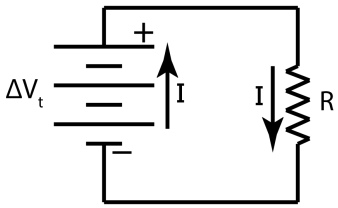
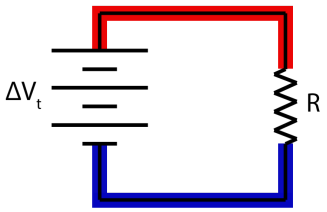
Flipping Physics Lecture Notes:

Basic Series and Parallel Resistor Circuit Demos and Animations
https://www.flippingphysics.com/series-parallel-resistors-basic.html

Before we analyze resistors in series and in parallel, let's get our bearings using a circuit with a battery and one resistor. First off, realize the current will go through the battery from the negative to the positive terminals of the battery. The current will therefore be up through the battery and down through the resistor. Because there is only one loop in the circuit, there is only one current, which we will simply label I.



Because there are only two elements in the circuit, both elements have the same magnitude electric potential difference equal to the terminal voltage, ΔV_t. You can see this by using the electric potential color-coding technique. Starting at the positive terminal of the power source we draw red on the wire until we come to another circuit element. Everything in red is at the same electric potential. Starting at the negative terminal of the power source we draw blue on the wire until we come to another circuit element. Everything in blue is at the same electric potential. Both the power source and the resistor have an electric potential difference which is between red and blue, so both the power source and the resistor have the same magnitude electric potential difference.



Now we can solve for the current in the circuit:

$$\Delta V = IR \Rightarrow I = \frac{\Delta V_t}{R} = \frac{5.0V}{5.0\Omega} = 1.0A = 1.0\frac{C}{s}$$

With a real example of a 5.0 volt power source and a 5.0 Ω resistor, we should expect to observe 1.0 amps of current through the circuit or 6.2 million million million electrons every second.

$$q = ne \Rightarrow n = \frac{q}{e} = \frac{1C}{1.6\times10^{-19}\frac{C}{electron}} = 6.25\times10^{18} \approx 6.2\times10^{18}\,electrons$$

Unfortunately, we only get 0.90 Amps through the power supply. Measuring the electric potential difference across the resistor shows that the resistor actually has 4.7 volts across it. Likely this means two things. One is that we have real wires which have resistance instead of ideal wires which do not have resistance. And the power supply is actually delivering slightly less than what it is displaying.

We can also determine the rate at which the resistor is converting electric potential energy to heat:

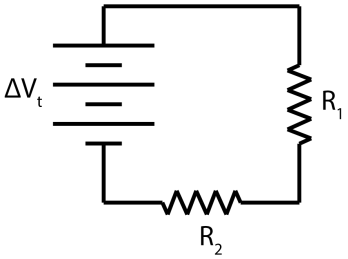
$$P = I\Delta V = (1)(5) = 5.0watts$$

This means our resistor is converting 5.0 joules of energy to heat every second, which is why the resistor is getting HOT!

Please watch the video to see the animations relating charged particle location and electric potential energy. I could try to describe it here, but it's an animation. You should watch it instead.

Next, let's analyze two resistors in series with a 5.0 V power source. Both resistors have a resistance of 5.0 Ω. Let's determine:

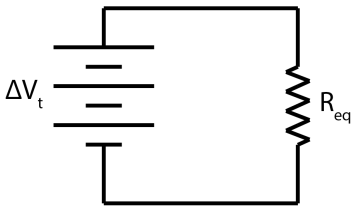
a) Current through each circuit element.
b) Electric potential difference across each resistor.
c) Power dissipated by each resistor.



First, we know these are two resistors in series because there are no other paths for charges to follow. Every charge which goes through resistor one must eventually go through resistor two. Because the two resistors are in series, their resistances add to get their equivalent resistance:

In Series: $R_{eq} = R_1 + R_2 = R + R = 2R = (2)(5) = 10\Omega$

Now we can replace the two resistors in our circuit with one equivalent resistor, R_{eq}. Notice how this is the same setup as our original circuit, one resistor and one power source, therefore:



$$\Delta V_t = IR_{eq} \Rightarrow I = \frac{\Delta V_t}{R_{eq}} = \frac{5}{10} = 0.50A$$

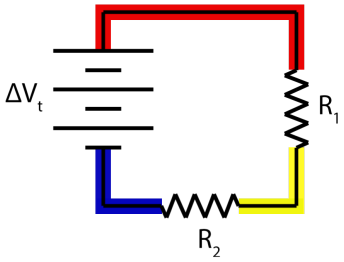
The observed value for the current in the circuit is 0.45 A, which is to be expected based on our observed value for the first circuit. We have answered part (a), the accepted current through all circuit elements equals 0.50 A.

Because we know the current through and resistance of each resistor, we can now determine (b), the electric potential difference across each resistor, 2.5 V.

$$\Delta V_1 = I_1 R_1 = (0.5)(5) = 2.5V \ \& \ \Delta V_2 = I_2 R_2 = (0.5)(5) = 2.5V$$

Because both resistors have the same resistance and current through them, the electric potential differences across each resistor are equal.

Also, I want to use the electric potential color-coding technique to show that the electric potential differences across the two resistors add up to the terminal voltage. The highest electric potential wire is in red, the lowest electric potential wire is in blue, and the wire with a middle value electric potential is in yellow. Therefore, the terminal voltage is from blue to red, and across the resistors the electric potential goes from red to yellow plus yellow to blue. This means that:



$$\Delta V_t = \Delta V_1 + \Delta V_2 \Rightarrow 5 = 2.5 + 2.5$$

Again, we showed this because 2.5 volts plus 2.5 volts equals 5 volts.

The electric potential difference across each resistor is observed to be 2.3 volts, which, again, is consistent with our previous observed values.

Again, please watch the video to see the animations relating charged particle location and electric potential energy. I could still try to describe it here, but it's still an animation. You should still watch it instead.

For part (c), the power dissipated by each resistor is:

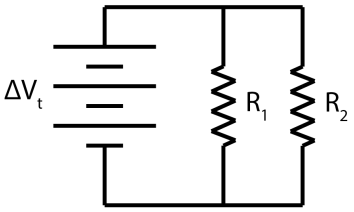
$$P_1 = P_2 = \frac{\Delta V_1^2}{R_1} = \frac{\Delta V_2^2}{R_2} = \frac{(2.5)^2}{5} = 1.25 \approx 1.2 watts$$

Therefore, the total power dissipated by both resistors is 2.5 watts; which is the same as the power delivered by the power source:

$$P_{both\ resistors} = P_1 + P_2 = 1.25 + 1.25 = 2.5 watts \ \& \ P_{power\ source} = I\Delta V_t = (0.5)(5) = 2.5 watts$$

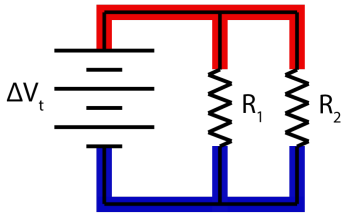
Next, let's analyze two resistors in parallel with a 5.0 V power source. Both resistors have a resistance of 10.0 Ω. Let's determine:

a) Current through each circuit element.
b) Electric potential difference across each resistor.



c) Power dissipated by each resistor.

Let's start by color-coding the circuit to show that the two resistors are in fact in parallel. You can see all electric potential differences are the same, therefore the resistors are in parallel.



Part (b) $\Delta V_t = \Delta V_1 = \Delta V_2 = 5.0V$

We can determine the equivalent resistance of the two resistors by using the equation for resistors in parallel:

$$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1} = \left(\frac{1}{10} + \frac{1}{10}\right)^{-1} = \left(\frac{2}{10}\right)^{-1} = \left(\frac{1}{5}\right)^{-1} = 5.0\Omega$$

The equivalent resistance for two 10.0 Ω resistors in parallel is 5.0 Ω. In other words, we can replace the two 10.0 Ω resistors with one 5.0 Ω resistor and the current through the circuit should remain unchanged. But notice, this is exactly the same as the circuit we started with. Therefore, the current delivered by the power source is 1.0 A and the power delivered by the power source is 5.0 watts.

We know the electric potential across each circuit element is the same, so we can determine the current through each resistor:

Part (a) $$\Delta V = IR \Rightarrow I_1 = \frac{\Delta V_1}{R_1} = I_2 = \frac{\Delta V_2}{R_2} = \frac{5}{10} = 0.50A$$

And we know the currents in parallel add: $I_t = I_1 + I_2 = 0.5 + 0.5 = 1.0A$

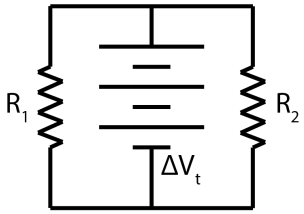
Which confirms our previous calculation for the current thorugh the battery.

And now we can calculate the power dissipated by each resistor:

Part (c) $$P = I^2R \Rightarrow P_1 = P_2 = I_1^2R_1 = I_2^2R_2 = (0.5)^2(10) = 2.5watts$$

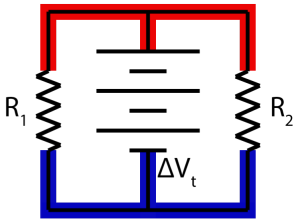
This makes sense because the total power delivered by the power source should equal the total power dissipated by the resistors:

$$P_{both\ resistors} = P_1 + P_2 = 2.5 + 2.5 = 5.0watts\ \&\ P_{power\ source} = I\Delta V_t = (1)(5) = 5.0watts$$

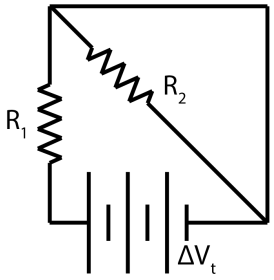


Next, let's analyze two resistors in this circuit with a 5.0 V power source. Both resistors have a resistance of 10.0 Ω. Let's determine:

a) Current through each circuit element.
b) Electric potential difference across each resistor.
c) Power dissipated by each resistor.



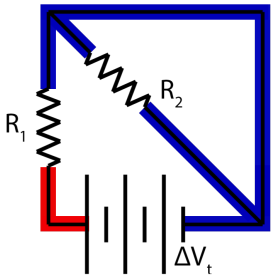
Let's start by color-coding the electric potential of the wires to determine if the resistors are in series or parallel. Hopefully you now recognize, because the electric potential color-coding is exactly the same, that this is the same circuit we just did, only drawn slightly differently. All the answers are the same.



Next, analyze two resistors in this circuit with a 5.0 V power source. Both resistors have a resistance of 5.0 Ω. Let's determine:

a) Current through each circuit element.
b) Electric potential difference across each resistor.
c) Power dissipated by each resistor.

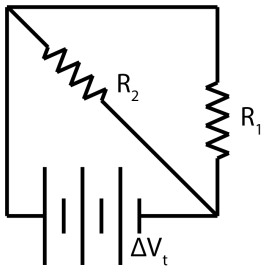
Let's start by color-coding the electric potential of the wires to determine if the resistors are in series or parallel. Notice the electric potential difference across resistor 2 is zero, this means no current will flow across resistor 2. This is because the wire in the upper right corner completely shorts resistor 2 out of the circuit. Because that wire has zero resistance, all charges will flow along that wire and none will flow through resistor 2. In other words, this circuit behaves the same as our very first circuit, other than resistor 2 having no current, no electric potential difference, and therefore no power dissipated. Therefore, our answers are:



a) $I_1 = 1.0$ A and $I_2 = 0$
b) $\Delta V_1 = 5.0$ V and $\Delta V_2 = 0$
c) $P_1 = 5.0$ Watts and $P_2 = 0$

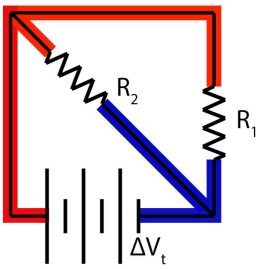
Okay, one last example. Analyze two resistors in this circuit with a 5.0 V power source. Both resistors have a resistance of 10.0 Ω. Let's determine:

a) Current through each circuit element.
b) Electric potential difference across each resistor.
c) Power dissipated by each resistor.



Again, we start by color-coding the electrical potential differences of the circuit.

Both resistors have the same electric potential difference. This is two resistors in parallel with a power source. This is actually the same as two circuits we already analyzed.



Please, be careful to look at circuits carefully before throwing equations at them. You need to first determine which circuit elements are in series and parallel, then you can start using equations.