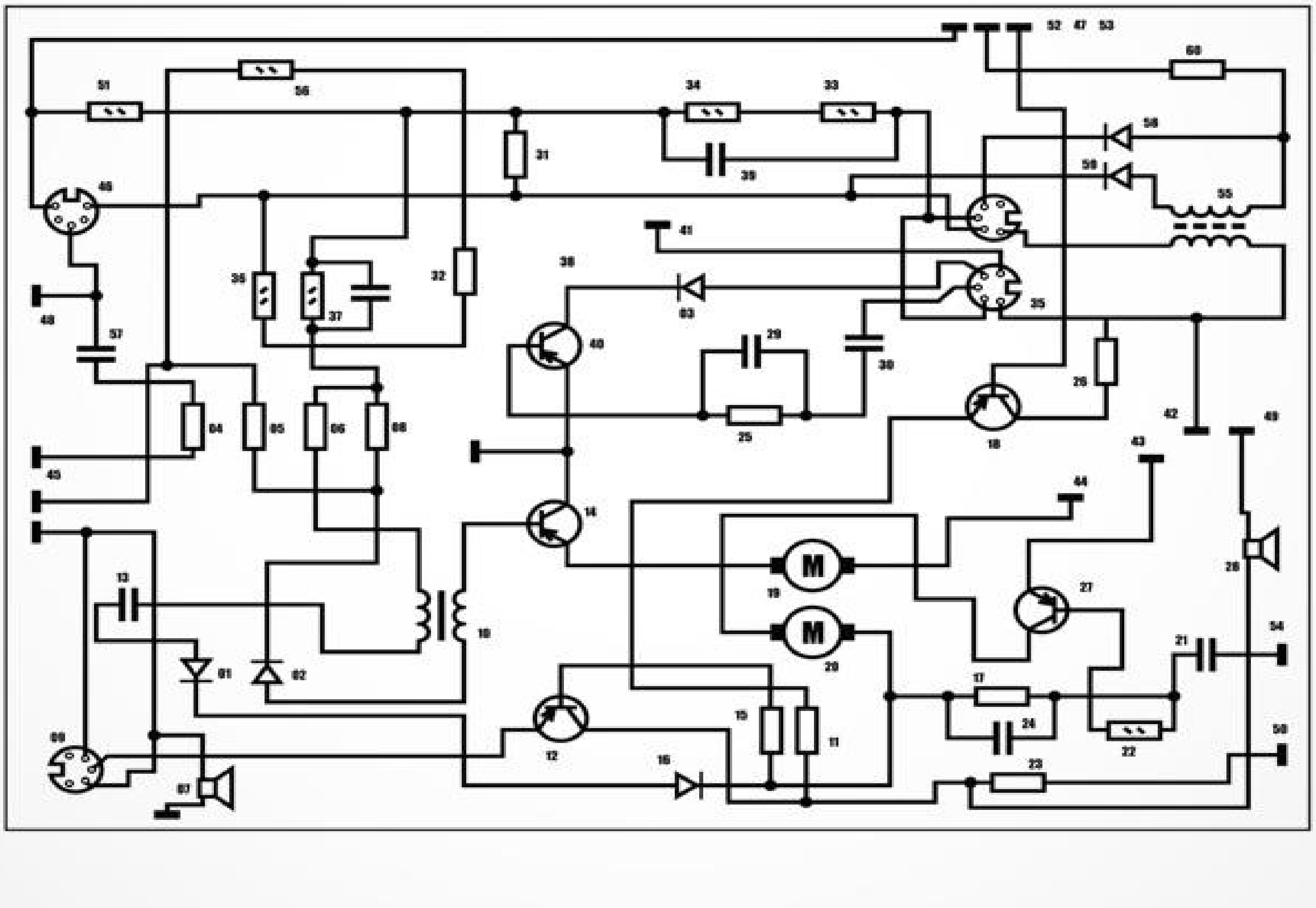
ELECTRIC CIRCUITS



SARAH ALLEN

Electric Circuits

Welcome to this tutorial on electric circuits. This tutorial covers some of the basics, including current, resistance, voltage, Ohm's Law, and Kirchhoff's Laws.

If you get confused while working on it, please email me at
SarahAllenPhysics@gmail.com
so I can improve it!

Or, say hello on my website: StickFigurePhysicsTutorials.com

Table of Contents

Electric Circuits

Conductors

Current

Resistance

Voltage

Circuit Diagrams

Series and Parallel

Finding Equivalent Resistance

Ohm’s Law

Kirchoff’s Loop Law

The Node Law

Example Circuit Problem

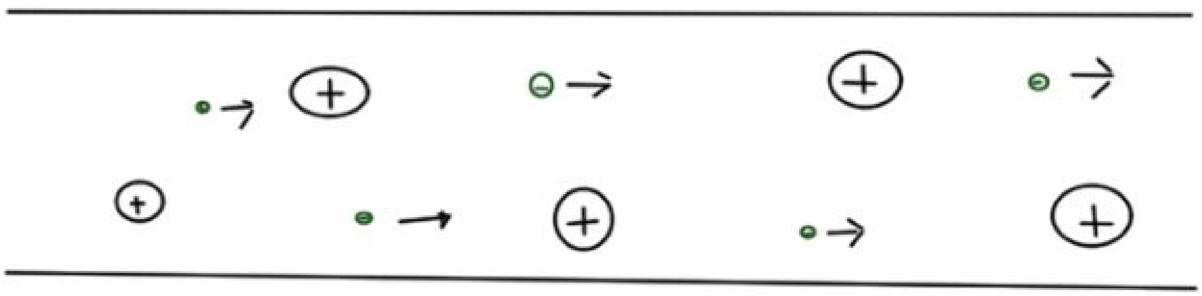
Conductors

A conductor is something that electric current can flow through. An insulator is something that electric current has a hard time flowing through.

Electric current is simply electrons moving around. Some materials hold their electrons very tightly so they can't move (these are insulators,) some have electrons that can move around (these are conductors.)

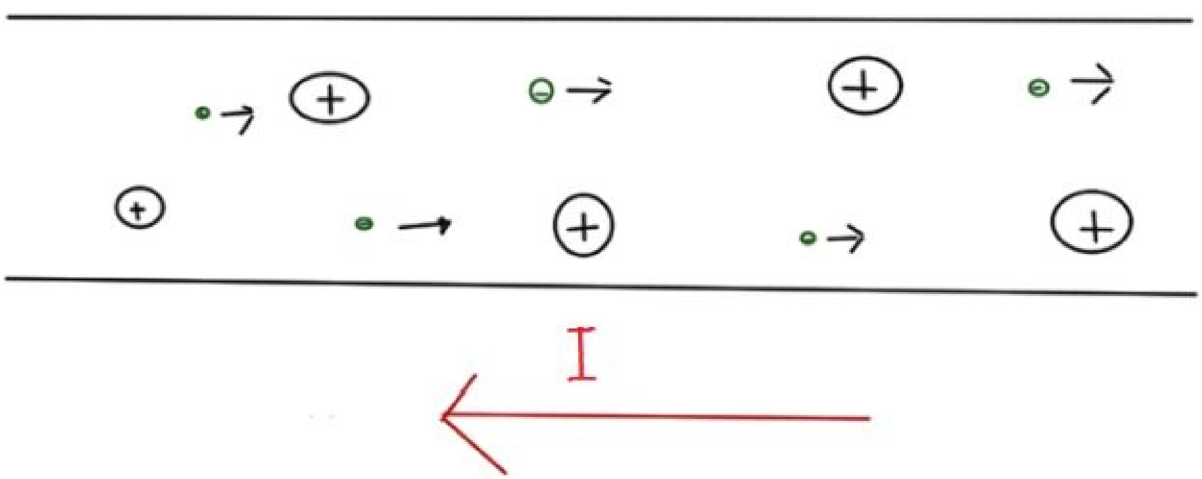
Current

Electric current is made up of electrons moving through a conductor. Here is a zoomed-in view of part of a wire:



This is REALLY not drawn to scale. The positively charged things are nuclei, the little green circles are electrons. Also, the electrons don't just travel in one direction, they bounce all over the place, but if there is current then overall they do move in one direction.

Even though the electrons are moving to the right, we say that the current is going to the LEFT. It's the opposite.

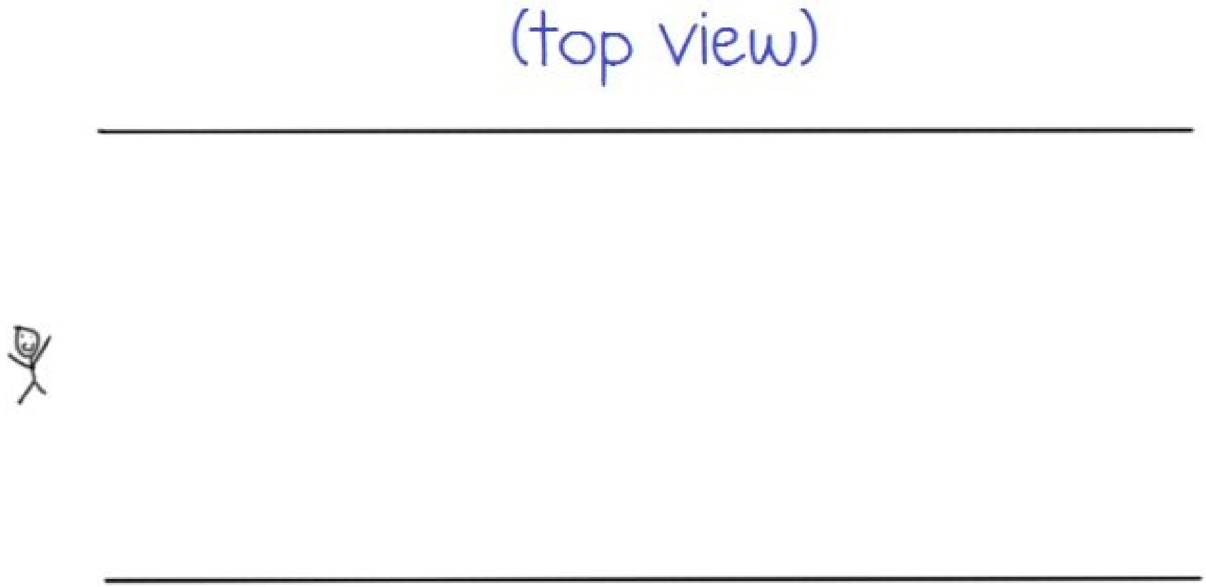


The symbol for current is I, and it is measured in Amps, which are Coulombs per Second. (Because current is flowing charge, it is measured in the amount of charge (coulombs) that flow through the wire per second.

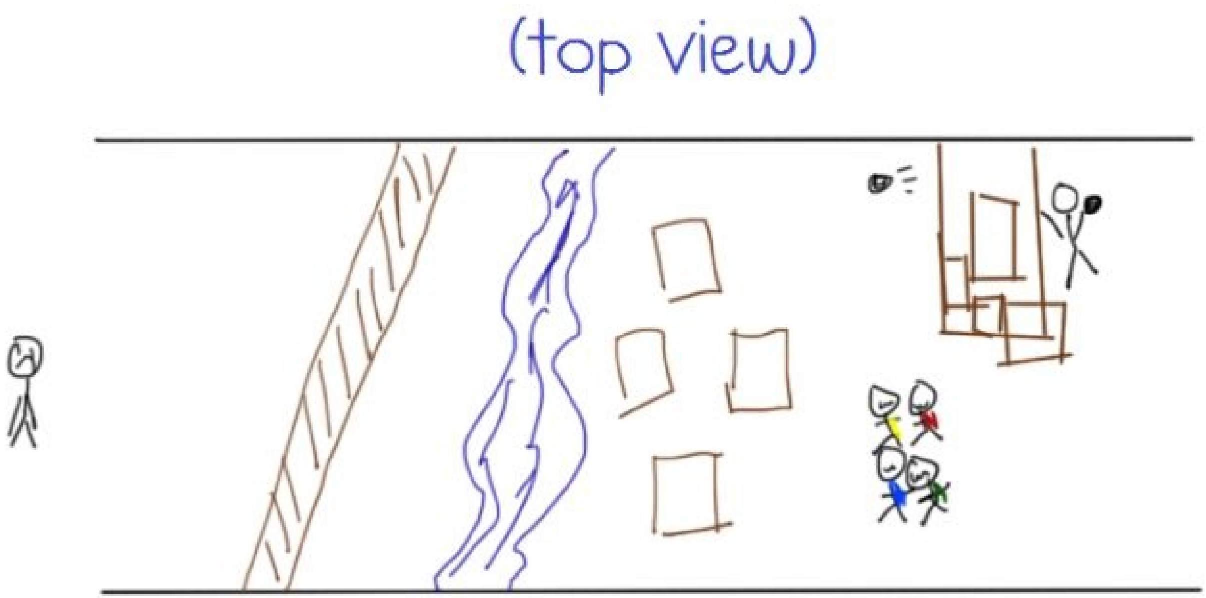
Resistance

Resistance is a measure of how hard it is for current to flow through something.

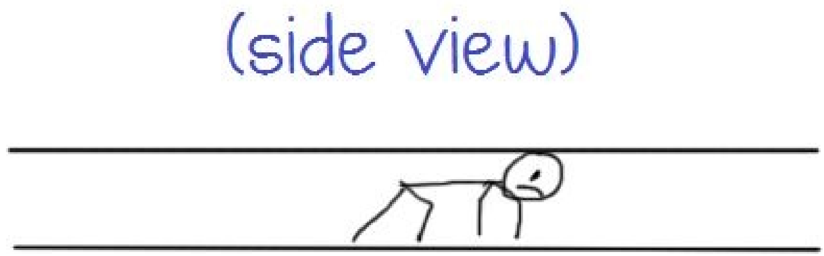
Here is an analogy. Imagine you are an electron. You are at school trying to get to your next class. A low-resistance hallway looks like this:



A high-resistance hallway looks like this:



Or maybe like this:



Resistance is measured in Ohms:

Voltage

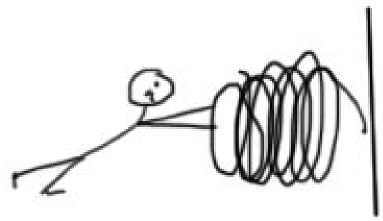
Voltage is a pretty confusing concept. It's confusing because it's an abstract concept based on another abstract concept.

It is the change in potential energy per charge from one place to another.

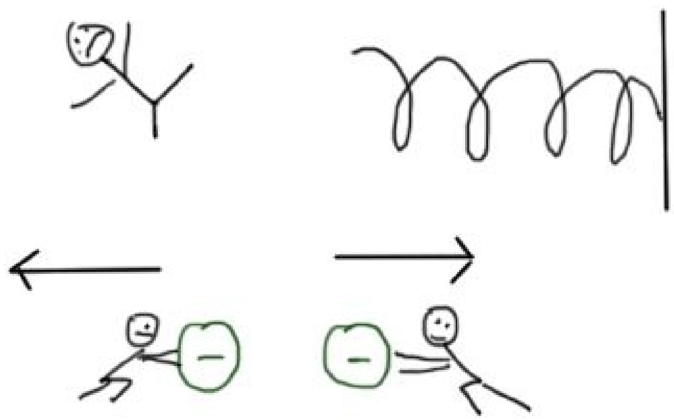
You can also think of it as the "push" on the electrons in a conductor.

First, what is potential energy? It is "the ability to do work." We know that things that have lots of potential energy have lots of potential to do things, like move. Here are some ways you can have potential energy:

Being up High (because you can fall)



Compressing a spring (because the spring wants to expand)



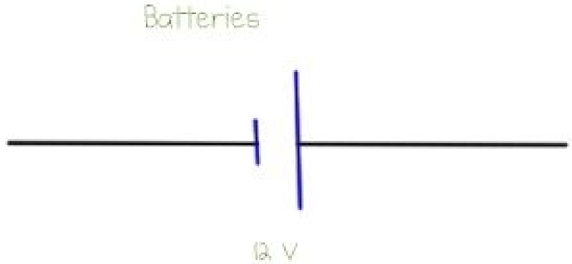
Bringing like charges close together (because they want to repel)

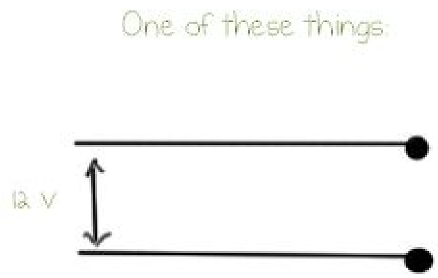
This last one is especially important for circuits. Like charges will repel each other. If there is a place for them to flow to, they will flow away from one another, losing potential energy. We never talk about the "voltage" of a certain place. We only talk about "voltage drops" or the voltage between two places. Because, what we care about is the CHANGE in potential energy per charge from place to place.

Some books call voltage voltage, others call it the "electric potential difference" and later it might be referred to as the "electromotive force" (emf.) These are all the same thing.

Voltage is measured in volts. Or, joules per coulomb (energy per charge!)

Possible sources of voltage:



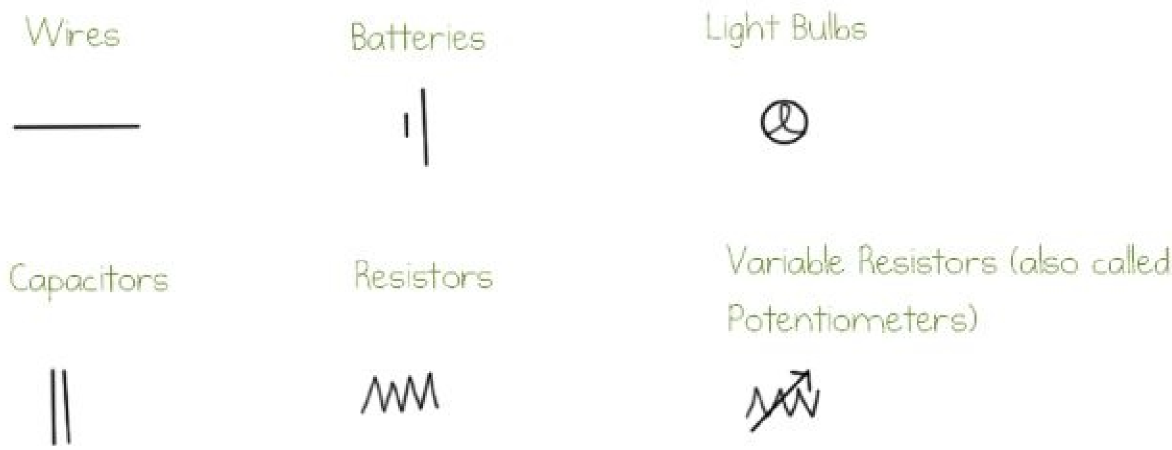


The second one just means that the difference in potential energy per unit charge between the top ball and the bottom ball is 12 volts. It's exactly the same as if there were a battery there, we just don't know where the voltage difference is coming from. (Like, is there a generator there? A battery? Little fairies carrying charges around?)

Circuit Diagrams

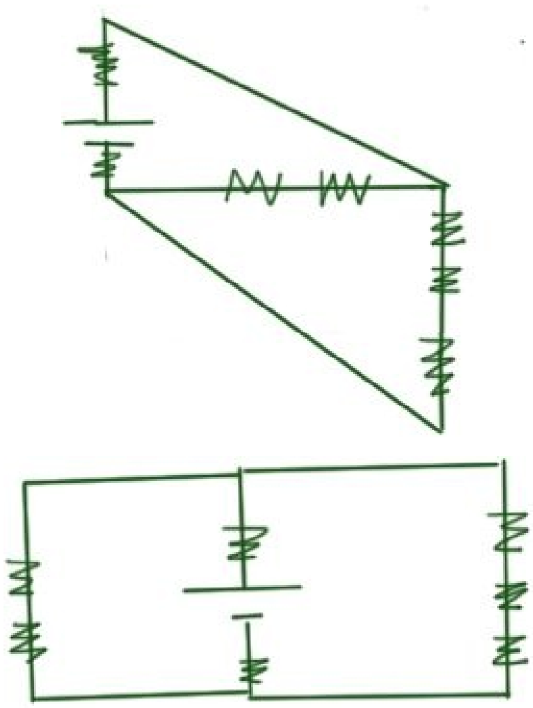
Circuit diagrams are like maps of circuits.

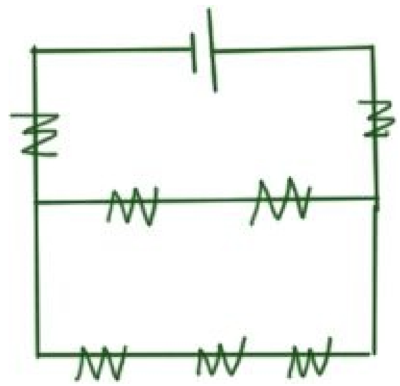
Here are the symbols you need to know (there are others, but these are the main ones you'd see in AP physics):



The same circuit diagram can be drawn in many different ways. The lengths and arrangement of the wires aren't important, only the connections.

For example, these are all the same circuit:

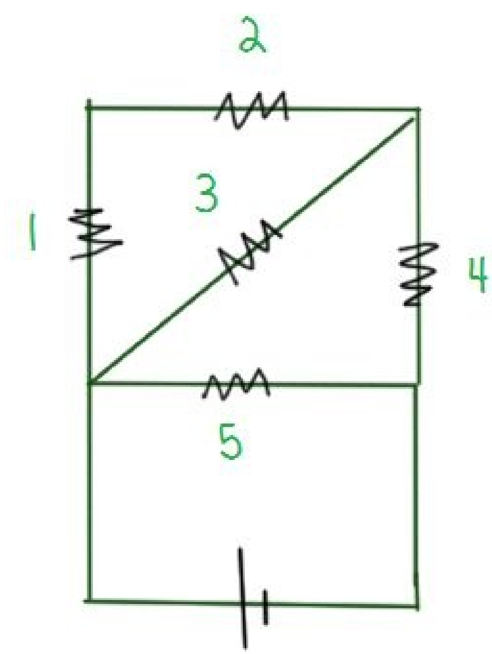




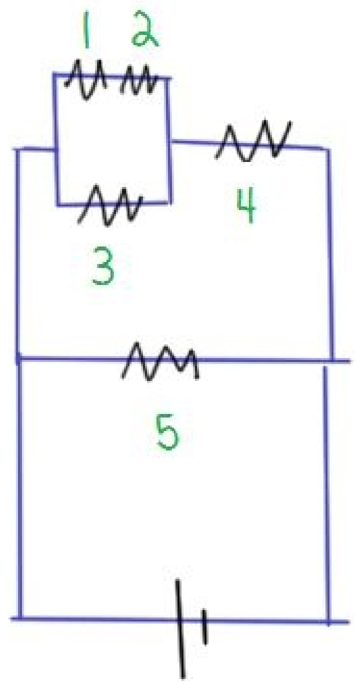
Keep in mind that sometimes if you redraw a circuit diagram, it will make the problem easier to solve. A good way to do this is to aim for putting all resistors on horizontal lines.

Try This:

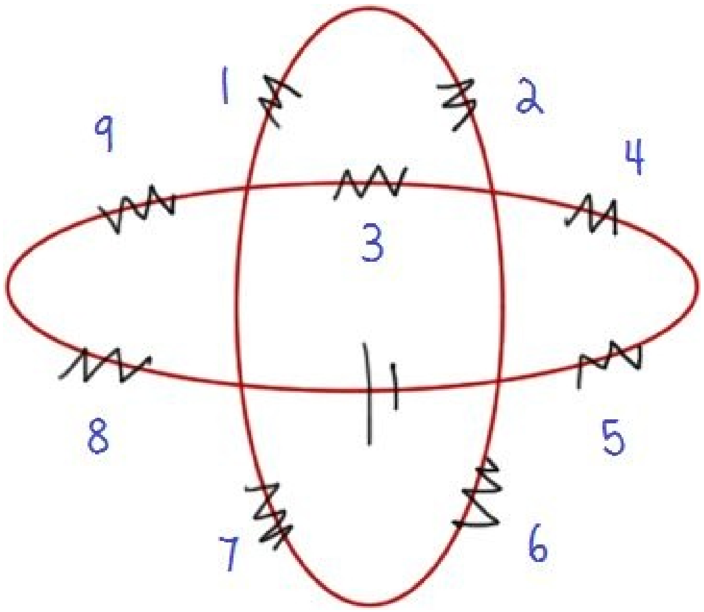
Redraw the following circuit:



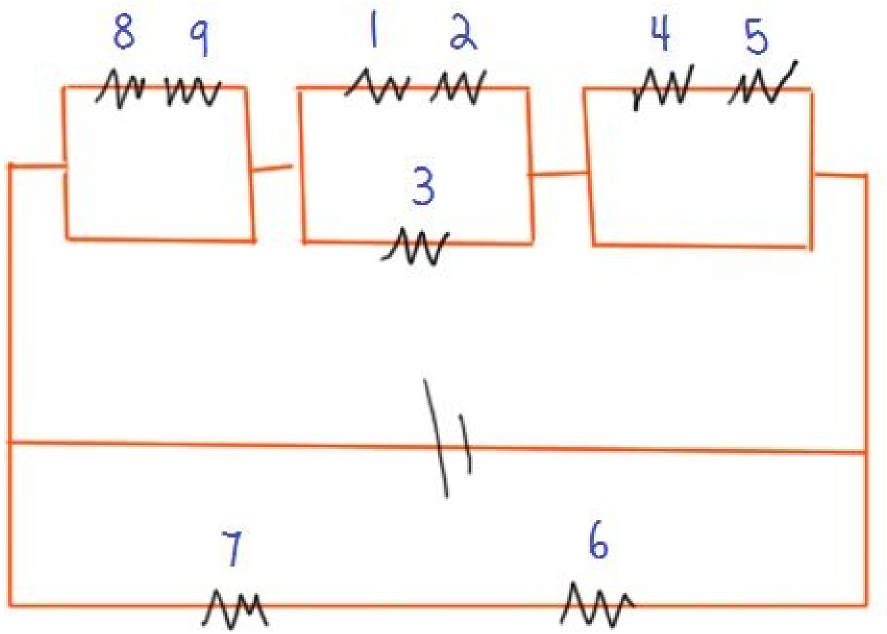
Check Your Answer: (There are lots of possible answers)



Try This: Redraw the following circuit diagram:



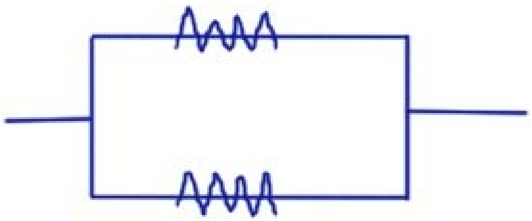
Check your Answer: (There are lots of possible answers)



Series and Parallel

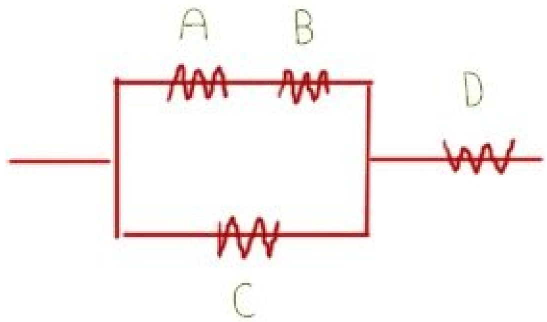
Here are two resistors “in series”:

Here are the same two resistors “in parallel”:



When you’re working with circuits, you need to be able to tell whether things are in parallel, series, or neither, so that you know how to work with them.

Try This:

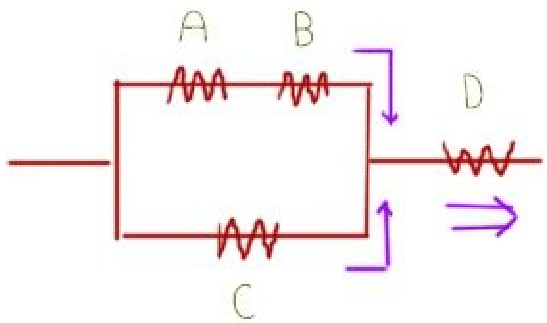


Are C and D in parallel, series, or neither?

Check your answer:

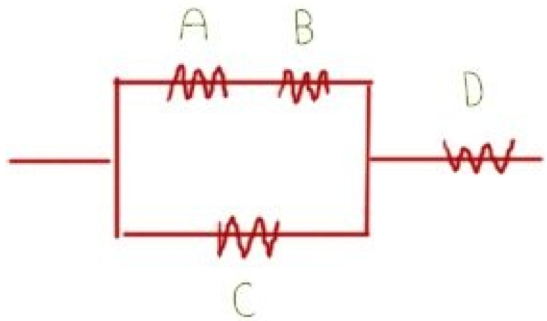
Neither.

A precise definition of series is that if two elements are in series then all the current that goes through one also goes through the other. Take a look at the currents in this circuit:



Some of the current that goes through D goes through C, but not all of it, so they're not in series.

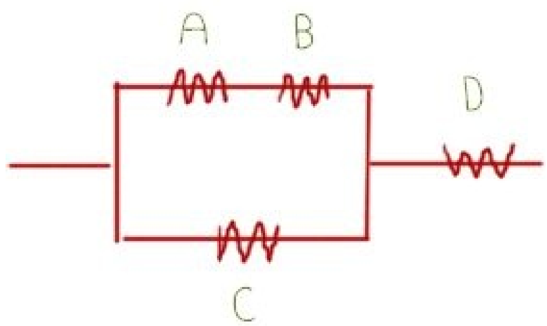
Try This: Are A and B in series, parallel, or neither?



Check your answer:

Series.

Try this: Are A and C in parallel, series, or neither?

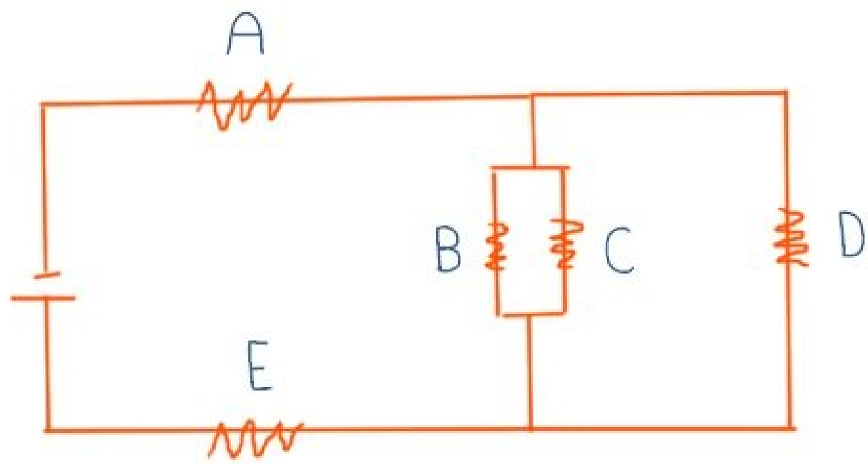


Check your answer:

Neither. Although, C is in Parallel with A and B together, just not either one alone.

Try This:

Which of these resistors are in parallel, and which are in series?

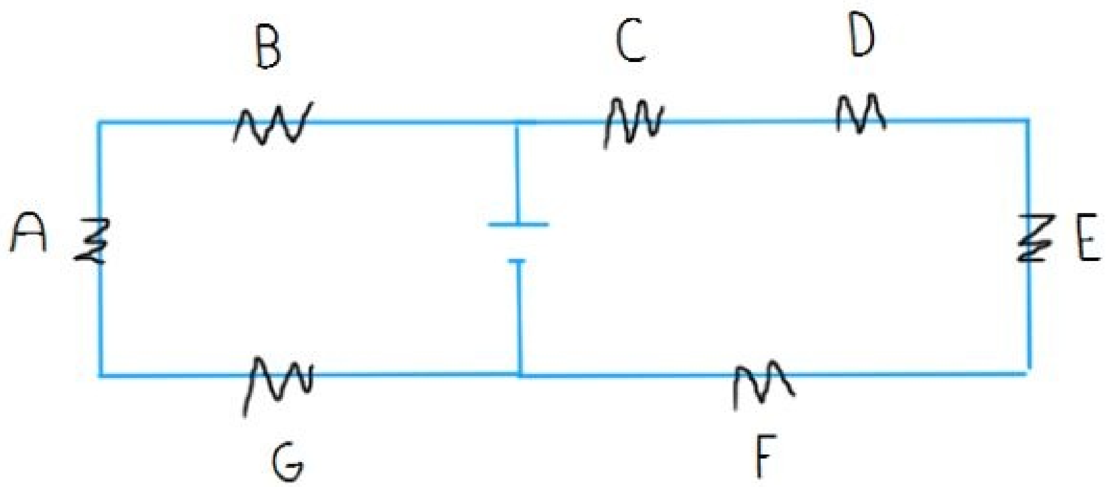


Check your Answer:

B, C, and D are in parallel. A and E are in series. A and E are also in series with the BCD network.

Try This:

Which of these are in parallel or series?

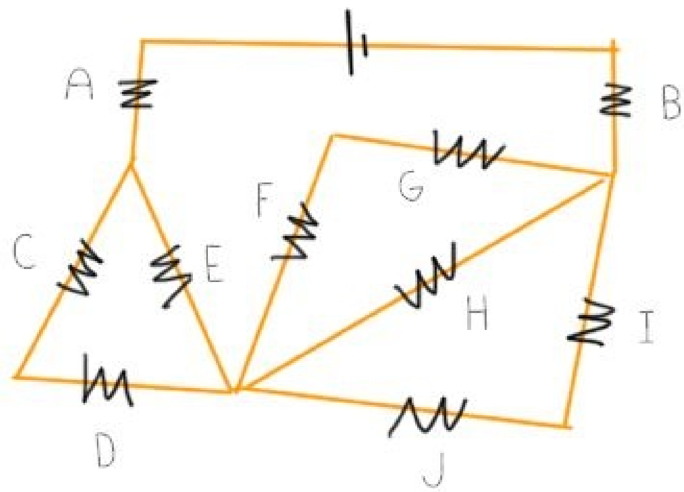


Check your Answer:

A, B and G are in series. C, D, E, and F are in series. The ABG network is in parallel with the CDEF network.

Try This:

Which of these are in parallel or series?



Check your Answer: E is parallel to CD, H is parallel to FG and IJ. A and B are in series with CDE and FGHIJ.

Finding Equivalent Resistance

If you have more than one resistor in a circuit, you can often combine their resistances together and treat them as one resistor.

For example, these two resistors below:

Can be treated as one resistor with a resistance of 3 ohms:

How you do this, though, depends on whether the resistors are in parallel or series.

If they are in series, like they are above, you just add them together.

Try This: What is the equivalent resistance of the three resistors below?

Check your answer:

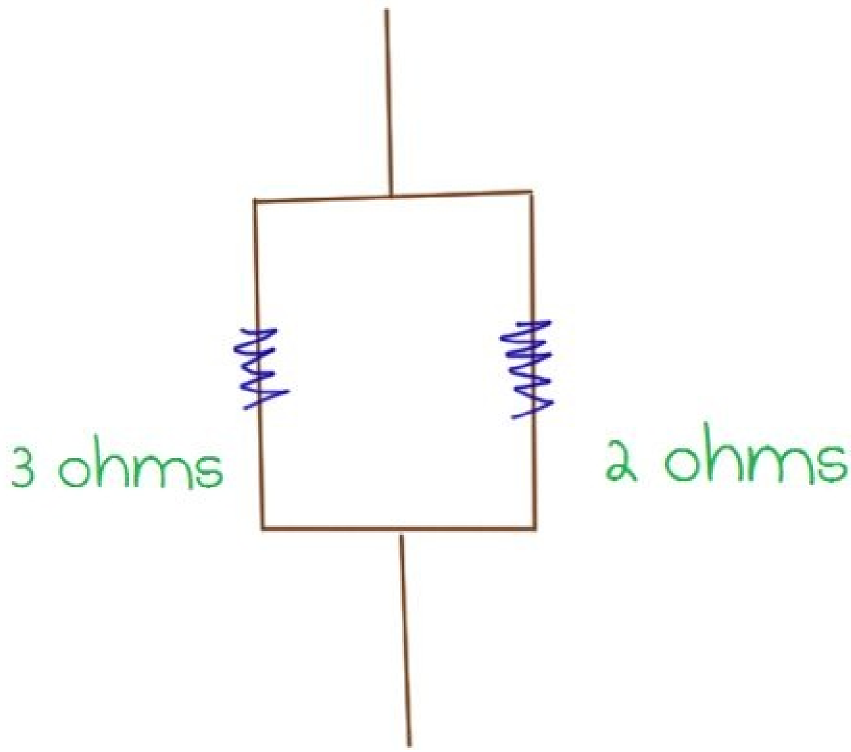
$$12 + 3 + 1 = 16 \text{ ohms}$$

If the resistors are in parallel, you add them in kind of a weird way:

$$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Here, Rtot stands for “Total Resistance” and R1 and R2 are the two resistors you’re trying to add together.

Try This: What is the total resistance (or equivalent resistance) of the resistors shown below?



Check your Answer:

$$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$R_1 = 3$ ohms

$R_2 = 2$ ohms

$$\frac{1}{R_{tot}} = \frac{1}{3} + \frac{1}{2}$$

find common denominator (or just use your calculator):

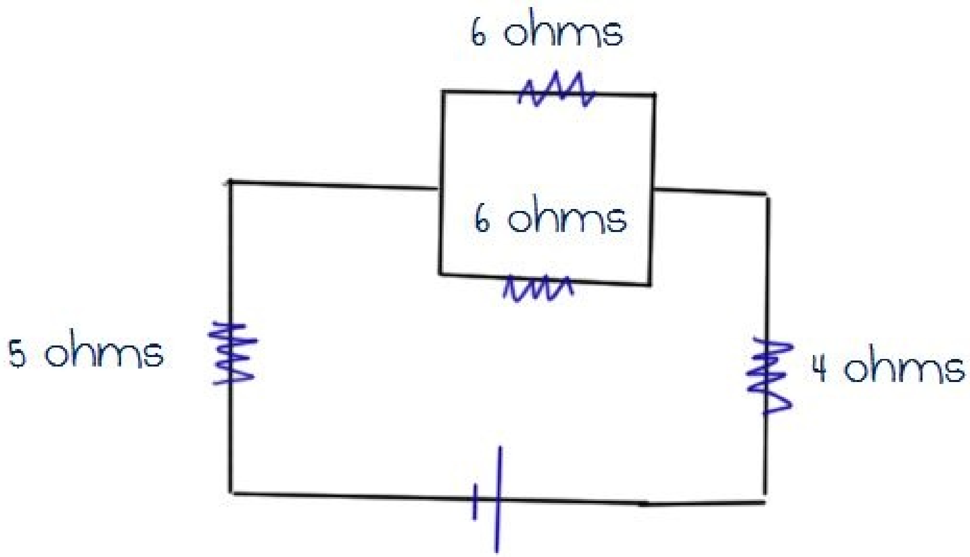
$$= \frac{2}{6} + \frac{3}{6}$$

$$= \frac{5}{6}$$

Lastly, we just have to invert both sides:

$$= \frac{6}{5} \text{ ohms}$$

Try this: What is the equivalent resistance of the circuit below:



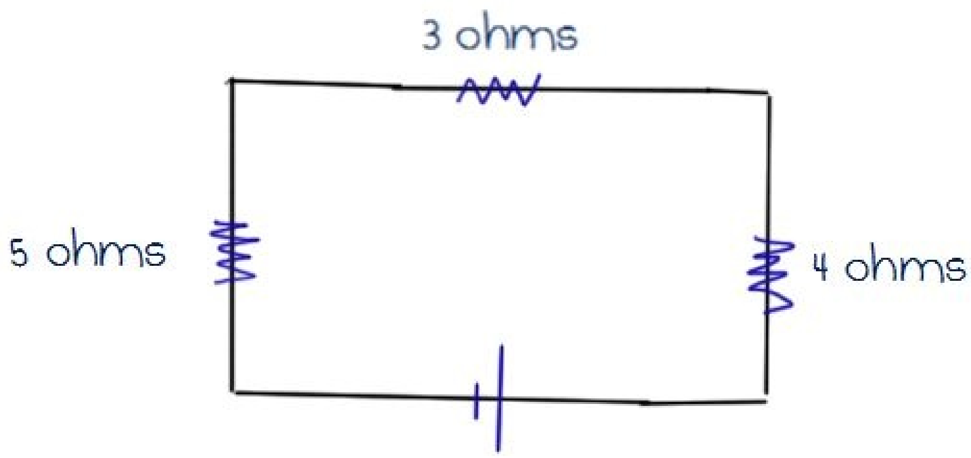
Check your Answer:

The 6 ohm resistors are in parallel with each other so we'll start there (the 5 and 4 ohm resistors are in series, so we could also start there, but this way is easier.)

$$\frac{1}{R_{tot}} = \frac{1}{6} + \frac{1}{6} = \frac{2}{6} = \frac{1}{3}$$

$$R_{tot} = 3 \text{ ohms}$$

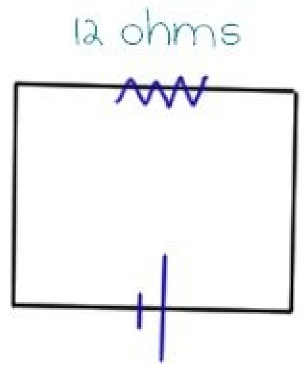
Now the circuit looks like this (because we replace the two 6 ohm resistors with 1 3 ohm resistor):



Now we just have 3 resistors in series, so we can add their resistances:

$$5 + 3 + 4 = 12 \text{ ohms}$$

So, our total resistance is 12 ohms, and the original circuit is equivalent to, or the same as, this circuit:


12 ohms

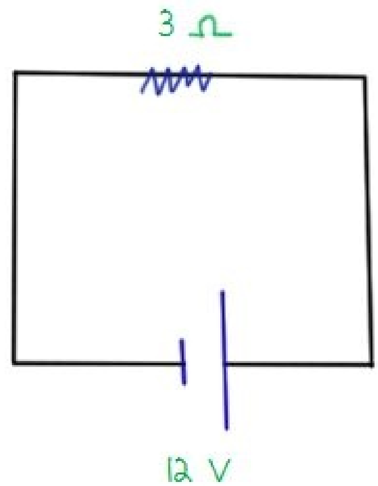
Ohm’s Law

Ohm’s law is super useful. It relates the current, voltage, and resistance. Here is the equation:

$$V = IR$$

V is voltage in volts, I is current in amps, and R is resistance in ohms.

Try this: What will the current through the resistor below be?



Check your answer:

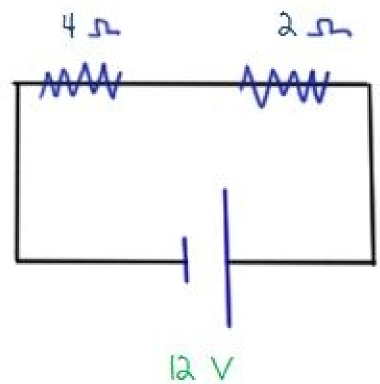
The voltage across the resistor is 12 volts, the resistance is 3 ohms. We plug that into our equation:

$$12 = I \times 3$$

And solve:

$$I = 4 \text{ amps}$$

Try this: What is the current through this circuit?



Check your answer:

The 12 volts is across the whole circuit, not just one of the resistors. So, before we find the current, we need to add the resistors together to get the total resistance:

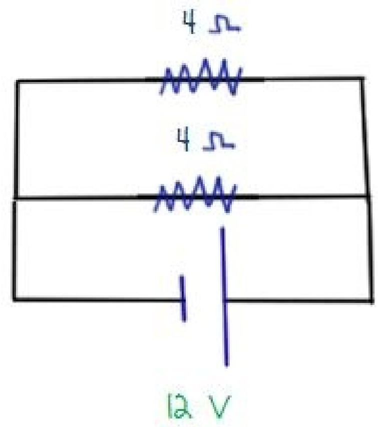
$$4 + 2 - 6 \text{ ohms}$$

Now we can use ohm's law:

$$12 = I \times 6$$

$$I = 2 \text{ amps}$$

Try this: What is the current through this circuit:



Check your answer:

Again, we'll need to get the total resistance. This time the resistors are in parallel, so we add them like this:

$$\frac{1}{R_{tot}} = \frac{1}{4} + \frac{1}{4}$$

$$\frac{1}{R_{tot}} = \frac{2}{4} = \frac{1}{2}$$

$$R_{tot} = 2 \text{ ohms}$$

So, the total resistance is 2 ohms. Now we'll use ohm's law:

$$12 = I \times 2$$

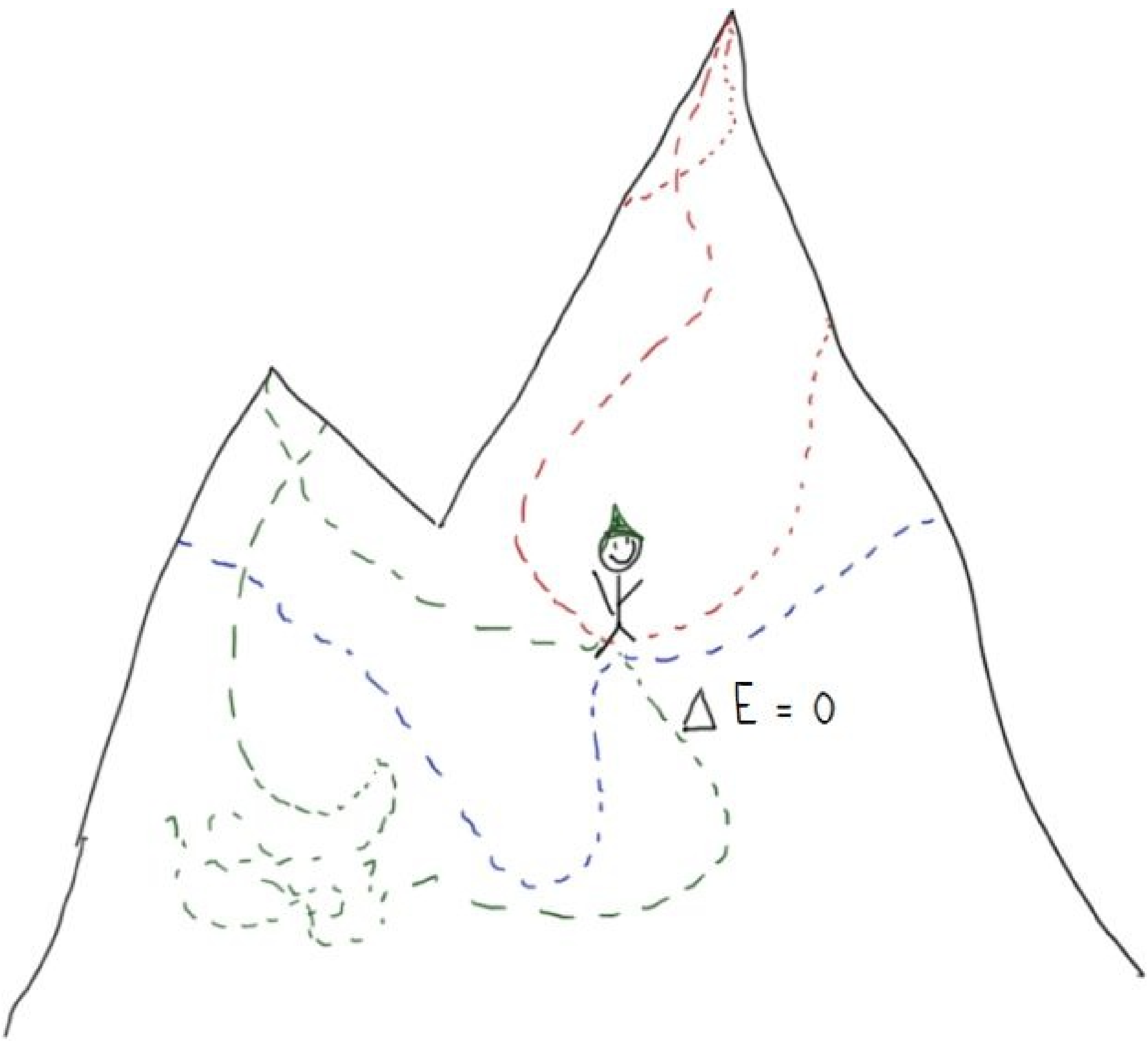
$$I = 6 \text{ amps}$$

Kirchhoff’s Loop Law

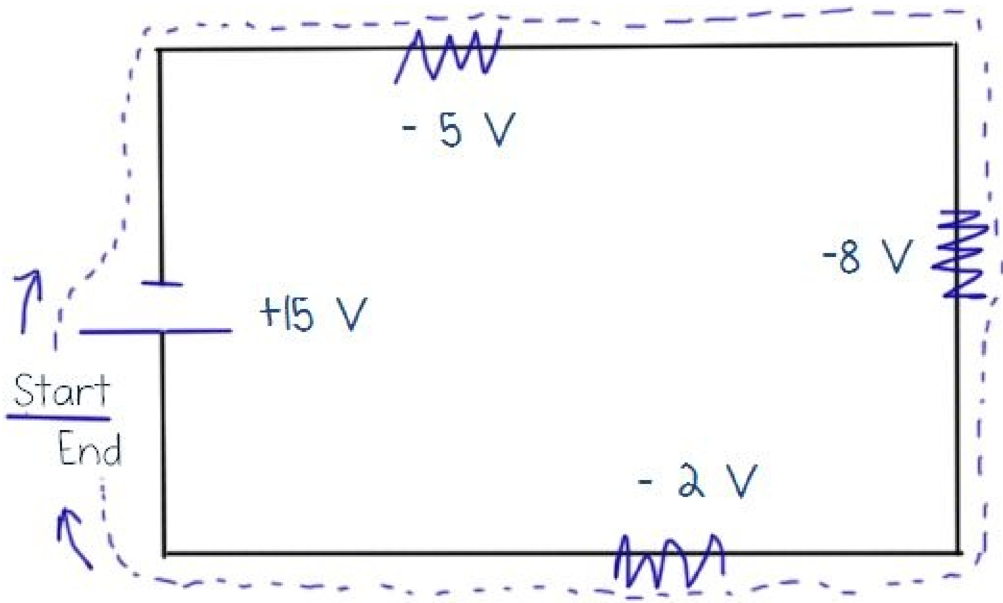
To solve circuit problems, you need Ohm’s law, but you also need Kirchoff’s Loop Law and Node Law.

The loop law says that for any loop you take around a circuit, the total change in voltage must be zero.

This is like taking a walk around a mountain. If you come back to the same place on the mountain, your total change in gravitational potential energy is zero:



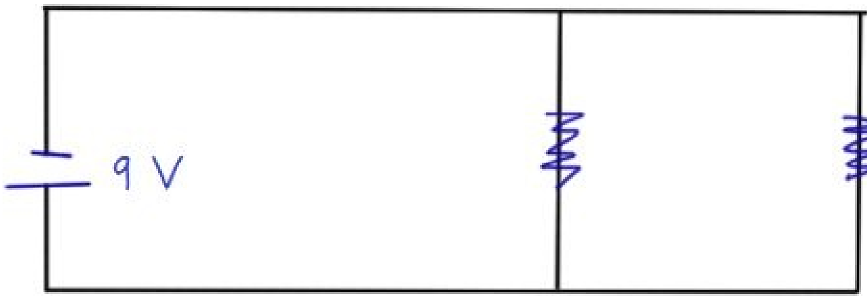
For example, here is a circuit with a “loop” drawn on, and their total changes in voltage:



Notice that we gain voltage across the battery, and lose voltage going across the resistors. Here's the equation we would write for this:

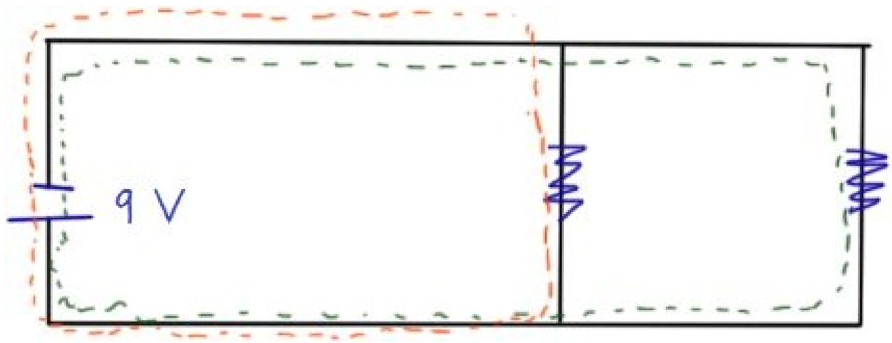
$$15 - 5 - 8 - 2 = 0$$

Try This: What must the voltage drops be across each of the two resistors below?



Check your answer:

The voltage drop must be 9 volts across each of the resistors. Here are the two loops we could draw:



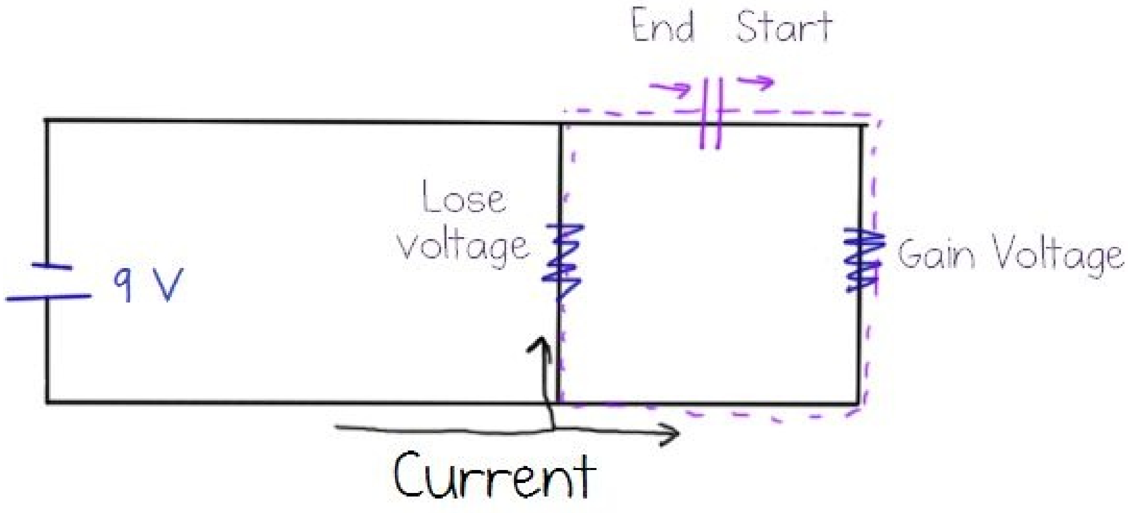
The equation for the orange loop looks like this:

$$9V - 9V = 0$$

The equation for the green loop looks the same, but the -9v is for the second resistor rather than the first:

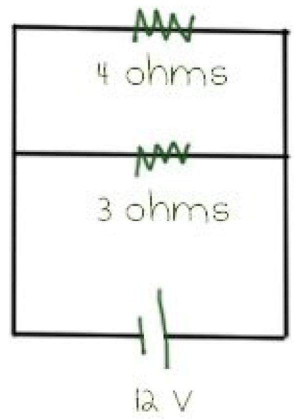
$$9V - 9V = 0$$

Do loops always have to go through the battery? No. But, now we need to know the direction the current is going. The current in this circuit flows from the positive terminal of the battery (the wide end) to the negative terminal.



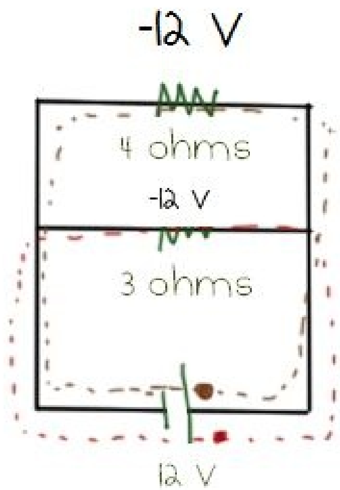
If you go through a resistor in the same direction as the current, you lose voltage. If you go through the resistor against the current, you gain voltage.

Try This: How much current will flow through each of the resistors below?



Check your answer:

First, we need to know the voltage across each of the resistors. Taking two loops, we can see that the voltage must be 12 volts across each.



Now we'll use ohm's law to find the currents:

$$12 = I \times 4$$

$$I = 3 \text{ amps}$$

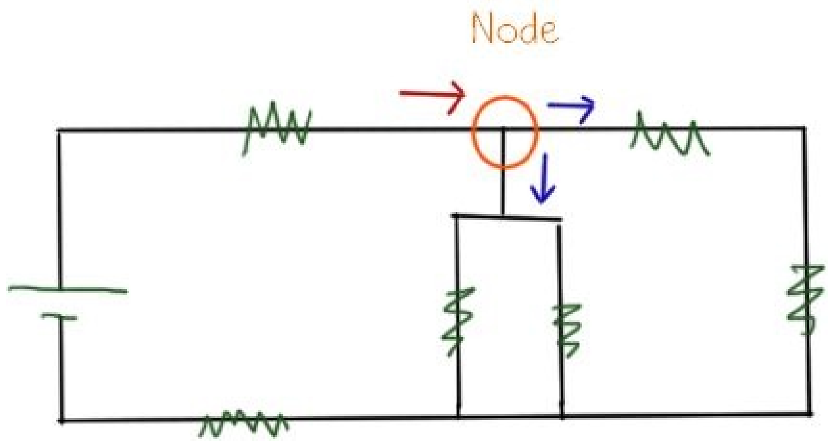
$$12 = I \times 3$$

$$I = 4 \text{ amps}$$

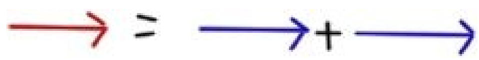
So, the current through the upper resistor is 3 amps, and the current through the lower resistor is 4 amps.

The Node Law

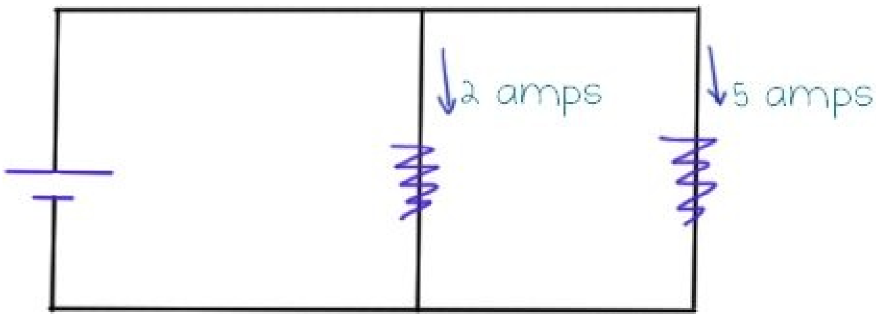
The node law has to do with current. Basically, that you can't lose any of it.
The node law says that at any node you pick in the circuit, (the arrows represent current)…



…the current flowing into that place must equal the current flowing out.

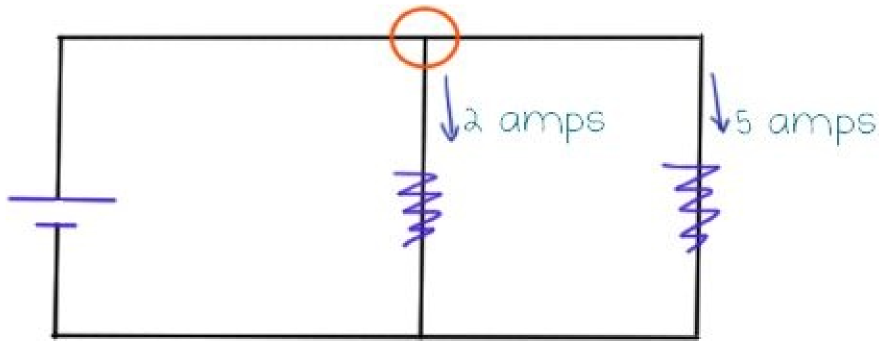


Try this: How much current is flowing through the battery?



Check your answer:

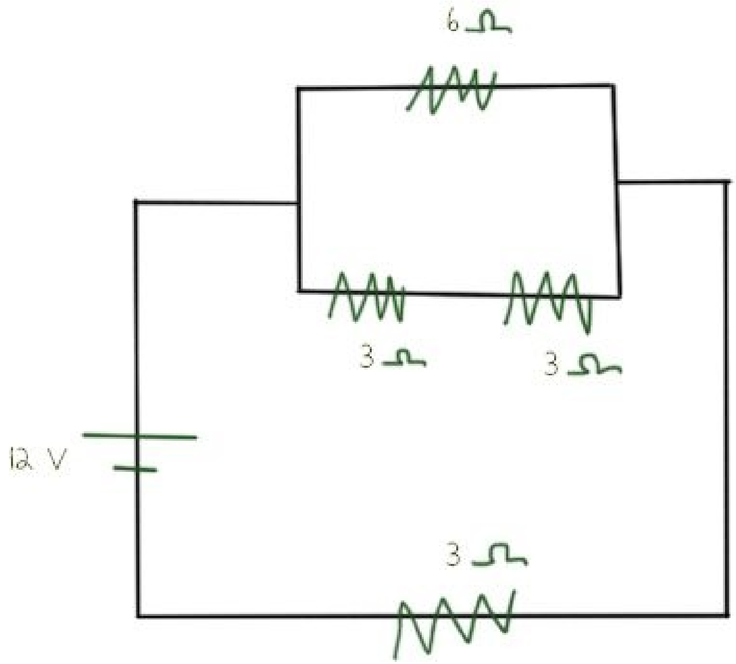
7 amps. Pick this node:



2 amps and 5 amps are flowing out of that node and into the resistors, so 7 amps must be flowing in.

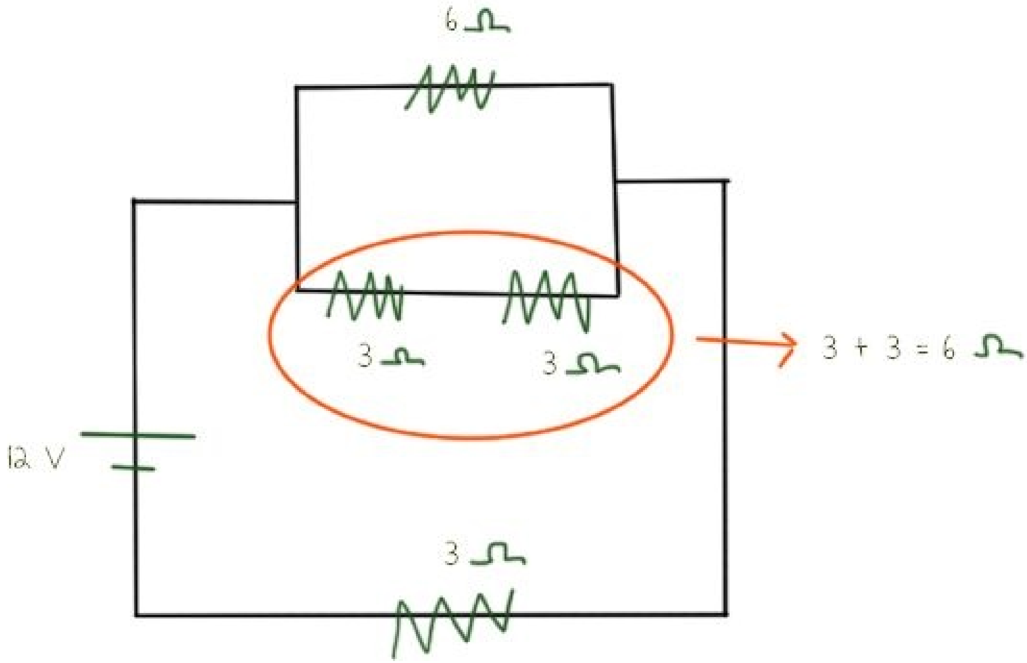
Example Circuit Problem

Try this: How much current will flow through each of the resistors below?

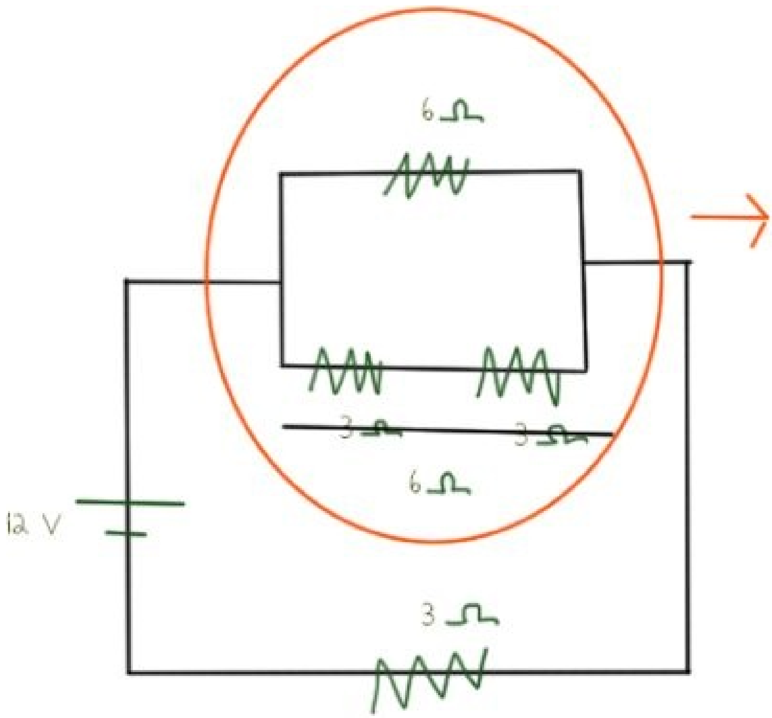


Check your answer:

The first thing we need to do is figure out the total resistance. First we'll add the two in series:



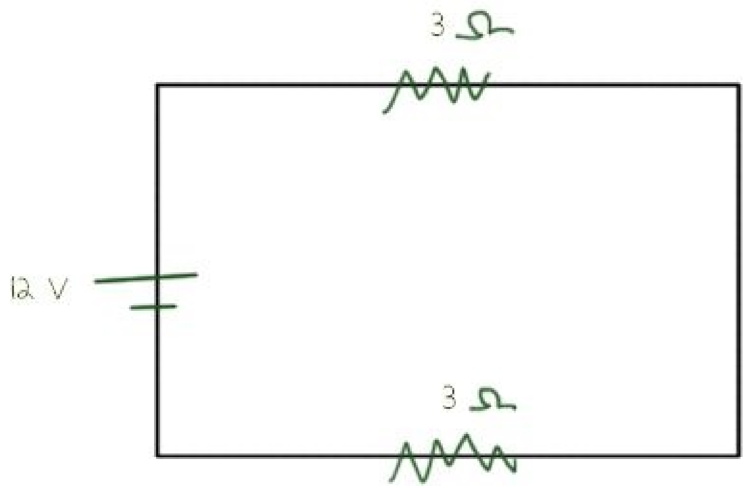
Now the two in parallel:



$$\frac{1}{6}+\frac{1}{6}=\frac{2}{6}=\frac{1}{3}$$

$$R_{tot}=3$$

Now, our circuit looks like this:



So, we'll add the last two resistors which are in series:

$$3 + 3 = 6 \text{ ohms}$$

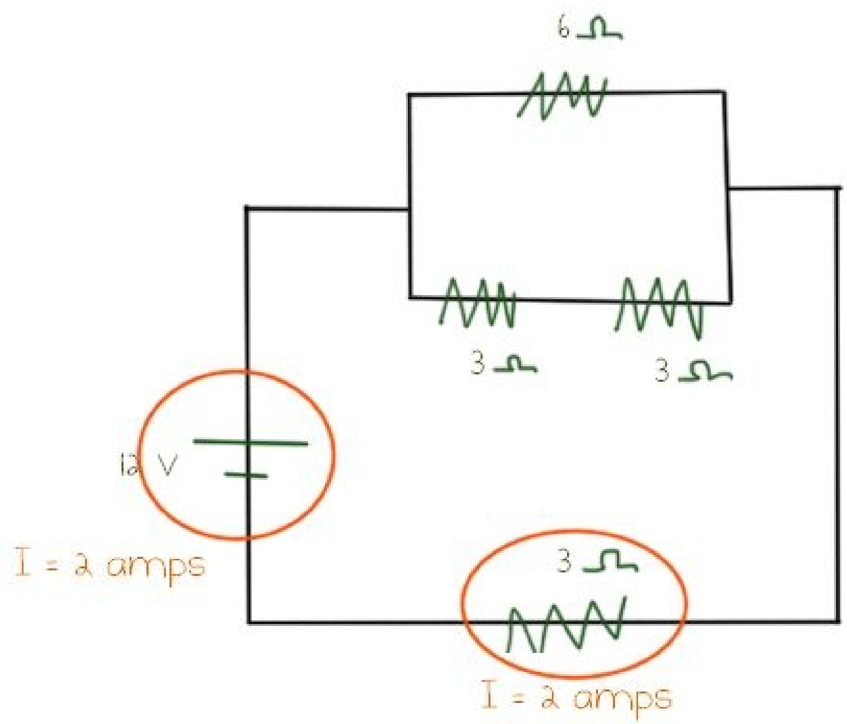
So, the total resistance of the circuit is 6 ohms. Now, we can use ohm's law to find the total current in the circuit. (Using the total resistance and the total voltage.)

$$V = IR$$

$$12 = I \times 6$$

$$I = 2 \text{ amps}$$

This means that we know the current through the battery and one resistor (because these two are in series.)



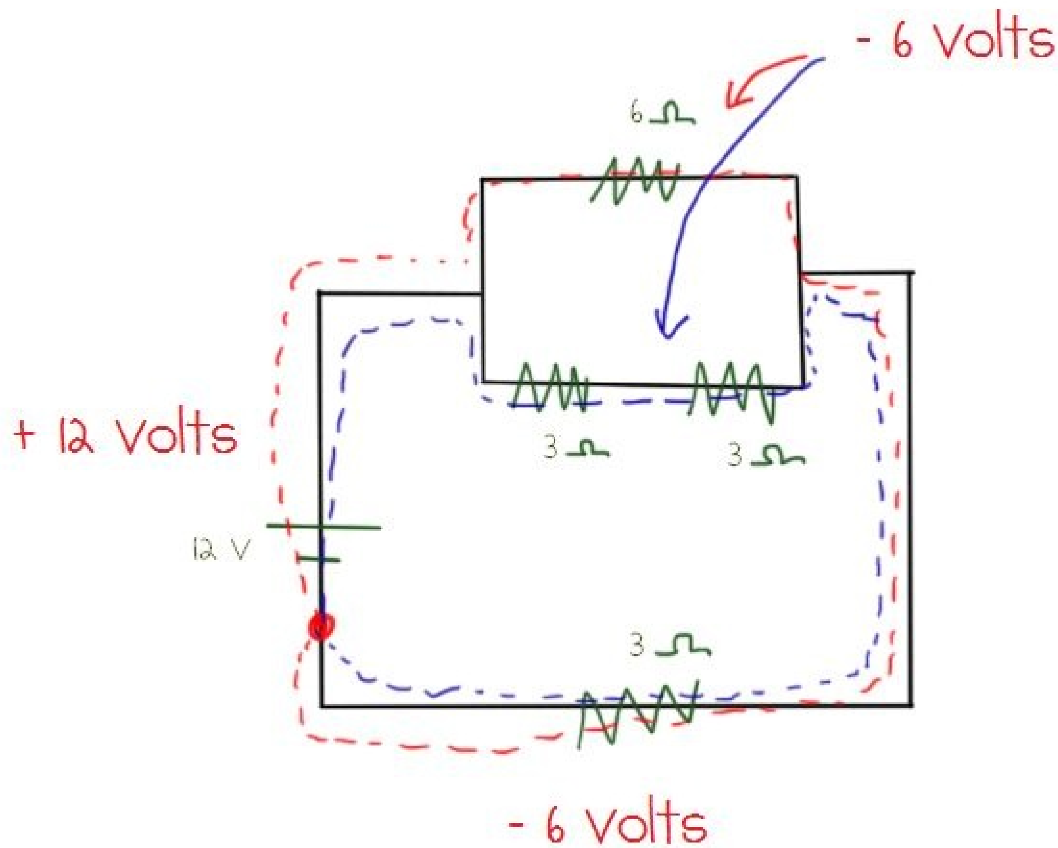
Now we need to find the current through the other three resistors. To do this, we need to know the voltage drop across that piece of the circuit. Since we know the current and resistance of the lower resistor, we can figure out the voltage drop using ohm's law:

$$V = IR$$

$$V = 2 \times 3$$

$$V = 6 \text{ volts}$$

Using Kirchoff's loop law, we can see that since 6 volts are lost across that resistor, and there are 12 volts total, 6 volts must also be lost across each of the other branches:



Let's start with the top resistor. There is a voltage drop of 6 volts across it, and it has a resistance of 6 ohms. We can use ohm's law to find the current:

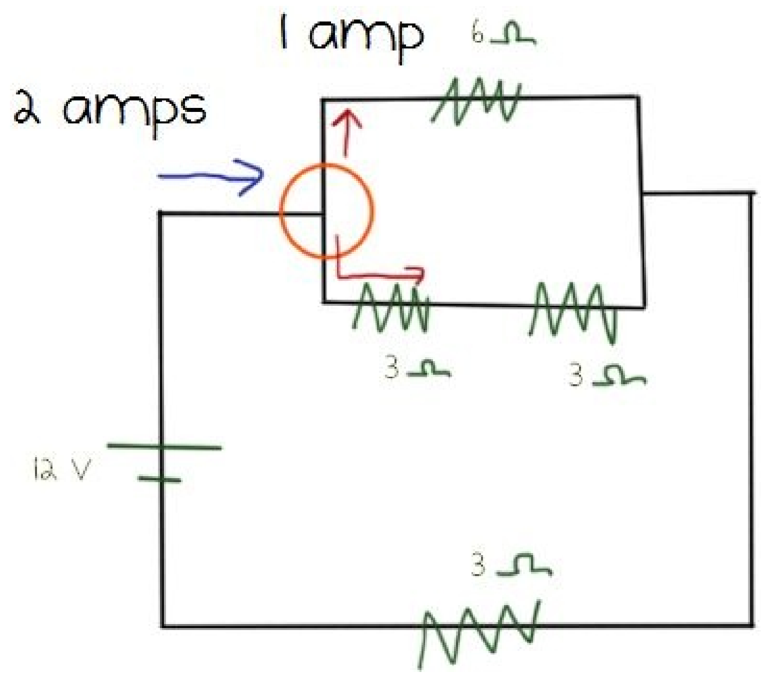
$$V = IR$$

$$6 = I \times 6$$

$$I = 1 \text{ amp}$$

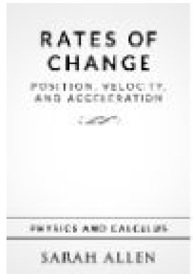
If you know two of the three, you can always find out the third!

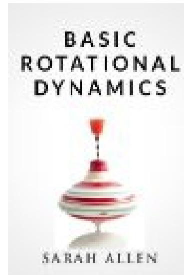
At this point, we could use the node law to figure out the current in the lower branch. (We could also add up the resistance and use ohm's law again, but this way is easier.)

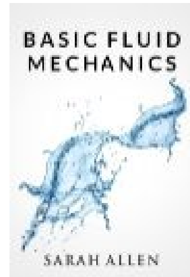


Two amps are flowing into the node I picked, and 1 amp is flowing out of the node into the top branch. So, 1 amp must be flowing into the bottom branch.

Thanks for reading, I hope it helped! For more stick figure physics check out these other tutorials (the pictures are links):







Or, if you would prefer to learn physics through fairy tales, check out my new series: