circuits

what is this electricity thing and why are you talking at us?

who are you?

Hi, my name’s Mike.

I’m an engineer.

I apologize for this in advance.

what are you doing here?

Twelve (12) two hour classes

Once a week

Every Sunday from 1PM to 3PM

are there any exceptions?

YES

Next week’s class had a conflict so:

Sunday, March 23rd is

3:30 PM to 5:30 PM

We’ve got the room booked at 1 to 3 otherwise

where are we going with this?

We're assuming no to very little knowledge (or, like, it's been a while).

The goal will be to leave you with a repertoire of circuit blocks you can combine to do stuff.

most importantly, though...

This class will try to instill the principles of solid circuit design.

And, it'll give you the confidence and tools to try new things and continue learning.

um, so when does this class start?

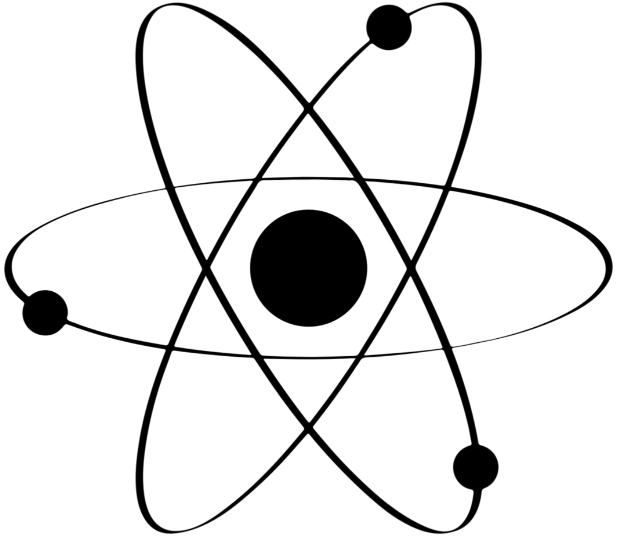
Now.

circuits lesson 1

in which electricity and circuits are described in a general manner

what is electricity

These



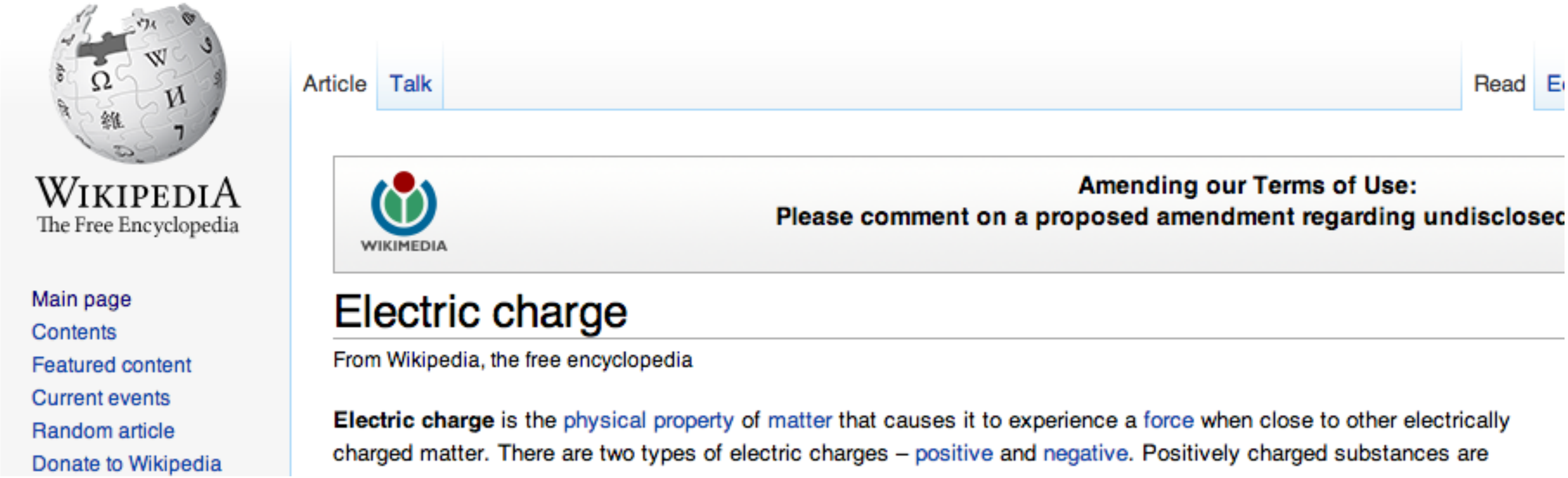
ok...

Electrons!

Electrons have an amount of negative **charge**

what is charge?

First thing's first:



thanks, I guess?

You can kind of think of it with an analogy:

Things with more mass experience more gravity

Things with more charge experience more electromagnetic force

summary of charge

Symbol: Q

Unit: coulomb = C

We don’t really need to know this, but it’s good for background information

moving right along

Charge just sitting around doesn’t do us a whole lot of good.

who wants a bad analogy?

A big lake of water just sitting around doesn’t give us any work.

But if that lake is behind a dam, and the pressure is used to flow water through turbines, we can get work.

that analogy wasn't so bad!

Thanks.

Basically, just like we want water flowing through turbines, **we want our charge moving** to be useful to us.

if only there was a name for that...

There is! Moving charge is called **current**.

Symbol: I or i (I'll use both interchangeably)

Unit: Ampere = A

1 Ampere = 1 Coulomb / second

so, how do we get current to flow?

Current will flow (charge will move) when there is something called an **electric potential difference**.

should we go back to the dam?

Yes, we should.

In the damn analogy, where the water is the electrons, the **pressure difference** is the **electric potential difference**.

electric potential difference is long

Which is why from now on we will call it:

voltage

Symbol: V or v

Unit: Volts = V

(Yes, that's a little confusing. Usually, we'll use v for voltage and V for Volts)

how does voltage become current?

Different materials respond differently to a voltage differential

The simplest of these materials to describe are called “ohmic”

how does voltage become current?

Ohmic materials obey Ohm's Law (Ohm was a cool dude):

$$I = V / R$$

Where R is **resistance**

what is resistance?

Resistance is the property of a material the describes its opposition to current flow.

what has resistance?

Technically, everything.

Wires have a resistance that is proportional to their length and inversely proportional to their cross-sectional area.

Longer wires have more, wider wires have less.

what has resistance?

We’re going to assume wires have no resistance, though.

We’ll focus our resistance efforts on discrete components called **resistors**.

what has resistance?

THIS IS A RESISTOR:

Source: http://en.wikipedia.org/wiki/File:Resistor.jpg

so, ohm’s law

Ohm’s law basically says:

- more voltage means **more** current
- more resistance means **less** current

so, ohm’s law

BUT REMEMBER:

Ohm’s Law is only applicable to ohmic materials. So **only use Ohm’s Law with resistors**. It’s not applicable elsewhere.

so, ohm’s law

Resistors:

$$I=V/R$$

Everything else:

Not that

let’s get practical

You should have a lot of things in a box in front of you.

Let’s start playing with them.

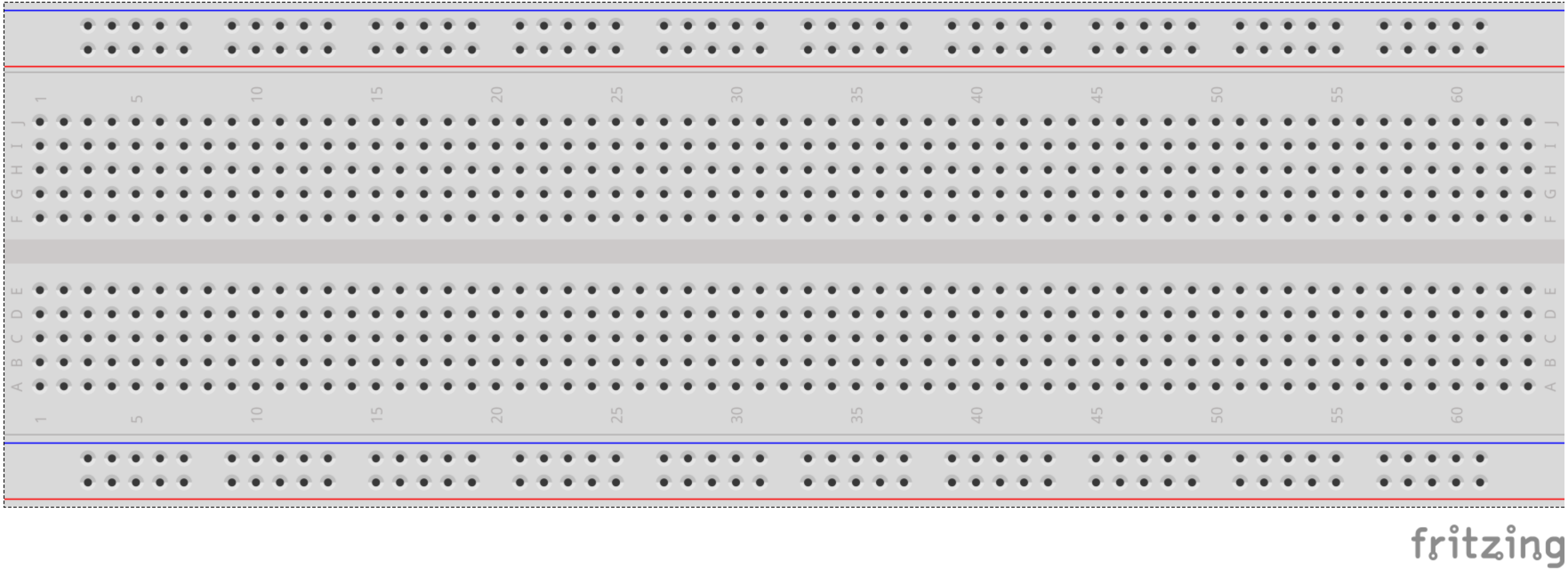
breadboard set up

That big white board is called a breadboard.

If you’ve never used one of these before, pay attention to this next part.

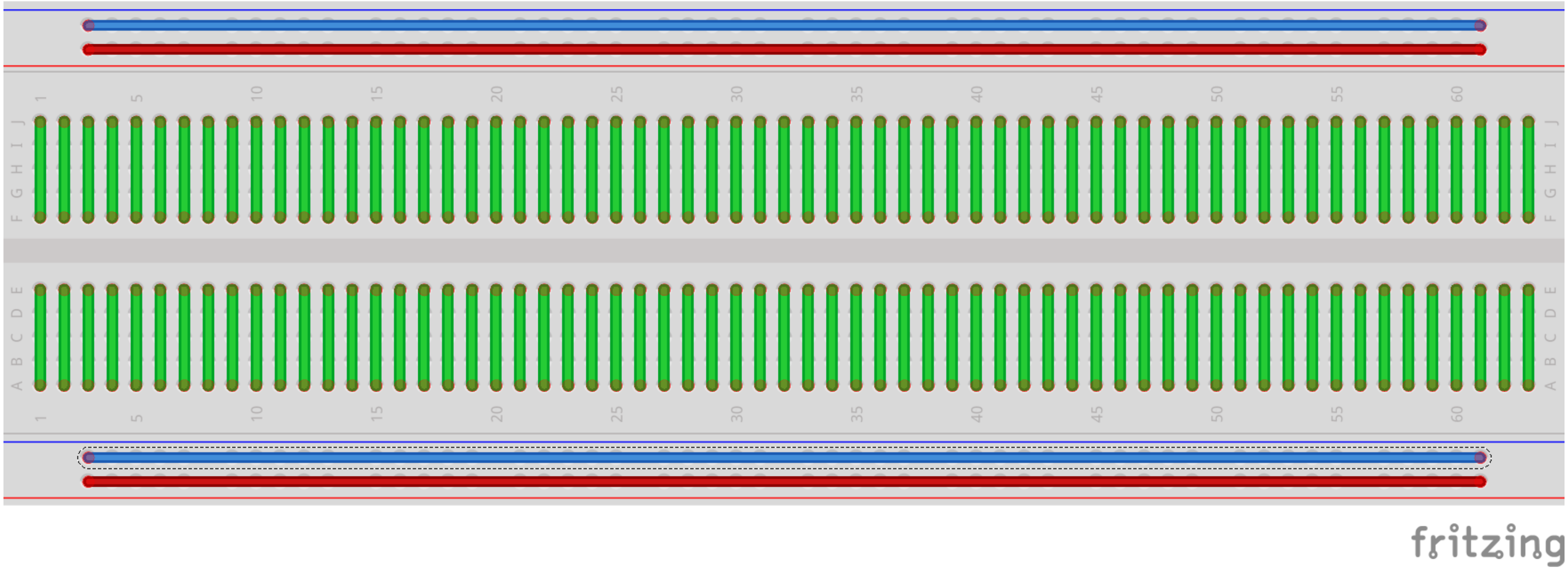
breadboard set up

This is a breadboard. Stick a resistor in yours.



breadboard set up

The holes are internally connected like:



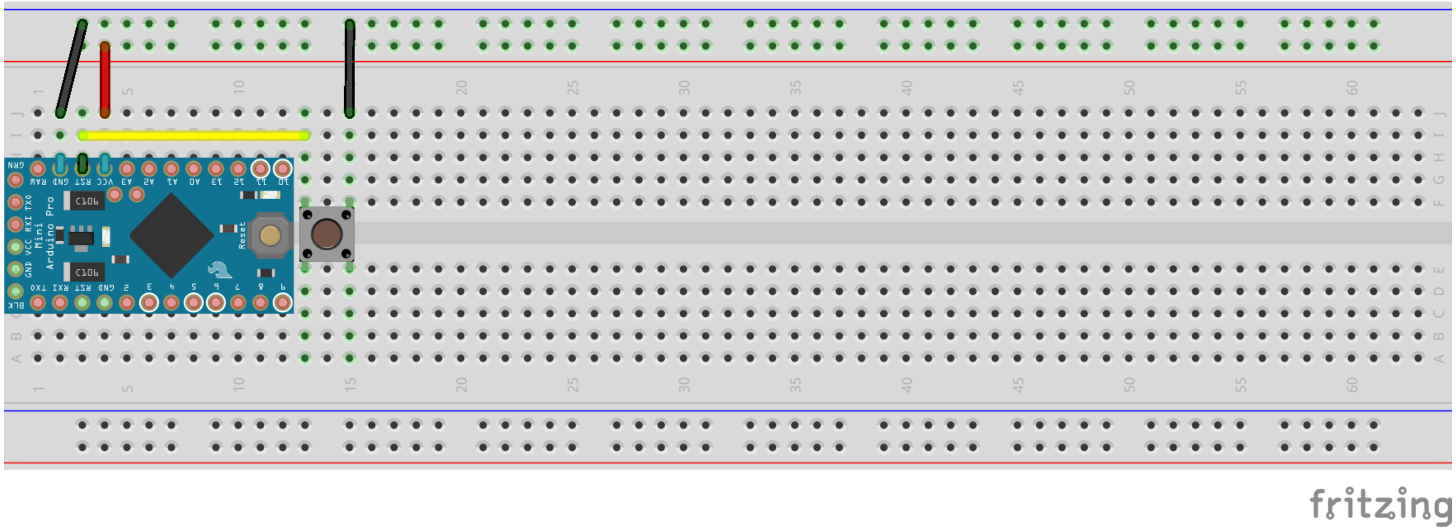
breadboard set up

You should have an Arduino of some sort. This will be our power supply, and later, it will be an oscilloscope.

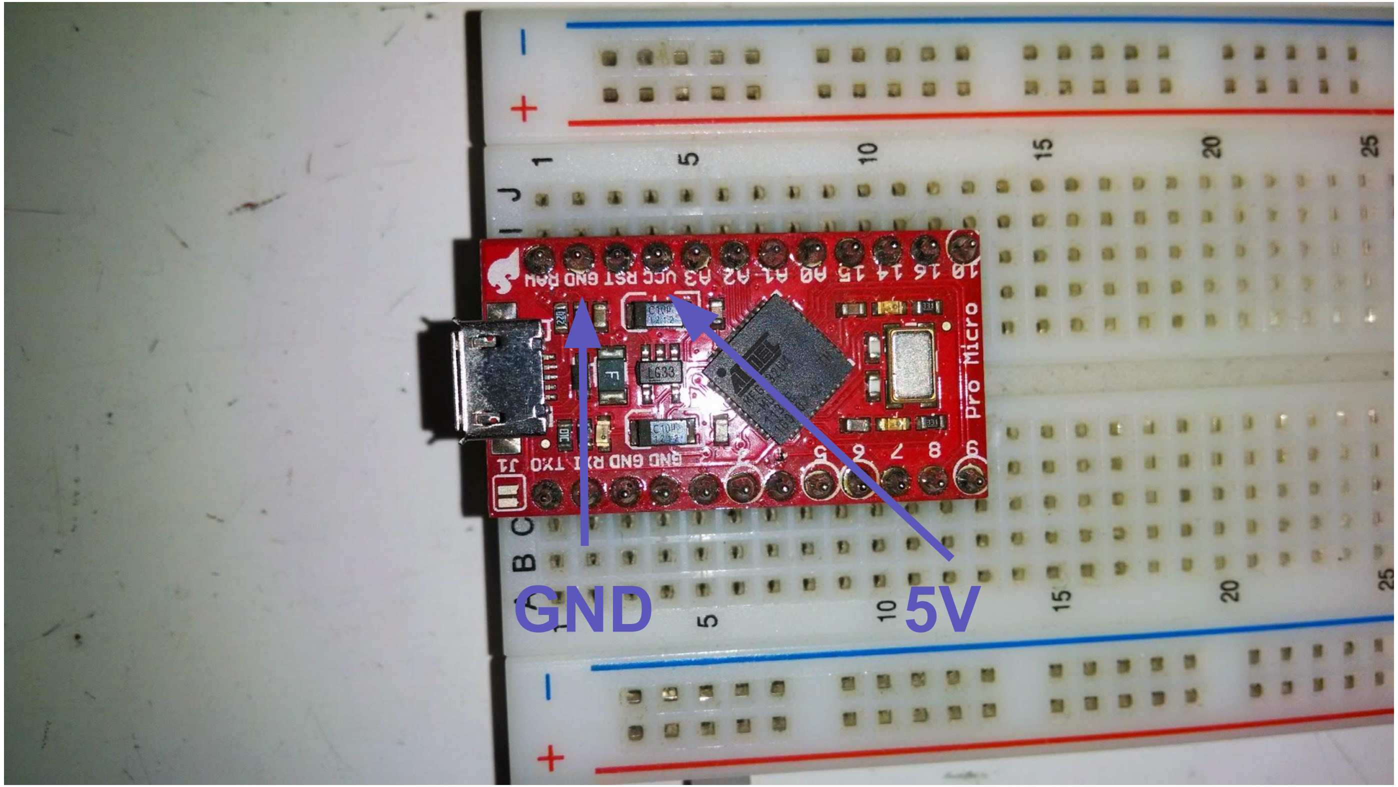
For now, we need to wire it up.

breadboard set up

If you are using the Arduino we gave you, it’s gonna look something like this:

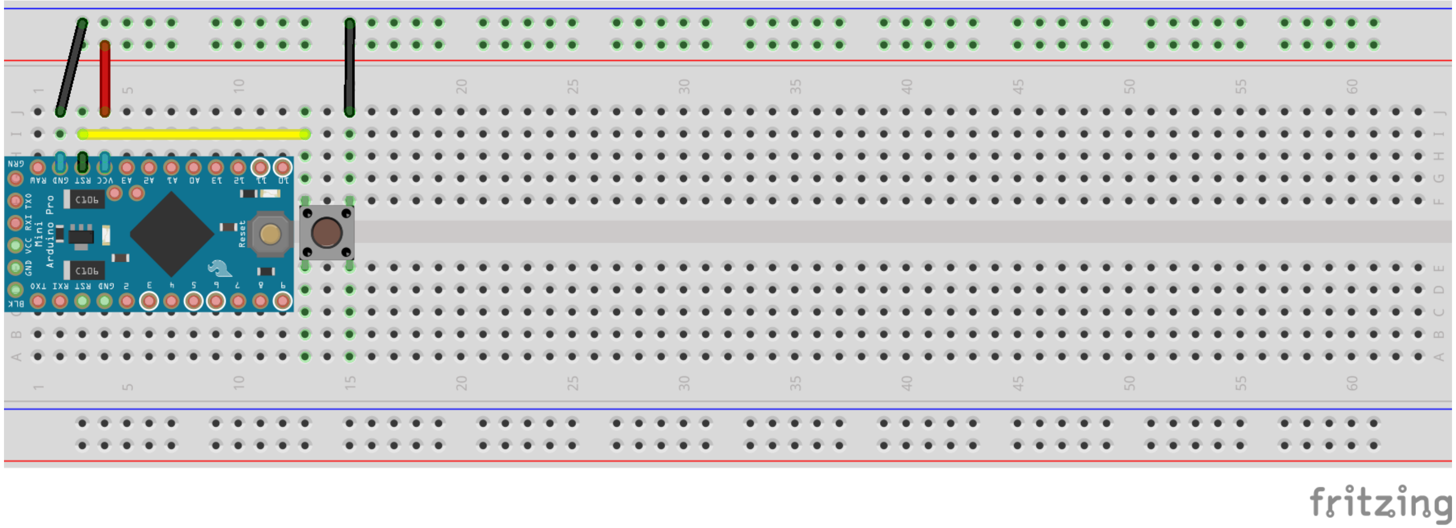


cell phone pictures are ugly



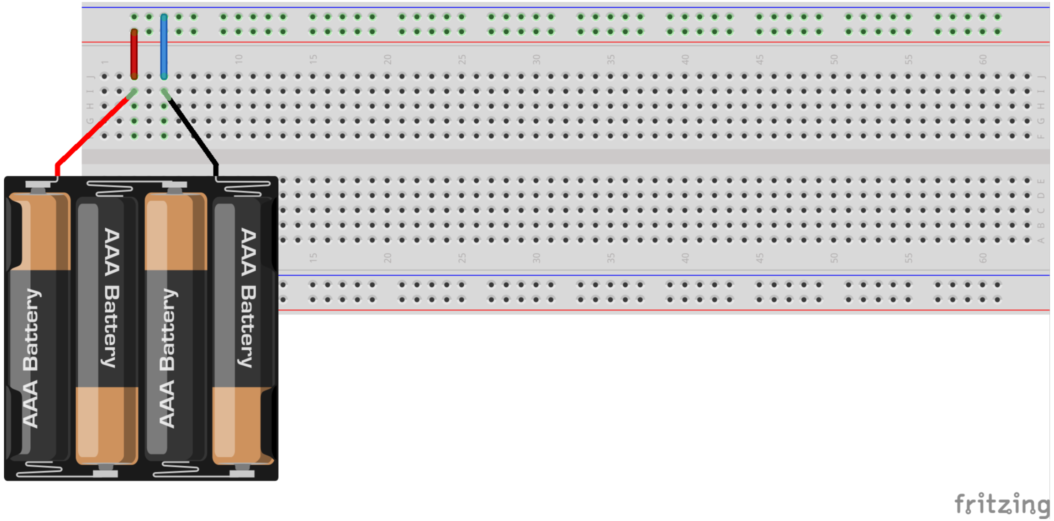
breadboard set up

Otherwise, the key detail is getting the rails down the side hooked into 5V and GND



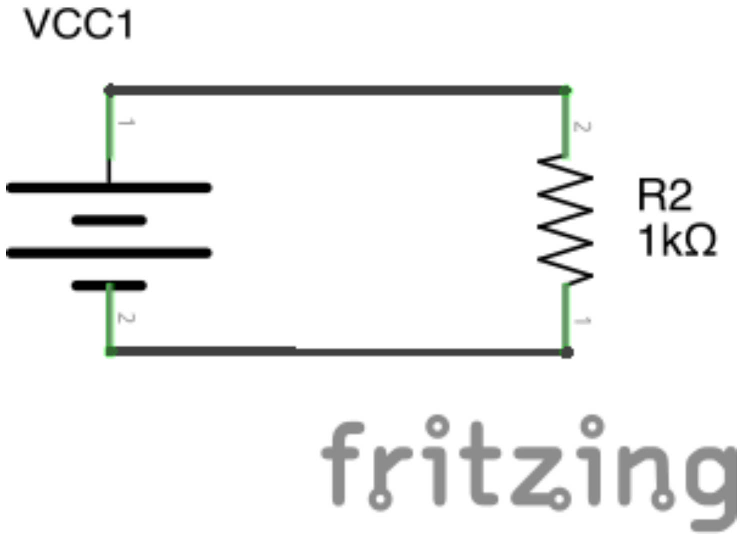
breadboard set up

This is effectively a battery; it gives us a voltage difference.



our first circuit!

Circuit 1-1

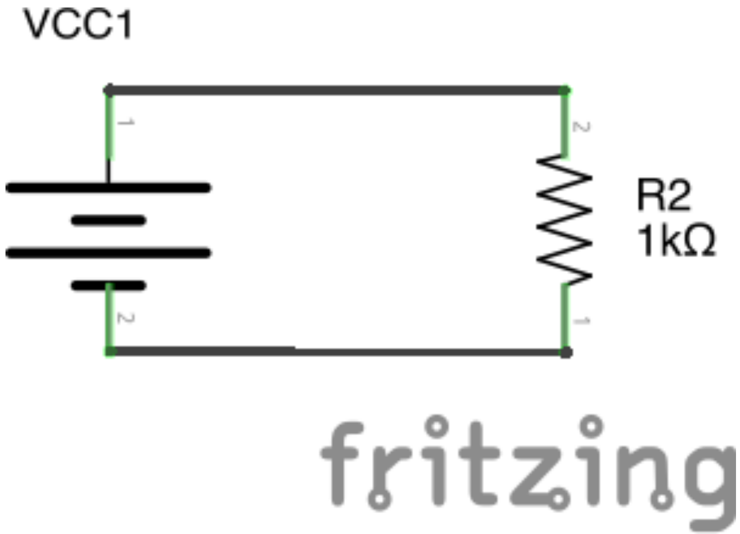


which resistor is right for me?

Circuit 1-1

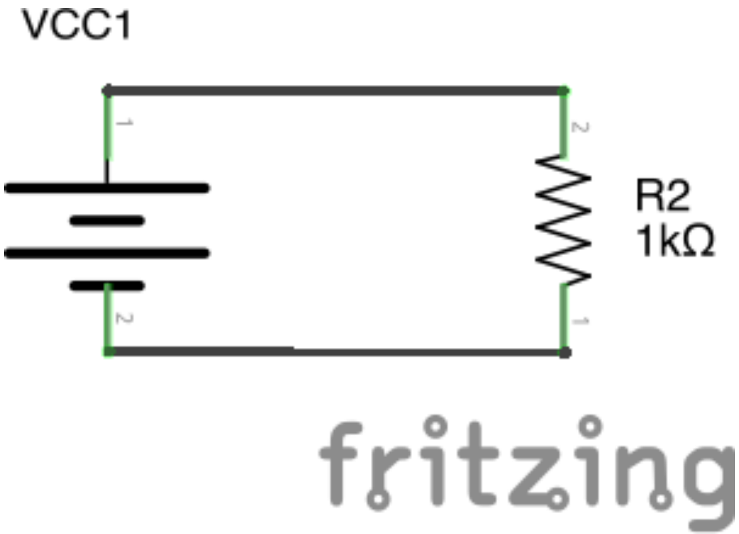
Notice how I’ve specified the resistor’s value in kilohms (or kiloohm)

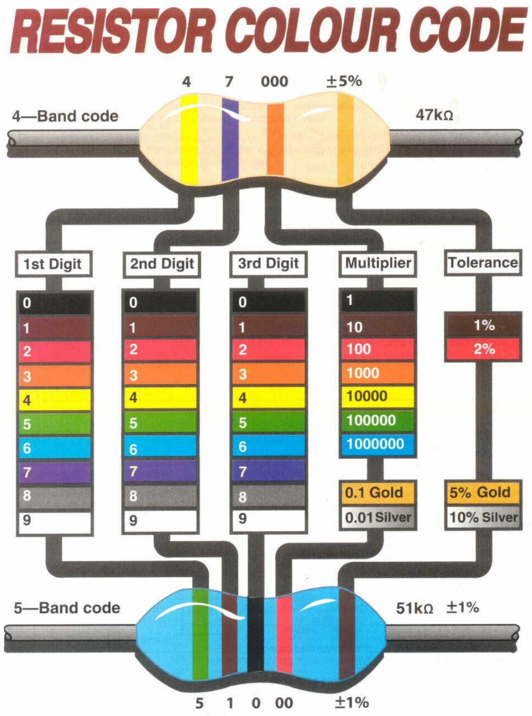
We want this resistor to have 1000 ohms of resistance



getting resistance

Circuit 1-1

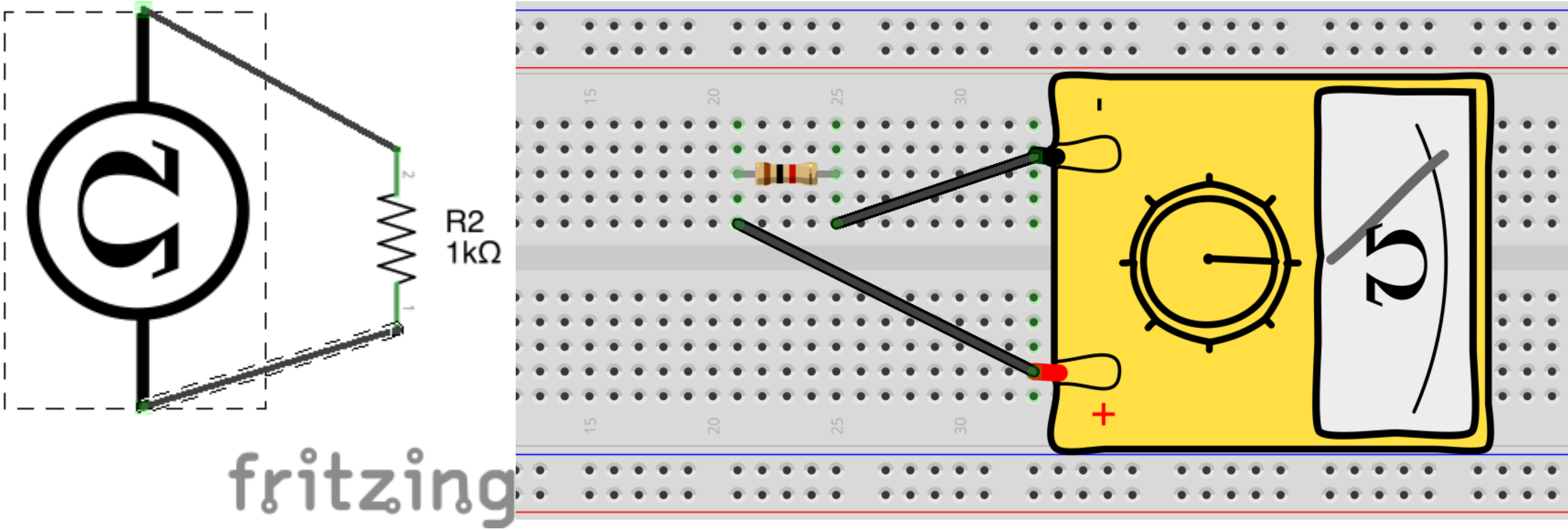




Source: http://electroschematics.com/wp-content/uploads/2013/02/4-and-5-band-resistor-colour-code.jpg

getting resistance

Measuring resistance:



can we measure other stuff?

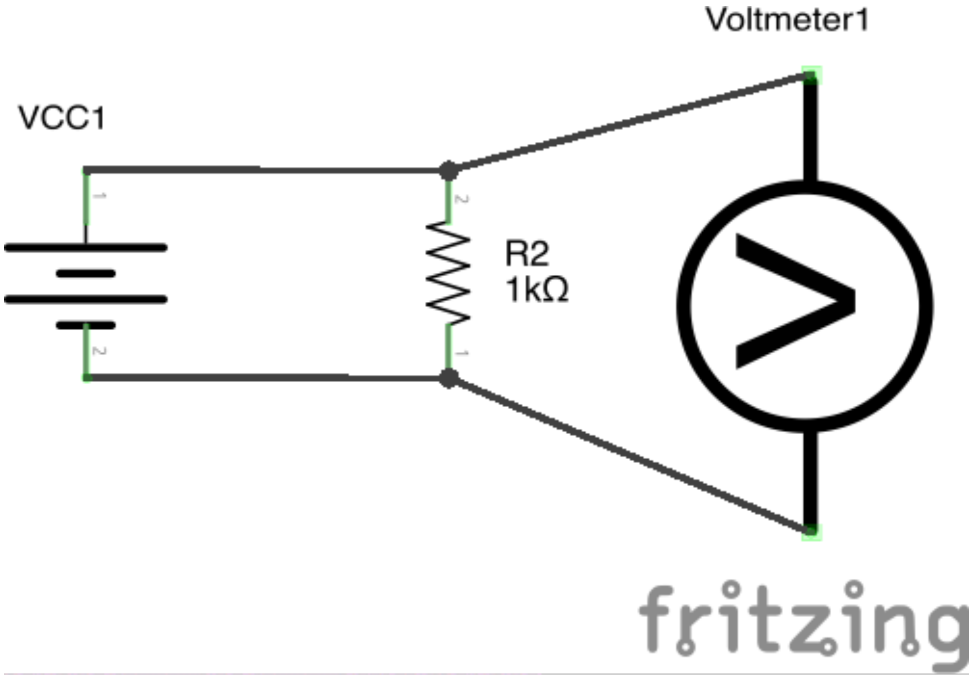
Yes!

We can measure continuity, resistance, voltage, and current.

Let’s take this time to discuss metric prefixes.

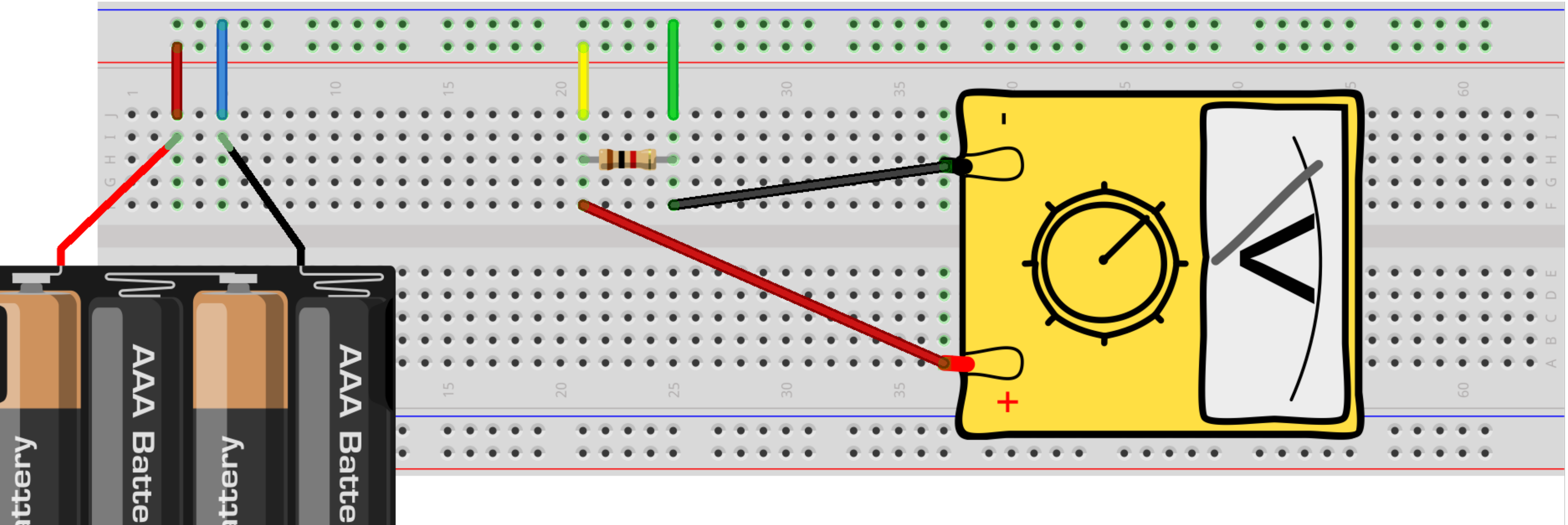
measuring other stuff

Measuring voltage:



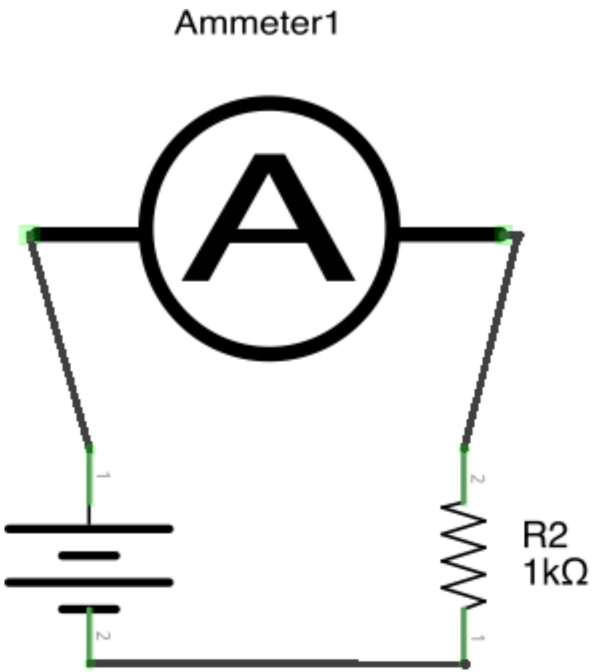
measuring other stuff

Measuring voltage:



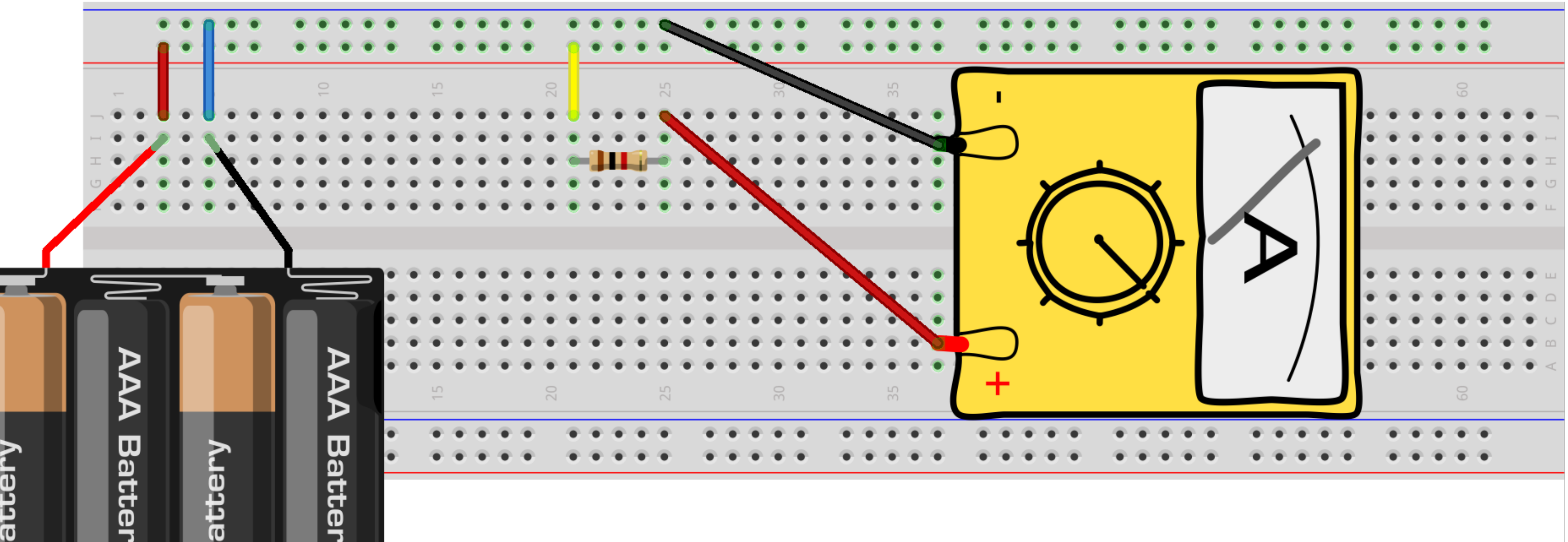
measuring other stuff

Measuring current:



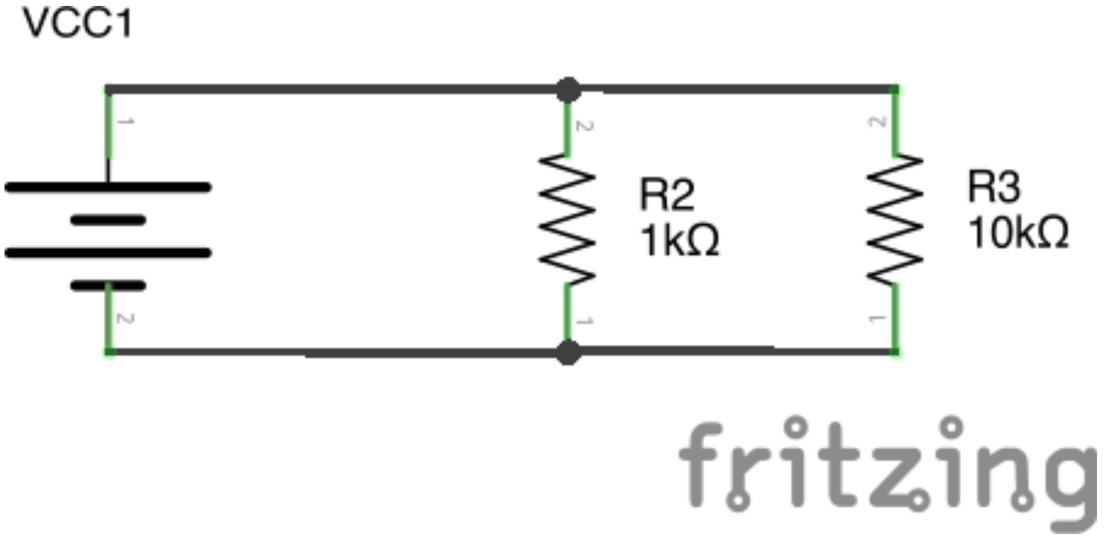
measuring other stuff

Measuring current:



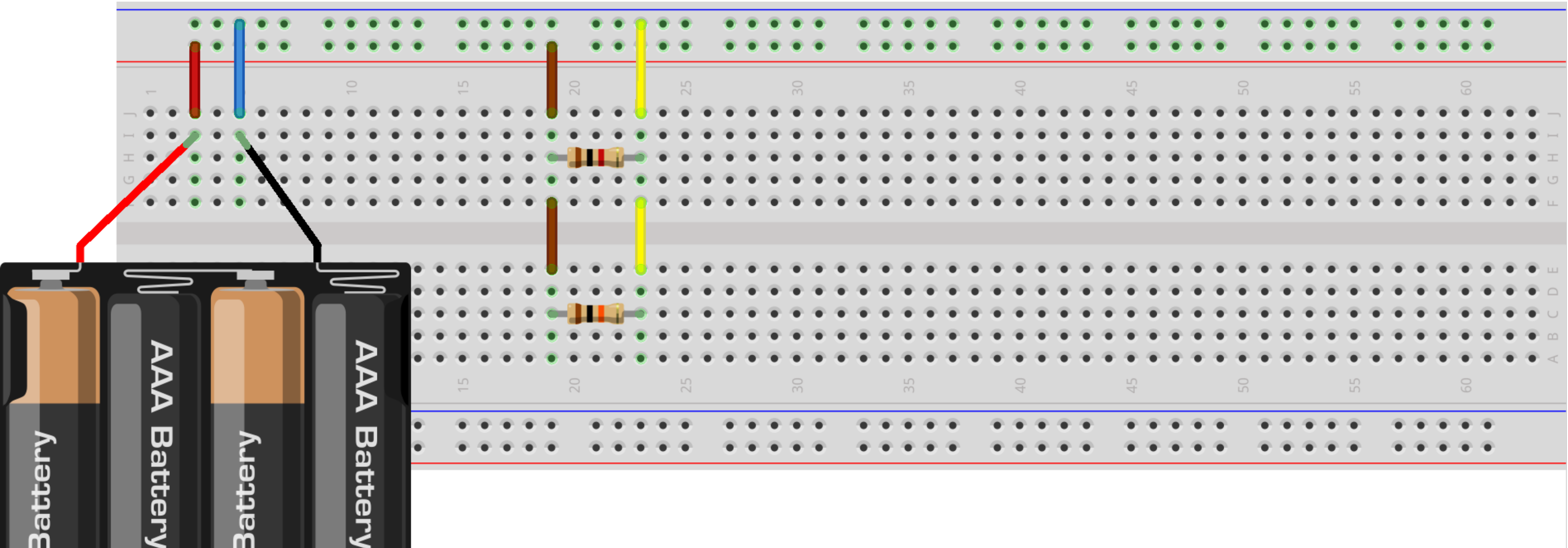
getting crazy up in here

Circuit 1-2



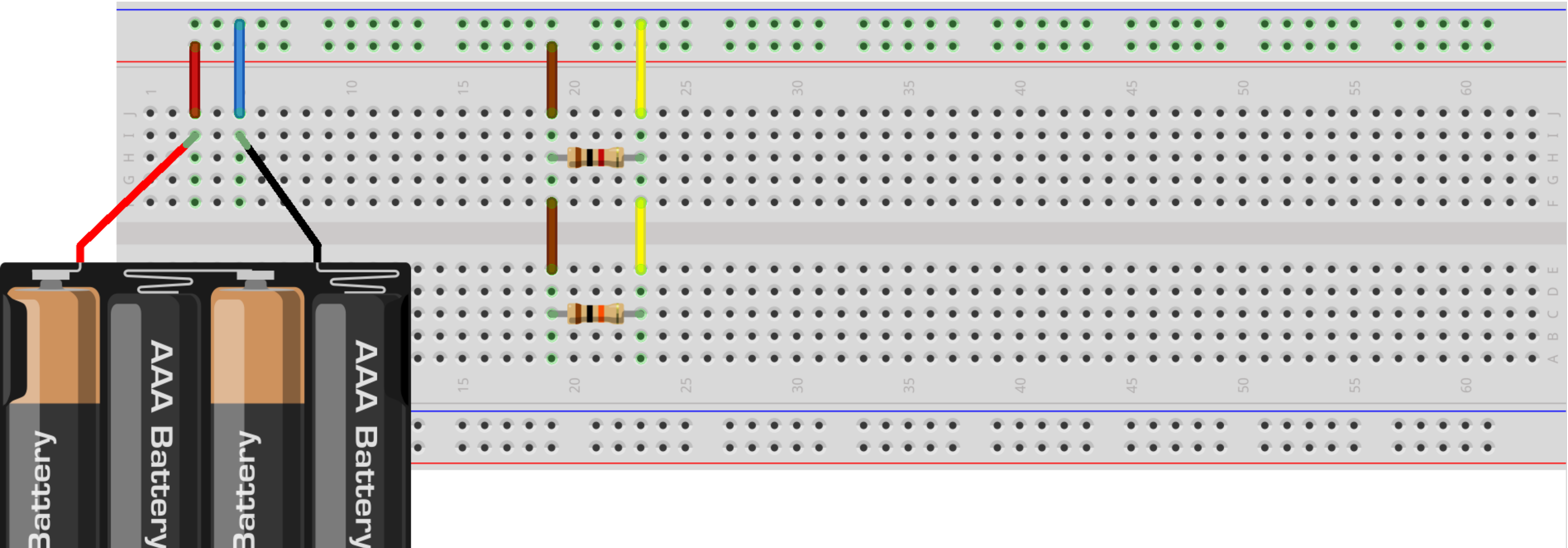
getting crazy up in here

Circuit 1-2



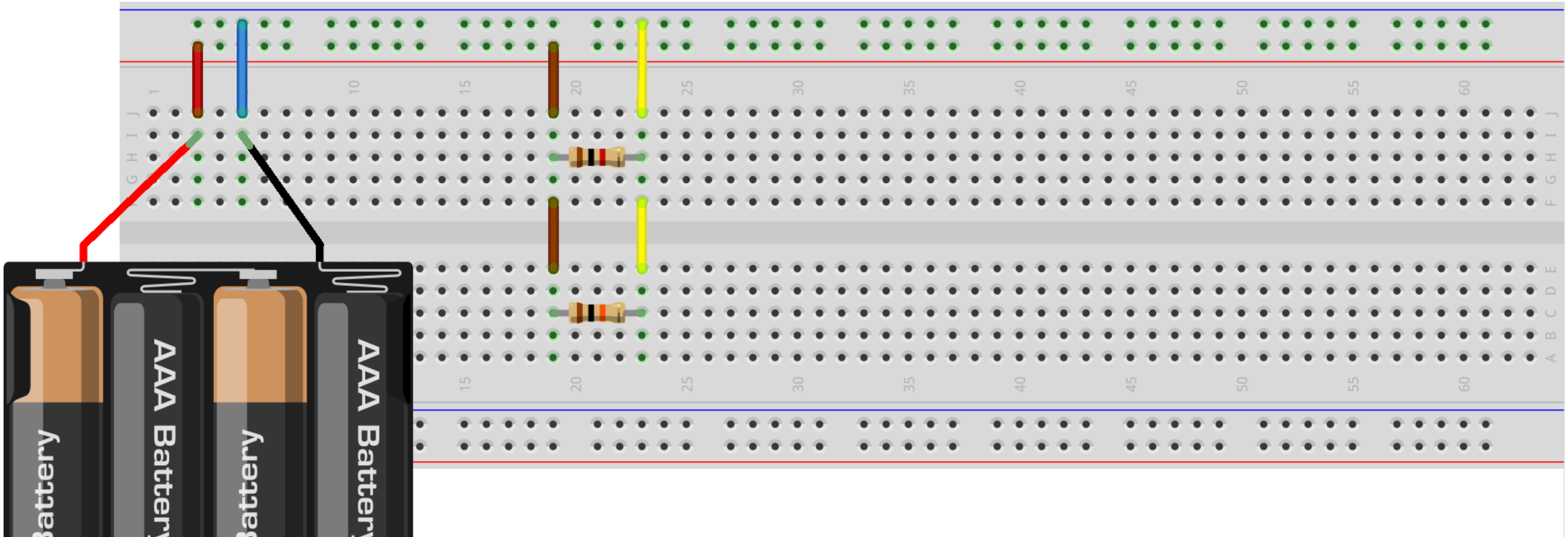
getting crazy up in here

Let’s take some time here to measure things



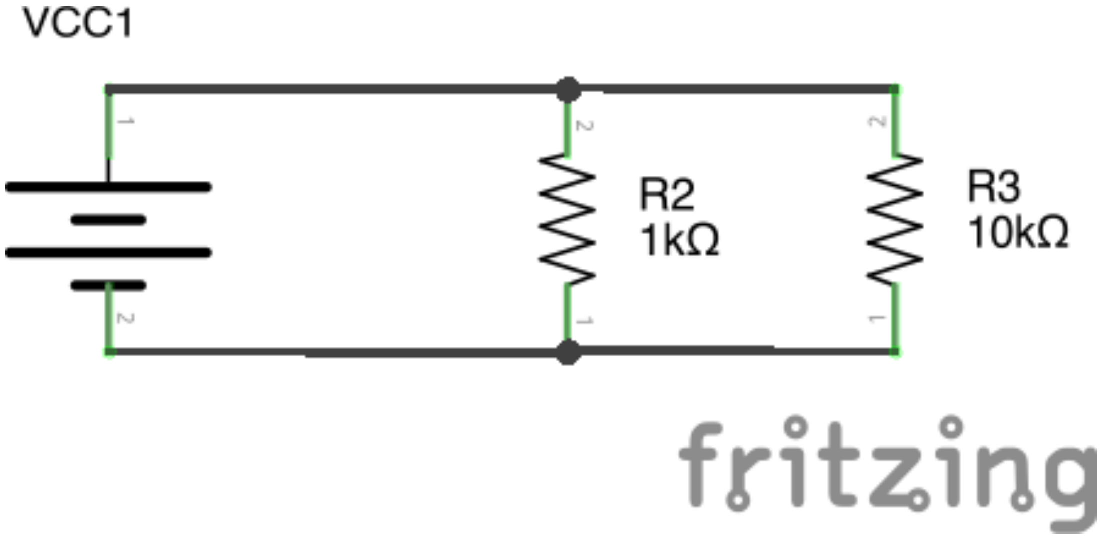
measuring circuit 1-2

Use your multimeter to measure voltage across and current through each resistor.



let’s talk about Kirchhoff

What’s a Kirchhoff?



Let’s talk about Kirchhoff

Kirchhoff was just this guy, you know?

He also happened to come up with some very important circuit rules (or laws).

We call these: Kirchhoff’s Circuit Laws

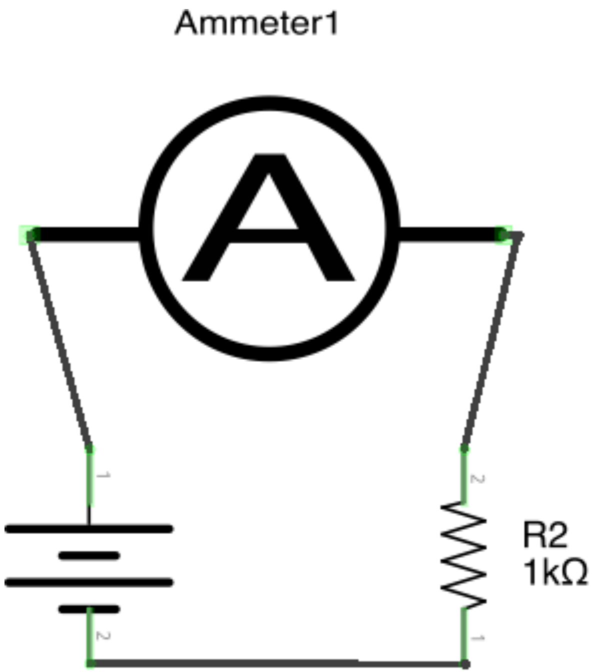
Kirchhoff’s current law

AKA Kirchhoff’s First / Junction Law

Much like mass, electric charge is conserved (this is a principle of matter). This implies that at any node (junction) in a circuit, the current flowing in equals the current flowing out.

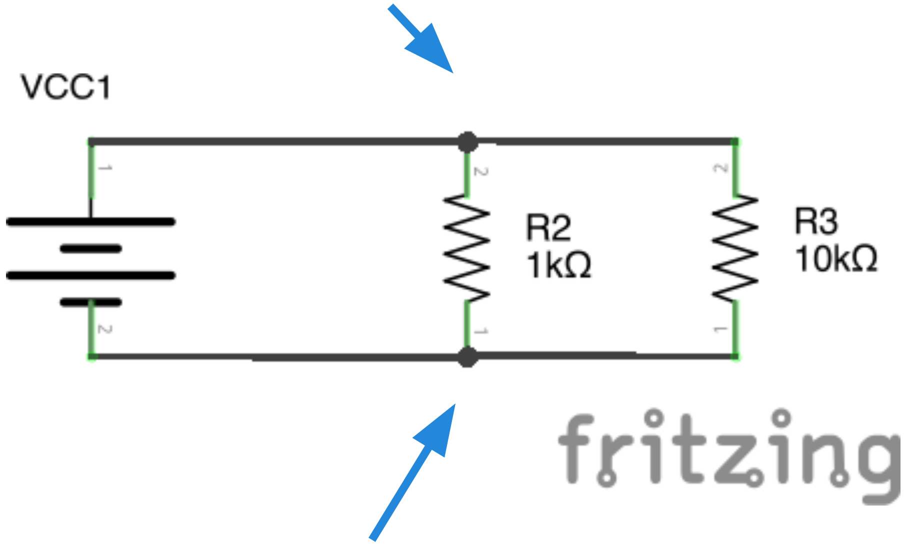
(reminder about using an ammeter)

Measuring current:



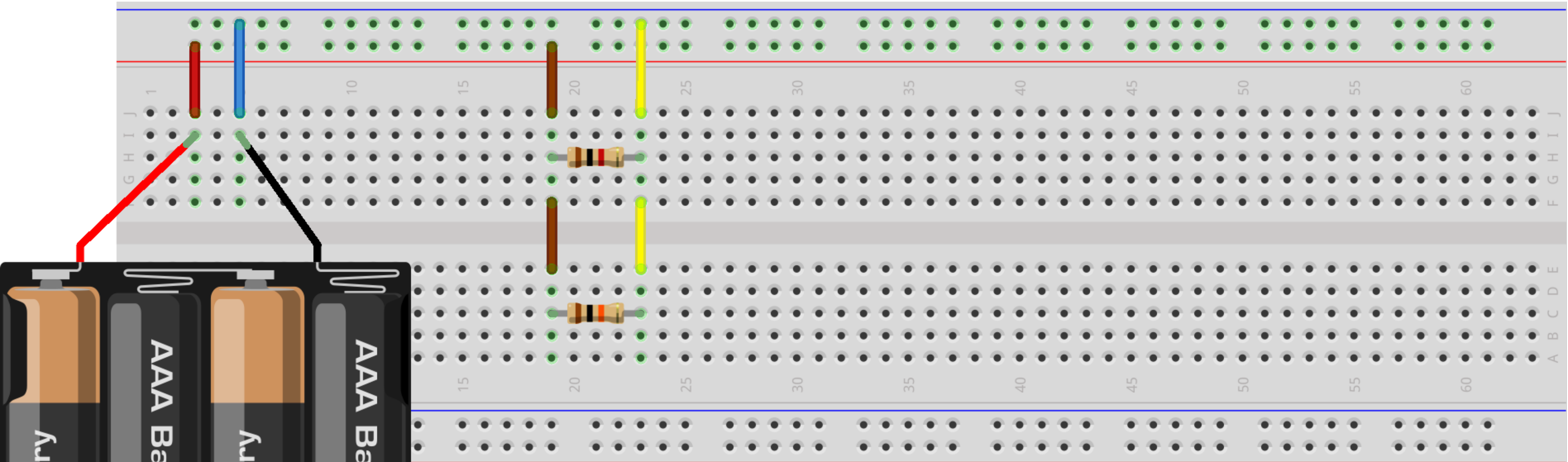
Kirchhoff’s current law

What’s a node? These:



Kirchhoff’s current law

Does this make sense to everyone? Let’s measure the currents in circuit 1-2 and see.



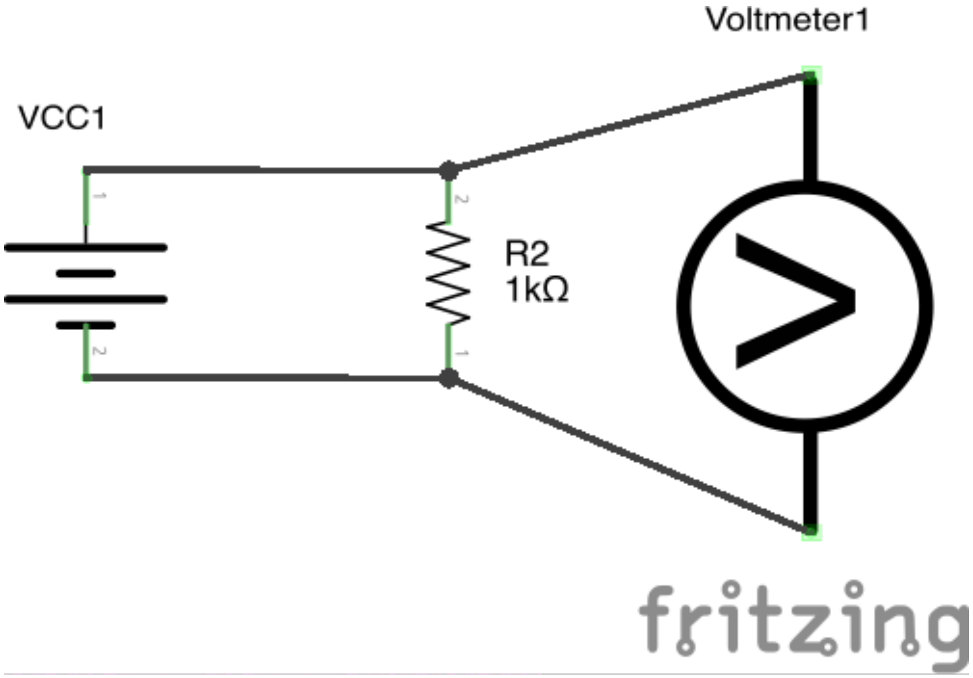
Kirchhoff’s voltage law

AKA Kirchhoff’s Second / Loop Law

Like uncle Einstein always said, energy is always conserved. This implies that the sum of voltage differences in any closed circuit loop is zero.

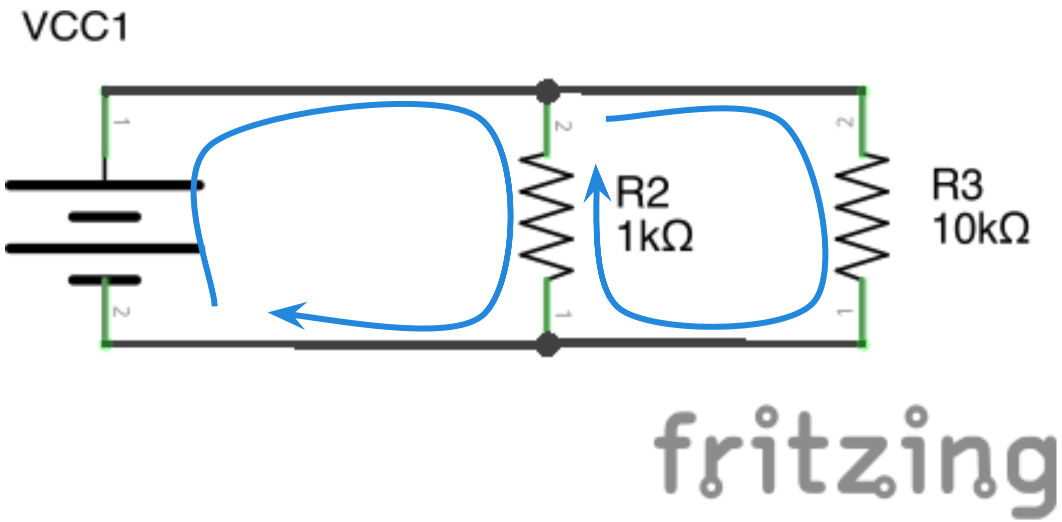
(voltmeter reminder)

Measuring voltage:



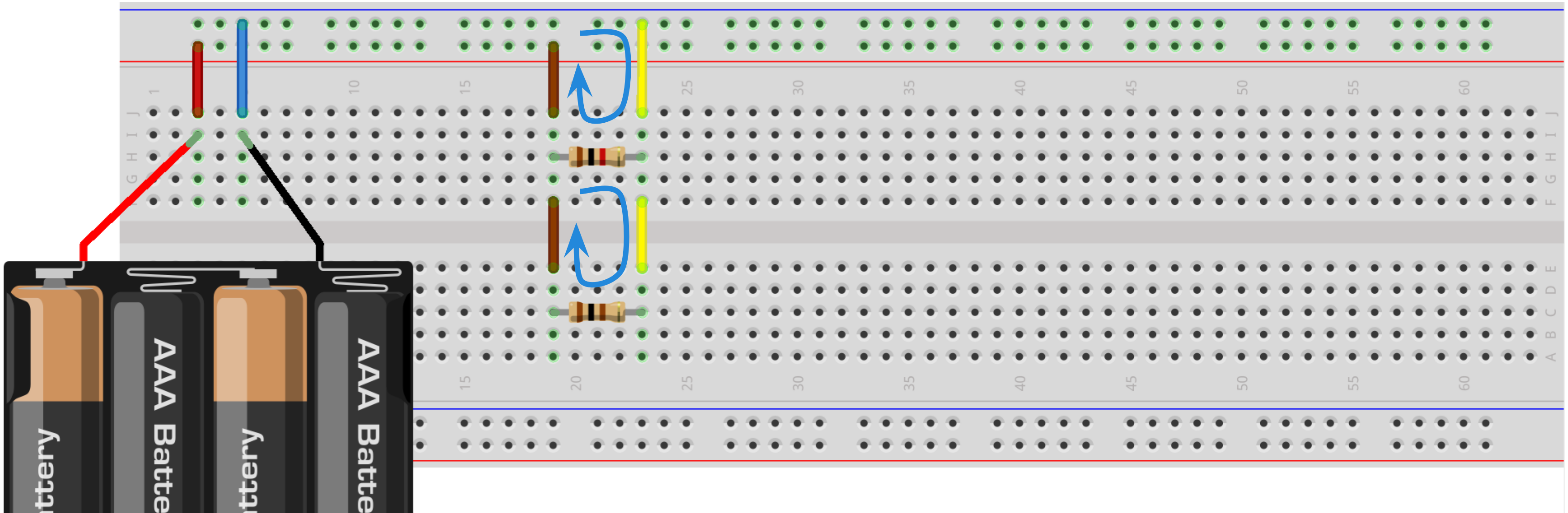
Kirchhoff's voltage law

What's a loop? These:



Kirchhoff's voltage law

Let's talk about sign conventions, then measure the voltages in circuit 1-2 and see if the add up.



analysis with Kirchhoff and Ohm

First law:

i_sup = i_R2 + i_R3

Second law:

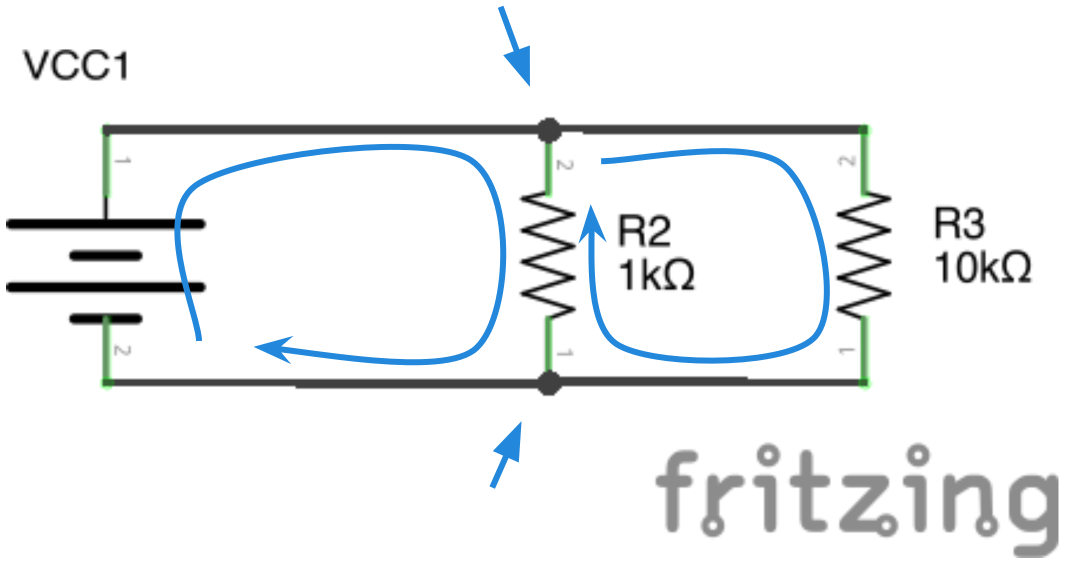
v_sup = v_R2

v_R2 = v_R3

Ohm's law:

i_R2 = v_R2 / R2

i_R3 = v_R3 / R3



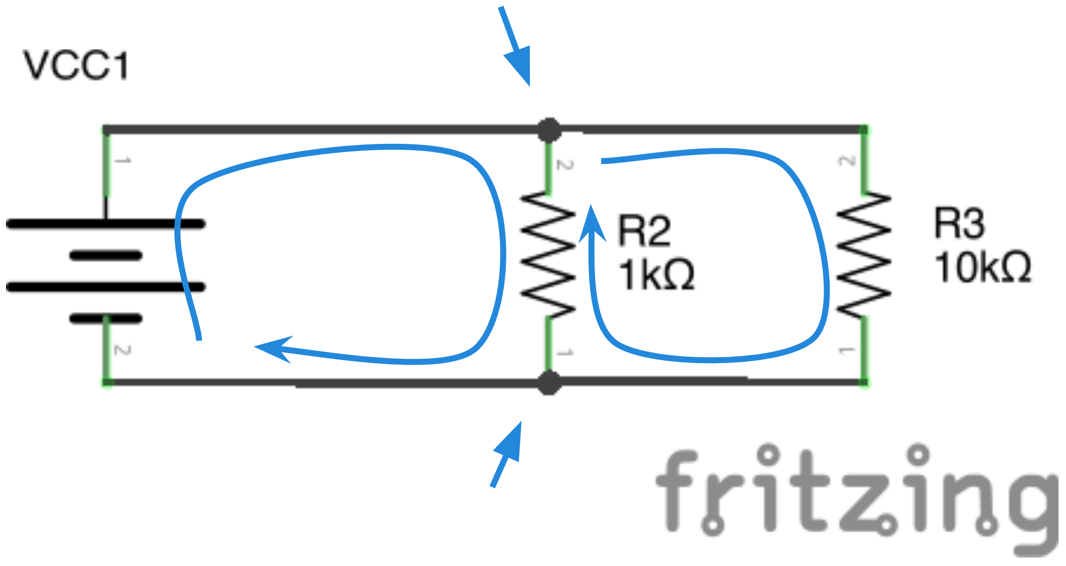
analysis with Kirchhoff and Ohm

Combine it all:

i_R2 = v_R2 / R2
i_R2 = 5 V / 1000 Ohm
i_R2 = 5 mA

i_R3 = v_R3 / R3
i_R3= 5 V / 10000 Ohm
i_R3 = 0.5 mA

i_sup = i_R2 + i_R3
i_sup = 5.5 mA



analysis with Kirchhoff and Ohm

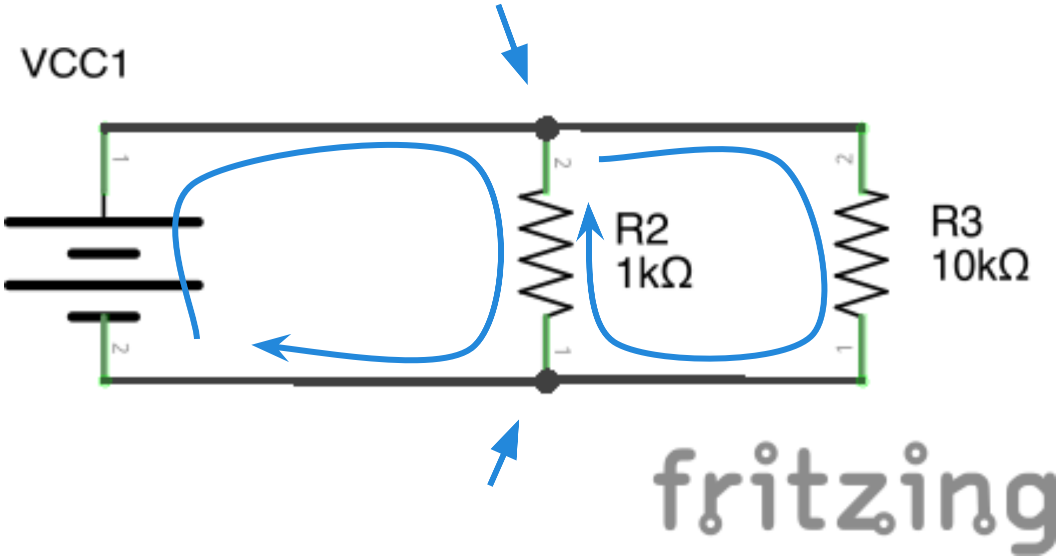
Did we get these results from our measurements?

Why or why not?

i_R2 = 5 mA

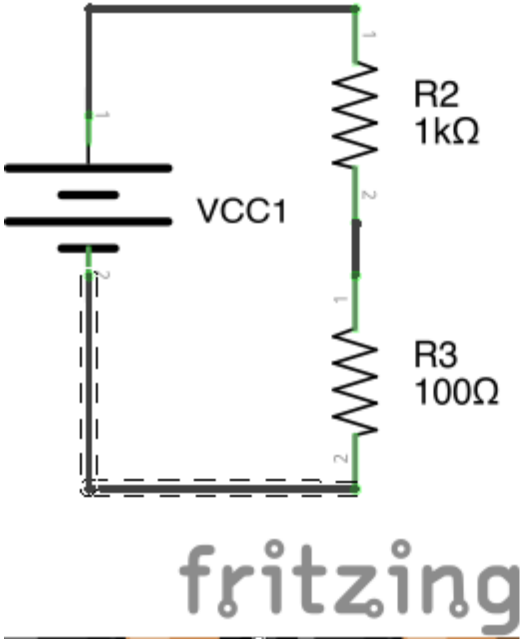
i_R3 = 0.5 mA

i_sup= 5.5 mA



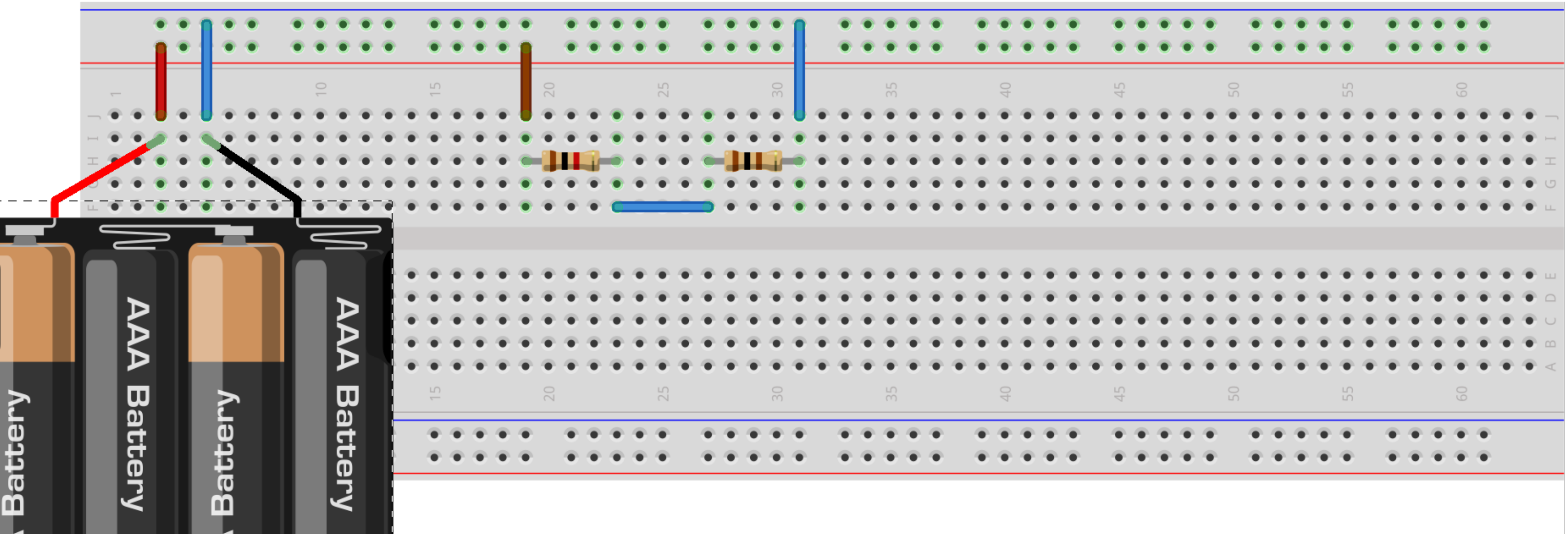
once more with resistors

Circuit 1-3



once more with resistors

Circuit 1-3

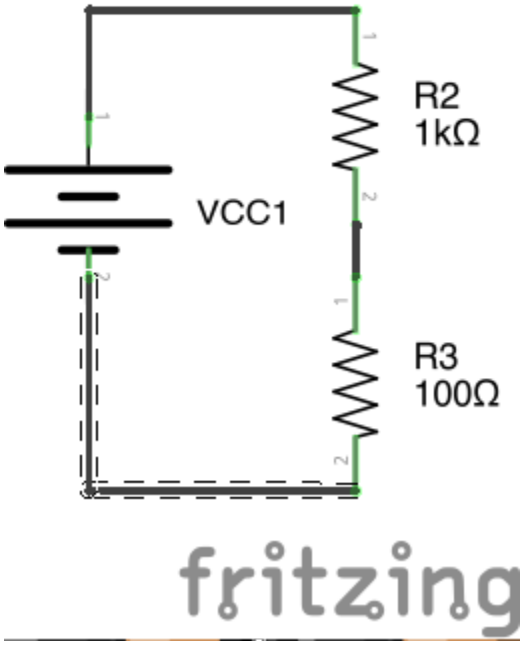


once more with resistors

Questions:

What is the current through each component and how are they related?

Ditto for voltage?

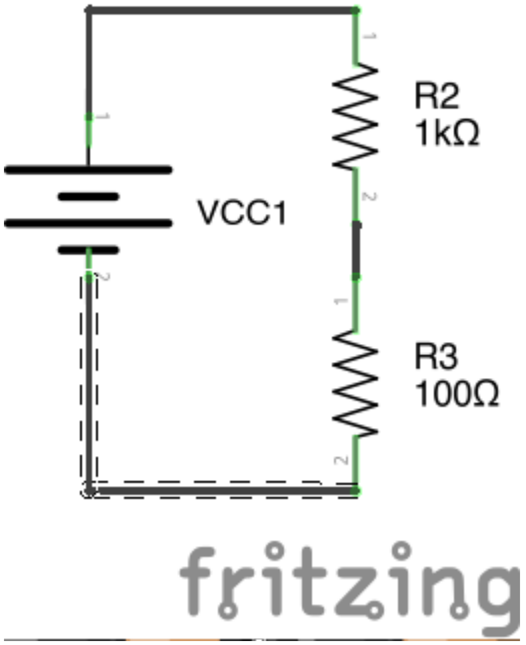


analysis

No junctions (all parts are in series) so current through each component is equal.

One loop, so:
vcc - v_R2 - v_R3 = 0

Ohm's law:
i = v / R -> v = i * R

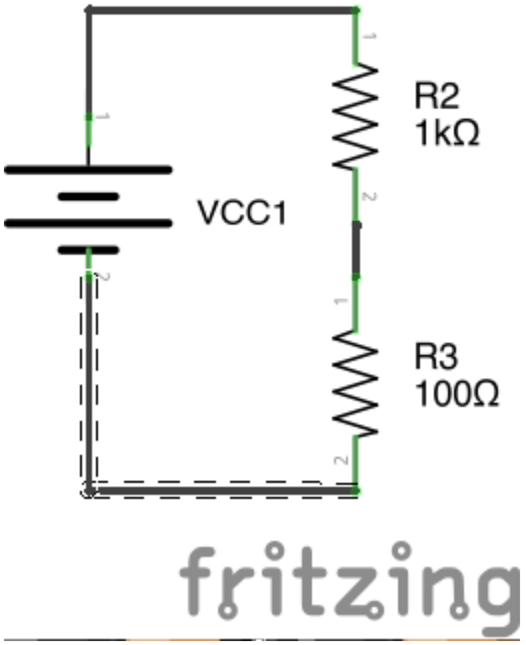


analysis

Substituting

$5V - i * 1k\Omega - i * 100\Omega = 0$

i = 4.55mA

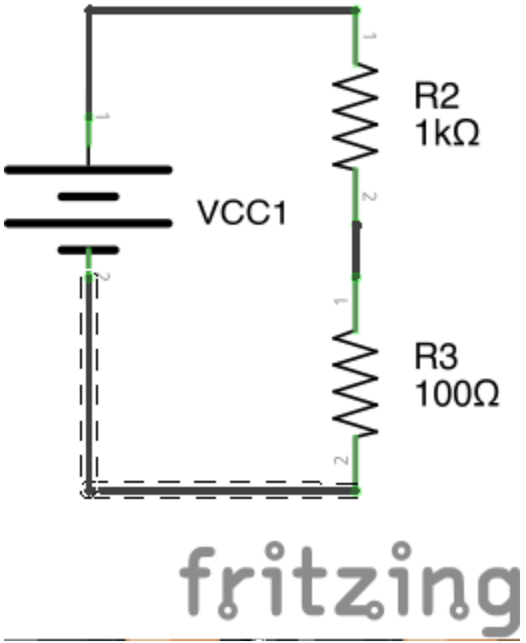


notice anything about this result?

$i = 4.55mA$

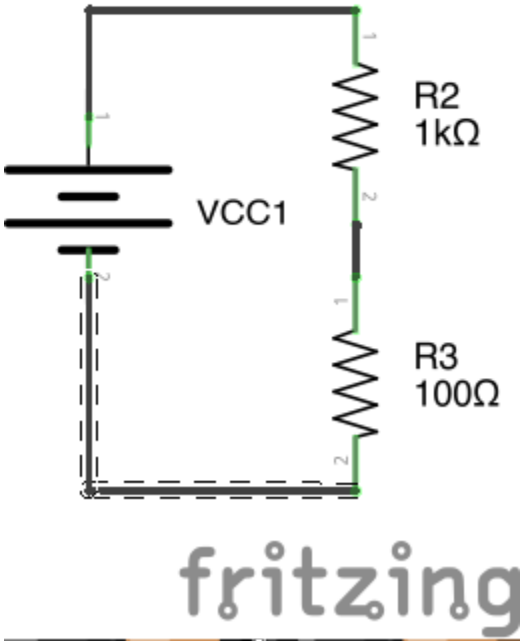
We would get the same result if we had just one resistor that was 1.1kΩ

$4.55mA = 5V / 1.1k$



resistors in series

If you have a number of resistors in series, they effectively act as one resistor with a resistance equal to the sum of their resistances.



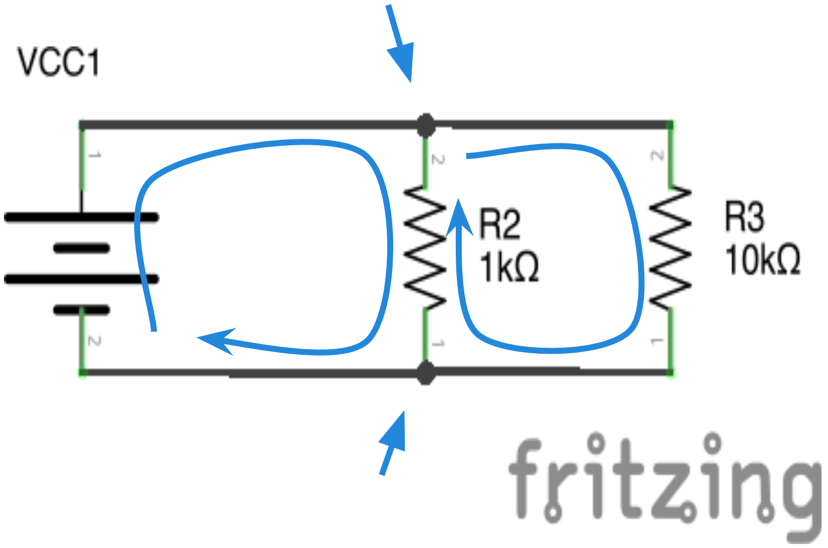
going back to circuit 1-2

Notice the current being drawn from the supply:

i_sup= 5.5 mA

We could get the same result with one resistor with 90.9Ω

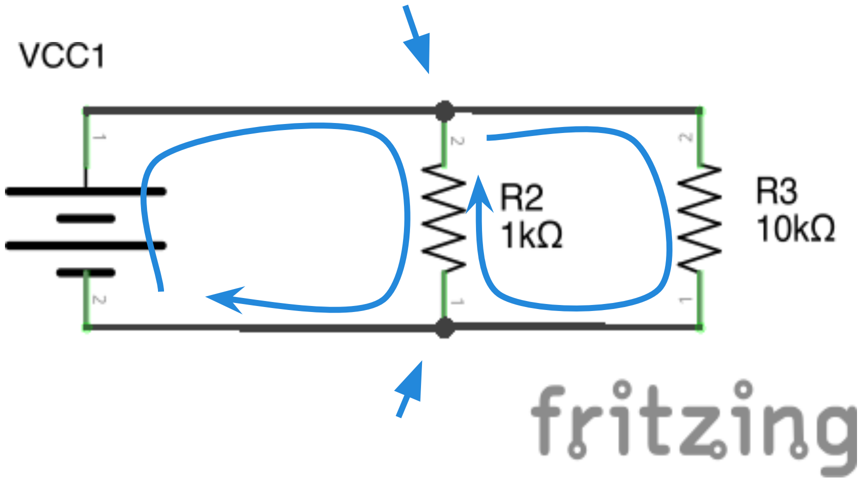
5.5mA = 5V / 909.1Ω



resistors in parallel

How do we get to 909.1Ω?
Well, let's just call the resistances R2 and R3.

Applying Kirchhoff's and Ohm's laws, we get:

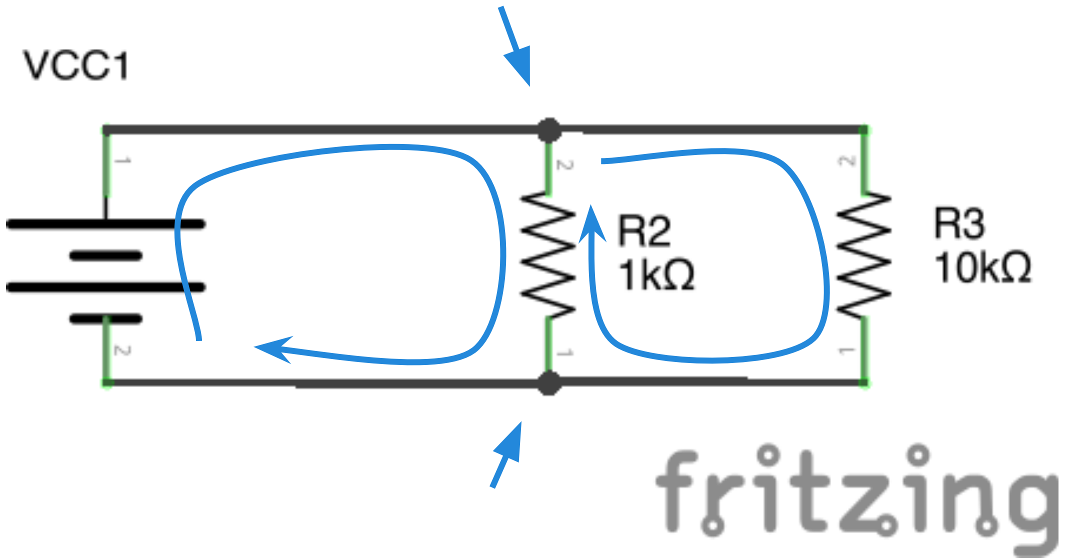


resistors in parallel

First law:
i_sup = i_R2 + i_R3

Second law:
v_sup = v_R2
v_R2 = v_R3

Ohm's law:
i_R2 = v_R2 / R2
i_R3 = v_R3 / R3

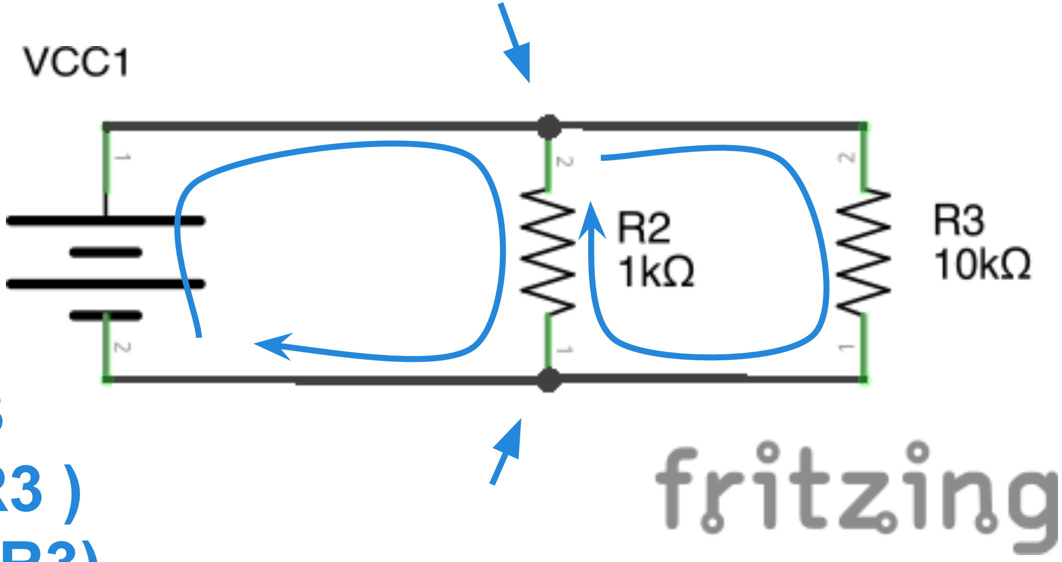


resistors in parallel

v_R2 = v_R3 = v

i_sup = v / R_eff
i_sup = v / R2 + v / R3
v / R_eff = v / R2 + v / R3

1 / R_eff = 1 / R2 + 1 / R3
R_eff = 1 / (1 / R2 + 1 / R3)
R_eff = (R2 * R3) / (R2 + R3)



resistor summary

- Ohm's law:
  - $i = v / R$
- Resistors in series:
  - $R_{eff} = \sum R_n$
- Resistors in parallel
  - $R_{eff} = 1 / (\sum (1 / R_n))$
  - $R_{eff} = (\prod R_n) / (\sum R_n)$

circuit summary

- Kirchhoff's Current Law:
  - at a node, $\sum i_n = 0$
- Kirchhoff's Voltage Law:
  - around a loop, $\sum v_n = 0$