Circuit Analysis: Crash Course Physics #30

Crash Course: Physics
https://youtube.com/watch?v=-w-VTw0tQlE
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When you study physics, you can start to see it everywhere. Even here! As an engineer who studied physics, I have to say one of the most interesting parts of the holidays is the lights. Just think of all the crazy displays that you see and what is would take to to figure out the current required to power all of the tiny light bulbs that make them glow. So many resistors!

Now I'm not going to ask you to diagram the holiday lights on your neighbor's house, but, one of the best ways to understand how electricity works in a system like that is through circuit analysis: the process of breaking a circuit into its key components, and studying each one to see what it can tell you about the others.

So far you've learned about the key components of every electrical circuit, namely: voltage, resistance, and current. These properties are all related to each other through Ohm's Law. This means that if you know two out of the three variables, you can solve for the remaining one.

For example, you can take a bunch of resistors in a circuit, find their equivalent resistance and then use the voltage to figure what the current is. And when you know the current, you can get even more important information, like the voltage across a particular component or the current through a specific wire. So, if nothing else, today's lesson in circuit analysis will help you appreciate holiday lights on a whole new level.

(Intro)

Let's keep things simple. There's an enormous number of circuit building methods that I'd love to go over with you, but we've going to stick to the basics, which you'll use it every circuit problem you'll encounter.

These are DC circuits with resistors in series and parallel formations. You'll recall that series formations occur when resistors are connected along the same path, so they have the same current passing through each one. And parallel connections are when resistors are placed on wires that branch out from a single point, all having the same voltage drop across them. And to find the equivalent resistance of resistors in series, you just add the resistances together. For resistors in parallel, meanwhile, you use a different method. One that gives you a resistor with an equivalent resistance that smaller than any of the individual resistors in the branches.

Now, let's put these equations to work. here's an example of the circuit with resistors in both series and parallel formations. Say they have a 20 volt battery immediately followed by a resistor of 10 Ohms. Following that, there's a parallel formation of more resistors: one branch consists of two resistors in series, one of 15 ohms, and one of two ohms. The other branch has a 6 ohm resistor and then another parallel formation of resistors, three and five Ohms each.

Our goal is to simplify everything down to one resistor, which will have the equivalent resistance of all these resistors combined. With that equivalent resistance, you can then know what the resulting current is in the circuit, then using Ohm's law, you can calculate the voltage across and the current through each resistor.

OK, let's do the easiest steps first. Start by finding the resistors in a series. You can collapse these down into a single resistor by simply adding their resistances together. In this case you add the 15 and the two ohm resistors into a single 17 ohm equivalent resistor. Now that branch contains a single resistor. Let's look at the other branch.

This one has a single resistor and then two in parallel, so lets start by turning the parallel connection of the 3 ohm and 5 ohm resistors into one equivalent resistor. Using our equation for resistors in parallel, you find that they simplify to a single resistor of about 1.88 ohms. Then you can add the newly-formed resistor into the 6 ohm one, and the branch simplifies even more to a single resistor of 7.88 ohms.

Alright, we're almost there. Now let's combine the 17 ohm and the 7.88 ohm resistors, which were in parallel, into one resistor, and its resistance turns out to be 5.38 ohms. And with that we're left with only two resistors in series, which you can combine by to form a single resistor with the equivalent resistance of 15.38 ohms.

Now there's only one resistor left which means you can easily find the current drawn from the battery. Using Ohm's law you can find that the current through the circuit with a 20 volt battery and an equivalent resistance of 15.38 ohms is about 1.30 amperes.

Just pause for a moment and appreciate what you've done so far. You were able to take what you knew about the power source and the number and configuration of the resistors to figure out the current that runs through the circuit. And it wasn't that hard, was it? And now that you've determined the current, you can learn so much more!

With the total current in the system, we can expand the equivalent circuit back to its original form and while you're doing that, you can determine both the current through, and the voltage drop across every single resistor. Just go back one step to the 10 ohm resistor and the 5.38 ohm resistor. Nothing has changed about the current in the circuit, and the two resistors are in series, so the current flowing through them is the same, but the voltage drop across each resistor is different. You can calculate the voltage drop across each resistor by using Ohm's law, V equals I times R.

You know the current, I, and you know each resistance, R, so you simply use them to find the distant voltage drop, V, across each resistor. The voltage drop across the 10 Ohm resistor turns about to be 13 Volts which leaves the remaining voltage drop across the rest of the circuit to be 7 Volts. And you don't have to do anything with the 10 Ohm resistor since that's not a combination of resistors.

So the current through and the voltage across that circuit element doesn't change. In order to complete the rest of the circuit, let's expand the 5.3 Ohm resistor back out again to those two resistors in parallel. Now, you know that any two resistor in parallel have the same voltage drop. So both the 17 Ohm resistor and the 7.88 Ohm resistor both have a voltage drop of 7 Volts, just like when they were collapsed into one. But the current through each branch is not the same.

Since you know the resistance of and the current across each resistor, you can just use Ohms law again to calculate the resistance through each wire. The 17 Ohm resistor, with a voltage drop of 7 Volts, will have a current of 0.21 Amperes. And the 7.88 Ohm resistor, with the same voltage drop of 7 Volts, will have a current of 0.89 Amperes. And look at this! If you add these two currents together, they equal the 1.3 Amperes. That's the same value for the current that enters the junction where the wires split.

This must be true to satisfy conservation of charge. Because remember: what goes in, must come out. Now let's expand the resistor on the right into its two components - a 6 ohm and a 1.88 ohm resistor. The current through these two is still 0.89 amperes, but the voltage drop of 7 volts is now split across the two resistors. All you have to do is implement Ohm's law, yet again - multiplying current and resistance in order to find the voltage drop. So 0.89 amperes times 6 ohms equals a 5.33 volt drop, and 0.89 amperes times 1.88 ohms equals the remaining 1.67 volt drop.

Now it's good to check that you're on the right track by looking at

the relationships of all these values. Keep in mind that for resistors in series, the larger the resistance is, the larger the voltage drop that's required. Think of a big light bulb and a tiny light bulb on the same wire of holiday lights, using the same current. The little light bulb doesn't draw nearly as much power so it uses less voltage for the same amount of current passing through it.

OK, back to work. Our 1.88 ohm resistor is a combination of a 3 ohm and a 5 ohm power of resistors in parallel. So the voltage drop across each resistor is still 1.67 volts, but the current passing through each will be different. Using Ohm's Law, you can divide the voltage across each resistor by its respective resistance - giving you the current through each branch. 1.67 volts divided by 3 ohms gives you a current of 0.56 amperes through the 3 ohm resistor, and 1.67 volts divided by 5 ohms gives you a current of 0.33 amperes. And since 0.56 plus 0.33 amperes equals the 0.89 amperes that enters the wire at the split, you know that you're on the right track.

One last step. The 17 ohm resistor is a series combination of the 15 ohm and 2 ohm resistor. Here the current through them, 0.41 amperes, stays the same, while the voltage drop across each one can be found using Ohm's Law. 0.41 amperes times 15 ohms equals 6.17 volts across the 15 ohm resistor. And 0.41 amperes times 2 ohms equals the remaining 0.82 volts across the 2 ohm resistor.

To check your work, you can go back and see that the two voltage drops equal the total voltage drop across each branch after the 10 ohm resistor. And you've done it! Congrats! You've taken a whole circuit, simplified it down to the bare minimum, then expanded it again, discovering the current and voltage values for every single resistor. But even though we all love math, what if that's not enough for you? What if you physically constructed this circuit yourself and you wanted to measure the values so that you knew your math checked out.

To measure voltage, you just need a tool known as a voltmeter. Pretty creative - I know. Now you want a way to measure voltage without altering the actual circuit. No solution is perfect, but you can get a pretty accurate reading by attaching a voltmeter on either side of the device that you want to measure. And you do it that way, because you know that any components connected in parallel will have the same voltage. But even if you measure the voltage, you still want to avoid changing the resulting circuit. So what you can do is give the voltmeter a resistance that's so high, it's considered infinite, relative to the rest of the circuit.

With an infinite resistance, the same voltage is read across both the voltmeter and the device you're measuring, and a tiny amount of current ends up running through the voltmeter. OK - you're a stickler, and even though you've confirmed your voltage, you want to do the same thing with the current. This time you'll use the fact that devices connected in series share the same current. So you need a device that can measure current in series with another component without changing the current.

This is known as an ammeter, and it measures the current in amperes by connecting in series with the circuit. It doesn't affect the circuit, because the device has a near zero resistance. But here's a pro-tip - when you use these devices in the lab, be very careful not to mix up the methods of connection. Attaching the ammeter, a device with a near-zero resistance, in parallel with another resistor will cause nearly all the current to run through the ammeter, possibly damaging it. And if a voltmeter is attached in series, you're not going to see any current flowing because the resistance is so large.

But used correctly, these devices can not only allow you to confirm your maths, but they can also give you a hands on way to measure the basic principles of Ohm's Law in action. And they might just help you raise your holiday lighting game to a whole new level.

Today we saw how circuit analysis can be used on any series in parallel configuration of resistors in a DC circuit. We used Ohm's Law to go from an equivalent circuit to solving for every current value and voltage drop in a system. Finally we saw how to measure voltage and current in a real circuit using voltmeters and ammeters.

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