LESSON 2

USING A MULTIMETER

OBJECTIVE

This lesson will teach you how to use a tool called a multimeter to measure voltage, current, and resistance in the circuits that you build.

MATERIALS

- Multimeter with leads
- 1 x 9-volt battery (not included in your kit)
- 1 x Small Phillips Screwdriver from your Level C kit
- 1 x Breadboard
- 3 x 1K-Ohm Resistors
- 1 x 3V Battery (2 x AA)

REVIEW CONCEPTS

If you do not feel comfortable with the following concepts, please review them before proceeding.

- Understanding Voltage, Resistance, and Current in Series vs. Parallel Circuits (Lesson A-3)
- Voltage Dividers (Lesson B-9)

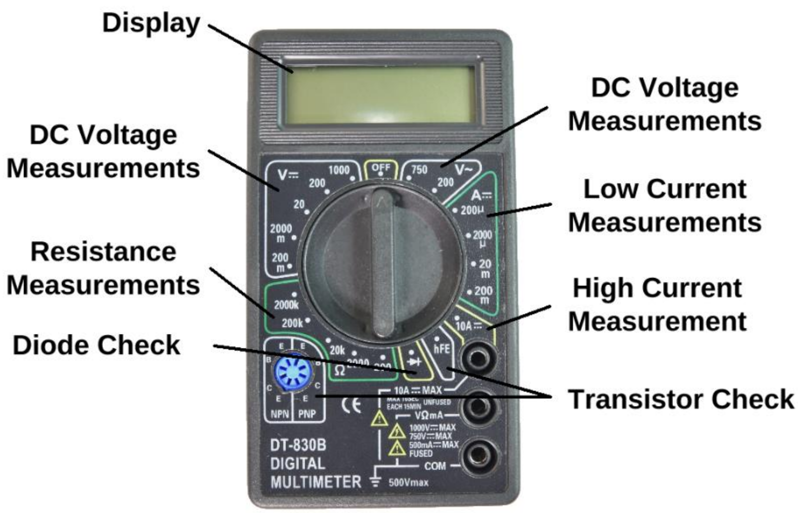
LESSON

A multimeter is a tool used throughout electronics for measuring voltage, current, and resistance. Some multimeters may also have additional specialized functions like testing diodes, transistors, or other electronic components. You may see multimeters referred to as voltmeters, but this is a legacy name that started back when some devices only measured voltage. The terms ‘voltmeter’ and ‘multimeter’ are often used interchangeably, but ‘multimeter’ is the more popular term for devices that have multiple measurement functions available.

MULTIMETER FUNCTIONS

Here are the functions available on the multimeter from your Level D kit:

- Voltage measurement – both DC and AC
- Resistance measurement
- Current measurement
- Diode check
- Transistor check

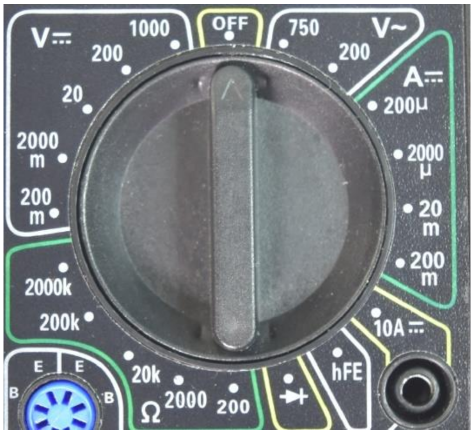


The voltage, resistance, and current measurements will be covered in upcoming sections. The diode and transistor checking functions will not be covered in this lesson due to the complexity of connecting these devices to the multimeter and interpreting the readings on the screen. For more information on these functions you can visit:

https://42electronics.com/pages/level-d-resources

MULTIMETER HARDWARE

A multimeter has a rotating selector switch that's used to turn the multimeter on and off as well as select the type of signal that will be measured:

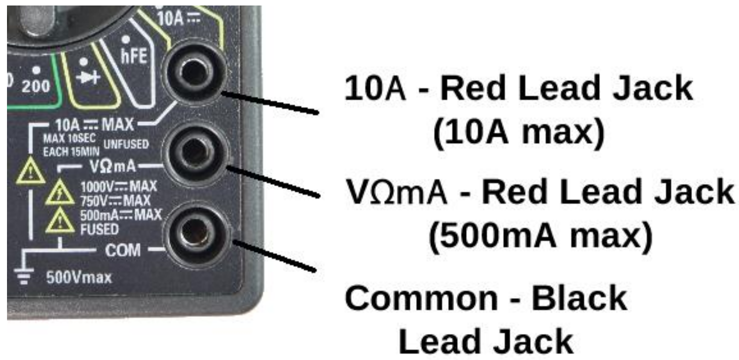


The multimeter runs on an internal 9-volt battery so it's important to make sure the multimeter is turned off when not in use to avoid unnecessarily draining the battery.

The multimeter has removable leads, also known as probes, that are used to touch areas of a circuit or components for measurement. These leads have handles with pointed tips to aid in touching only the specific component that you intend to measure.

> NOTE: The multimeter probe tips are made of conductive metal so it's important to be extremely careful when attempting to measure voltage or current levels in live circuits. If the probe tips are allowed to contact more than one component, a short circuit could occur, and electronic components or the Raspberry Pi could be damaged.

You may notice there are three jacks for leads and only two leads. This is because the red lead will be connected to one of two jacks when making different measurements:



The measurement taken will be displayed on the small LCD screen above the selector switch. Since there are a limited number of digits available on the display, the range selection will determine how accurately those digits are used.

RANGE SELECTION

The range selected for a measurement will determine the highest and lowest values that can be displayed. Since the LCD screen can only display four digits, you must select a measurement range using the selector switch that will allow you to get the most information possible from those four digits.

When a range that is too low is selected, a 1 will be displayed in the left-most digit. This indicates that a higher range must be selected to view this measurement. When a range that is too high is selected, the reading will be displayed, but you won't be able to see much accuracy in the reading.

Let's use an example of measuring the voltage in a single AA battery which is somewhere between 1.5 and 1.6-volts for a fresh battery, or around 1.2-volts for a rechargeable cell. Your multimeter has voltage ranges of:

- 1000V
- 200V
- 20V
- 2000mV
- 200mV

The AA battery can be measured using any of these ranges except for the 200-millivolt range. Trying to measure a 1.5-volt battery using this range will result in a 1 being displayed indicating that the voltage being measured exceeds the selected range.

Here are the various degrees of accuracy that will be displayed for an AA battery containing 1.529 volts by using the other ranges:

Range	Measurement	Units
1000V	Fluctuates between 001 and 002	Volts
200V	01.5	Volts
20V	1.52	Volts
2000mV	1529	Millivolts

The 2000mV range gives us the best accuracy on this measurement, but this range cannot be used to measure voltages over 2000 millivolts, or 2 volts. If you wanted to measure your 3-volt battery pack, you would use the 20V range which, unfortunately, loses one digit of accuracy over the 2000mV range.

Some higher-end multimeters have a feature called Autoranging, which means it can automatically adjust the range based on the voltage that's being measured. This is a very nice feature, but it does increase the cost of a multimeter generally 2-3x over models where the range must be adjusted manually.

MEASURING VOLTAGE

Measuring voltage can be very useful when building projects. You may want to do things like measure the voltage level of a battery or determine if proper voltage is getting to a sensor on your robot. With a multimeter you can measure the exact voltage that is present at any point in your project.

Just like you've seen in previous circuits that you've built; ground is the zero-volt reference that everything else is measured against. Another name for ground is common and this can be found on one of the lead jacks of your multimeter named COM. The black lead plugs into this jack and this lead will be connected to a ground point in your circuit to ensure that your voltage measurements are accurate.

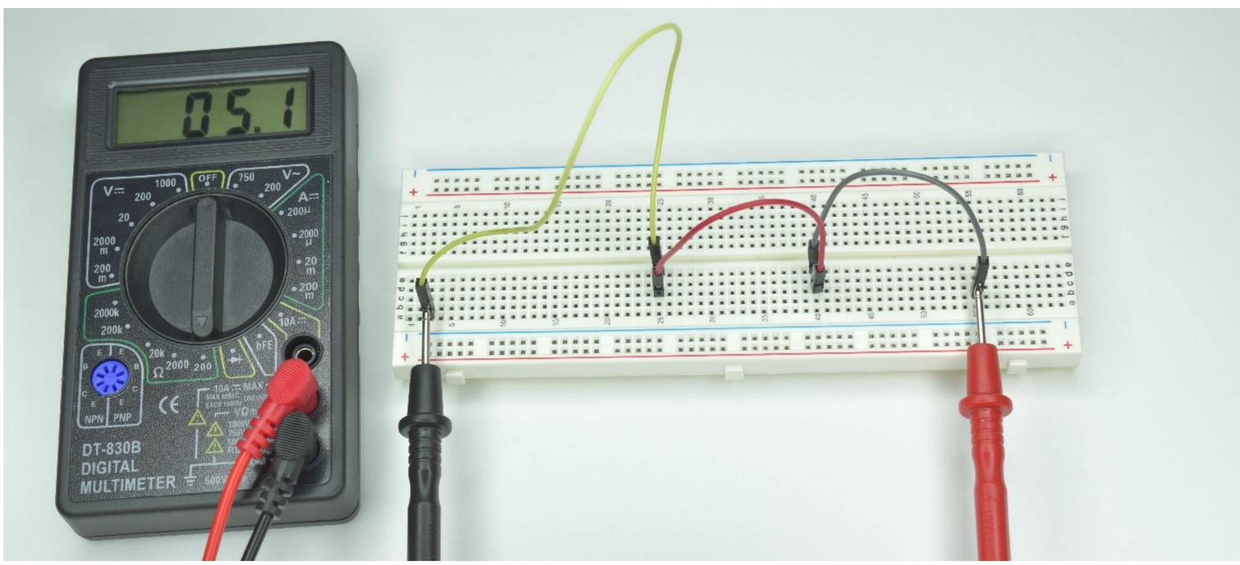
To measure voltage, ensure that your black lead is connected to the COM jack and your red lead is connected to the VΩmA jack. Next, select the appropriate range from the voltage measurement options; the 20V range will likely be the best range to use for most of your Raspberry Pi projects given most voltages are around 3.3 or 5 volts. With your circuit powered up and running, <u>carefully</u> touch the black lead to a ground point and the red lead to the point at which you would like to know the voltage.

The display will show the voltage currently being measured between the black and red leads. If the display shows a 1 or a very small number, then you likely have the wrong range selected. Change the range to a better value for your expected voltage and try again.

MEASURING RESISTANCE

Measuring resistance will come in handy when checking to see if two components are connected or if you can't remember the resistor color codes. The main thing to remember about measuring resistance is that the component cannot be powered on. The multimeter will run a tiny amount of current through the component in order to measure its resistance, and this measurement will be thrown off if there is additional current flowing through the component from the circuit. Your multimeter can also be damaged if there is enough current coming from the circuit, so always make sure components to be measured are disconnected from the circuit or the entire circuit is powered off before making resistance measurements.

A term you might see related to resistance is called continuity. When something has very low resistance between two points it is said to have continuity. This might apply to a single jumper wire or multiple connections made through wires and your breadboard:



In the image above, a multimeter is being used to measure the resistance between two pints on the breadboard that are connected by multiple jumper wires. With only 5.1 ohms of resistance present, these two points would be considered to have continuity.

You may see references later in this course to "checking the continuity" of component or connection. This just means using your multimeter to verify there is very low resistance between the points to be checked, which means you have verified there is a good electrical connection between these points. If higher than expected resistance or a complete open is measured, then you have located a problem that will need to be resolved before continuing.

This may come in the form of a bad jumper wire. If you're instructed to check a jumper wire for continuity, then the resistance of that wire should be measured. If the resistance in that jumper wire is very low (less than 10 ohms) then the jumper wire should be considered good, and additional troubleshooting will be required to find the problem. If higher resistance is measured in that jumper wire, then the wire or connections have failed, and that jumper wire should be discarded as you can no longer rely on it to perform reliably on your projects.

To measure resistance, ensure that your black lead is connected to the COM jack and your red lead is connected to the VΩmA jack. Next, select the appropriate range from the resistance measurement options for your expected resistance. If checking for continuity you can use the lowest range of 200 ohms. Make sure that your circuit is powered off and carefully touch the black and red leads of your meter to the points that you would like to measure:

- If your display is showing zeros to the left of the measured value, then you can switch to a lower range to obtain a better reading.
- If your display is showing a 1 then your selected range is too low for this measurement. Switch to a higher range to display the measured value. If your display continues to display a 1 on the highest range, then the two points you are trying to measure are not connected. This could be due to a failed component or a jumper being inserted into the wrong hole in breadboard.

Here are some common resistance measurements that you might make and what values to expect:

- Jumper wire – very low resistance, less than 10 ohms

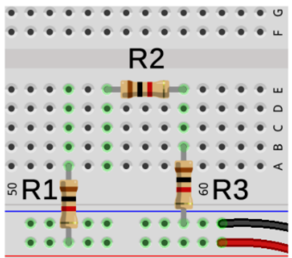
- Single Resistor – the resistance value of the resistor being measured

- Resistors in Series – resistor values added together

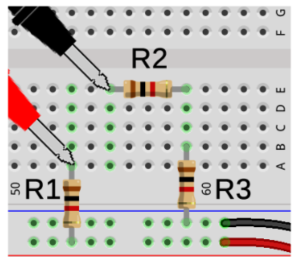
- Resistors in Parallel – the inverse of the inverse of all resistors in parallel, for more information see https://en.wikipedia.org/wiki/Resistor#Parallel

MEASURING CURRENT

Current measurements can be used to determine how much current is flowing through a specific point in a circuit. Measuring current is different than voltage or resistance in that to measure current you must break the circuit at the point you wish to measure and use your multimeter to complete that portion of the circuit:



Open Circuit



Multimeter Completing Circuit

The amount of current you plan to measure will determine which location you will use for the red lead connection to your multimeter. The standard VΩmA jack will only support 500mA of current. If you plan to measure current values greater than 500mA then the 10A jack should be used for the red lead connection. Running more than 500mA of current through the standard VΩmA jack can damage the internal electronics of your multimeter.

Here is a chart of the current measurement ranges that are available and the corresponding red lead connection that should be used:

Selection	Maximum Measurement	Red Lead Jack
200µ	200 microamps	VΩmA
2000µ	2000 microamps	VΩmA
20m	20 milliamps	VΩmA
200m	200 milliamps	VΩmA
10A	10 amps	10A

To measure current, you must first determine how much current you plan to measure and set the range selection and red lead position appropriately. If you're unsure if the current you plan to measure will exceed 500mA, then use the 10A range and 10A red lead jack. You can always select a lower range and move the red lead to the VΩmA jack to get a more accurate measurement. If you accidently overload the 500mA rating of the VΩmA jack then your meter may be damaged, so always error on the side of caution if you think you might exceed that 500mA limit.

After the proper range and red lead position have been selected you must power the circuit down and break the circuit at the point you would like to measure. Next, complete the circuit using the leads of your multimeter making sure to keep the black lead toward ground or negative of the battery. Reversing the leads won't damage anything but your current reading will indicate a negative current value which might be a little confusing.

When the circuit is powered back on, current will flow through the multimeter and the amount of current measured will be displayed on the screen. If there are components like switches or LEDs in the circuit that might affect the current at your measurement point, then you can try switching those components on and off to watch how they change your current measurement in real-time.

When you're done measuring the current, power the circuit down, and remove your multimeter from the circuit. Make sure to complete the circuit in the location you were measuring so it will operate properly with your multimeter removed from the circuit.

ACTIVITIES

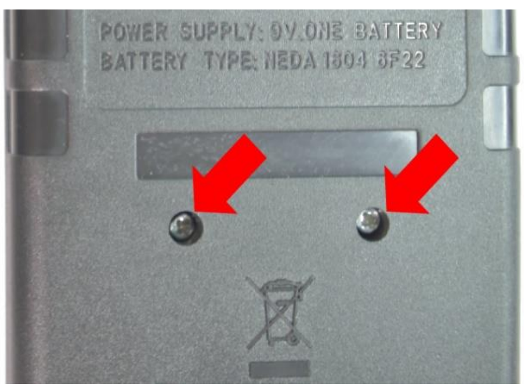
In the following activities you will insert a 9-volt battery into your multimeter and use it to take resistance, voltage, and current measurements in a small circuit that you build.

ACTIVITY #1 – INSTALLING THE BATTERY

In this activity, you will install a 9-volt battery into your multimeter so it can be used to take measurements in upcoming activities.

STEP #1

Place the multimeter face down on your work surface and use the small Phillips screwdriver (from your Level C kit) to remove two screws from the locations below:

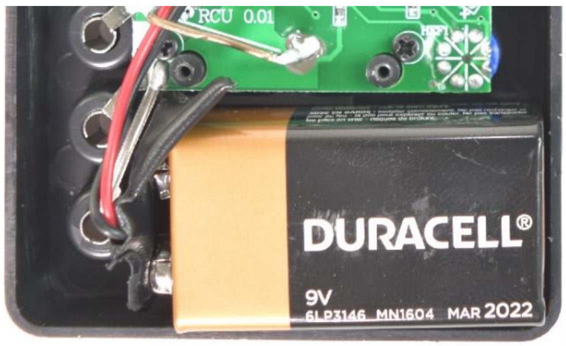


Once the screws are loose, remove the back cover and turn the back-cover upside down to fully remove the loose screws from the cover. Set these screws aside in a safe place on your work surface where they will not easily be lost.

STEP #2

Attach the 9-Volt battery to battery connection. Make sure to properly align the positive and negative terminals before trying to attach the connector to the battery to avoid applying reverse voltage to the power connector. Once properly connected, the battery connector should be secured to both battery terminals.

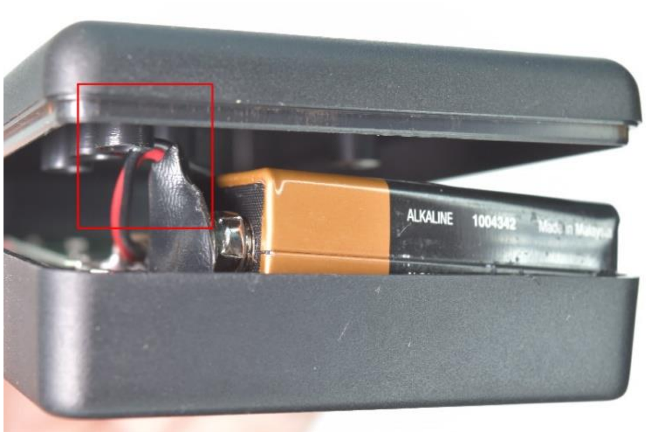
Slide the battery into the multimeter in the space provided:



The extra flap of plastic on the battery connector should be near the circuit board. This plastic is used to protect the battery from the metal blade connecting the COM jack to the circuit board.

STEP #3

Fit the back cover onto the multimeter taking care to avoid damaging the battery connector with the back cover. If the cover is not fitting on properly, gently bend the plastic flap and wires on the battery connection toward the battery. This will create more clearance for the features of the back cover to slide past the battery connector:



STEP #4

Once the back cover is fully seated, insert the two Phillips screws into the holes in the back cover and tighten them with your screwdriver. Use just enough force to fully tighten the screws. Overtightening the screws can damage the screw threads in the front cover of your multimeter.

STEP #5

The next step will be to make sure the multimeter powers up with your battery attached. Turn the multimeter over and switch the range from OFF to the DC measurement at 1000V range. The display on the multimeter should turn on and display HV and 000. Switch the multimeter back to OFF to avoid draining the battery when not in use.

If the display does not turn on, switch the multimeter back to OFF, remove the rear cover, and check the battery connection. If the battery connection is good, then your battery could be dead. Try connecting another battery and reassemble using steps 2 through 4 above.

STEP #6

Attach the test leads to the multimeter in the following locations:

- Black lead – COM jack
- Red lead - VΩmA jack

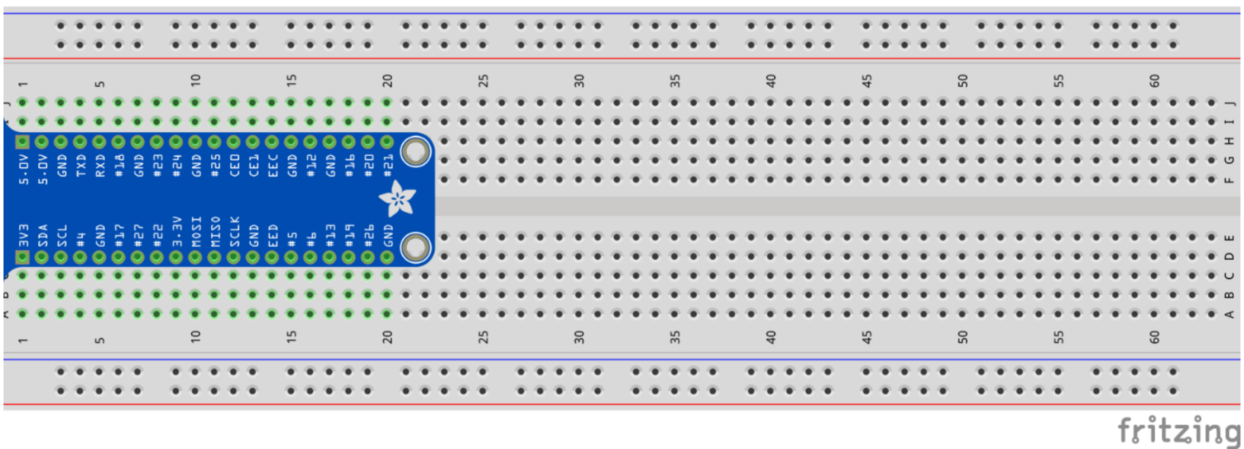
NOTE – Current measurements above 500mA will not be made during this lesson so the red lead will stay in the VΩmA jack for the entirety of this lesson.

ACTIVITY #2 – MEASURING RESISTANCE VALUES

In this activity, you will build a small circuit with three resistors and measure varying levels of resistance at different points throughout the circuit.

STEP #1

Clear the breadboard of all components except for the wedge. The wedge can be difficult to install and remove so it will be left in place, even though it will not be used for this lesson. When completed, your breadboard should look like this:



Be sure there are no jumper wires connecting the power rails to the wedge. Power will be applied to the P1/N1 rails using your 3V battery pack and this could damage your Raspberry Pi if the P1 and N1 power rails are still connected to the wedge.

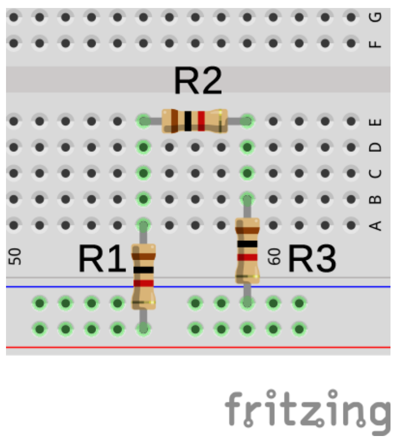
STEP #2

Next, insert three 1K-ohm resistors in series in the following locations:

1K- Ohm resistor - R1 – Between P1-55 and A55

1K- Ohm resistor - R2 – Between E55 and E59

1K- Ohm resistor - R3 – Between B59 and N1-59

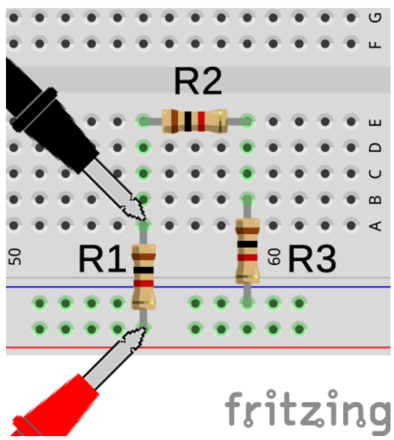


To avoid confusion, the reference designators R1, R2, and R3 will be used to refer to each of these resistors throughout the remainder of this lesson.

STEP #3

It's time to start measuring the resistance at different points in the circuit. The first measurement will be R1 by itself, which should measure right around 1K-ohms. Rotate the dial on your multimeter to the 2000-ohm position. The display will initially display a 1 because there is very high (infinite) resistance between the two leads.

Touch your red lead to the power rail end of R1 and your black lead to the other end of R1:



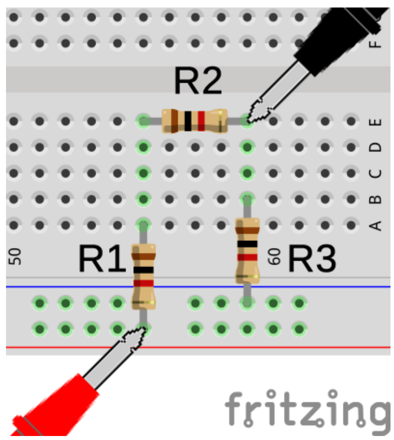
You should be measuring around 1000 ohms, but it will likely not be exactly 1000 ohms. Due to the 5% +/- tolerance on these resistors, you could measure anywhere between 950 ohms and 1050 ohms.

If your measurement is not displaying as expected, double-check that your multimeter is set to Ohms mode in the 2000 ohms range.

STEP #4

Now that you've measured the value of R1, let's measure R1 and R2 together. Since the values of two resistors in series are added together to get the total resistance, you should measure right around 2000 ohms. While this is the maximum value that can be measured with the 2000-ohm range that the multimeter is currently set for, this range will give us the most accurate measurement possible, so we will try that range first.

Touch your red lead to the power rail end of R1 and your black lead to the end of R2 located in breadboard position E59:



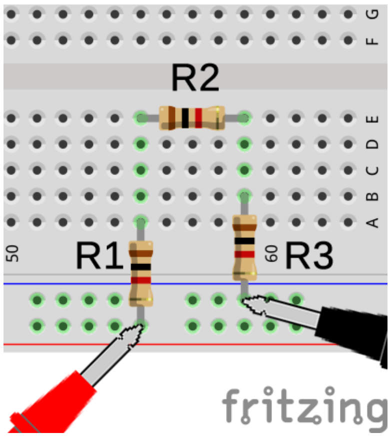
You should be measuring somewhere around 2000 ohms. If the value is below 2000 ohms, then it will be displayed on the screen of your multimeter. If the value is above 2000 ohms, then it will exceed the selected range and you will only see a 1 on the display to indicate that the value being measured is out-of-range. If this happens, switch your meter into the 20K-ohm range and the measured value will be displayed.

If you still cannot get a good reading for R1 and R2 using the 20K-ohm range, confirm that your resistors are placed into the breadboard properly, so they are connected in row 55.

STEP #5

Now, let's measure R1, R2, and R3 together. These three resistors connected in series should give us a measurement of around 3000 ohms. Since the expected measurement is 3000 ohms, this will exceed the range of the 2000-ohm setting, so switch your multimeter into the 20K-ohm range (you might already be in this range if you had to switch ranges in Step #4 to get the value of R1 and R2 to display).

Touch your red lead to the power rail end of R1 and your black lead to the end of R3 located in breadboard position N1-59:



Switching to the higher range reduces the accuracy of the reading you can now receive. Instead of ohms, the reading will now be in K-ohms, so your display should be showing somewhere around 3.00 K-ohms. The actual reading will vary based on the exact values of the resistors in your circuit, so considering the 5% +/- tolerance rating of these resistors, your reading could be anywhere from 2.85 K-ohms up to 3.15 K-ohms.

If you still cannot get a good reading for R1, R2, and R3 using the 20K-ohm range, confirm that your resistors are placed into the breadboard properly so R2 and R3 are connected in row 59.

STEP #6

Now that we’re done with resistance measurements, turn the selector dial on the multimeter back to the OFF position to avoid accidentally leaving the multimeter on, wasting battery power. This is a good habit to get into as it will save you from having a dead battery the next time you want to use your multimeter.

ACTIVITY #3 – MEASURING VOLTAGE VALUES

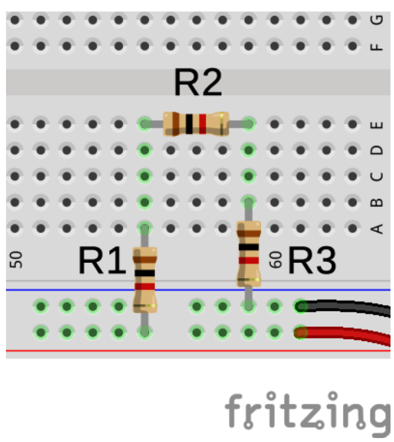
In this activity, you will connect a 3-volt power source to your circuit and use the multimeter to measure voltage levels at various points throughout the circuit.

STEP #1

Insert two AA batteries into the battery holder from your Level A kit and connect its wires to the following locations:

Battery positive – Red wire – P1-61

Battery negative – Black wire – N1-61

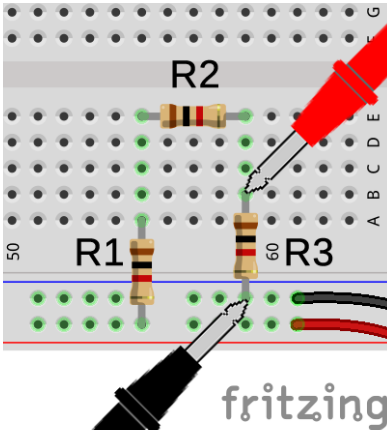


NOTE: Do not allow the wires from the battery box to touch once batteries are installed, as the resulting short circuit could cause damage to the battery holder or batteries.

STEP #2

With no switch in your resistor circuit, current will begin to flow through the circuit as soon as you connect the batteries. You can now measure the voltage level present at different components.

Switch your multimeter into the voltage measurement range of 20 volts. The first component that you will measure is R3. Touch the black lead of the multimeter to N1-59 end of R3 and the red lead to the leg in B59:

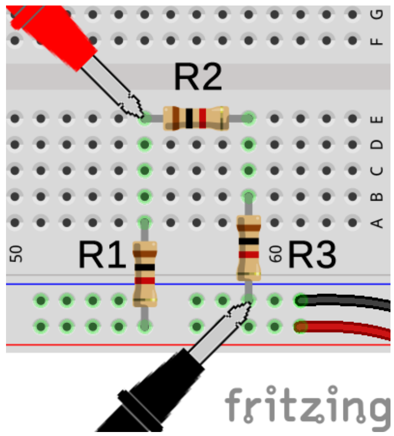


You will measure approximately 1-volt at this location. This circuit is just like the circuit in Lesson B-9 where you learned about voltage dividers. Since all three resistors are the same value, then each of them will drop 1/3 of the input voltage. With an input voltage of 3-volts, each resistor will drop about 1-volt. You are currently measuring the voltage drop across R3 at about 1-volt.

STEP #3

It’s now time to measure the combined voltage drops across R2 and R3.

Leave your black multimeter lead in its current location and move the red lead to the leg of R2 in E55:

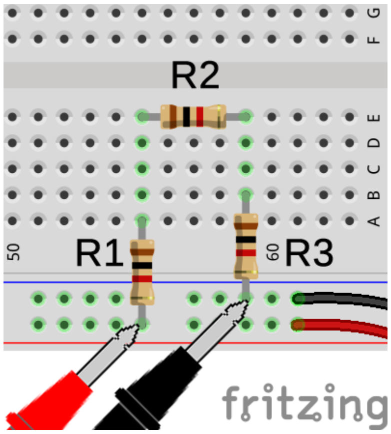


Each component is dropping about 1-volt, so your multimeter will now display approximately 2-volts, as this is the combined voltage drop of R2 and R3.

STEP #4

You will now measure the voltage drop across R1, R2, and R3.

Leave your black multimeter lead in its current location and move the red lead to the leg of R1 in P1-55:



Your multimeter will now display approximately 3-volts, as this is the combined voltage drop of R1, R2, and R3. This also happens to correspond with the total voltage coming from the battery pack.

STEP #5

Carefully remove your test leads from the components in the circuit and switch your multimeter back to the OFF position.

ACTIVITY #4 – MEASURING CURRENT IN A CIRCUIT

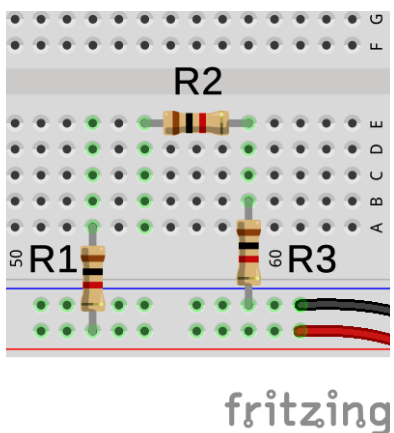
In this activity, you will measure the current flowing through your test circuit made of three 1K-ohm resistors in series.

STEP #1

In order to measure the current flowing through a point in a circuit, the circuit must be broken at that point, and the multimeter meter inserted as part of the circuit. The multimeter can then display the amount of current flowing through it as it completes the circuit.

To break the circuit, we will move R1 away from row 55 where it's currently connecting to R2. Remove R1 from the circuit and move it to the new location below:

1K- Ohm resistor - R1 – Between P1-53 and A53



STEP #2

The last step in measuring current will be to complete the circuit using the leads of your multimeter. Here is a quick calculation of the amount of current we can expect to measure at this point in the circuit using Ohm's Law:

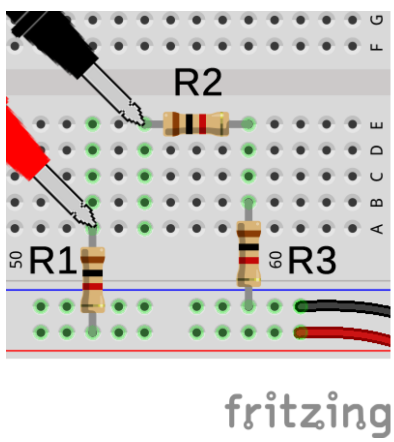
Current = Voltage / Resistance

Current = 3 volts / 3000 ohms

Current = 0.001 Amps or 1 milliamp

We can expect to measure about 1mA of current in this circuit. Switch your multimeter to the current measurement range of 200mA.

Touch the red multimeter lead to the leg of R1 in A53 and the black multimeter lead to the leg of R2 in E55:



As soon as your multimeter completes the circuit, it will begin to display the amount of current flowing through that point in the circuit. You should see a value of right around 1mA displayed on the multimeter. Since all of these components are connected in series, it does not matter where you measure the current. We could have broken the circuit between R1 and the positive battery connection, between R2 and R3, or between R3 and the negative battery connection. These points will all still have only 1mA of current flowing through them.

STEP #3

Now that all measurements have been taken let's prepare the components for storage. Switch the multimeter to the OFF setting and remove the AA batteries from the battery holder. You can also remove R1, R2, and R3 from the breadboard as they will not be needed in the next lesson.

QUESTIONS FOR UNDERSTANDING

1. Should you leave the multimeter from your kit powered on all the time?

2. Does it matter if a circuit is powered on when measuring resistance values?

3. When checking two points for continuity, are you looking for very high resistance or very low resistance?

Answers can be found on the next page.

ANSWERS TO THE QUESTIONS FOR UNDERSTANDING

1. *Should you leave the multimeter from your kit powered on all the time?*

   ANSWER: No, the dial on the multimeter should be switched back to the OFF position when you're finished with measurements. This will ensure the longest life possible from the 9V battery inside.

2. *Does it matter if a circuit is powered on when measuring resistance values?*

   ANSWER: **Yes**. A circuit or component should never be powered on when taking resistance measurements. Always make sure the circuit is powered off before taking resistance measurements to avoid possible damage to your multimeter or the components in the circuit.

3. *When checking two points for continuity, are you looking for very high resistance or very low resistance?*

   ANSWER: Two point with very low resistance between them are considered to have continuity. If high resistance is found, then there is no continuity between those points.

CONCLUSION

In this lesson you learned how to use a multimeter to measure resistance, voltage, and current values in a circuit. A multimeter can be an extremely useful tool to use for troubleshooting when attempting to locate why a component or circuit might not be working as expected.

In the next lesson you will build the main chassis of the robot using chassis plates, wheels, motors, and multiple pieces of hardware.