intro to circuits

lesson 2 - where stuff lights up

about this document

The actual class was taught on a whiteboard, so this is my attempt at translating it to a presentation that can be looked at.

Please let me know if any areas are unclear and I can amend it.

about this document

Also I'll stick to mostly just including circuit schematics here.

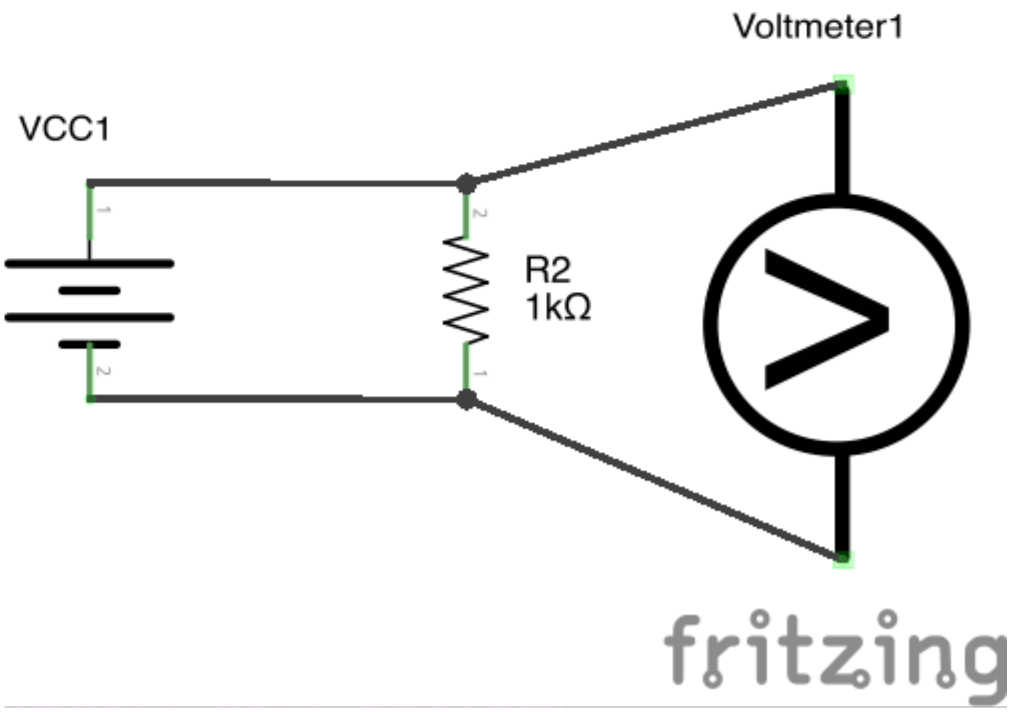
Accompanying example breadboard layouts are at https://github.com/wileycousins-edu/intro_to_circuits/

multimeter review

Here’s a quick (and important) reminder about the difference between measure voltage and current with your multimeter.

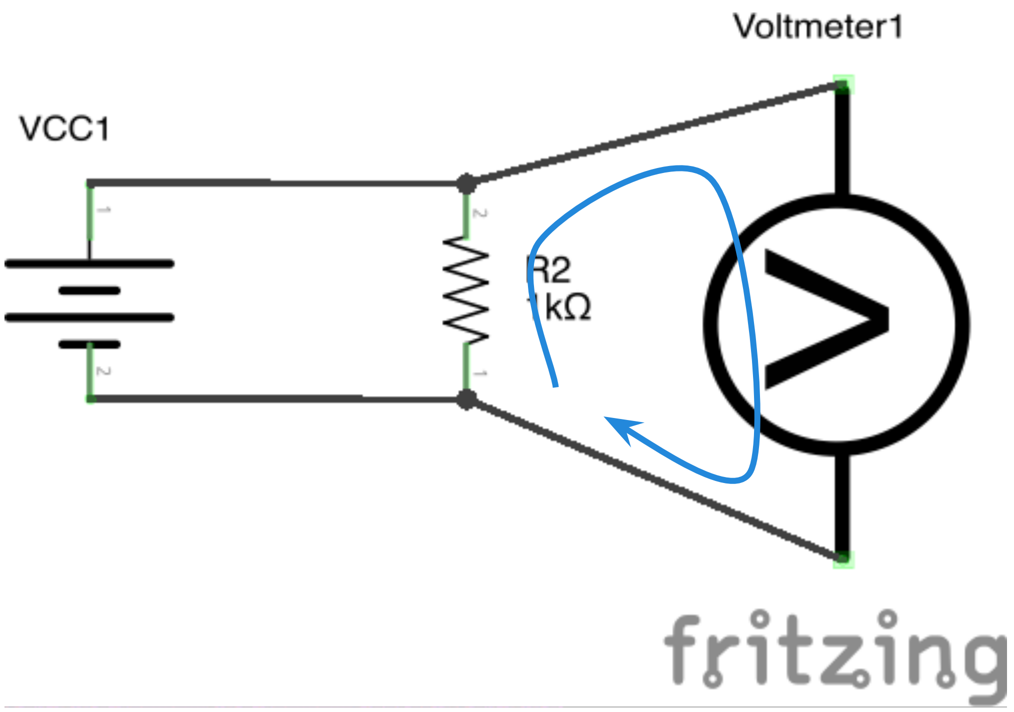
measuring voltage

To measure voltage, put the voltmeter IN PARALLEL with the component being measured



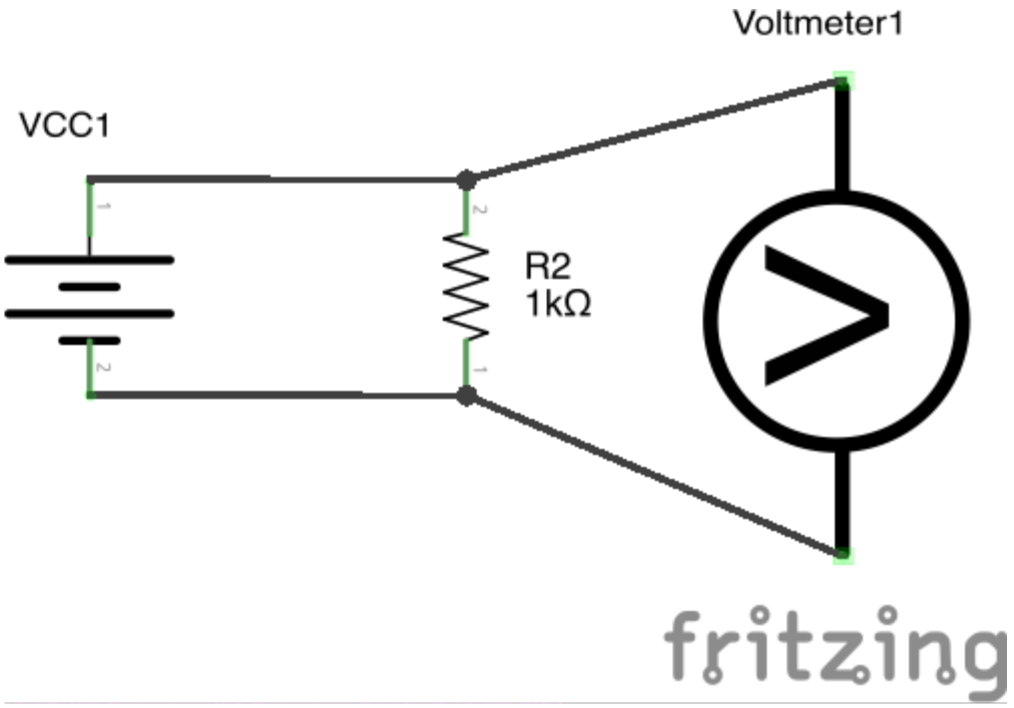
measuring voltage

Because of Kirchhoff's Voltage Law, we know that the voltage across the meter and the resistor are the same.



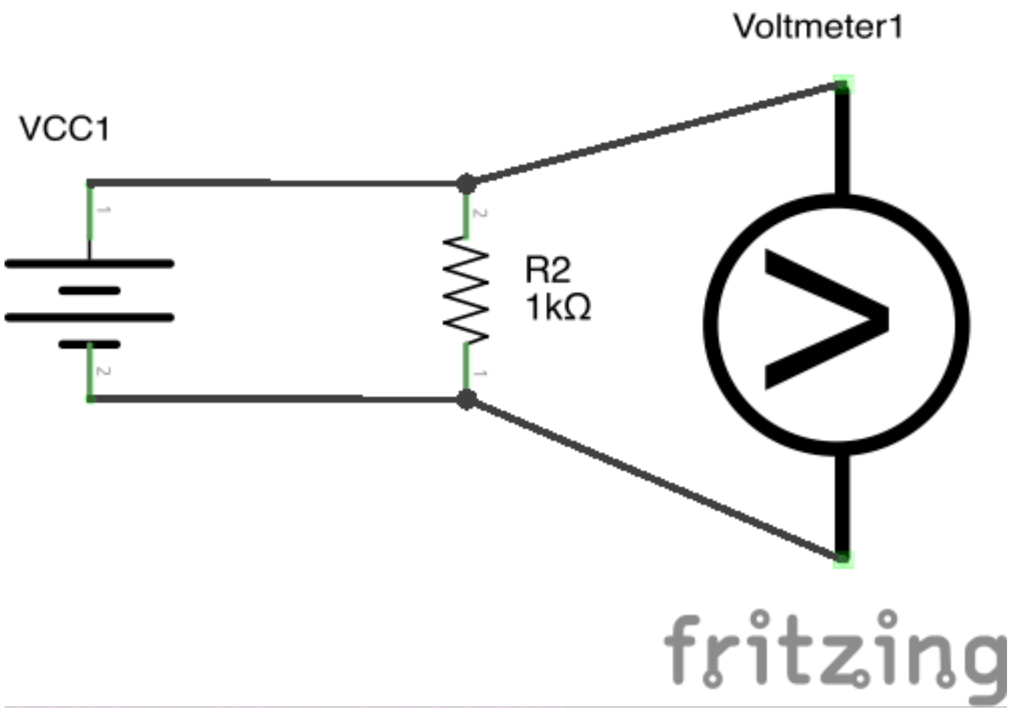
measuring voltage

In this circuit, the voltmeter can be modeled by a resistor with very high (~10MΩ) resistance.



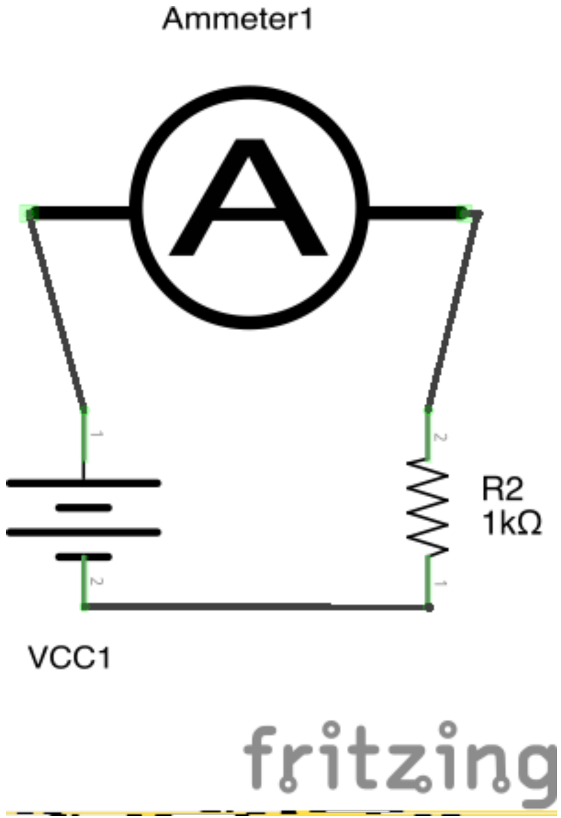
measuring voltage

This way, the voltmeter is only an observer. Because the resistance is so high, basically no current is lost to it.



measuring current

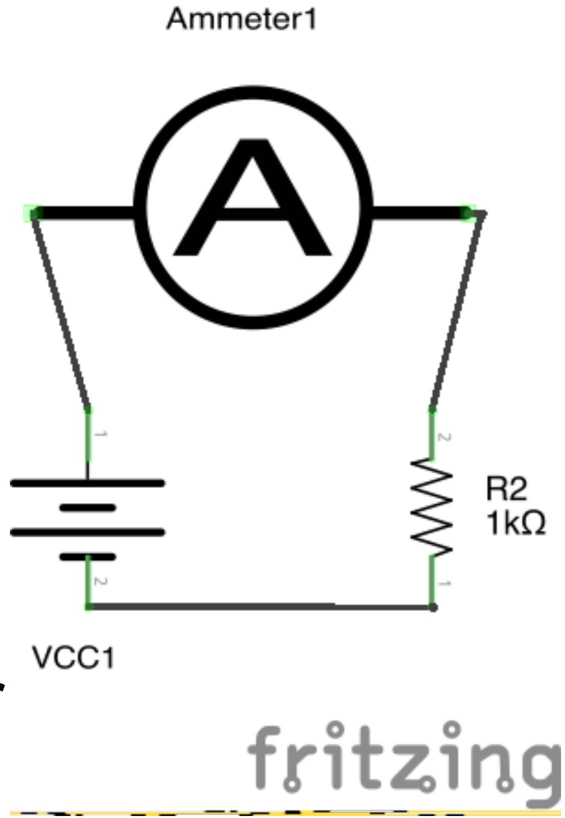
For measuring current, the ammeter must be placed IN SERIES with the part being measured.



measuring current

This is so the current through the ammeter and the resistor are the same.

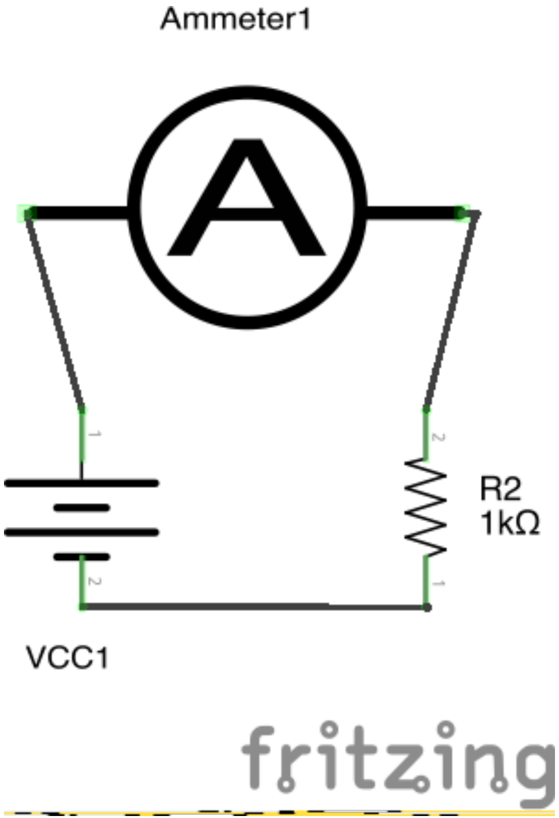
Remember Kirchhoff's Current Law? Notice how there are no nodes between the part and meter



measuring current

In this circuit, the meter can be modeled as having basically no resistance.

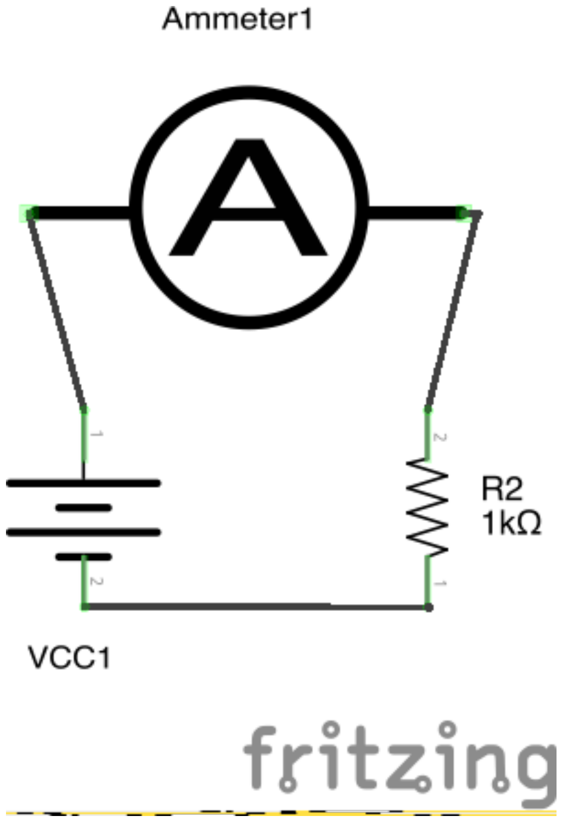
It needs to observe the current, so if it had an resistance, it would affect the current.



if you mess up

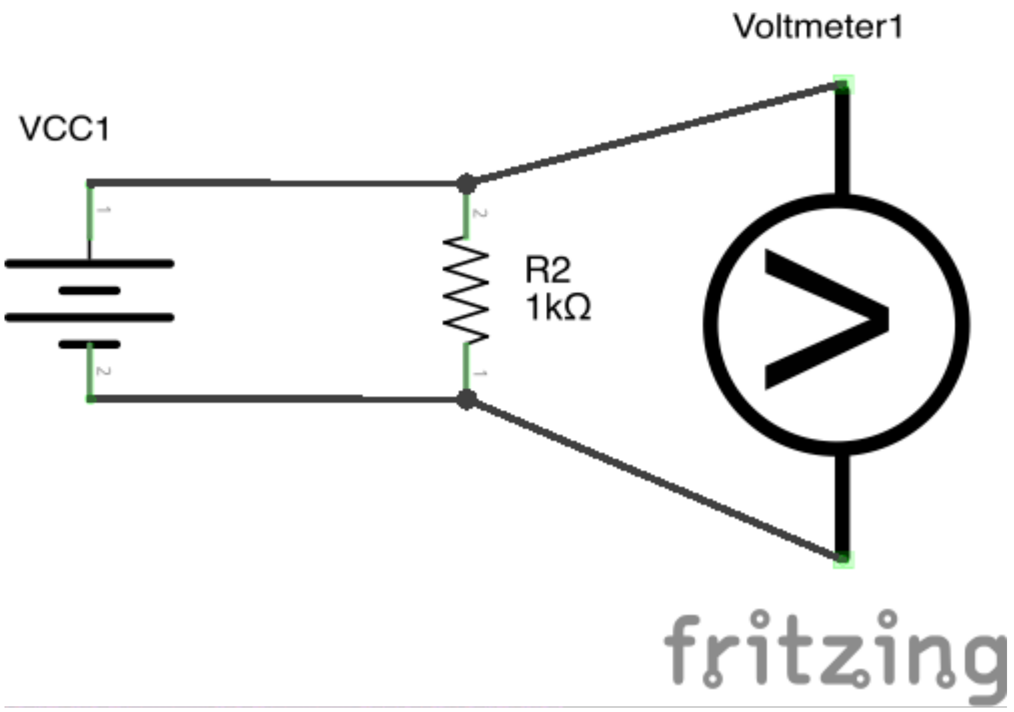
Let's think about what would happen if you turned this multimeter to a voltage setting.

Whatever you got, would the number be at all valid? No.



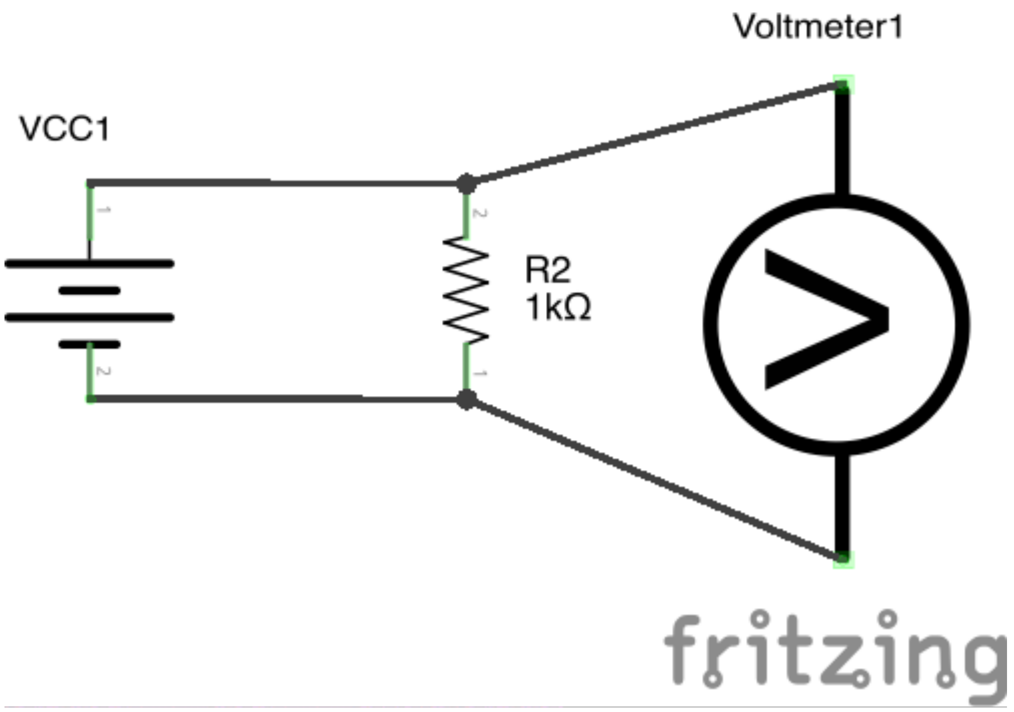
if you mess up

Now, let's think about what would happen if you turned this multimeter to current.



if you mess up

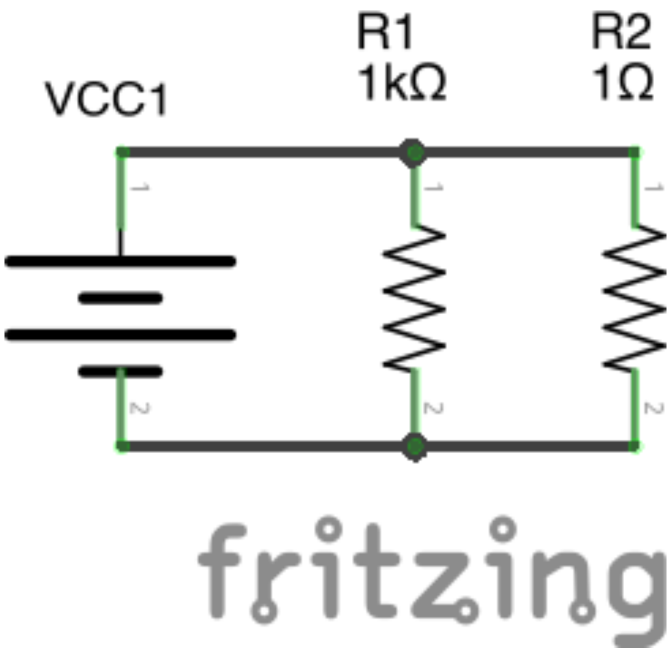
Remember that a multimeter in current mode has effectively no resistance.



if you mess up

So, with an ammeter in parallel to the part, we basically have this circuit.

How much current is going to flow through our ammeter (R2)?



if you mess up

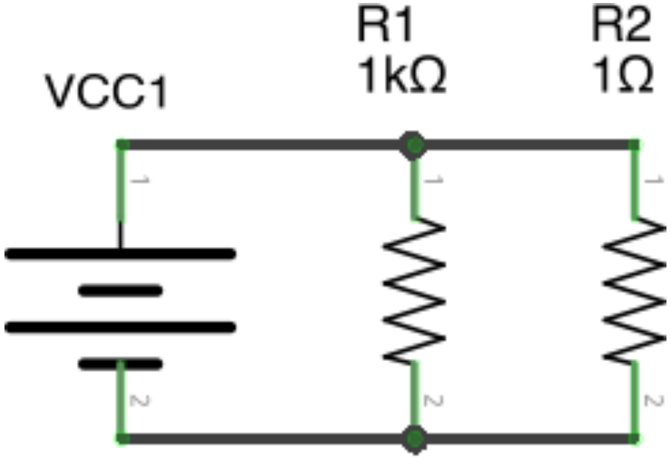
V_R1 = V_R2 = 5V

i_R2 = V_R2 / R2

i_R2 = 5V / 1Ω

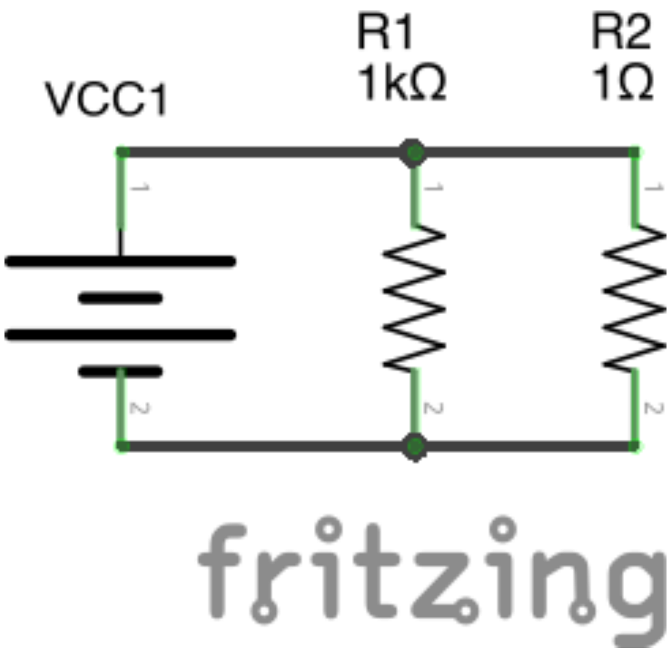
i_R2 = 5 A

Guess what: That's a lot of current!



if you mess up

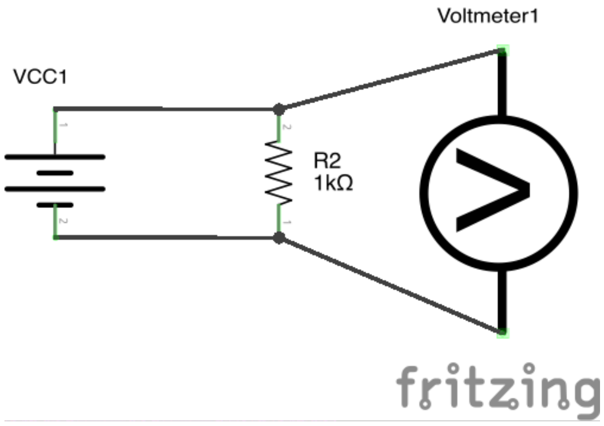
It’s actually so much current that the protective fuse in your multimeter will trip, so you will be unable to use your multimeter until you get a new fuse from RadioShack

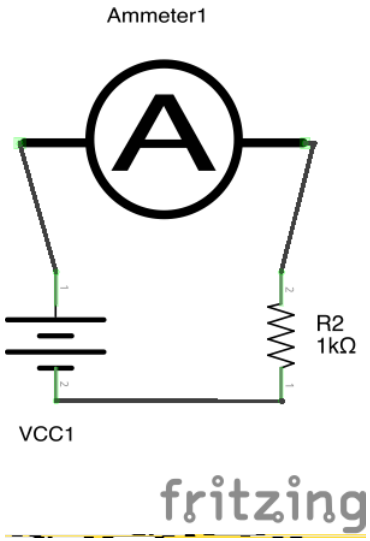


nobody wants to go to RadioShack

So, always remember:

Voltmeter in parallel, ammeter in series





lesson 1 recap

In lesson 1, we learned about:

- Charge, current, and voltage
- Resistors and Ohm’s Law
- Kirchhoff’s Circuit Laws
- Breadboards
- Multimeters

lesson 1 recap

At this point, if any of those words seem unfamiliar, I would recommend going back over the lesson 1 presentation and spending some time with the recommended reading.

switching it up

Before getting into the super fun stuff, we're going to look at a component called a switch.

They're very complicated.

switches (pushbuttons)

You have about five of these in your kit:

switches (pushbuttons)

This switch is what's called "normally open". This means that normally, the internal connection is not connected (open). When you press the button, the two sides of the button connect (close).

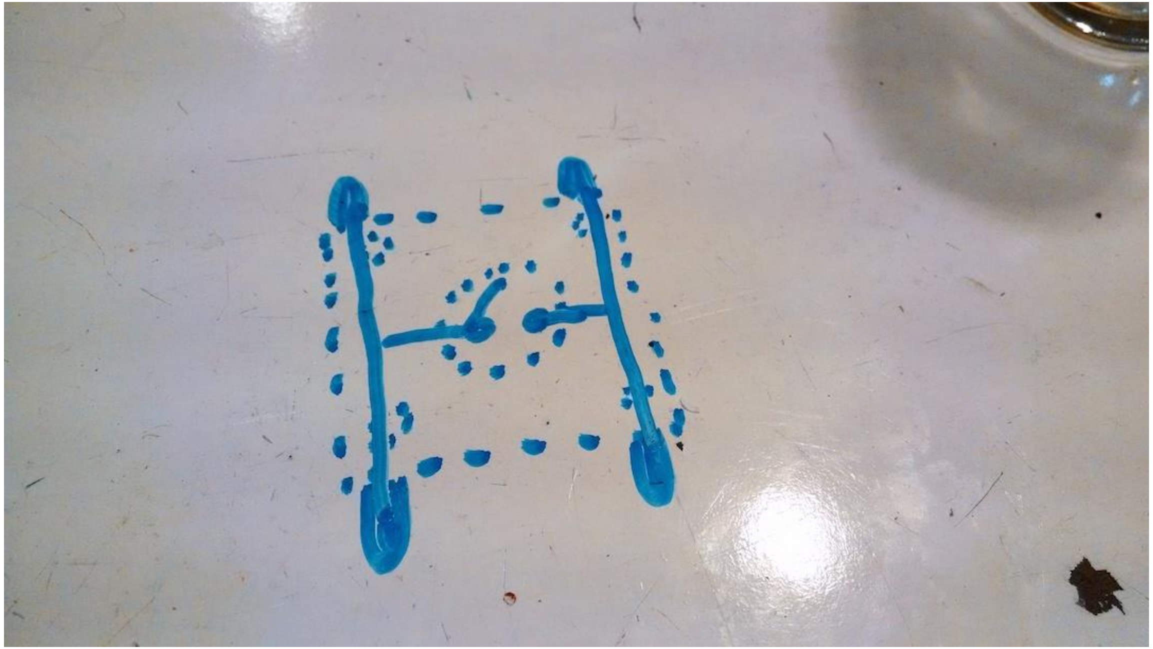
switches (pushbuttons)

Notice that I said two sides, despite the fact that the switch has four legs.

In this particular switch, there are two pairs of legs that are always connected to each other, but only connect to the other pair if the button is pushed.

switches (pushbuttons)

Because pictures are better than words:

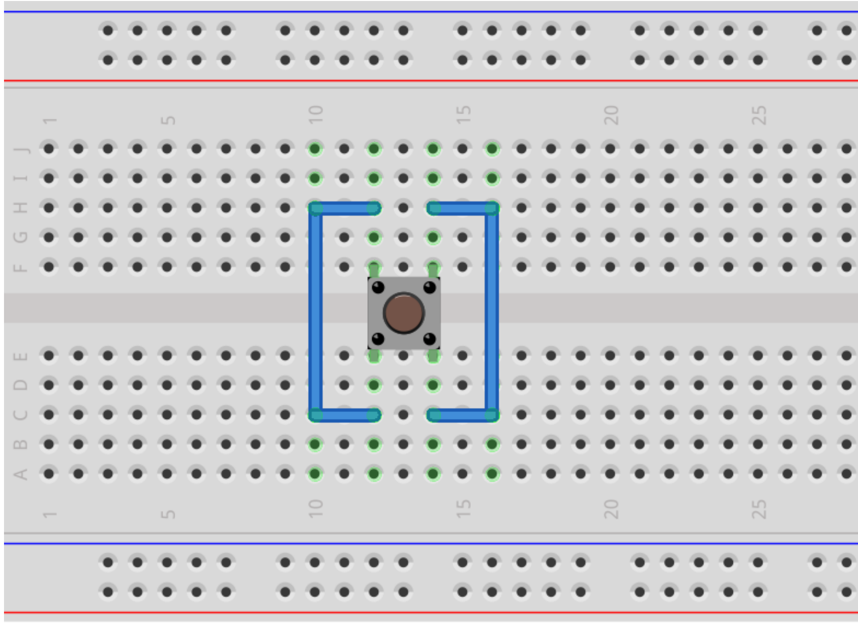


switches (pushbuttons)

Use your multimeter in continuity mode to check which legs are always connected to each other, and how the legs connect when you press the button.

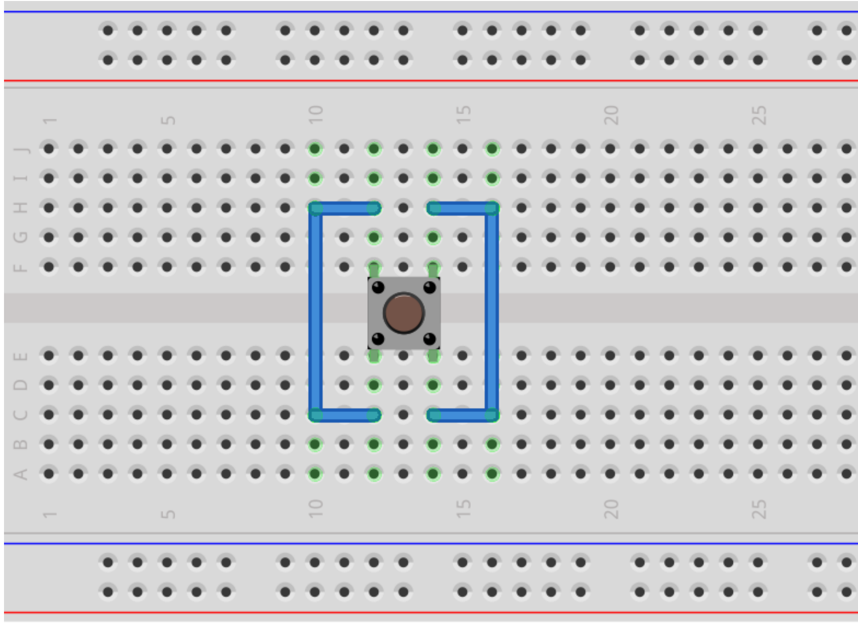
switches (pushbuttons)

I would recommend plugging it into your breadboard like this. The wires are there to show you which legs are connected; don't put the wires in your breadboard.



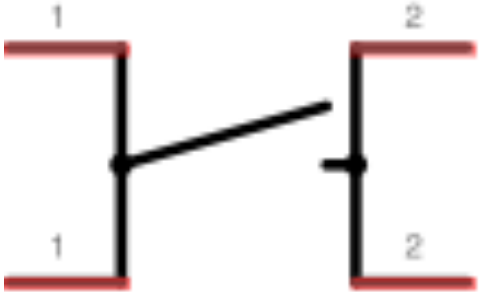
switches (pushbuttons)

If you build a circuit with a switch and it’s not behaving properly, use your continuity meter to make sure the switch is oriented and placed properly.



switches (pushbuttons)

In circuit diagrams (which you should ALWAYS draw before you build a circuit, a switch will look like:



diodes

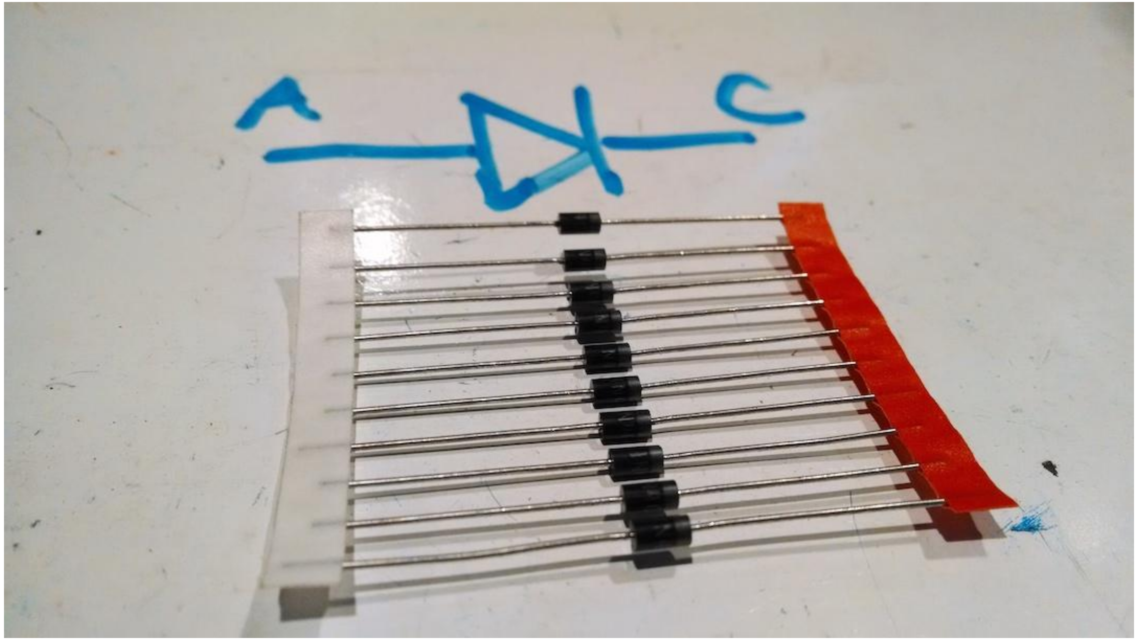
What’s a diode? Well, a diode is another type of component.

What it do?

Source: http://en.wikipedia.org/wiki/Diode

what diodes do

First off, these are your diodes:



what diodes do

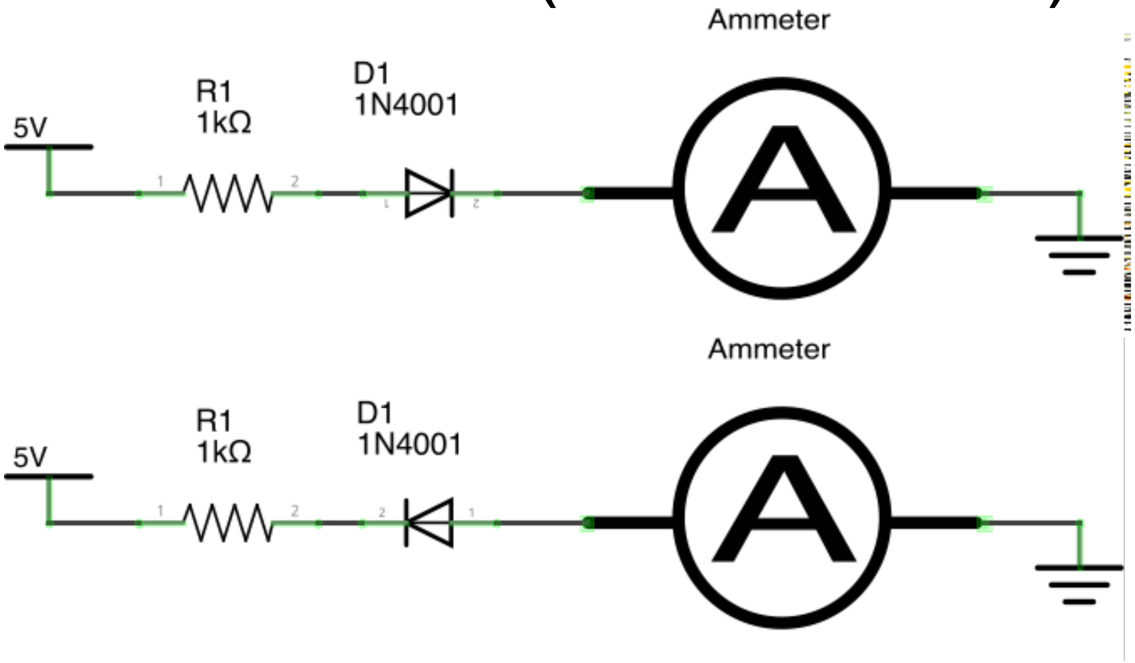
Notice how the symbol of the diode is an arrow.

That's because diodes only allow current to flow in the direction of the arrow, from anode to cathode (A to C).

Source: http://en.wikipedia.org/wiki/Diode

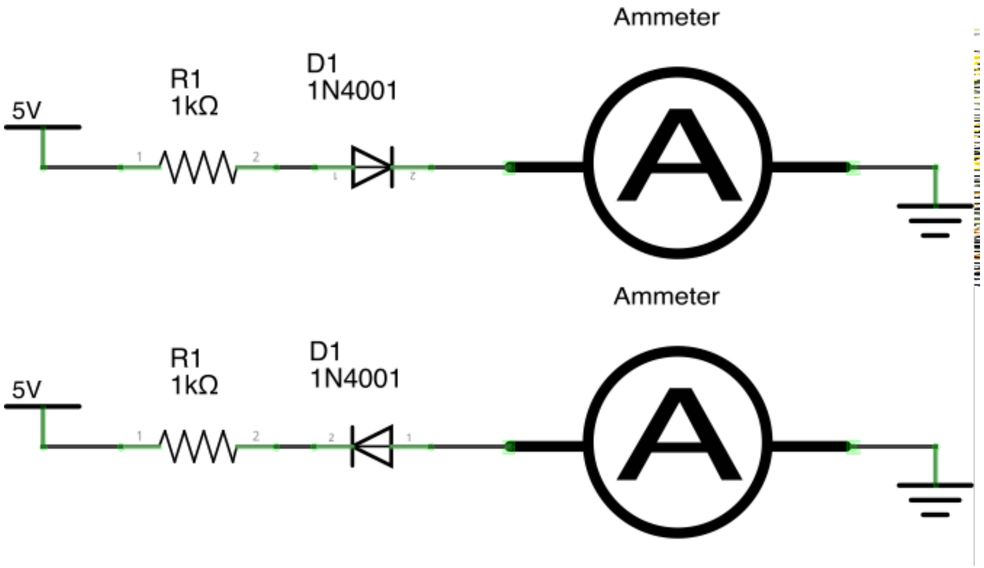
what diodes do

Try these two circuits (circuit 2-1-a/b):



what diodes do

In the top one, your ammeter will read a few milliamps. In the bottom one, it’ll read 0.



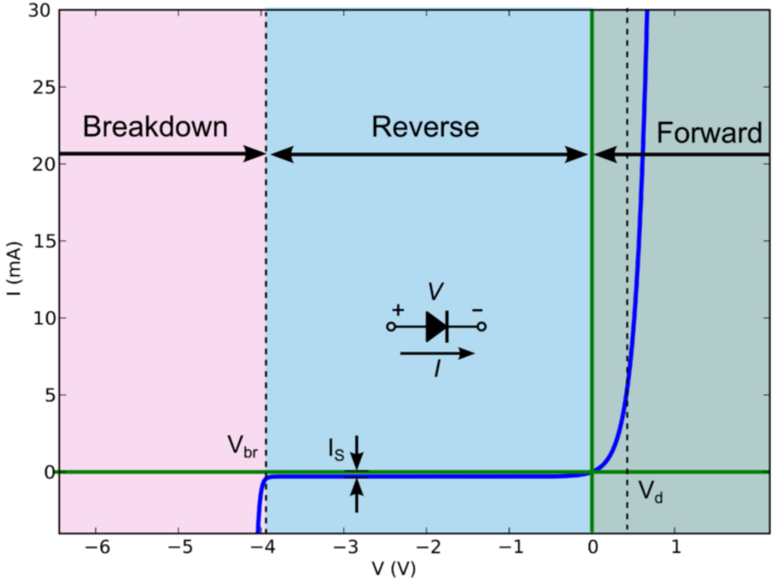
getting more involved with diodes

Every component reacts differently to an applied voltage.

For example, a resistor will allow current to flow in a proportional amount to the voltage ($i = v/R$).

getting more involved with diodes

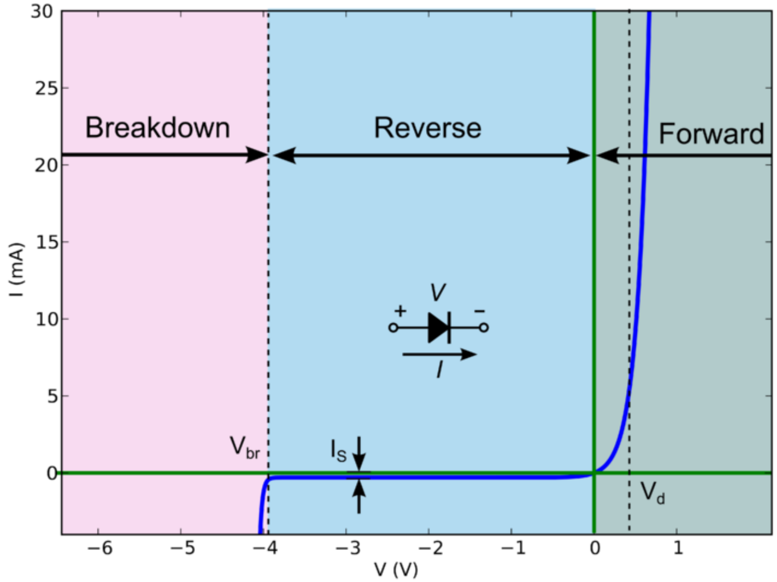
Diodes have their own relationship. It looks like this:



http://en.wikipedia.org/wiki/Diode

things to notice about diodes

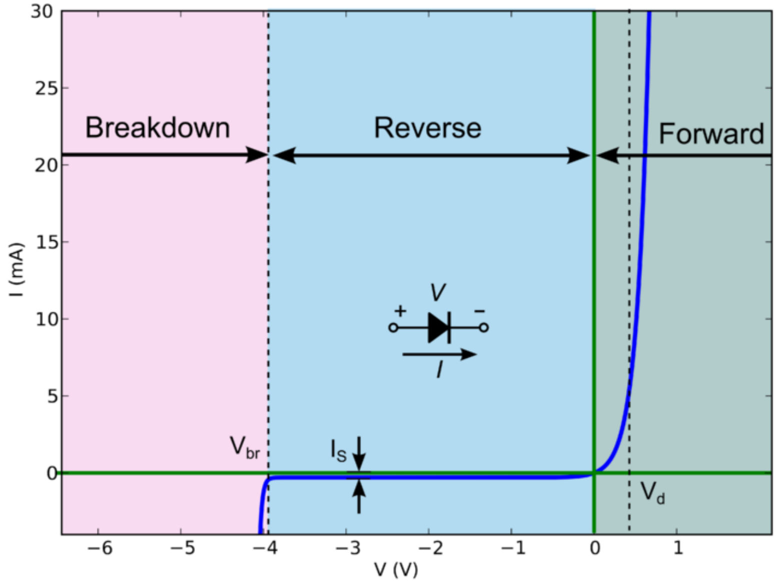
Diodes have a breakdown voltage. If more than this voltage is applied backwards across the diode, it will break and allow current to flow the "wrong" way



http://en.wikipedia.org/wiki/Diode

things to notice about diodes

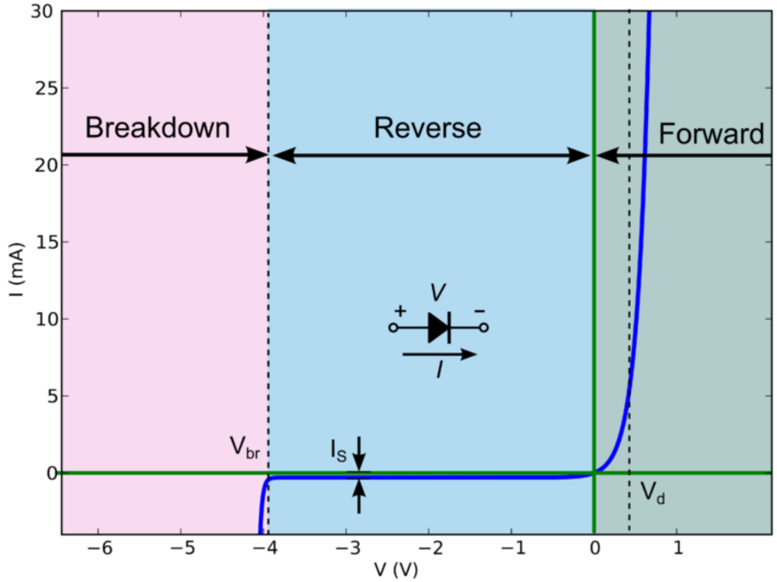
If the voltage is negative but above the breakdown voltage, basically no current will flow (in reality there is a slight current leakage).



http://en.wikipedia.org/wiki/Diode

things to notice about diodes

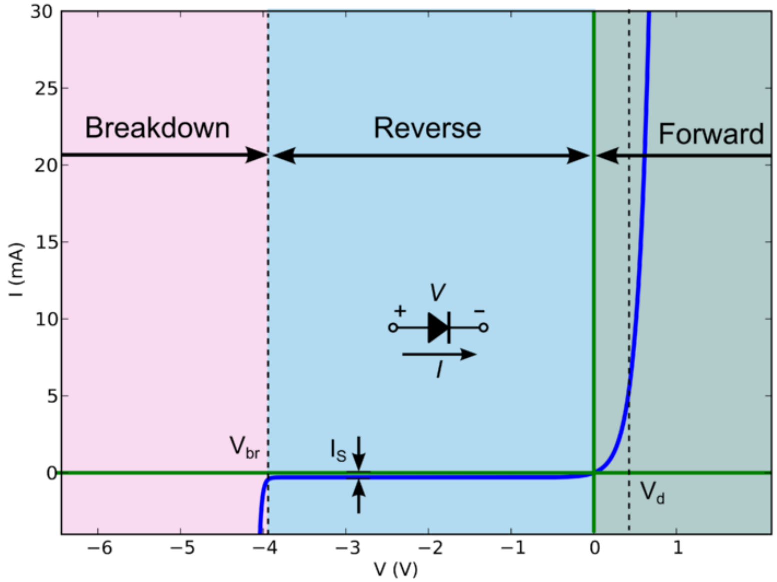
Finally, if there is a positive voltage applied, the amount of current will increase very rapidly.



http://en.wikipedia.org/wiki/Diode

things to notice about diodes

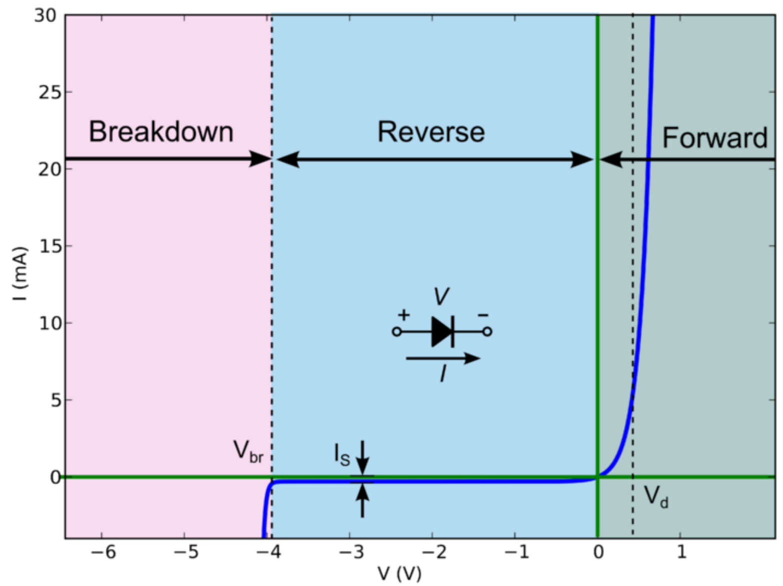
However, if we can control the current going through the diode, no matter what the current is, the voltage drop across the diode will be pretty much the same.



http://en.wikipedia.org/wiki/Diode

things to notice about diodes

Compare the voltage drop for 25 mA to the voltage drop for 5 mA. It's something like 0.6 V vs 0.4 V. For our purposes, this is effectively equal.



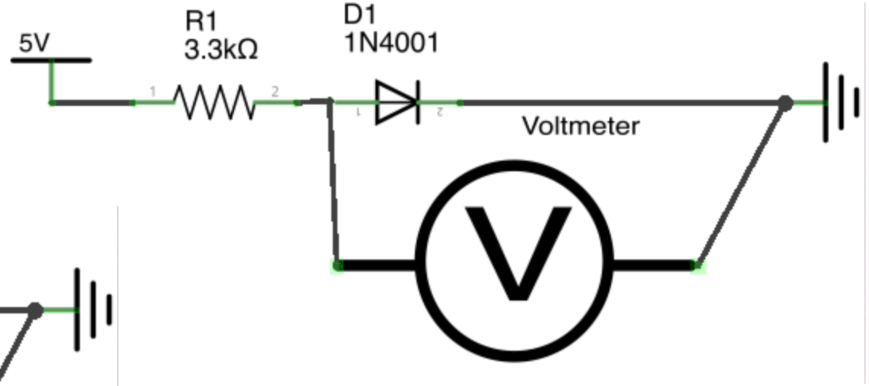
http://en.wikipedia.org/wiki/Diode

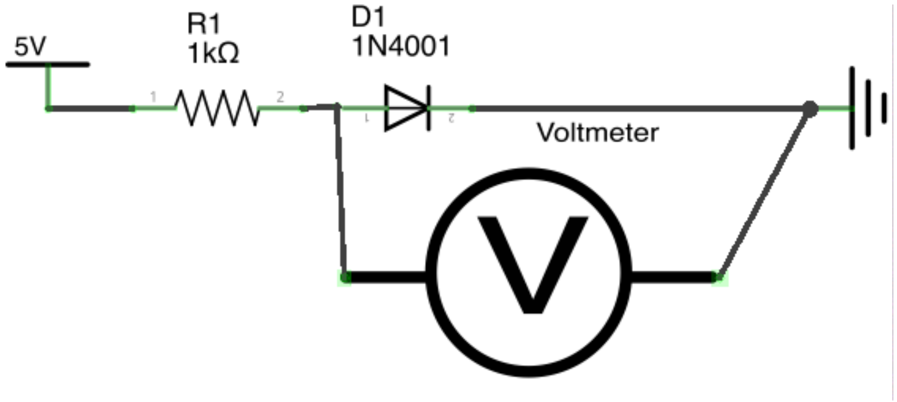
controlling diode current

How do we control the current? With a resistor! Remember that resistor in Circuit 2-1? That’s why that was there.

controlling diode current

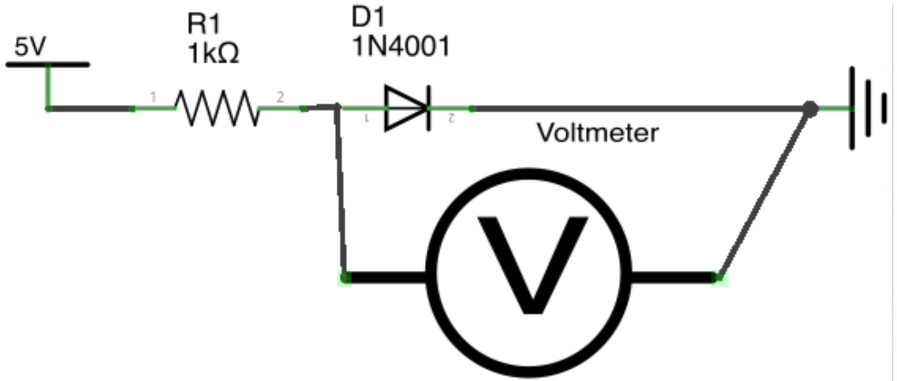
Let’s build these guys (circuit 2-2-a/b):

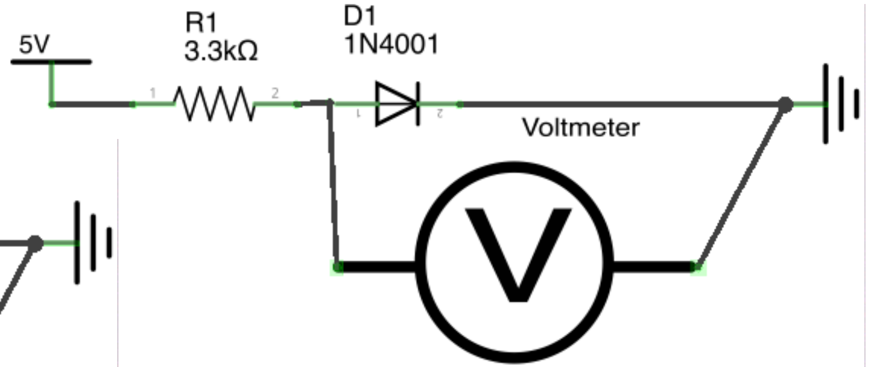




controlling diode current

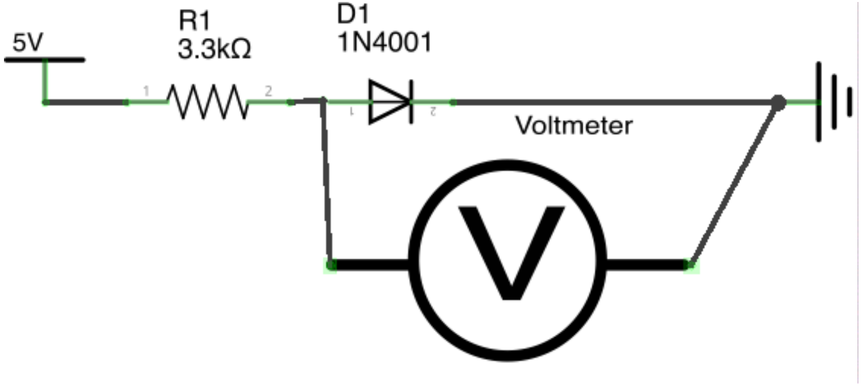
You'll notice that your voltmeter reads about the same (~0.4 to 0.6V) for both.





controlling diode current

How much current is flowing though? Well, from Kirchhoff, we know that 5V = v_R1 + v_D1, and from the properties of a diode, we know that v_D1 = 0.4 V.



controlling diode current

So:

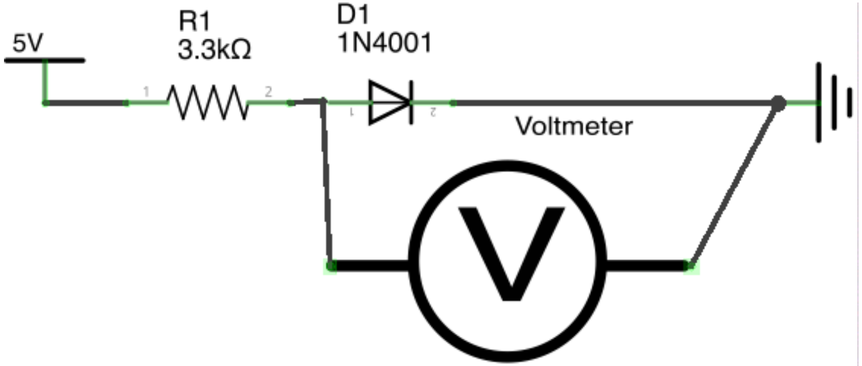
V_R1 = 4.6 V

i_R1 = v_R1 / R1

i_R1 = 4.6 V / 3.3 kΩ

i_R1 = 1.4 mA

(these numbers will not be exact)



diodes aren’t that exciting...

Oh yeah? Well how about you meet my friend Light Emitting Diode? LEDs!

I’ve seen an LED before man

Look, you’re taking an introduction to circuits class. It’s the best I can do right now.

And if we’re honest, they’re probably the biggest reason you took this class.

light emitting diodes

Light emitting diodes are diodes that emit light. Shocking (please don't shock yourself) stuff.

light emitting diodes

You have 10 each of red, yellow, and green LEDs. As opposed to a normal diode (~0.6 V), these all have a forward voltage of about 2.1 V.

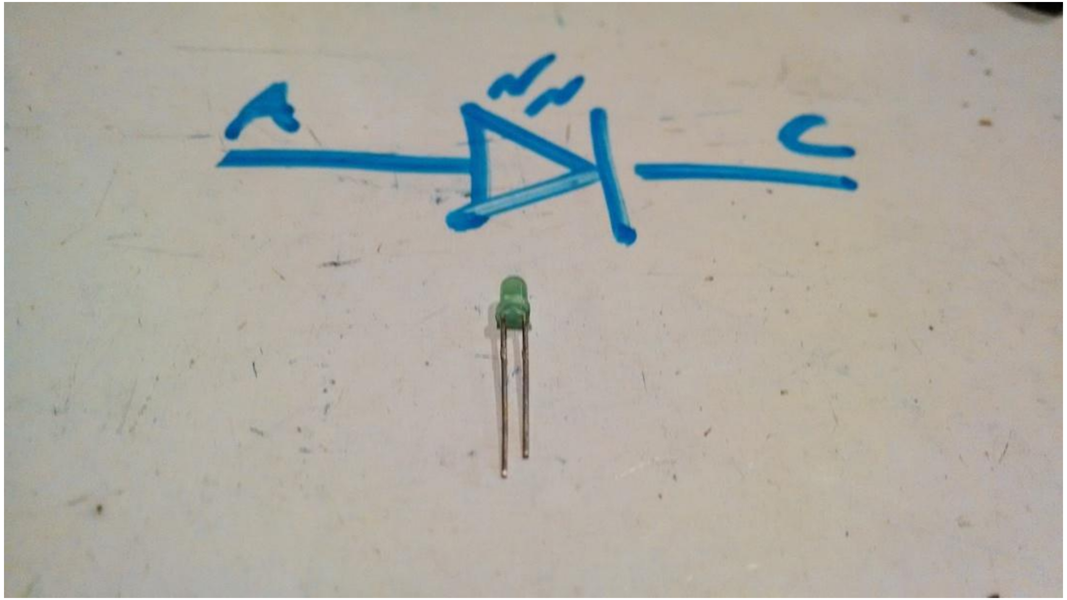
They also have a breakdown voltage in the neighborhood of 5 V (the normal diodes are like 50 V).

light emitting diodes

Also, you will likely fry the LED with anything more than 30 mA for an extended period. So, don’t hook your LEDs directly to your power rails, forwards or backwards. Either way could fry it.

light emitting diodes have direction

Speaking of forwards and backwards, which is which for an LED? Look at the legs of the LED. The longer leg is the anode (positive end).

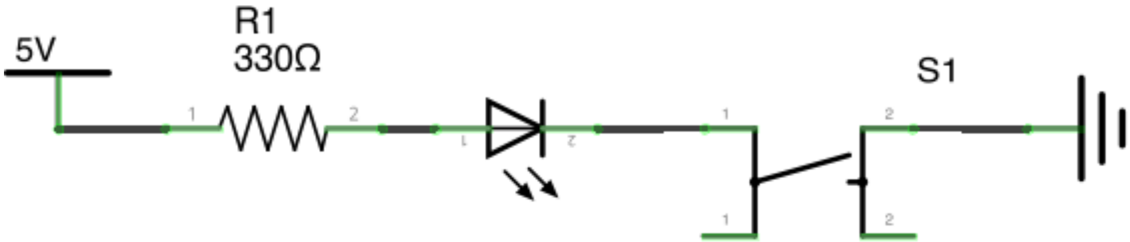


light emitting diodes

So, let’s design a circuit to light up an LED with 10 mA (which is a generally good number to go with for LED current. Go for 20 if you want it brighter).

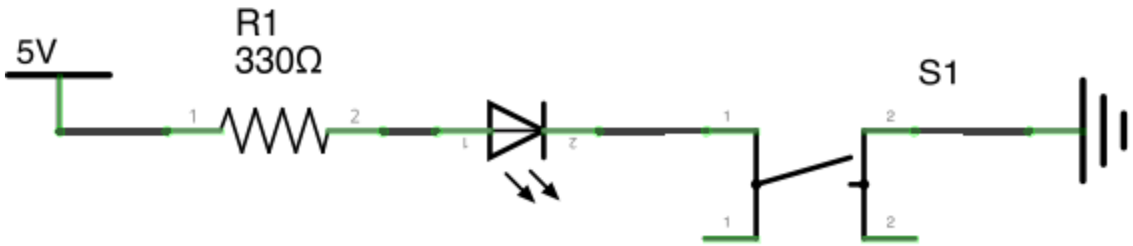
light emitting diodes

Using our same diode current control circuit (note that it doesn't matter which side of the LED the resistor is on; since it's in series with the LED they'll have the same current regardless).



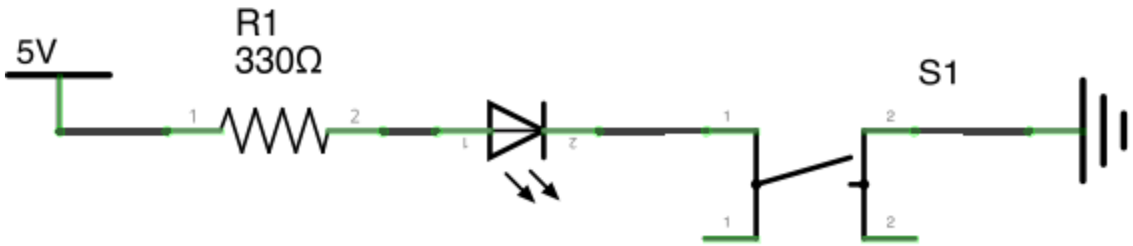
light emitting diodes

Press the button, and the LED will light up. Woo. But also, how did we get 330Ω?



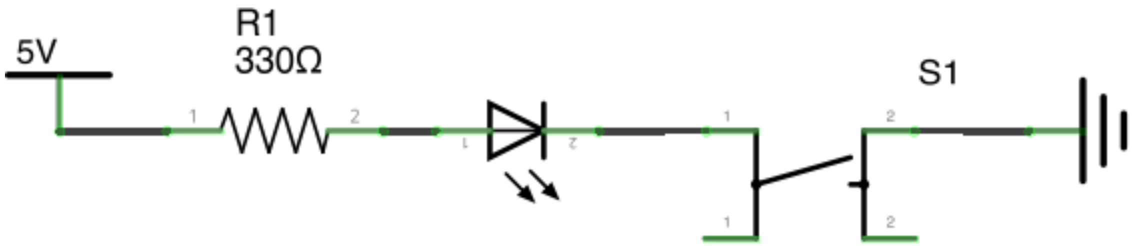
light emitting diodes

Well, we know: 5V = v_R1 + v_LED, and we know that v_LED = 2.1V. So v_R1 = 2.9 V.



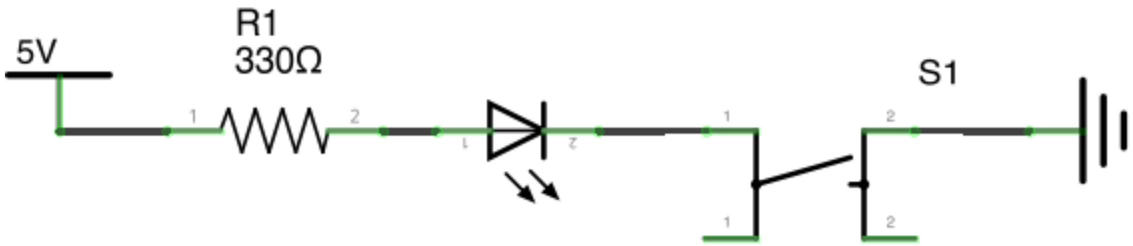
light emitting diodes

We want i_LED = 10mA, and we know that i_LED = i_R1. And i_R1 = V_R1 / R1



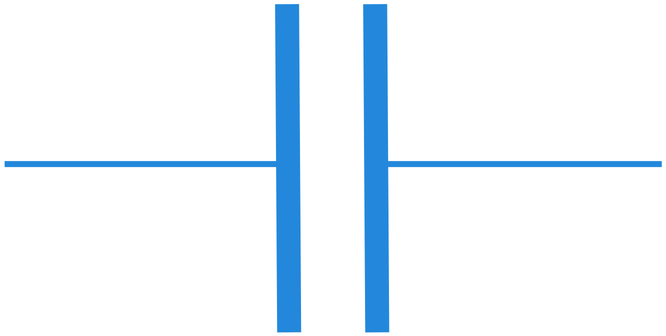
light emitting diodes

$10mA = 2.9V / R1 \rightarrow R1 = 290\Omega$. The closest value to 290Ω we have in our kits is 330Ω, and that is definitely close enough™.



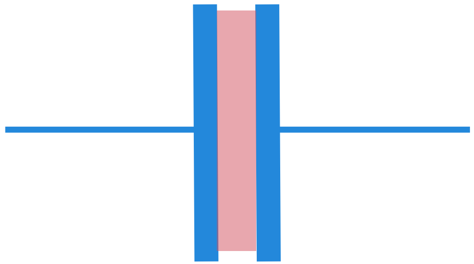
capacitors

The last component we're going to do this lesson is called a capacitor. This is the symbol:



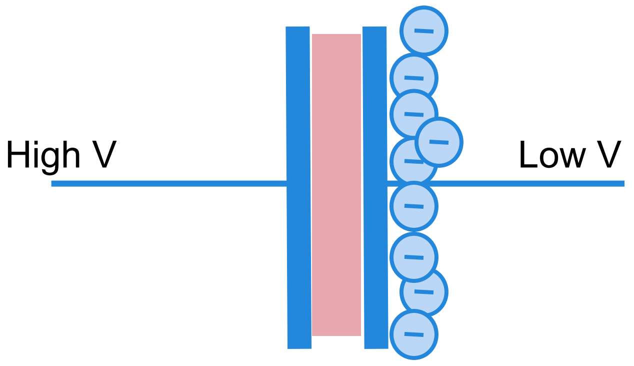
capacitors

Capacitors are two metal plates that are very close together, but separated by an insulating material that can align itself with an electric field, called a dielectric.



capacitors

If you apply a voltage across the capacitor, electrons will want to flow*. But the dielectric will stop them, so the electrons will pile up on one side, and the voltage difference will remain the same.

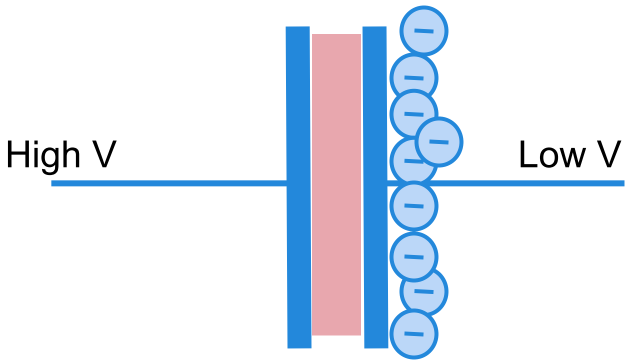


*Aside: electrons have a negative charge, so if positive current is “flowing” in one direction, what is physically happening is that electrons are moving in the opposite direction. This is because science is stupid, and because scientists discovered electricity before they discovered electrons were the charge carriers. They had assumed the charge carriers were positive. (Fun fact thanks to Kaben)

capacitors

The measure of how much charge (i.e. how many electrons) the capacitor can hold vs the voltage applied is called its:

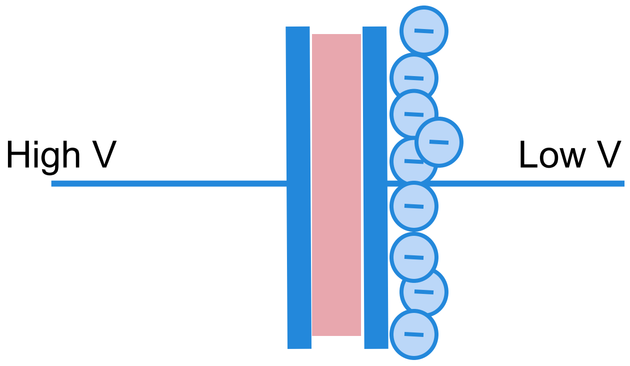
capacitance = C [=] Farads



capacitance

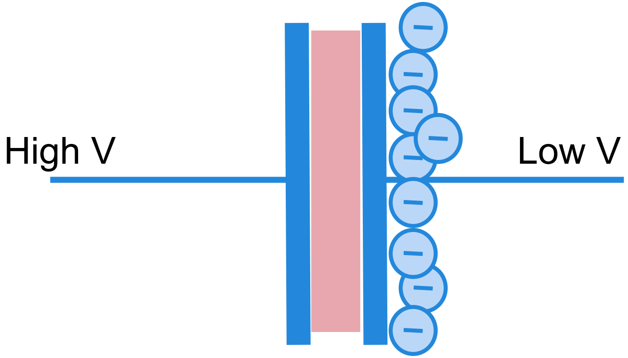
C = q / v where q is charge (from lesson 1)

C is measured in Farads. Because 1 Coulomb (measure of charge) is enormous, so is 1 Farad

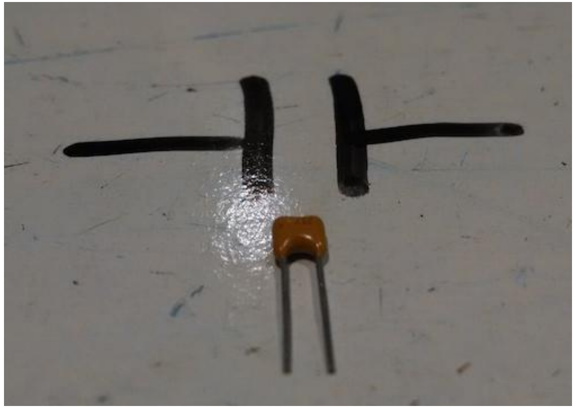


capacitance

You have 4 values of capacitors. The capacitors are the little yellow things.



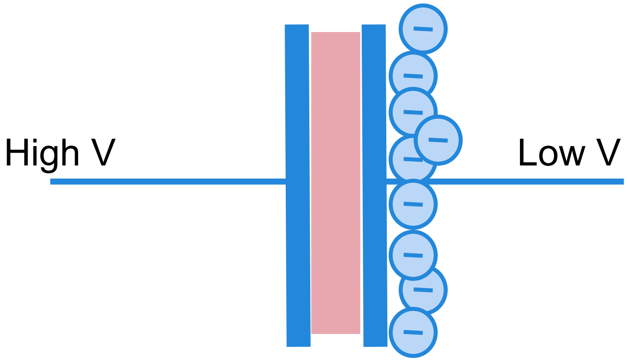
These particular capacitors are not directional.

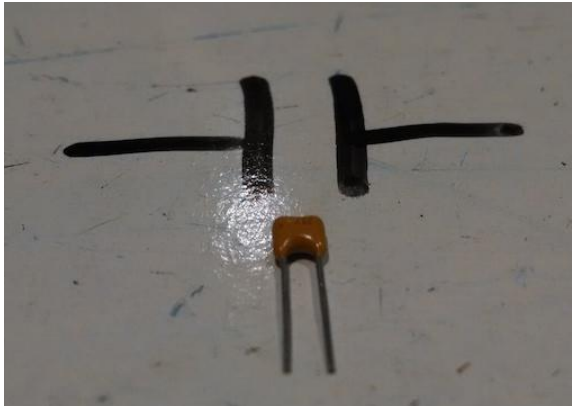


capacitance

On each of these caps, there will be a four-digit code. They mean:

- 101 - 0.1 nF = 100 pF
- 102 - 1 nF = 1000 pF
- 103 - 0.01 µF = 10 nF
- 104 - 0.1 µF = 100 nF





metric prefixes!

p = pico = N * 10^(-12) = N / 1 trillion

n = nano = N * 10^(-9) = N / 1 billion

μ = micro = N * 10^(-6) = N / 1 million

Like I said, 1 Farad is an enormous capacitance. Our capacitors are fractions of a Farad.

capacitance

That code (let's take 104 as an example) is read like:

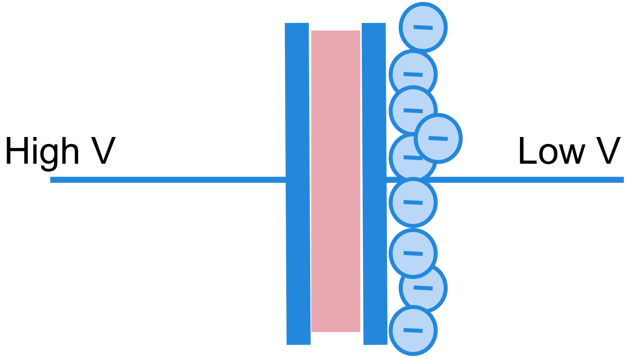
104

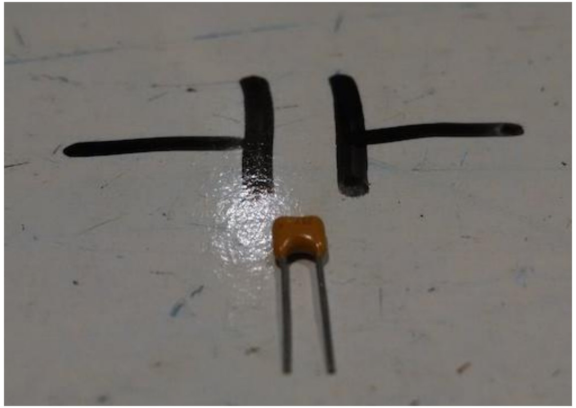
10 pF * 10^(4)

10^(1) * 10^(-12) * 10^(4) F

1 * 10^(-7) F (exponents add)

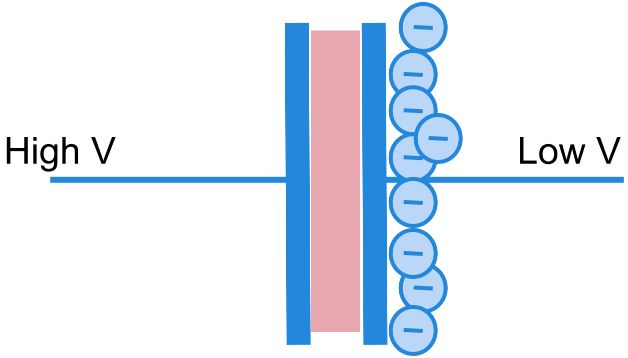
0.1 * 10^(-6) = **0.1µF**



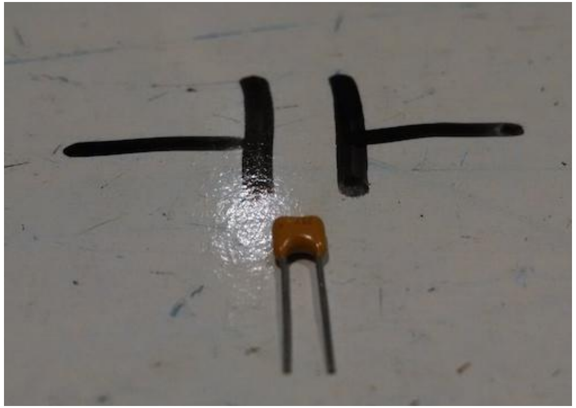


capacitance

Sorry about that. You'll get the hang of it eventually.

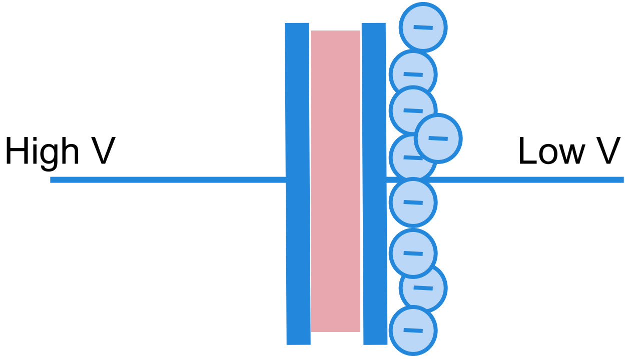


Or you won't, and then Google will be your friend every time you need to remember.



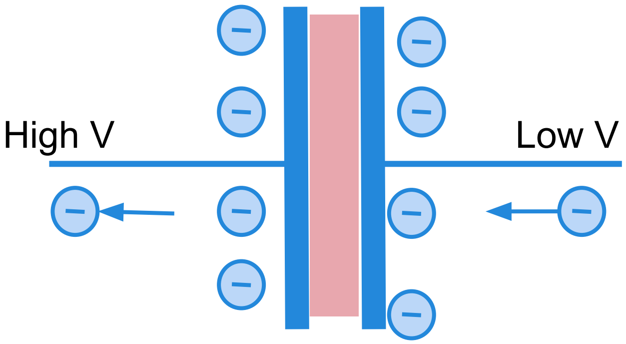
charging a capacitor

Knowing what happens to the charge inside a capacitor involves a little bit of calculus, which we won't do. Instead, we'll look at two points time: when voltage is first applied, and after a while has passed



charging a capacitor

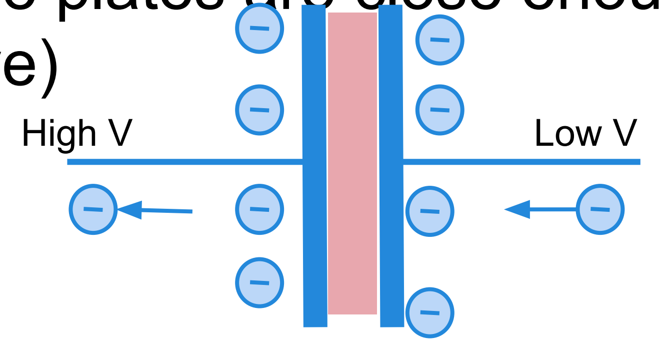
At t=0, there are some electrons hanging out. When the very first electrons arrive from the voltage source, they repel some of the electrons that are already there, and current can flow.



charging a capacitor

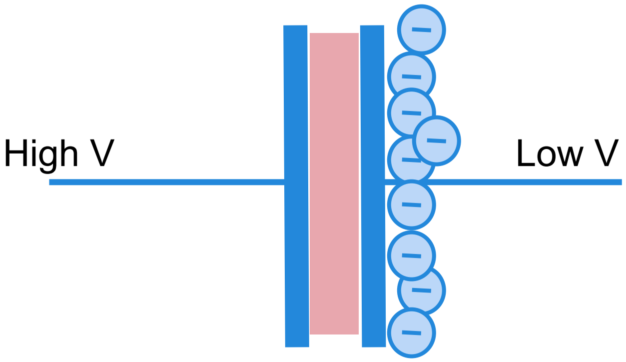
So, at t=0, the capacitor is effectively a bare wire

(remember, though, electrons are not going through the dielectric. It’s just there’s already some electrons there on either side, and the plates are close enough that negative still repels negative)



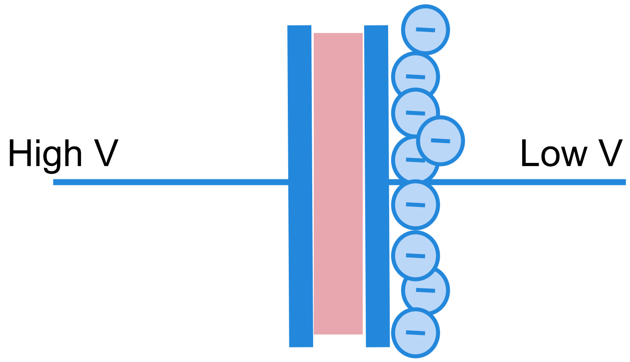
charging a capacitor

After a long time has passed (t=T), there are no more electrons on the high V plate of the capacitor, and no more current flows.



charging a capacitor

So, at t=T, the capacitor is effectively an open switch.



RC circuits

This leads us to a type of circuit that is imaginatively called an RC circuit. The R is for Resistor, and the C is for Capacitor.

RC circuits

How quickly a capacitor is charging at a given instant (i.e. the amount of current flowing through the capacitor) is how much charge is already stored in the capacitor and how much resistance the charge encounters getting to the capacitor.

RC circuits

If there was no resistance, the capacitor would charge almost instantly. The would result in a very large current spike through the power supply, though (remember, bare wire at t=0), and it also wouldn’t be that interesting for us to watch

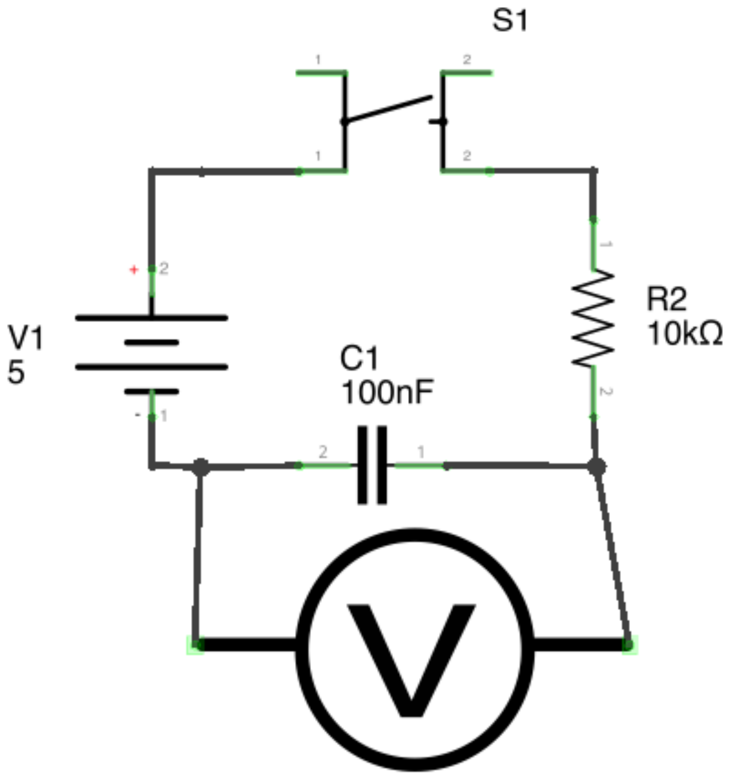
RC circuits

If there was no resistance, the capacitor would charge almost instantly. The would result in a very large current spike through the power supply, though (remember, bare wire at $t=0$), and it also wouldn’t be that interesting for us to watch

RC circuits

So let's build this one (circuit 2-4):

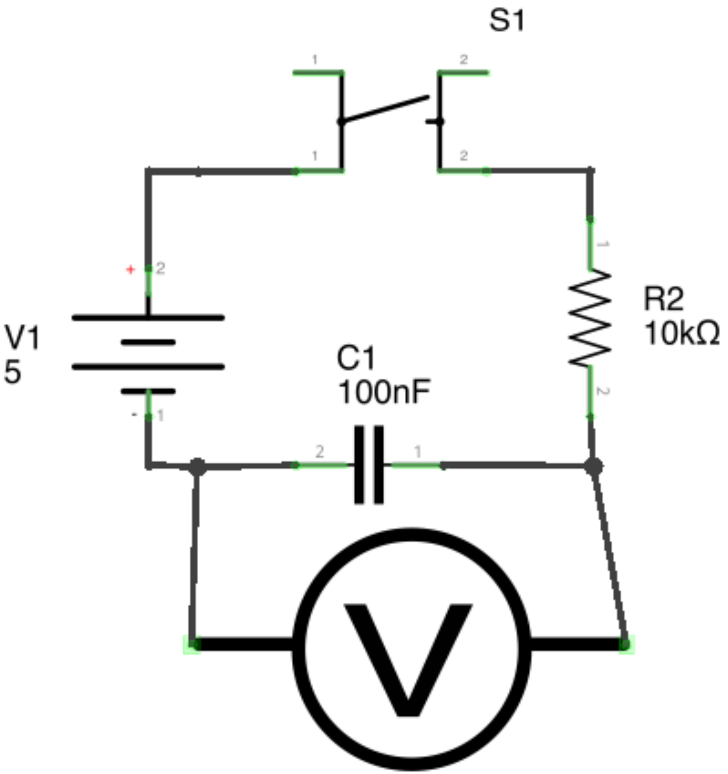
When you hold your switch down, you should see your voltmeter go up to 5 quickly.



RC circuits

You'll notice it doesn't go all the way to 5V. Any idea why?

It's because the voltmeter, even though it tries to be, is not a truly neutral observer. It actually give a little path for the cap to discharge.

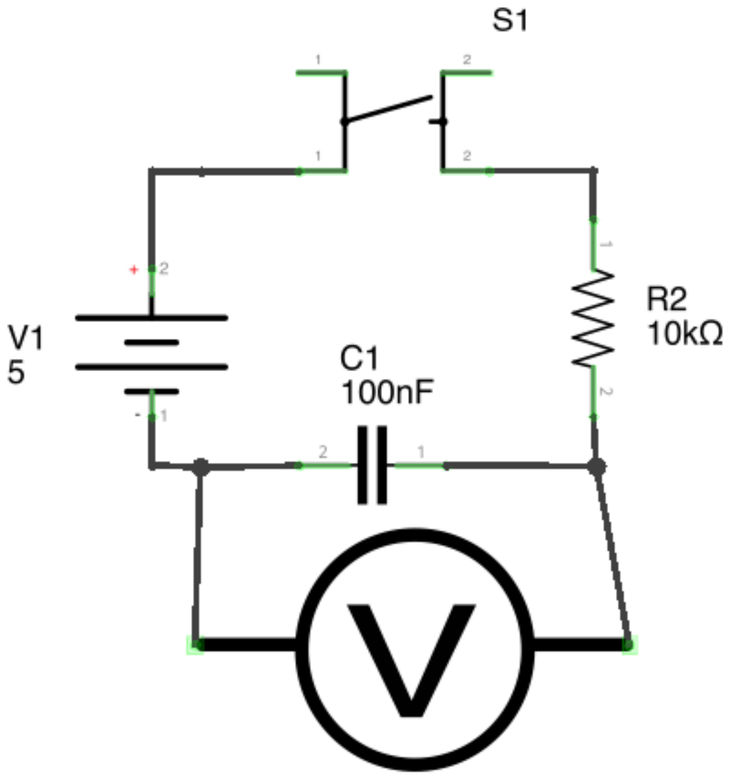


RC circuits

The speed at which the capacitor is charged is determined by the RC constant τ.

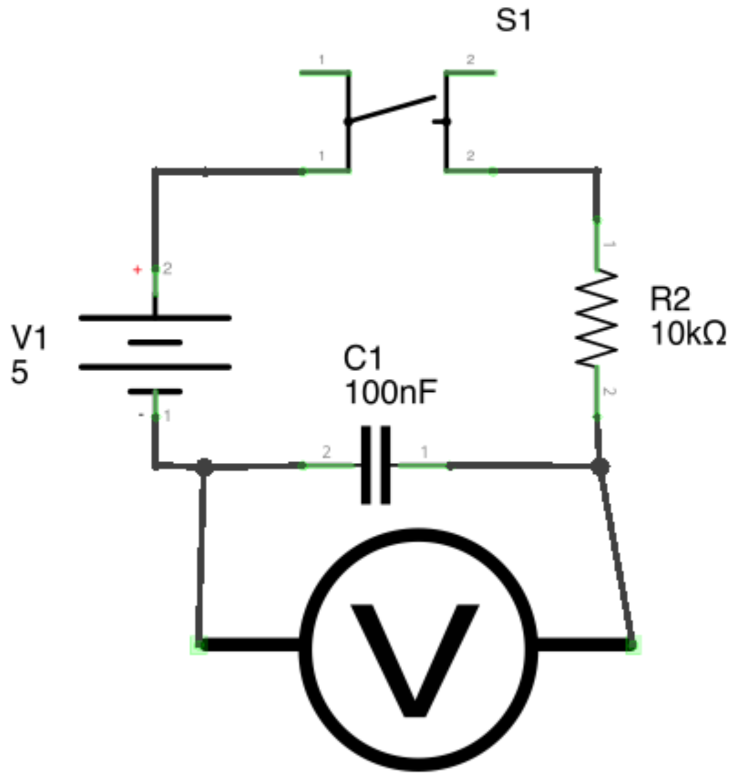
$\tau = R * C$ [=] seconds

where R is resistance and C is capacitance



RC circuits

τ is the amount of time it will take a capacitor to charge to about 63% of its final value, or the time it will take to discharge to about 37% of its starting value



RC circuits

So, for this circuit:

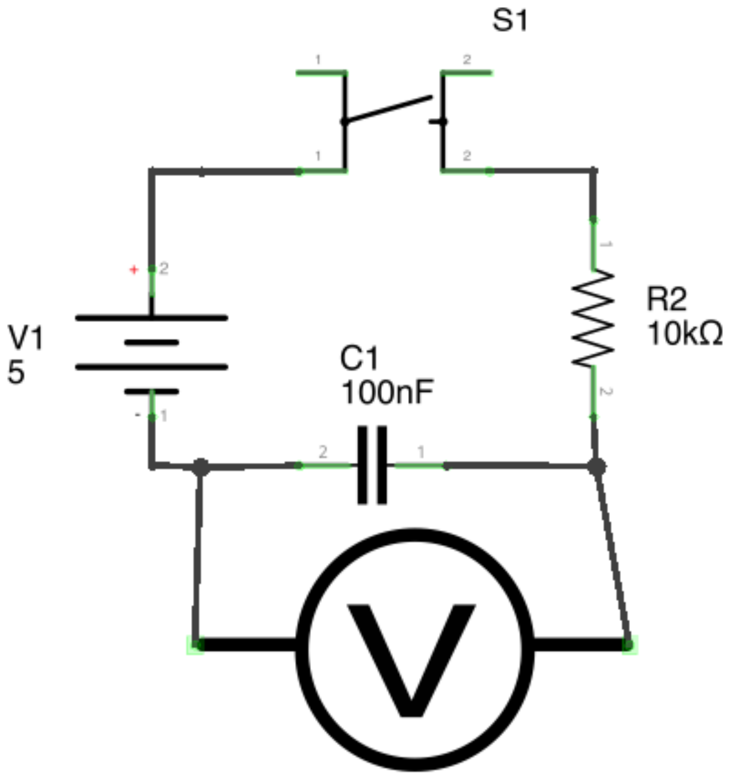
(10*10^3 Ω) * (100 * 10^(-9) F)

= 10 * 100 * 10^(-6) s

= 10^(-3) s

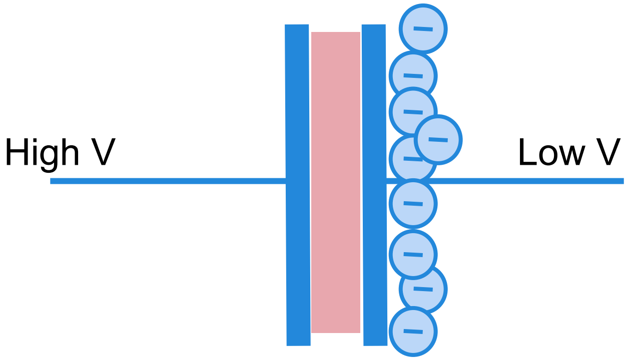
= 1 ms

Which is not very much time at all.



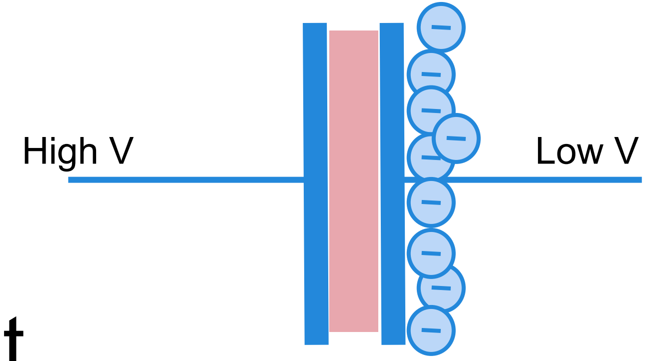
discharging a capacitor

Yup, you can discharge a cap, too. If you charge a capacitor and remove the voltage, those electrons are still going to be there. And they will stay there as long as there is nowhere else for them to go.



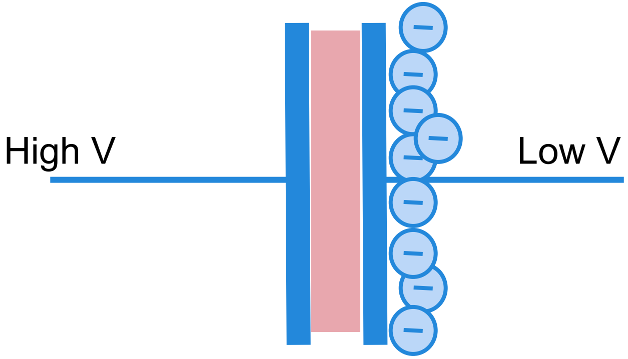
discharging a capacitor

If you do give the electrons a path, they will leave the capacitor to try to even out the voltage difference. This current will flow in the opposite direction that it did when it was charging.



discharging a capacitor

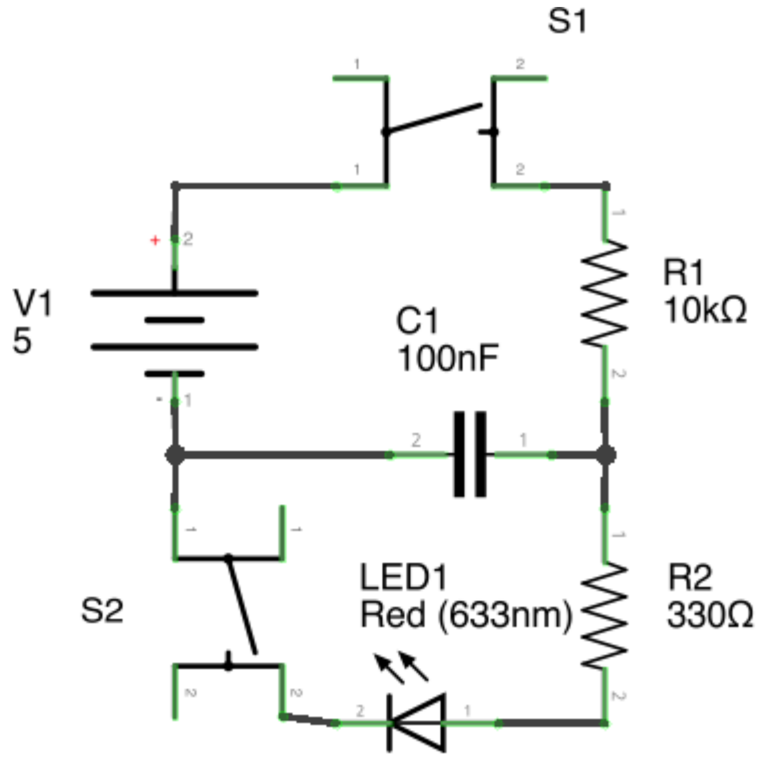
Since the voltmeter was discharging the cap, let's try to observe the discharge without using our meter.



Hey, look, LEDs.

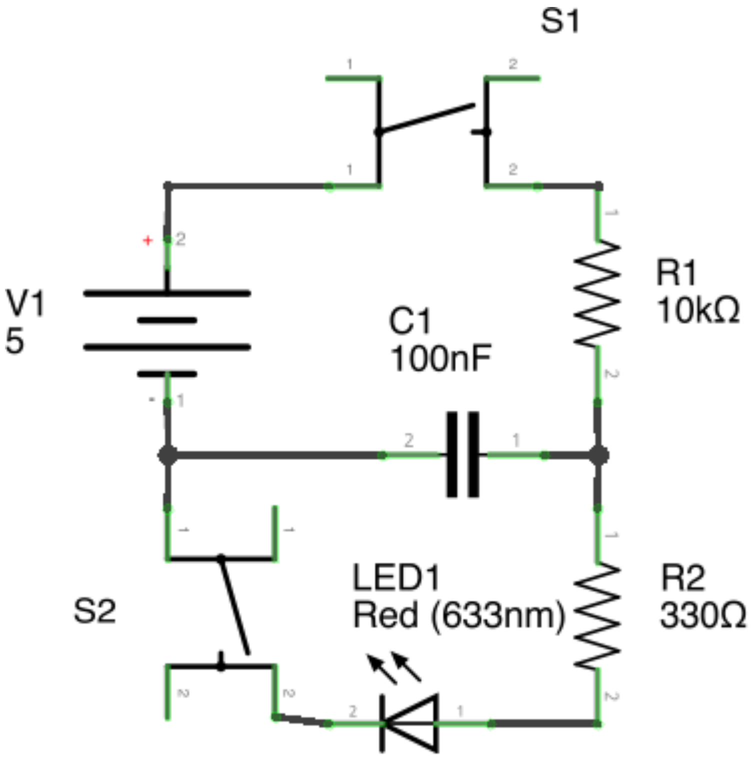
discharging a capacitor

Try this circuit (2-5) out. We're adding to circuit 2-4, adding a discharge path through LED1 whenever S2 is pressed down.



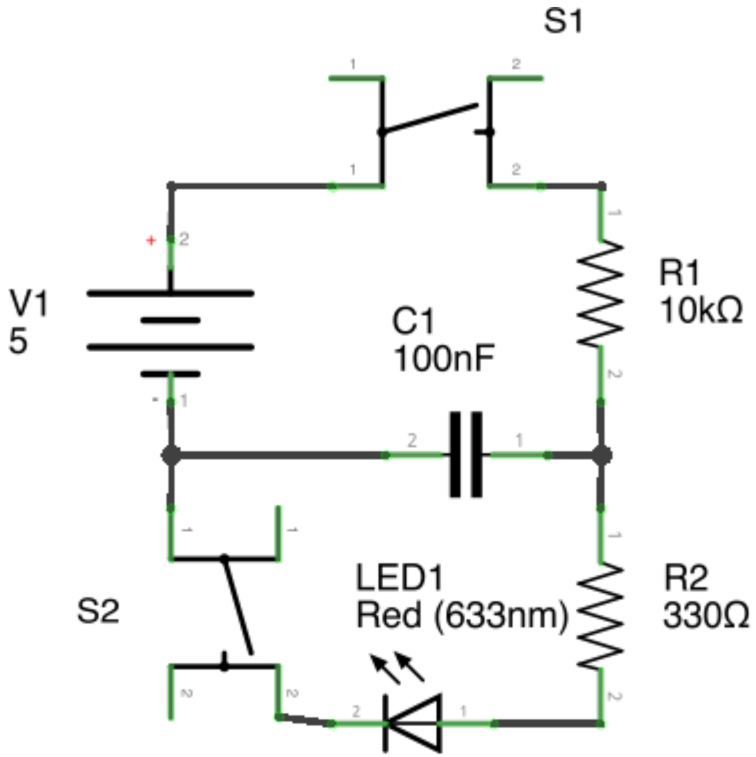
discharging a capacitor

Hold S1 to charge the cap, then let go, then hold S2 to discharge it. You will (hopefully) notice the tiniest of blips from the LED



discharging a capacitor

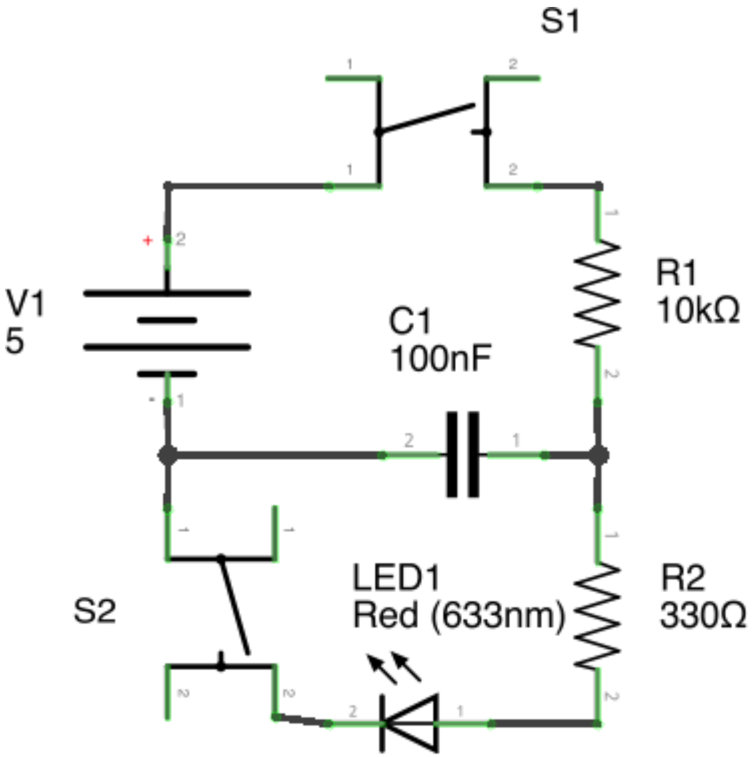
Notice how when S1 is up and S2 is down, the power supply isn't involved at all. The LED is being lit purely by stored charge from the cap.



MOAR LED PLZ

Ok, let’s see how bright we can get it.

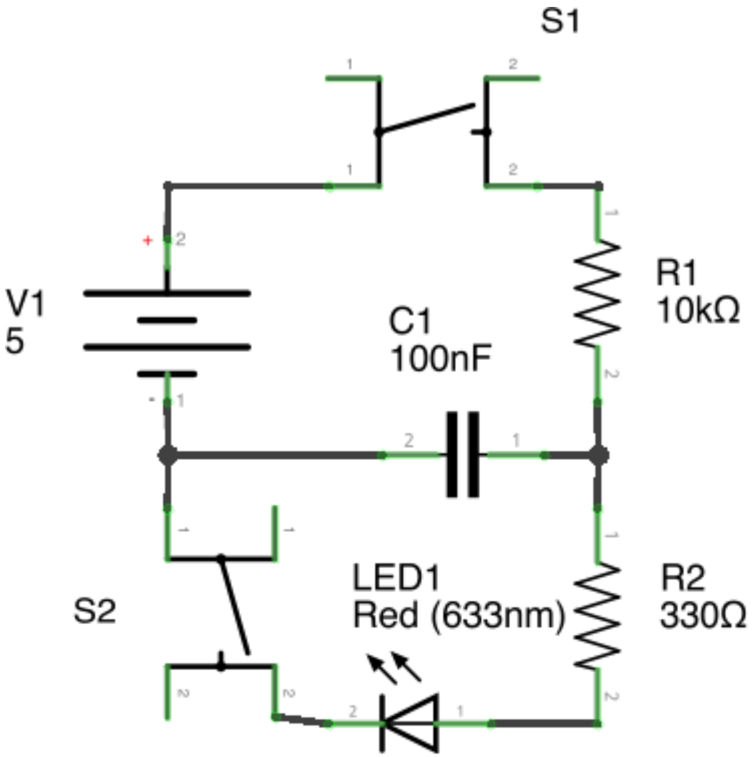
The brightness of the blip is a function of how much current can flow through the LED and how long the blip lasts



MOAR LED PLZ

More current is easy; let's drop R2 to 100Ω.

A longer blip means we need more charge stored. But 100nF = 0.1µF is the biggest capacitor we have.



blast from the past

Remember from Lesson 1 how we could wire resistors in series to effectively make a bigger resistor, and in parallel to make smaller ones? If not, please go review that.

We can do the same thing with caps, only it’s switched.

blast from the past

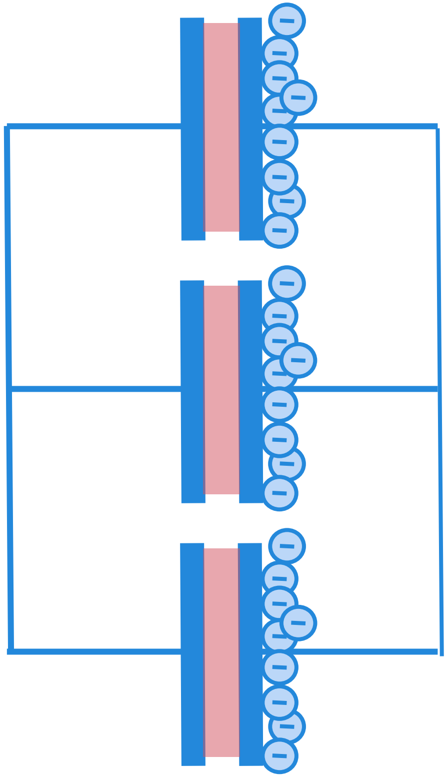
Remember from Lesson 1 how we could wire resistors in series to effectively make a bigger resistor, and in parallel to make smaller ones? If not, please go review that.

We can do the same thing with caps, only series and parallel are switched.

capacitors in parallel

If we wire capacitors in parallel, we increase our effective plate surface area, so we can hold more electrons

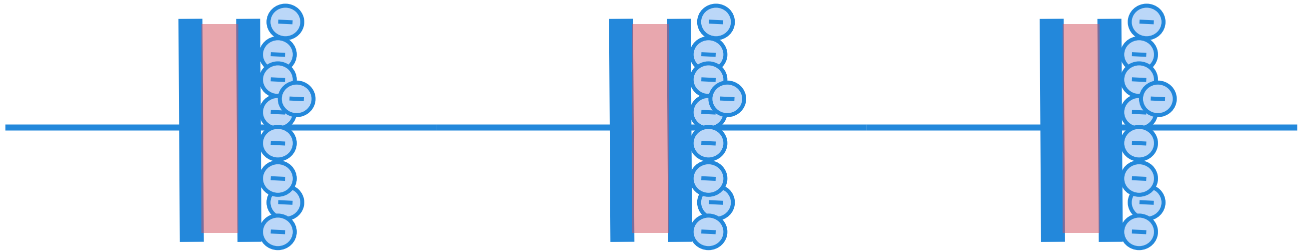
C_eff = ∑C for capacitors in parallel



capacitors in series

If we wire capacitors in series, the effective capacitance is reduced, because each cap has to hold the same amount of charge.

So, $C_{eff} = \sum C / \prod C$



capacitors in series and parallel

Summary:

Series:

$C_{eff} = \sum C$

Parallel:

$C_{eff} = \sum C / \prod C$

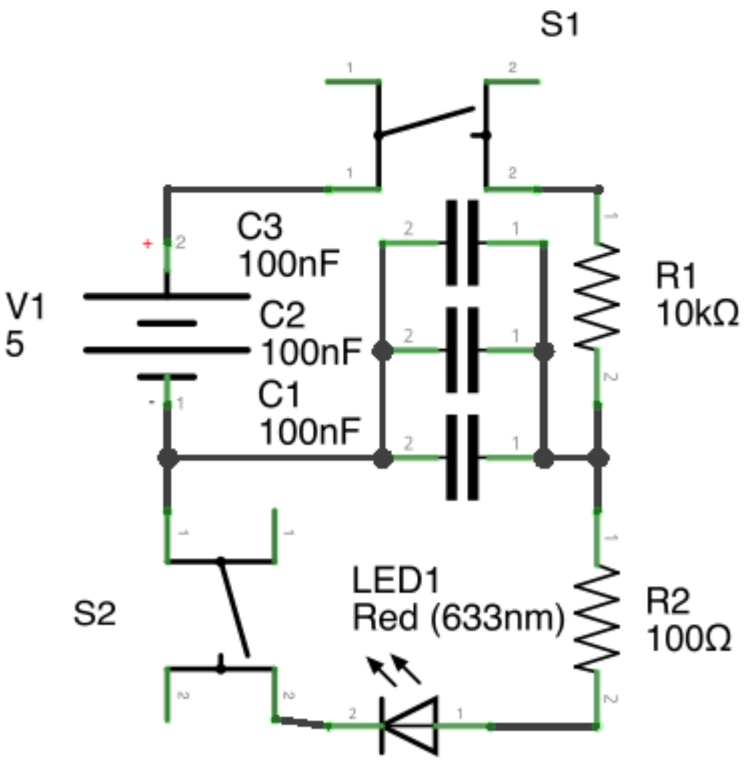
These things with math:

http://farside.ph.utexas.edu/teaching/302l/lectures/node46.html

MOAR LED PLZ

Back to this, let's put three 100 nF caps in parallel to make one 300 nF cap.

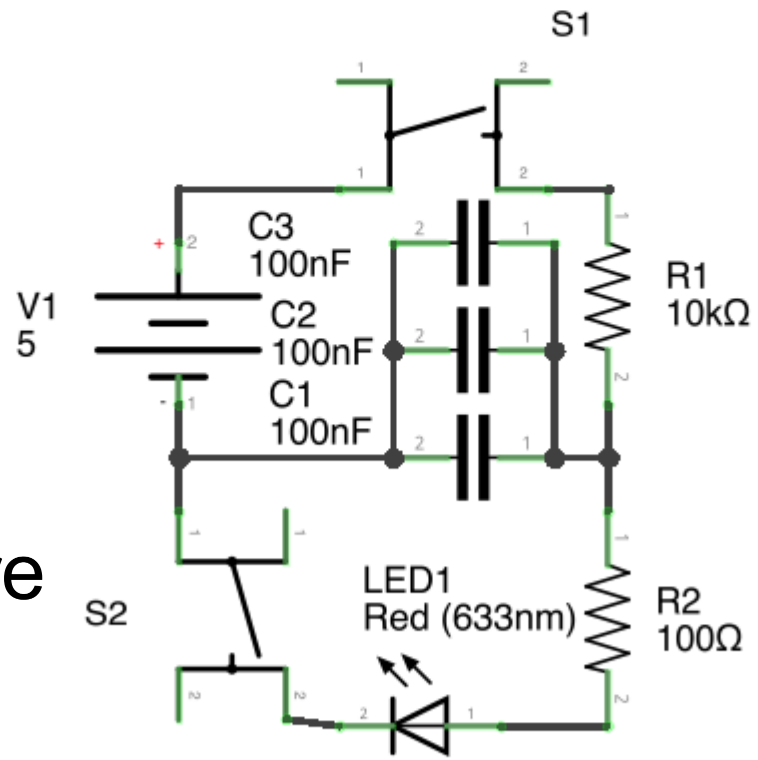
So, our circuit will look more like:



MOAR LED PLZ

Did it work any better? See if other color LEDs work better.

Also see if you can wire more caps in parallel, and reduce R2 even further by wiring more 100Ω resistors in parallel



next class

That’s all for this lesson.

Next lesson, we will be learning about:
Transistors (photo and otherwise)!
How to read a datasheet!
Building big circuits out of little circuits!

i got 99 problems

And this slide is the 99th.