. The coin battery produces 3V.
Current: determined by the components of the circuit. Will often need to be limited using a resistor
Short circuit: directly connecting the + side of a power supply with

its – side. The current will be unlimited, only limited by the power supply's properties. Heat will be produced and something might explode!

LED: light-emitting diode

Diode: only lets electricity pass in one direction

Resistor: limits the current in a series ("chain") of components. Voltage ÷ resistance = current limit

Capacitor: stores a small amount of electricity, usually much less than a battery. Can be used to delay the flow of electricity

Transistor: allows us to use electricity to control whether to let electricity through or not. Requires a current limit on the base.

Multimeter usage

Multimeters are called *multi*meter because they can measure multiple (many) things. Most multimeters can measure voltage, resistance, diodes, and current. To measure voltage, resistance, or diodes, you just have to hold the multimeter's probes to the spot you want to measure.

To measure current, however, you have to hook the multimeter into the circuit. Maybe you can ask your parents to show you how to do it! Beware though, the current measurement mode can be dangerous. When measuring current, all the electricity has to pass through the multimeter. (So you have to wire the multimeter into the circuit.)

Remember, the current depends on the components in the circuit. If there are no components, that's a short circuit! A lot of current will pass through the multimeter. Multimeters have some protection built in – if a certain amount of milliamps or amps pass through the multimeter (and many multimeters only allow up to 200 mA; this is a rather small current), a replaceable component called a “fuse” inside the multimeter will break. Replacing the fuse isn’t hard, but you have to go to a store selling fuses (for example, a home improvement store) and purchase a fuse. Make sure it’s the correct fuse, otherwise the multimeter will be very unsafe! The fuse has markings on it, and a shop selling fuses would be able to read these markings and sell you a replacement fuse.

Other multimeters allow 10A or more, but give a time limit of (for example) 10 seconds. The multimeter will usually have this information printed on it! If you aren’t sure, ask someone or check the multimeter’s manual.