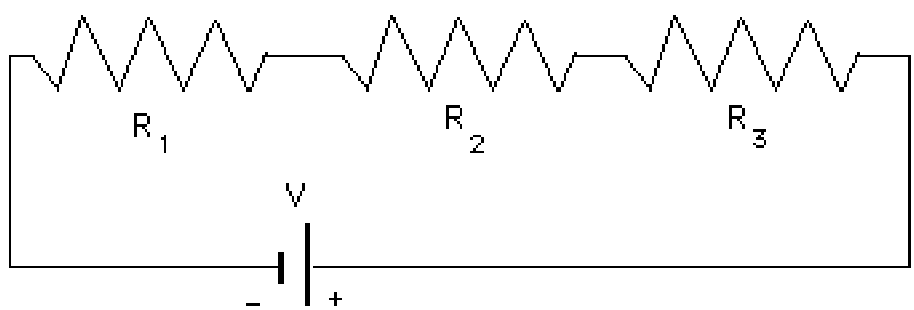
Electronics Lab #3

Voltage Dividers and More Complicated Circuits

The voltage divider consists of two or more resistors in series and is a surprisingly useful laboratory device for providing reduced voltages from a power supply. The voltage divider circuit having three or more resistors is not much harder than the two resistor circuit discussed in the previous lab.

A Three Resistor Voltage Divider

A circuit having three resistors R_1 , R_2, and R_3 in **series** is indicated below:



If three resistors are in **series**, then same current i flow through each resistor. Suppose for example, the voltage source V=12 volts and the resistors have values $R_1 = 10,000\,\Omega$, $R_2 = 20,000\,\Omega$., and $R_3 = 30,000\,\Omega$.

IMPORTANT NOTE: You should repeat this experiment using three resistors in your parts box.)Remember, if you use an ohmmeter to measure the values of the resistors, do NOT have the battery attached while making the measurement otherwise you will get incorrect measurement for the resistance.

Since the three resistors are in series, the total resistance is

$$R_{Total} = R_1 + R_2 + R_3 \qquad (1)$$

and numerically you have

$$R_{Total} = 10,000\,\Omega + 20,000\,\Omega + 30,000\,\Omega = 60,000\,\Omega \qquad (2)$$

Check that the total resistance of three resistors in series is indeed correct using an ohmmeter with the battery not attached.

The current i in this series circuit is given by Ohm's law as

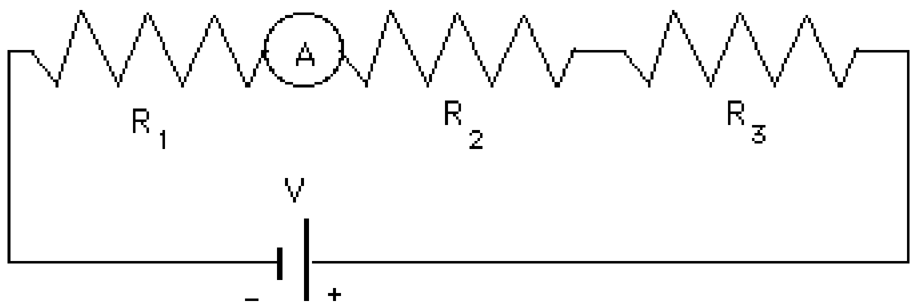
$$i = \frac{V}{R_{Total}} = \frac{12\ \text{Volts}}{60,\ 000\ \Omega} = 0.2\ \times 10^{-3}\ \text{A} \tag{3}$$

or 0.4 milliamps. You can have *Mathematica* does the calculation obtaining

$$\frac{\mathbf{12}}{\mathbf{60\,000.}}$$

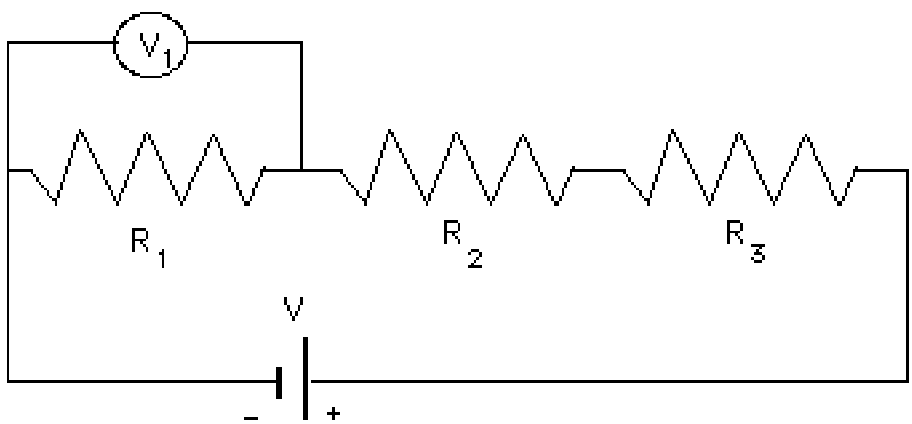
0.0002

If you place an ammeter in each spot indicated in the circuit below, you should get the value of the current i just calculated.



Actually you can place the ammeter anywhere in the above circuit and you will get the same measured value of the current.

The voltage across each resistor is **different** for the case of resistors in series. For example, the voltage across resistor R_1 is determined with a voltmeter as indicated below:



It is also easy to calculate the voltage V_1 since we already know the current i in resistor R_1. In general,

$$V_1 = i\ R_1 \tag{4}$$

and for the particular example at hand

$$V_1 = \left(0.2 \times 10^{-3}\ \text{A}\right) \times (10,\ 000\ \Omega) = 2\ \text{Volts} \tag{5}$$

since using *Mathematica* we obtain

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(0.2 × 10^-3) × (10000)
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2.
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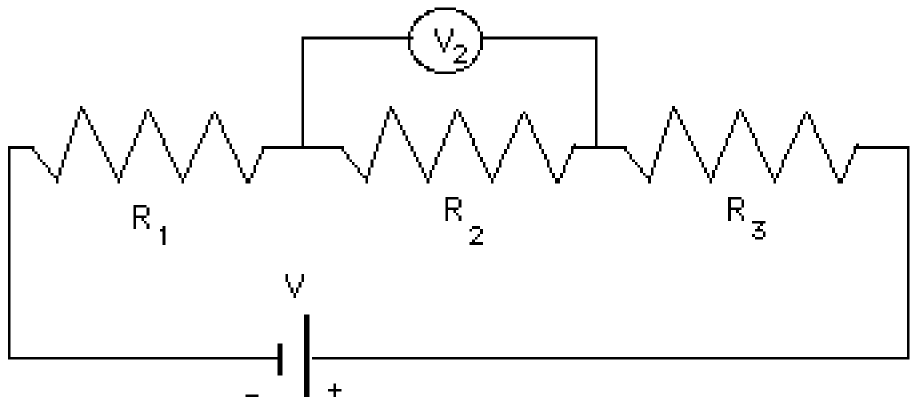
Similarly the voltage V_2 across the resistor R_2 is measured as indicated below:



The voltage V_2 is calculated as below:

$$V_2 = i\ R_2 \tag{6}$$

since the same current flows through both resistors since they are in series. For the particular example at hand

$$V_2 = \left(0.2 \times 10^{-3}\ \text{A}\right) \times (20,\ 000\ \Omega) = 4\ \text{Volts} \tag{7}$$

since using *Mathematica* we obtain

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(0.2 × 10^-3) × (20000)
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4.
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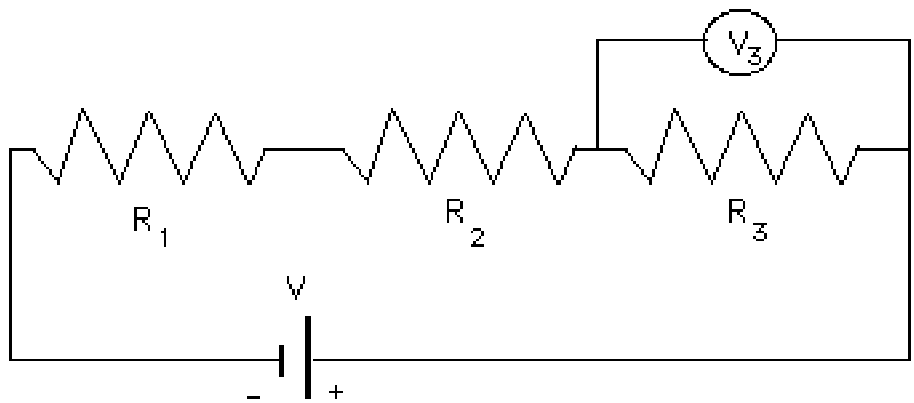
Similarly the voltage V_3 across the resistor R_3 is measured as indicated below:



The voltage V_3 is calculated as below:

$$V_3 = i\, R_3 \tag{8}$$

since the same current flows through both resistors since they are in series. For the particular example at hand

$$V_2 = \left(0.2 \times 10^{-3}\ \text{A}\right) \times (30,\ 000\ \Omega) = 6\ \text{Volts} \tag{9}$$

since using *Mathematica* we obtain

$\left(0.2 \times 10^{-3}\right) \times (30\,000)$

6.

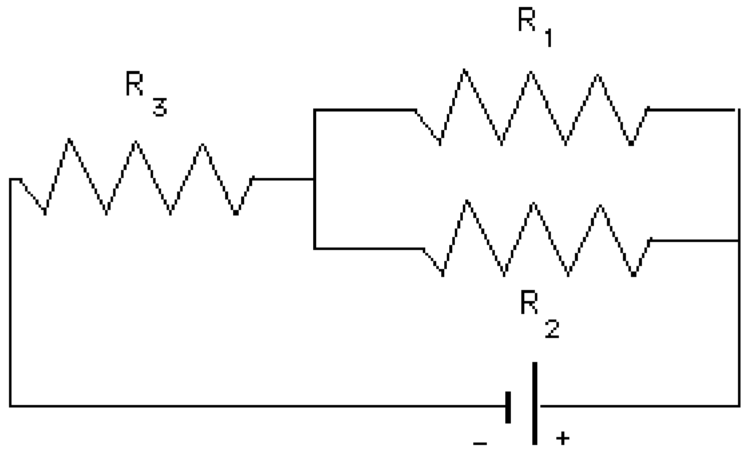
Notice the sum of the voltages across the resistors

$$V = V_1 + V_2 + V_3 = 2\ \text{V} + 4\ \text{V} + 6\ \text{V} = 12\ \text{V} \tag{10}$$

is just the battery voltage. The battery voltage is "divided" across the three resistors in a manner proportional to the value of the resistors. The voltage divider can be used to produce any voltage necessary for lab experiments provided the required voltage is LESS THAN the battery or power supply voltage (less than 12 volts in the example above).

Resistors in Series and Parallel

A circuit having three resistors R_1, R_2, and R_3 is indicated below:



The "solutioin" to this circuit problem follows a reduction procedure whereby the original, more complicated circuit above is replaced successively by simpler circuits. Two of the resistors R_1 and R_2 are in parallel. If two resistors are in **parallel**, then the same **voltage** is across each resistor. The total resistance of two resistors in parallel is given by

$$\frac{1}{R_{Parallel}} = \frac{1}{R_1} + \frac{1}{R_2} \tag{11}$$

Suppose the same two resistors as before, $R_1 = 30,000\,\Omega$ and $R_2 = 50,000\,\Omega$ are in parallel, and this combination is in series with $R_3 = 20,000\,\Omega$ Then the total (or effective) resistance R_P of the two resistors in parallel is

$$\frac{1}{R_P} = \frac{1}{30,000\,\Omega} + \frac{1}{50,000\,\Omega} \tag{12}$$

Using *Mathematica* we obtain

$$\frac{1}{30000.} + \frac{1}{50000}$$

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0.0000533333
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and thus

$$R_P = \frac{1}{0.000053} = 18,868\,\Omega \tag{13}$$

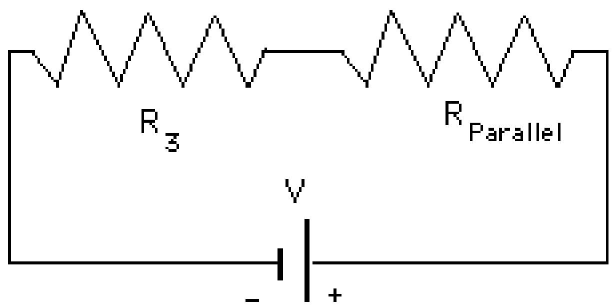
since *Mathematica* yields

$$\frac{1}{0.000053}$$

18 867.9

IMPORTANT NOTE: Once again, when you work on your own laboratory circuit, make sure the resistance measurement using the ohmmeter is done without the battery source attached.

The two resistors in parallel may be replaced in the circuit by the equivalent parallel resitance just calculate. So the original circuit is equivalent (or effectively the same) as



at least for calculating the current supplied by the battery. The total effective resistance is of two resistors in series so

$$R_{Total} = R_3 + R_P \tag{14}$$

Using the numerical values of the resistors we obtain

$$R_{Total} = 20,\ 000\,\Omega + 18,\ 868\,\Omega = 38,\ 868\,\Omega \tag{15}$$

and using *Mathematica*

20 000 + 18 868.

38 868.

The current i supplied by the battery is obtained via Ohm's Law

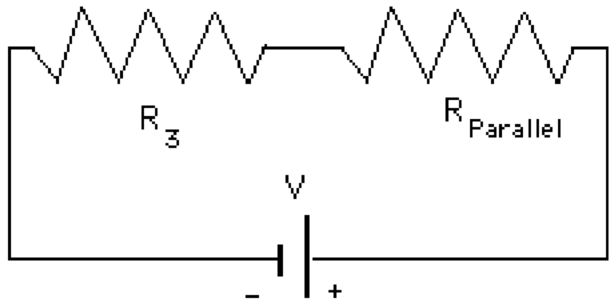
$$i = \frac{V_{Battery}}{R_{Total}} = \frac{12\,V}{38,\ 868\,\Omega} = 0.3\times10^{-3}\,A = 0.31\,ma \tag{16}$$

since *Mathematica* yields

$$\frac{12}{38\,868.}$$

0.000308737

The procedure now is to **reverse** the reduction process above and step by step reconstitute the original circuit. Along the way all the currents and voltages are calculated as shown below. The next step is to return to the two resistors in series and calculate the voltage across each:



The voltage across R_3 is given by Ohm's law as

$$V_3 = i\,R_3 = 0.31\times10^{-3}\,\text{A}\times20,\,000\,\Omega = 6.2\,\text{V} \tag{17}$$

since *Mathematica* gives

0.31 × 10^-3 × 20 000.

6.2

Similarly, the voltage across R_P is given by

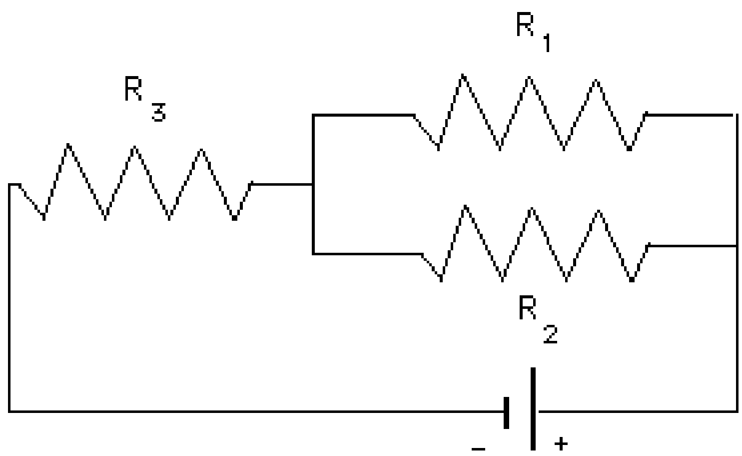
$$V_P = i\,R_P = 0.31\times10^{-3}\,\text{A}\times18,\,868\,\Omega = 5.8\,\text{V} \tag{18}$$

since *Mathematica* gives

0.31 × 10^-3 × 18 868.

5.84908

Notice that the sum of the voltages 6.2 V+5.8 V = 12 V is the battery voltage. Next return to the original circuit



and notice the voltage across the parallel combination of resistors is just 6.2 Volts just calculated. It follows from Ohm's law that the current through resistor R_1 is given by

$$i_1 = \frac{5.8\text{ Volts}}{R_1} = \frac{5.8\text{ Volts}}{30,\ 000\ \Omega} = 0.19\times 10^{-3}\text{ A} = 0.19\text{ ma} \tag{19}$$

since *Mathematica* yields

$$\frac{5.8}{30\,000}$$

0.000193333

This current is measured with an ammeter in series with resistor R_1. Similarly it follows from Ohm's law that the current through resistor R_2 is given by

$$i_2 = \frac{5.8\text{ Volts}}{R_2} = \frac{5.8\text{ Volts}}{50,\ 000\ \Omega} = 0.12\times 10^{-3}\text{ A} = 0.12\text{ ma} \tag{20}$$

since *Mathematica* yields

$$\frac{5.8}{50\,000}$$

0.000116

This current is measured with an ammeter in series with resistor R_2. Notice that the sum of the currents through R_1 and R_2 is just 0.19 ma+0.12 ma=0.31 ma which is the same as the current supplied by the battery.

Experiments You Should Do

Voltage Divider Circuit: Pick three resistors from your parts box in the 10,000Ω range. Measure the resistances using the Ohmmeter and make sure the values agree with the color code. Connect the resistors in series and measure the total resistance and see that this resistance agrees with what you expect from numerical calculation. Calculate the current using Ohm's law. Measure the value of the current in each resistor and make sure this agrees with the theoretical numerical value of the current. Calculate the voltage across each resistor using Ohm's law. Verify that these voltages are correct using the voltmeter attached to the circuit in the proper manner described above.

Series and Parallel Circuit: Again, pick three resistors from your parts box in the 10,000Ω range. Measure the resistances using the Ohmmeter and make sure the values agree with the color code. Connect the resistors in the series and parallel combination discussed above and measure the total resistance and see that this resistance agrees with what you expect from numerical calculation. Calculate the total current supplied by the battery using Ohm's law. Measure the value of the total current and make sure this agrees with the theoretical numerical value of the current. Calculate the current through each resistor using Ohm's law. Verify that these currents are correct using the ammeter attached to the circuit in the proper manner described above. Also, make sure the total current supplied by the battery is the sum of the currents through the resistors.