# Experiment #5: Ohm's Law

Purpose: To measure the equivalent resistances of series and parallel combinations of resistors, and measure an unknown resistance.

Equipment:

- Electronic Components: Breadboard, Several 500–5000 Ω Resistors, 1 kΩ High-Precision Resistor
- Multimeter
- Decade Resistance Box

## Part 1—Series and Parallel combinations of resistors

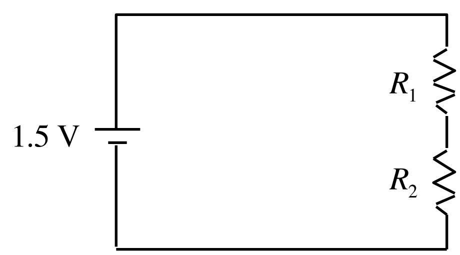
Discussion:

Ohm's law states that the current $I$ in a resistor is proportional to the potential difference $V$ across it, provided that the temperature of the object is constant. In equation form, it says

$$V = IR \tag{1}$$

where the proportionality constant $R$ is the resistance of the device.

Now let's consider what happens when there are two resistors in a circuit instead of one. There are two possibilities: the two could either be in series or in parallel with each other. The figure below shows two resistors $R_1$ and $R_2$ connected in series, with a 1.5-V battery wired across the combination.




Recall from last lab that this circuit is called a voltage divider. For a single-loop circuit such as this one, the same current $I$ flows through all of the components. The potential drop across each resistor is then given by Eq. (1) as

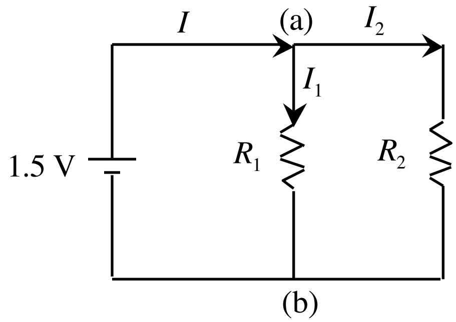
$$V_1 = IR_1 \text{ and } V_2 = IR_2. \tag{2}$$

But by Kirchhoff's Voltage Loop Rule, the potential gain across the battery must equal the sum of the potential drops, $V_1$ and $V_2$, across the two resistors so that

$$V = V_1 + V_2 = IR_1 + IR_2 = I(R_1 + R_2) = IR_{eq} \tag{3}$$

where $R_{eq} = R_1 + R_2$ is the equivalent resistance. That is, two resistances in series are equivalent to a single resistance equal to the sum of the two. If the two resistors are removed and a single resistor whose resistance is equal to the sum of the two original resistances is used in their place, the circuit behaves the same way as before, that is the current in and total voltage drop across the equivalent resistance is the same as that of the original pair of resistors.

Next consider a parallel combination, as depicted in the figure below. Two resistors $R_1$ and $R_2$ are connected parallel to one another and to a power supply.




In this case, the voltage $V$ across each resistor is the same (since both are connected directly to the battery terminals) but the current in each is in general not the same. Rather, the sum of the currents $I_1$ and $I_2$ through the resistors must be equal to the total current $I$ drawn from the power supply. In other words, the current $I$ flowing into junction (a) must equal the sum of the currents $I_1 + I_2$ flowing out of junction (a). More generally, the sum of the currents flowing into a junction equals the sum of the currents flowing out of that junction, which is known as Kirchhoff's Current Junction Rule. For example, applied to junction (b), it tells us that the two currents $I_1$ and $I_2$ recombine into $I$.

Applied to junction (a), the Current Rule says

$$I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2} = V\left(\frac{1}{R_1} + \frac{1}{R_2}\right). \tag{4}$$

If a single equivalent resistor $R_{eq}$ is to replace the parallel combination, then the current $I$ drawn from and potential difference $V$ supplied by the battery must remain unchanged (since that is what is meant by an equivalent resistor) and therefore,

. (5)

Comparing Eqs. (4) and (5), we find

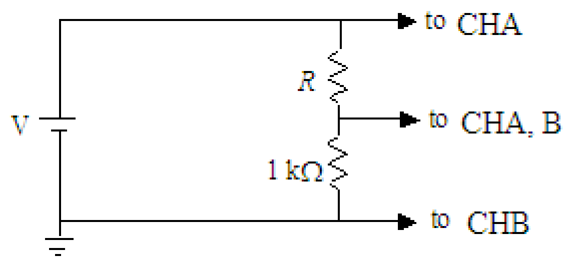
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}. \tag{6}$$

In contrast to a series combination where the resistances add in accordance with Eq. (3), for a parallel combination one must add the reciprocals of the resistances and then take the reciprocal of the resulting sum to get the equivalent resistance. Note carefully that dimensional consistency requires that you take the reciprocal of the sum---if you carry the units in your mathematical calculations, you'll avoid the common but silly error of reporting $1/R_{eq}$ to be the equivalent resistance!

<u>Procedure</u>:

1. Select two resistors, one between 500 and 2000 Ω, which we'll call $R_1$, and a second between 3 and 5 kΩ, which we'll call $R_2$. Measure both resistances with the handheld ohmmeter and record their values on paper. Carefully note their color codes, so you can tell which is which.

2. Set up the circuit shown below, where the variable resistor is a decade box, the 1 kΩ resistor is the black high-precision one, and where initially $R$ is $R_1$. The voltage source V is the output of the interface box.




In this circuit, we are treating $R$ as an unknown resistance to be determined, using procedures similar to what you did in the last lab. The 1-kΩ known resistance is used to find the current in the circuit as follows: the computer measures the voltage difference between the two end points of the 1 kΩ resistor and displays it in CHB. Divide the result by 1 kΩ to obtain $I$. Since this is a single-loop circuit, the current through the 1 kΩ resistor is the same as that through $R$, and is also the same as the current output from the source. You can verify that the value of $I$ that you get is same as that shown in the OUTPUT CURRENT display on the screen. Channel A measures the voltage across he unknown resistor R. You can therefore measure the voltage across R and the current through R for different voltages, and can test that the two are directly proportional to each other as Ohm's law predicts. That is, if the voltage $V$ is plotted against the current $I$, the graph should be a straight line passing through the origin, whose slope gives resistance R.

3. Start the program Expt05 in the phylabii folder on the desktop. The screen is identical to the previous lab. You have a DATA display, and meters for OUTPUT CURRENT, Output Volts, Voltages in CH A and B, and a SIGNAL GENERATOR window.

4. Click on the OFF and DC buttons on the Signal Generator. Click on the DC Voltage, setting and set it to 5 V. Click the Monitor button in the DATA window.

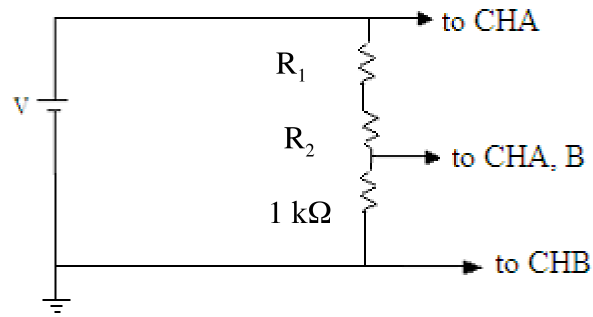
5. Note the voltage shown in CH B. Divide it with 1 kΩ to get the current $I$. Check if this is the same as that shown in OUTPUT CURRENT (A) window. Now note the voltage V across the unknown resistance R, shown in CH A. Divide the CH A voltage with the current $I$ that you calculated. This gives the resistance R. Repeat in steps of 0.5 V down to and including 0 kΩ, for a total of 11 readings.

6. Make a table of these readings in Excel, for V vs $I$. Plot V vs $I$ and get the slope. This gives the value of R. (In this case, this is $R_1$). Check if this is close to the value according to the color code. Report the difference.

7. Click the signal generator OFF. Replace the resistance $R_1$ in the circuit with the second resistor

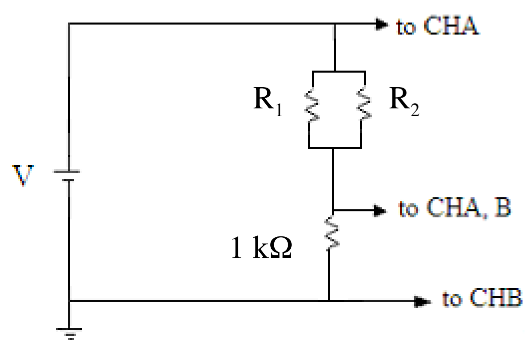
$R_2$ that you chose in step 1. Repeat steps 4 through 6 to measure $R_2$.

8. Replace $R_2$ in the circuit with a series combination of $R_1$ and $R_2$ as shown in the circuit below.




9. Repeat steps 4 through 6 to measure this series combination. Check if this value is equal to $R_1 + R_2$ as expected, where the values of $R_1$ and $R_2$ have already been measured by you.

10. Replace the series combination of R with a parallel combination as shown below, repeat steps 4 through 6 to measure the parallel combination. Check if this value agrees with the expected value as given in equation (6). Report any discrepancy.




Supplemental Questions:
1. If the voltage across a 1.2-kΩ resistor is 3.6 V, what is the current (in mA) flowing through it?

2. A 1.5-V battery is connected in series with a 3.3-kΩ resistor, a 4.7-kΩ resistor, and a 1.0-kΩ resistor. Calculate the current (in mA) through and the voltage (in V) across each resistor.

3. What is the effective resistance of a series combination of a very large resistance and a very small resistance? First try 10 kΩ and 10 Ω, rounding the answer off to two significant figures, to get a feel for what is happening, and then state the general rule for finding the result given any large and small resistances, not necessarily these exact two values. If used as a voltage divider connected across a 1.5-V battery, approximately what will be the potential drop across each resistor?

4. What is the effective resistance of a parallel combination of a very large resistance and a very small resistance? First try 10 kΩ and 10 Ω, and then generalize the result. If connected to a power supply delivering 100 mA of current, approximately what will be the current through each resistor?