ECE 1245: Lab 1
Resistors in Series and Parallel

Learning Objectives:

- Get acquainted with laboratory protocols.
- Understand how to use a breadboard.
- Measure resistance using a digital multimeter/ohmmeter.
- Classify resistors using standardized color coding.
- Calculate/measure resistance in series and parallel.
- Measure the resistance of a potentiometer (pot).

Materials Needed:

- Digital Multimeter
- Breadboard and Parts Kit

Name: Hayden Walpole

Date: Sept 24, 2023

Laboratory Protocol

Welcome to your first hands-on circuit exercise! Before we begin with our tutorial, it is important to introduce the basic procedures and expectations of these sessions. For starters, you may have noticed that every page of this document has a space for you to sign your name and date it. The reason for this is to instill a habit of signing/dating every page in official laboratory notebooks. Although this class does not require students to maintain a proper lab notebook, it will eventually become a regular requirement in later classes.

To receive full credit, simply print out this document and fill in the blanks wherever indicated. You will also be asked to scan this document, along with any other supplemental documents (e.g., code, derivations, etc.), and then combine everything into a single PDF file. Please submit your PDF to the appropriate CANVAS page online so that the TA may grade it accordingly.

Note that many smart phones have free scanner-to-PDF apps available. Alternatively, Adobe products are freely available to University of Utah students through the Office of Software Licensing (OSL.utah.edu). If you would rather not print out a hard copy, Adobe Acrobat Pro will allow you to type directly into this PDF and then add your code to the end of the document. For Mac users, you should be able to accomplish the same thing with Preview.

Students are strongly encouraged to work together and help each other solve problems. However, each student must also perform their own work for each lab submission. That includes simulations, building circuits, taking data, writing code, submitting results, etc. Simply copying/pasting other people's work is plagiarism, and it may result in course failure if discovered.

Remember that your TA is here to help you. If you get stuck, need help, or have any other concerns, always feel free to ask questions!

Experiment 1: Classify and Measure Resistors (10 points)

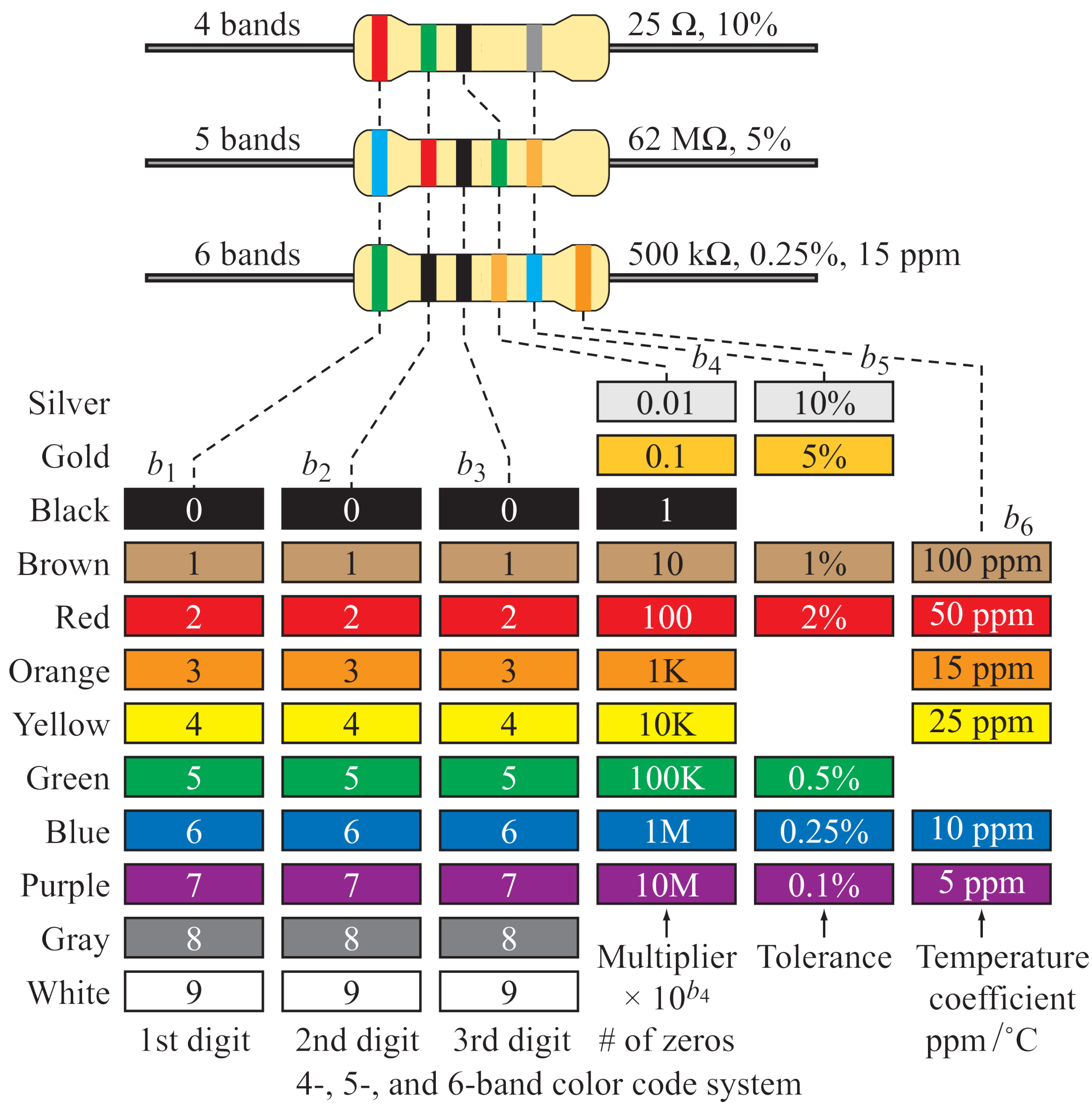


Figure 1: *Color code convention for determining resistor values.*

Pick up any resistor from your lab kit, and you may immediately ask yourself what value this particular component has. Resistance, after all, can take on any value between zero and infinity, and so we need a simple way to mark each device with its engineered value. Unfortunately, many electronic components are very small, which means printed text would be far too difficult to read with the naked eye. To solve this problem, resistors are often marked with a distinct color code that indicates their approximate value.

Figure 1 shows a broad overview of the color coding convention used to mark resistors. For this lab, your resistors should have a total of four stripes, or bands, though some resistors on the market can have as many as five or six. Since we will not be using such devices in this lab, you can ignore the extra 5-band and 6-band entries in the chart.

The first two bands, b_1 and b_2, are used to indicate the first two digits of the resistor value. If we used a 5-band or a 6-band resistor, then the third band would simply add a third digit of precision. However, since we are only using a 4-band resistor, the b_3 band is just assumed to be zero. Thus, the “third” band is actually b_4, and it is used to indicate multiplication by 10^x. For example, a color code of brown-black-red would translate into 1-0-2, thus indicating “10×10^2”, or 1000 Ω.

The final band, b_5, is used to indicate the *tolerance* of the resistor. Since no manufacturing process can ever be 100% perfect, it is necessary to accept some natural degree of variation in the ultimate resistor values. For example, a silver band indicates 10% tolerance, and it simply means that the resistor is guaranteed to fall within 10% of the specified value. Depending on your application, this may or may not be perfectly reasonable, but lower tolerances almost always come with higher costs.

Look at the table below and see if you find the corresponding resistors from your starter kit. Using the color-coding convention in Fig. 1, fill in the table with the expected resistance of each device. When finished, use your digital multimeter to measure the actual resistance and compare against the expected value. Note that to complete this step, you will need to dial your meter to the *ohmmeter* setting, which is indicated by the capital omega symbol on the knob (Ω). Next, simply touch the tips of the probes to the metal contacts of the resistor (make sure to have a solid contact between the metals). The display should immediately show the true resistance of the part.

Figure 2: *A digital multimeter dialed to the ohmmeter setting for measuring resistance.*

Band 1	**Band 2**	**Band 3**	**Band 4**	**Expected Resistance (Ω)**	**Measured Resistance (Ω)**
brown	black	yellow	gold	100k	98k
orange	orange	red	gold	3300	3260
red	red	brown	gold	220	217
brown	black	orange	gold	10k	9.89k

Name: Hayden Walpole Date: Sept 24, 2023

Experiment 2: The Breadboard (10 pts)

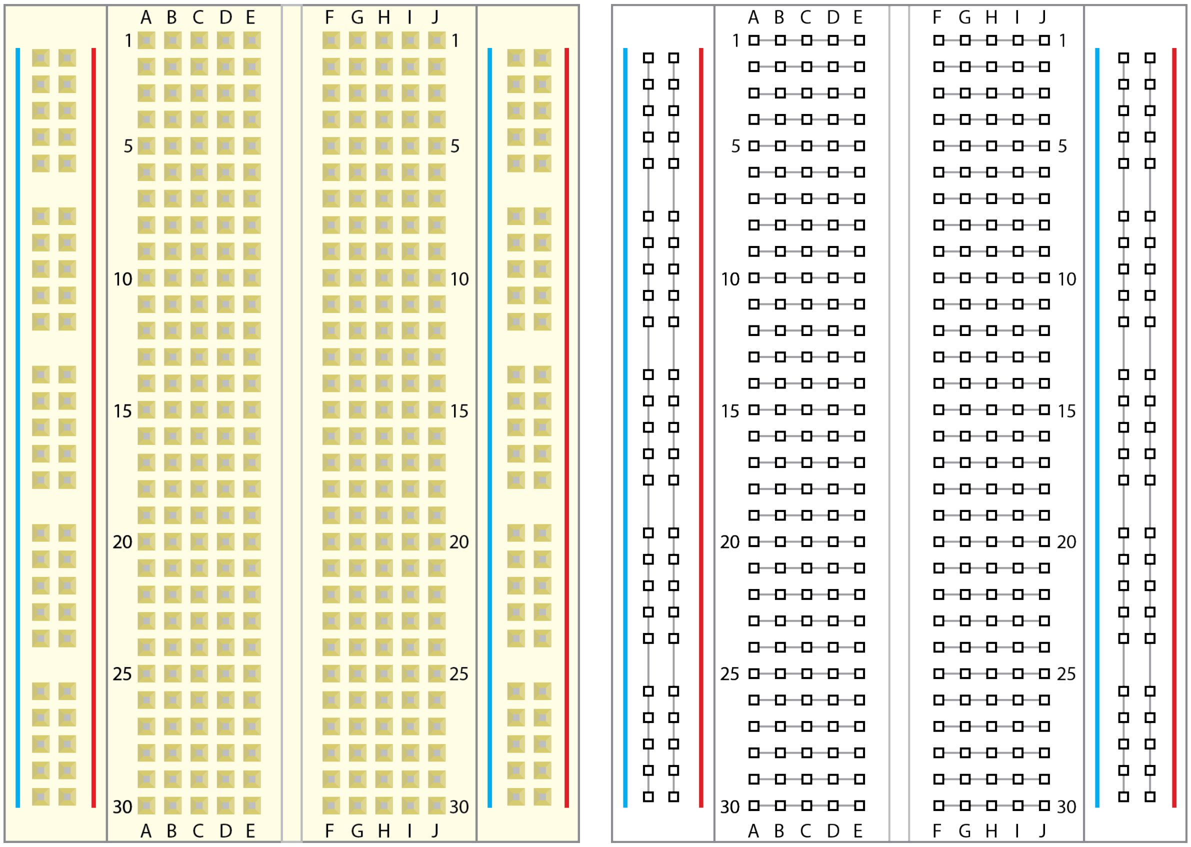


Figure 3: *(Left) Typical breadboard configuration. (Right) Electrical connection between nodes.*

One of the most important tools in your electrical supply kit is the breadboard. Depicted in Fig. 3, the breadboard is an ingenious tool for quickly assembling and disassembling electrical circuits. As you can imagine, this makes it very easy to experiment with different circuit configurations.

Looking closely at the breadboard, you will notice a bunch of little holes spread around everywhere. Buried underneath each little hole is a special gripping mechanism that will grab a piece of metal when crammed inside. The grip is purely frictional, which means a little tug is all you need to remove the part when finished.

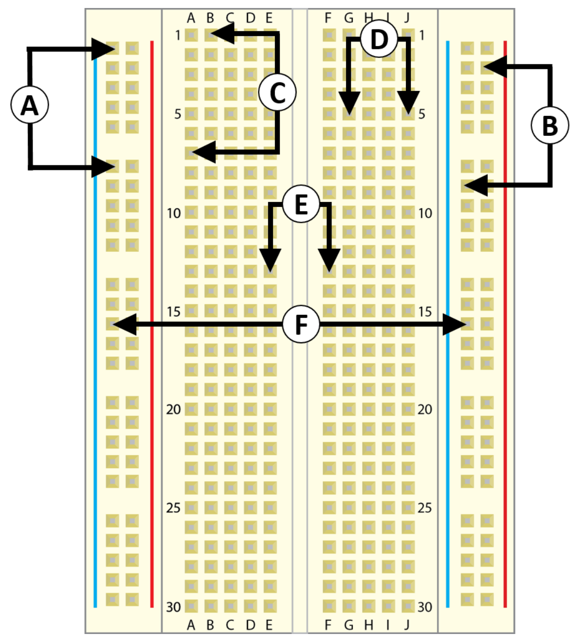
Try it now for yourself. Select a random wire or resistor from your electronics kit and see if you can squeeze it into one of the little plugs. Repeat the process a few times to get a feel for the strength of the grip. Notice how connections can easily be made and then broken using nothing but your fingertips.

Making and breaking connections is nice, but the real value of the breadboard is what happens underneath. Look closely at the right image in Fig. 3. If you had X-ray vision, you would see that many of the little holes are electrically connected (i.e. *shorted*) to each other in a fancy pattern. For example, the blue and red lines indicate the *rails*, which are all connected vertically across the length of the breadboard. Between the rails are a number of rows and columns, which are indicated by numbers and letters. Looking again at the diagram, you can see that the rows are all connected horizontally, but with a break in the center.

Set your digital multimeter to the *continuity* setting, which is typically indicated by a little sound wave cartoon (•))). On most devices, the continuity dial is the same as the resistance dial, since both measurements are essentially the same. The only difference is that the multimeter will emit a beeping sound if the measured resistance is very small (thus indicating an electrical short). You will also have to push the "select" button on the multimeter to choose the correct option for this particular dial setting. You will know you have the right setting when the little sound icon appears in the digital display. Test it now by touching the tips of the probes together and listening for the beep.

Using your multimeter, test the continuity between the nodes indicated by the figure below. Note that you will need to cram the tips of the probes into the breadboard holes to get a good connection. Mark the spaces below to indicate whether or not each test resulted in a positive continuity.

A:	X	YES?		NO?
B:		YES?	X	NO?
C:		YES?	X	NO?
D:	X	YES?		NO?
E:		YES?	X	NO?
F:		YES?	X	NO?



Name: Hayden Walpole

Date: Sept 24, 2023

Experiment 3: Resistors in Series (10 points)

One of the most important skills in circuit theory is the ability to imagine complex arrangements of components as simplified equivalent values. A good example of this is the array of resistors depicted in Fig. 4. Resistors arranged in this way are said to be in *series* with each other, and we can treat the array as if it were all squished into a single resistor. According to circuit theory, the equivalent series resistance R_s is just the sum of the individual resistor values. In other words,

$$R_s = R_1 + R_2 + R_3 \ .$$

Using your lab kit, find three resistors with the values specified in the diagram. Measure the individual resistances with your ohmmeter and then record the values below. When finished, use your measured values to calculate the expected series resistance of the bunch.

$R_1 =$ 0.98 Ω .

$R_2 =$ 3.24 Ω .

$R_3 =$ 1.58 Ω .

$R_s =$ 5.8 Ω (expected) .

Now take your three resistors and connect them all in series on your breadboard like in the image below. Use the multimeter to measure their actual series resistance and compare it against your expected value. Did they match?

$R_s =$ 5.95 Ω (measured) .

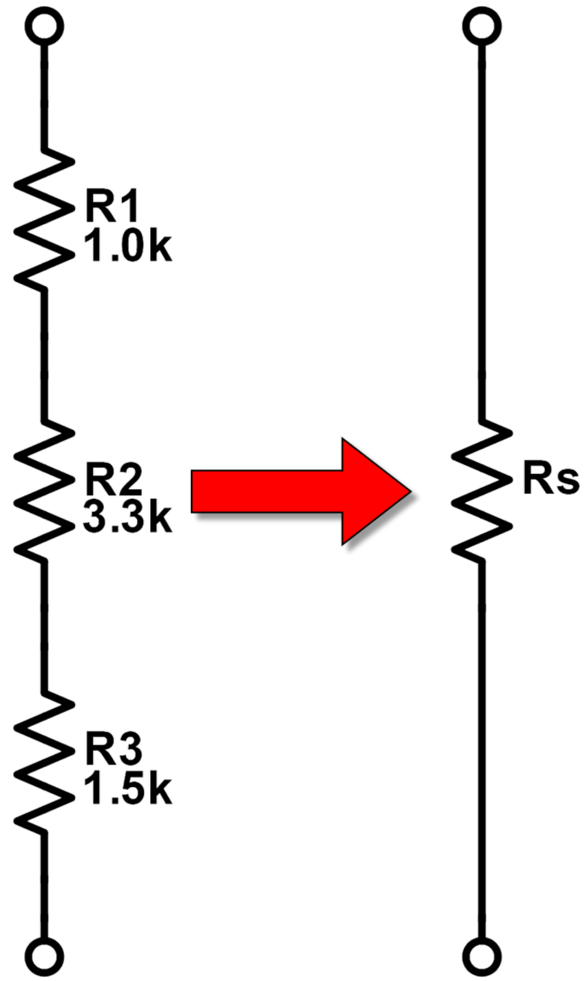
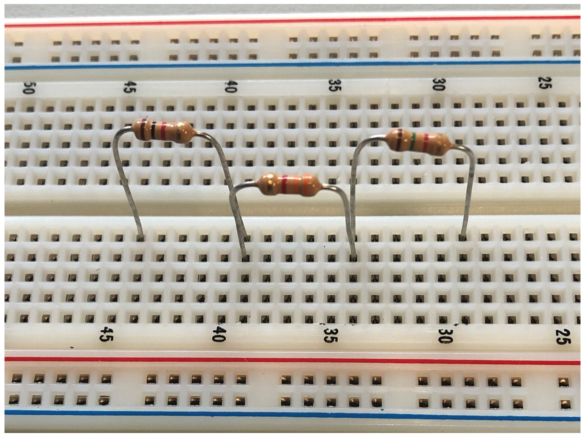


Figure 4: *Three series resistors imagined as a single equivalent resistance.*



Name: Hayden Walpole

Date: Sept 24, 2023

Experiment 4: Resistors in Parallel (10 points)

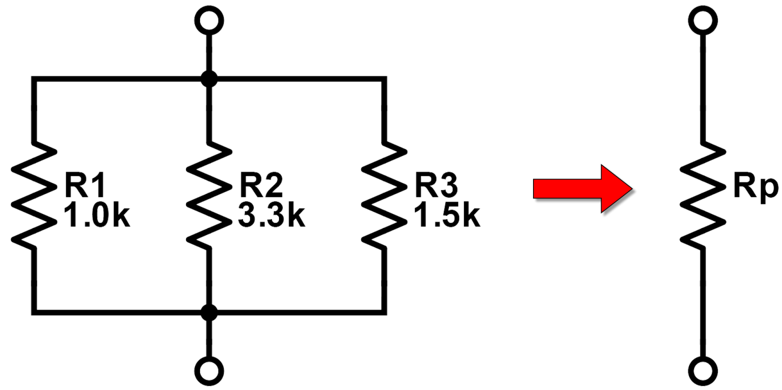


Figure 5: *A simple circuit of three parallel resistors.*

Recall that resistors in parallel can also be treated as a single, lumped resistance. However, rather than add resistance, we need to add *conductance*. Using the same resistors as the previous exercise, calculate their individual conductances, where conductance G is defined as $G = 1/R$. The total parallel conductance then satisfies $G_p = G_1 + G_2 + G_3$, which finally tells us the equivalent parallel resistance $R_p = 1/G_p$.

Fill in the blanks below with your calculations. When finished, use your breadboard to connect your three resistors in parallel and then measure their total parallel resistance with the multimeter. How well did your calculation agree with the measurement?

$G_1 =$ 1.02 S .

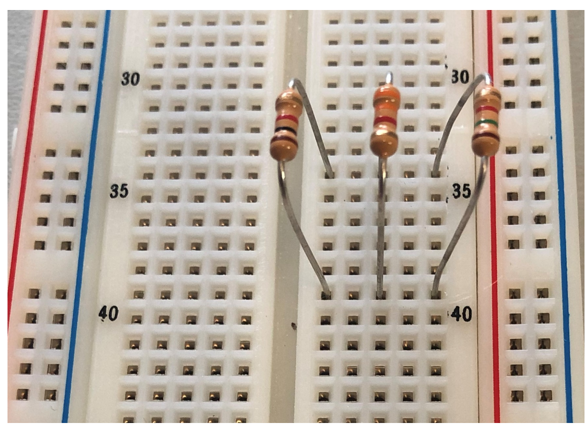
$G_2 =$ 0.308 S .

$G_3 =$ 0.63 S .

$G_p =$ 1.961 S .

$R_p =$ 0.509 Ω (expected) .

$R_p =$ .53 Ω (measured) .



Name: Hayden Walpole

Date: Sept 24, 2023

Experiment 5: The Potentiometer (10 points)

The potentiometer (or simply *pot* for short) is essentially a fixed two-port resistor that has a third, adjustable port placed somewhere in the middle. Depicted in Fig. 6, the mechanical construction begins with some fixed length of material that has a constant electrical resistance between each end. The adjustable port, often called a *tap* or a *wiper*, is then placed in electrical contact while freely sliding back and forth between each end.

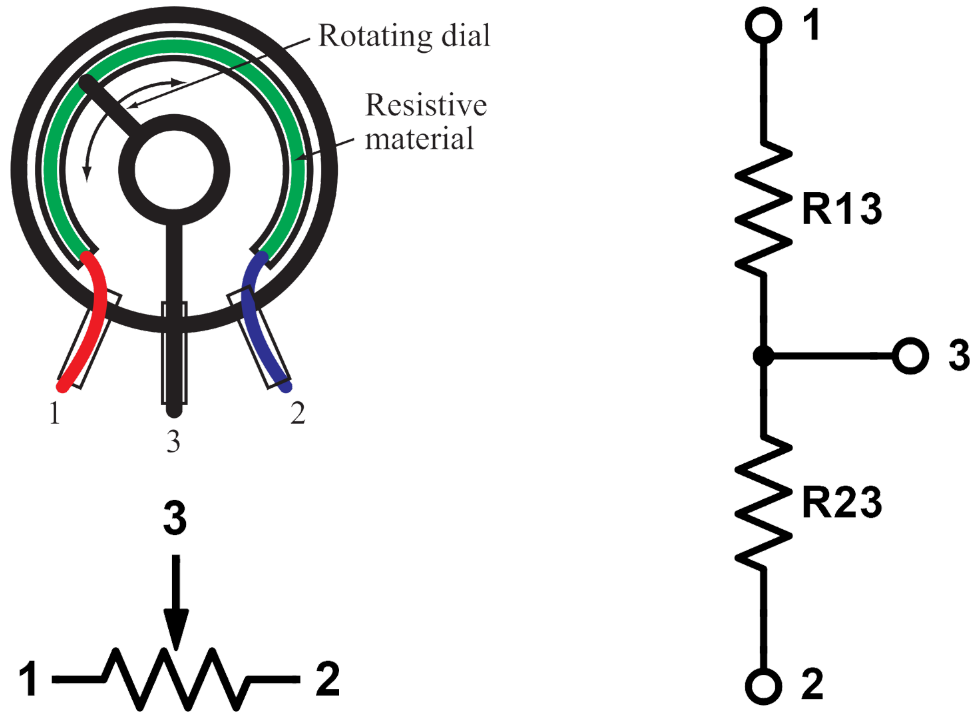


Figure 6: *(Left) Mechancial cosntruction for a typical potentiometer with its corresponding electronic symbol underneath. (Right) Equivalent circuit model with $R_{max} = R_{13} + R_{23}$ being constant.*

Also depicted in Fig. 6 is the equivalent circuit for a potentiometer, which is basically just two resistors in series with a tapped node between them. As the wiper is turned, the two resisters R_{13} and R_{23} may vary continuously, but the total, end-to-end resistance remains a fixed constant of $R_{max} = R_{13} + R_{23}$. This allows the potentiometer to also function as a *variable resistor*, or *rheostat*. For example, if we simply disconnect node 1 entirely and just connect nodes 2 and 3 to a circuit, the resistance R_{23} can be freely adjusted to any arbitrary value between 0 and R_{max}.

When working with potentiometers, it is important to be aware of the specific *taper* function along the wiper. The simplest form of taper is called a *linear* taper, meaning the resistances R_{13} and R_{23} change linearly with the wiper position. Often times, however, it is far more useful to implement a logarithmic change in resistance. This is especially prominent with audio applications, because human hearing is far more sensitive to logarithmic changes in signal strength. Taper functions of this variety are thus said to have an *audio* taper.

For this next exercise, you will need a 100 kΩ potentiometer from your kit. You will recognize the pot by the small, white numbers marked “104,” which indicate a total resistance of 10×10^4 Ω. Pots like this

Name: Hayden Walpole   Date: Sept 24, 2023 are often called *trim pots*, or simply *trimmers*, because they are require a small screwdriver to adjust (check your lab kit and make sure you have such a tool). This allows them to be used for precision fine-tuning without having to worry about stray human hands accidentally changing things later.

Connect your pot to your breadboard as shown in the Fig. 7 and use your ohmmeter to measure the resistance between two of its ports (if the alligator clips give you trouble, then just try cramming the tips of the ohmmeter into the breadboard like you did earlier). If you look very closely at the pot, you may notice a tiny arrow in the adjustment knob that indicates the direction of the wiper. Match this direction with the arrows in the table below and then measure the resistance between ports. Repeat the measurement for R_{12}, R_{13}, and R_{23}.

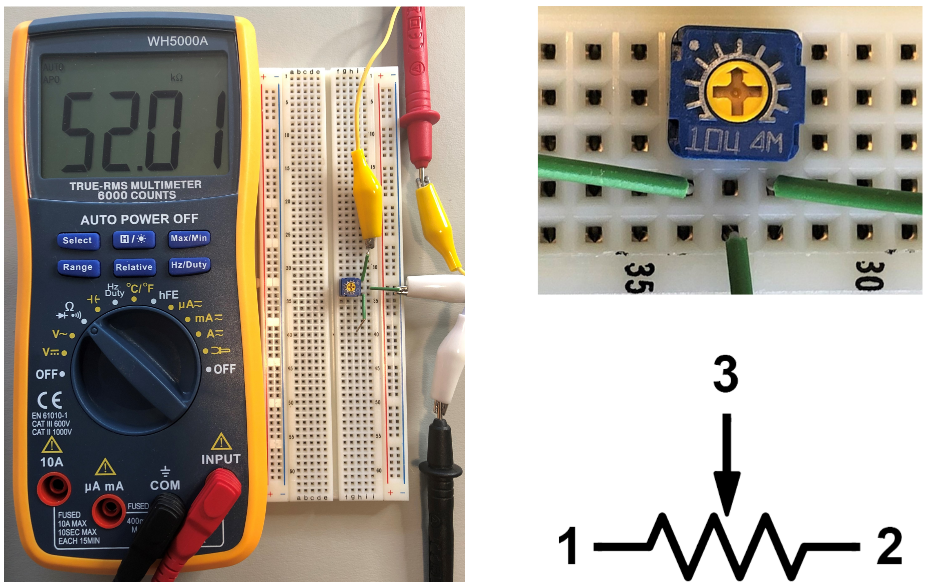


Figure 7: *(Left) Digital multimeter used as an ohmmeter to measure resistance of a* 100 *k*Ω *trim pot between ports 2 and 3. (Right) Close-up view of the trim pot with corresponding circuit diagram.*

Arrow Direction	R_{12} (kΩ)	R_{13} (kΩ)	R_{23} (kΩ)
↙	103	.2	103
←	103	8	97
↖	103	26.9	78
↑	103	45.7	59.4
↗	103	73.2	31
→	103	94.1	11.2
↘	103	103	0

Name: Hayden Walpole

Date: Sept 24, 2023