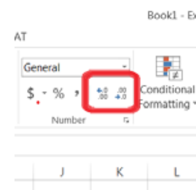
Measuring w/ DMM's

Apparatus: Each group should have ten 10 Ω resistor and one 56 Ω resistor banana cables, alligator clips, 1.5 V D-cell batteries, single battery holders, 1 handheld digital multimeter per station, 1 benchtop multimeter per station, DMM red leads, DMM black leads, galvanometers (coil with compass…might need both the large 40 turn and smaller 15 turn coils)

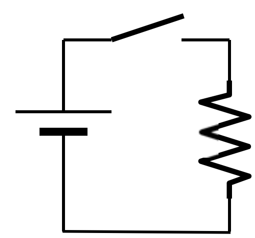
Objectives: Learn how to use a DMM to measure resistance, voltage, and current.



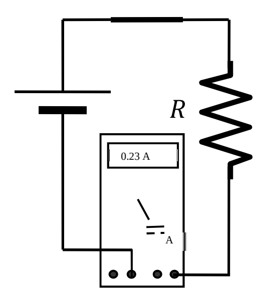
Comment on DMM data. Sometimes the DMM will output 4 sig figs and sometimes only 3. Always record all sig figs output by the DMM. In Excel, look for these buttons somewhere in the top/middle that allow you to change the sig figs in each cell. Also, when measuring with a DMM start with the dial at the highest possible setting then work the dial down to the lowest setting *which does not overload*. This gives the maximum number of sig figs for each measurement. Lastly, turn off the DMM and open the switch on any circuit when not in use to save battery life. This is important with two 3-hour labs back to back!

PART I: The nominal value of a resistance is the value stated by the manufacturer (e.g. 10 Ω or 4.7 kΩ). Obtain 10 resistors with a nominal value of 10 Ω. Before you start measuring them, verify they all have the same color bands in exactly the same order. Google "resistor color code" to verify each resistor's color bands match the nominal value stated on the little plastic bag. If you have trouble discerning the colors (for instance orange and red often look similar) get a second opinion. Give your instructor any resistors which are not in the correct bag. If you do not have 10 resistors after checking all the resistor color codes, try a different nominal value of resistance and start over.

As a group measure the resistance of all 10 resistors with a DMM and tabulate the data. Note the tolerance band of each resistor in your table. They will *probably* each be 20%, 10%, or 5% but check it just in case. For each resistor, compare the resistance measured with a DMM to the nominal value and state if each resistor is within the tolerance stated by the manufacturer. Lastly, obtain the average and standard deviation of your measured values using the AVERAGE and STDEV functions in Excel. If you divide the standard deviation by the average this roughly gives you a "% spread" of your measured resistors. Compare this to the tolerance band stated by the manufacturer…



PART II: Obtain one additional resistor with nominal resistance 56 Ω. If 56 Ω resistors are unavailable, ensure your two resistors have different nominal values. Prepare a simple circuit that employs a 1.5 V battery, your resistor, and a switch. Note: if no switch is available, you may consider the act of connecting and disconnecting one of your wires as your switch. Also, ensure you have a benchtop DMM and a handheld DMM at your station for this part.



You will be measuring voltage, resistance, and current for this circuit. The measurement of current is often done improperly by students just starting out. This can cause blown fuses, frustration, and confusion. **Use the break and replace method.** Put the DMM in *series* with the resistor, not in parallel. See the lower figure at right.

Note: if you don't know how large the current will be, first use the 10 A setting and the 10 A cable positions. If your measured current is less than 0.20 A using this mode, switch both the cables and the dials to the 200 mA or less positions on the DMM. If you don't know what I'm talking about, ask the instructor for help in person BEFORE you attempt current measurements.

Measure the following quantities with an *OPEN SWITCH* (open circuit):

- The resistance R of the load resistor with the benchtop DMM
- The voltage V_o across the battery with the benchtop DMM

To notice:

1) Measuring the resistance of a resistor is best done before the resistor is placed in the circuit. Other elements in the circuit will mess with the reading of your resistor. If you tried to measure the resistance while the circuit was connected, you perhaps found an over limit error message on the DMM screen.
2) The open circuit voltage and closed voltage are nearly, but not exactly the same. For small values of load resistance the difference can actually be quite dramatic!

Measure the following quantities with the DMM with a *CLOSED SWITCH* (closed circuit):

- The voltage V_c across the battery with the benchtop DMM
- The current i through the load resistor with the handheld DMM.

Notice the measured values can differ depending on the status of the circuit (open versus closed). We will learn later that no battery is ideal; all real batteries have internal resistance. The internal resistance of the battery effectively lowers the voltage of the battery while in operation.

In addition, putting a DMM in *series* to measure *current* will also add some hidden resistance. Further complicating matters, the internal resistance of DMM while measuring current changes as the dial is rotated (as sensitivity setting is changed). If we restrict ourselves to resistors between 10 Ω and 56 Ω we should be able to set the dial to the 200mA setting and leave it there. We can then lump this internal resistance of the ammeter in with the internal resistance of the battery. Note: the DMM in *parallel* measuring *voltage* is does not significantly affect the internal resistance for reasons we can discuss when we get to circuits.

The amount the voltage is lowered is a function of both the load resistance and the total internal resistance (including both battery and DMM used as an ammeter). In our circuit internal resistance (r) is given by

$$r = R_{tot} - R$$

where R_{tot} is given by

$$R_{tot} = \frac{V_o}{i}$$

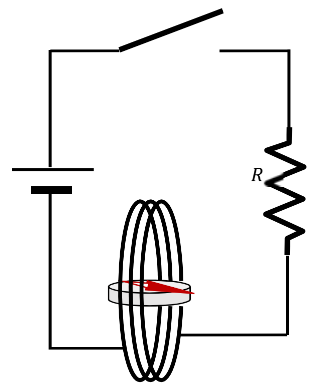
Do four total trials (use both the 10 Ω & the 56 Ω with two different batteries).
Have each different student do one set of measurements so each student gets the practice.

Use $\delta R_{tot} = R_{tot}\sqrt{\left(\frac{\delta V_o}{V_o}\right)^2 + \left(\frac{\delta i}{i}\right)^2}$ where $\delta r = \sqrt{(\delta R_{tot})^2 + (\delta R)^2}$. Make Excel formulas do the calculations for you but check one by hand to verify you typed in the formulas correctly. Remember to use your unrounded result for δV_o in your calculation of δr when checking by hand…that's what Excel does! Also, think about your units!

Be sure to check the following items:

- **Use the DMM value, not nominal value, of resistance; measure *R* before it is connected to a circuit!**
- Get the max sig figs possible for each measurement (should almost always be 3…4 if first digit is 1)
- Adjust sig figs of each cell in Excel to include all sig figs from DMM (important if last digit is zero)
- The delta symbol (δ) can be created using lower case "d" in the symbol font.
- The capital omega symbol (Ω) can be created using upper case "W" in the symbol font.
- Variables like R, V_o, and I are italicized (with the exception of numerical subscripts).
- Units like V and A are NOT italicized.
- The lower case delta symbol (δ) indicates uncertainty or error. Estimate the errors based on your readings from the DMM or by searching for the uncertainty in an online manual for the DMM.
- δr is different from the other uncertainties. Since you *calculated* r you must also calculate δr.

PART III: A galvanometer is a device used to measure current. A simple galvanometer can be made by placing a compass at the center of a coil of wire. If current flows through the wire the compass needle deflects. Try building the circuit shown at right. Start with a large resistor. When the switch is closed, observe the compass.



Now open the switch and replace the large resistor with a significantly smaller resistor. Upon closing the switch, once again observe the deflection of the compass needle. Does it deflect more, less, or the same amount as the larger resistor.

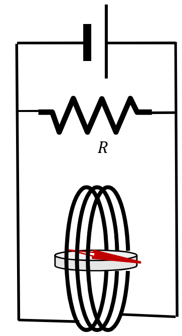
Finally, take the coil out of the circuit. Measure the resistance of the coil with a DMM. Make a mental note: is the coil resistance negligible compared to R in your opinion?

Don't re-write the questions. Answer in full sentences which make obvious what question was asked.
Conclusions:

1) When measuring the resistance of a resistor with the DMM one often gets 3-4 sig figs. For example, suppose a 1.0 kΩ resistor with 10% tolerance band is measured with the DMM. The student determines resistance is $R = 1023 \pm 1\Omega$. Even with a 10% tolerance band, the measuring error is **not** $\pm 100\Omega$. What is the point of the tolerance band if it doesn't really tell you the error in the resistors value? What *does* the tolerance band tell you?
2) The manufacturer of the resistor uses the tolerance band to alert users of the *possible range* of resistance values. A 1.0 kΩ resistor with 10% tolerance band implies *measured* resistance should be a value between 900 & 1100 Ω (even though it is *nominally* 1000 Ω). When you use a DMM, you typically get a much smaller measurement error (δR). That said, if no DMM measurement is made, the tolerance band can be used as a worst case scenario number for δR. No question here; no answer required. I just want to stress you should measure resistors with a DMM in this class (as opposed to using the nominal value).
3) If internal resistance (r) is less than 1% of load resistance (R), r has negligible effect on measurements. What minimum *load* resistance is required to make internal resistance negligible for your circuits? Support your answer by stating numerical values of internal resistance from your circuits in the answer to this question. Random Note: we will learn later power is delivered to the load resistor at maximum rate if load resistance equals internal resistance.

4) Why does running current through the coil of wire cause the compass needle to deflect? You can probably web search for this answer if needs be. In particular, when current is running through the coil, what type of field is created?

5) Consider the circuit shown at right. Assume R is a large resistor. Assume the coil is essentially a wire with MUCH less resistance. It is very possible the coil in this circuit will get hot and melt (and no longer be functional). Explain why the coil will get very hot and possibly be destroyed. Hint: in a circuit you may have heard that most of the current takes the path of least resistance.



6) Do web searches for "dead battery voltage" and "internal resistance over time". From your research, answer the following (listing websites you used to determine the answers):
   a) When a battery dies does battery voltage drop to zero?
   b) As a battery dies, does internal resistance increase, decrease, or remain relatively constant?