PHYB10 Experiment Guide

Lab 1: Voltage Dividers and Resistance Sensors

Welcome to the first PHYB10 lab!

This lab will introduce equipment that will be used throughout the course. At the workstation there will be: power supplies, multimeters, an oscilloscope, and a function generator. These tools are often called “bench equipment”. You will also be introduced to the important equipment in your student kit: a bread board, wires and cables, and an Arduino microprocessor.

Figure 1: Typical PHYB10 Bench Equipment

The first parts of the lab will introduce you to a very useful circuit component, a voltage divider.

Later you will build a digital thermometer with the Arduino to take measurements.

Breadboard Basics

Circuits in this course will be built using breadboards a platform. A breadboard is a standard piece of equipment used for prototyping circuits. It allows a way to quickly make connections between many different components without soldering (using a melted metal alloy to create a permanent connection) and easily swap out components of different values to test many variations of similar circuits. As you will soon learn, electrical components cannot be manufactured perfectly, so it is very important to build protypes of circuits with real components to see if they match the functionality of theoretical designs.

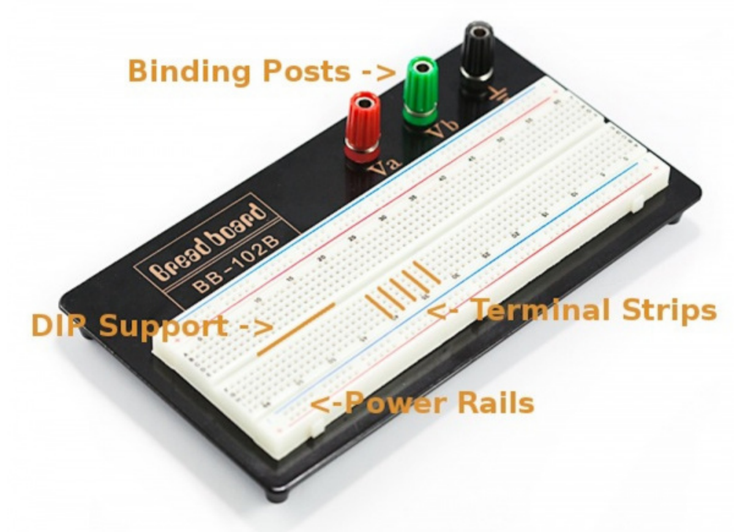


Figure 2: Typical breadboard and key features.

Most components will be inserted into the terminal strips. Each row allows for 5 connections between components. Each row is separated by a DIP support channel. There are no electrical connections across this channel. The channel allows for the placement of Integrated Circuit (IC) components built using a common design called the "Dual In Line" (DIP) package. (*A type of IC that uses a DIP package will be used later in the course*.) The Power Rails allow for connections all the way down a column. In the first exercise for this lab, you will be shown how to connect a power supply to a breadboard using the binding posts and power rails.

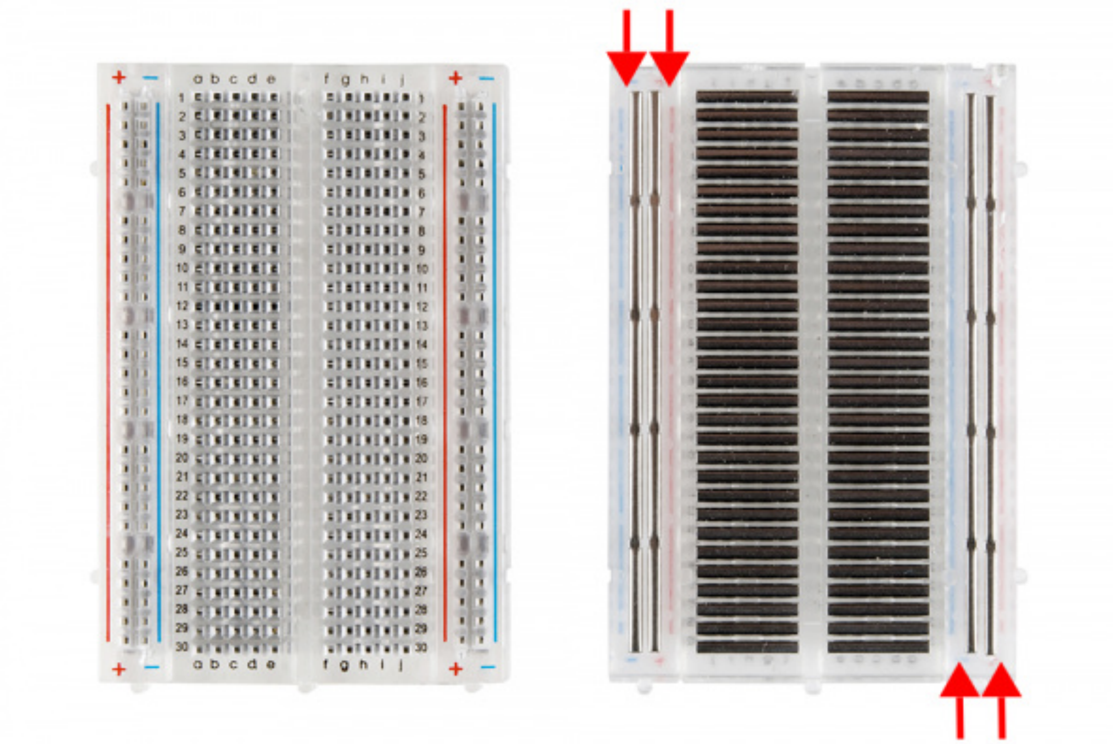


Figure 3: Left: top side of the breadboard. Right: underside of breadboard, showing conductive connections. Breadboard power rails noted by red arrows.

Wires & Cables

Jumper cables are a type of wire often used to build breadboard circuits. They are coloured to help visualize the connections. They have bare wire at either end that can be inserted into the breadboard.

Banana cables are a standard type of wire that is used to connect equipment and circuits. They can be connected to equipment such as power supplies and can be connected to other banana cables as well.

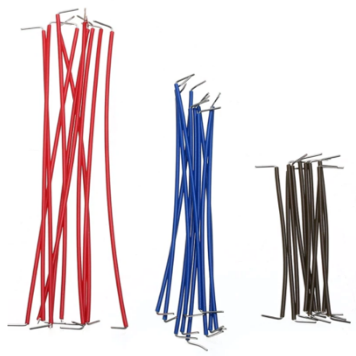


Figure 4: jumper cables.

Figure 5: banana cables

Power Supply Basics and Safety

Power supplies will be used in all the PHYB10 labs to supply a controlled voltage to the circuits. It is somewhat of a misnomer; unlike a battery, they are not a source of power at all. A better name might be “electric power converters” because they convert the 120 V, 60 Hz alternating current from a wall outlet to a direct current voltage required for the experiments’ circuits.

For all circuits you will be making in this course (and any circuit you make), you should be conscious of the amount of power they are consuming. All circuits will generate heat from their resistance as current goes through them. Every component is rated for the maximum power they can safety use. Above these rating the component will not be able to dissipate the heat building up inside and their temperature will rise until there is material failure. Some components can catch fire while others, particularly capacitors, can explode. We do not want explosions happening in our labs! If you are unsure about something, please ask the lab technician, TA, or instructor.

Luckily, modern power supplies have settings that when used properly allow us to avoid these scenarios. In addition to controlling voltage, you are also able to set a current limit. This limit can be determined by reading the data sheet of the components. Finding and reading component data sheets will be covered throughout this course.

Exercise 1: Power Supply, Multimeter, and Breadboard Basics

In this exercise you will be setting up the power supply with your breadboard and making a simple circuit with a single resistor. The main goal is to familiarize yourself with the BK Precision 1550 power supply, its settings, and how to monitor voltage and current.

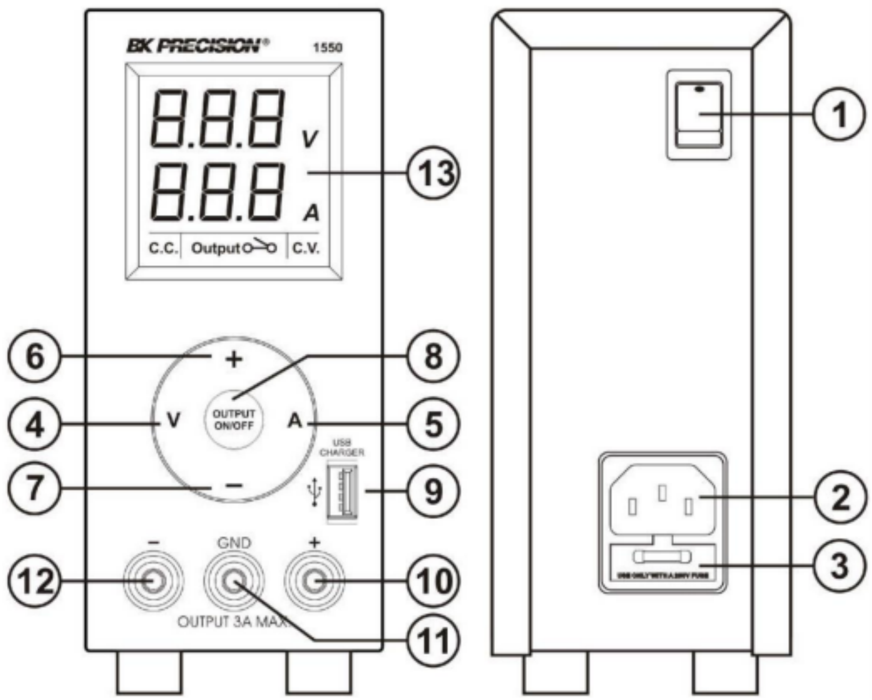


Figure 1 Front Panel

1. Power Switch:
   Turns the power supply on-o, when it is on the front display lights up
2. AC Input Socket with Fuse
3. Concealed Fuse box (open the cover to get to the fuse)
4. V: Output Voltage Setting keypad
5. A: Output Current Setting keypad
6. "+" ascend Setting keypad:
   Press to ascend the numerical values
7. "-" descend Setting keypad:
   Press to descend the numerical values
8. Output On/Off push button.
9. USB Output Socket:
   Standard USB DC power 5V, 400mA
   To charge or to power portables and cell phones
10. Output Terminal Positive (+) Red color
11. GND Terminal (:) Green color:
    Chassis ground terminal, normally this is to be short to (+) or (-) as required by user
12. Output Terminal Negative (-) Black color
13. LCD Display panel showing:
    3 digit voltage, current meter, (CV) constant voltage mode, (CC) constant current mode, Output Terminal on/off state

Figure 6: Power supply controls diagram

Step 1: Determine the current limit.

We will be using resistors that are rated at 0.5 W. The maximum amount of current we should have in our circuit can be calculated using the equation relating power, current, and voltage:

$$P = IV = I^2R \rightarrow I = \sqrt{\frac{P}{R}}$$

For this calculation, we will use the resistor in the circuit with the smallest resistance: 200 Ω. That calculation yields a maximum current of 0.05 A or 50 mA.

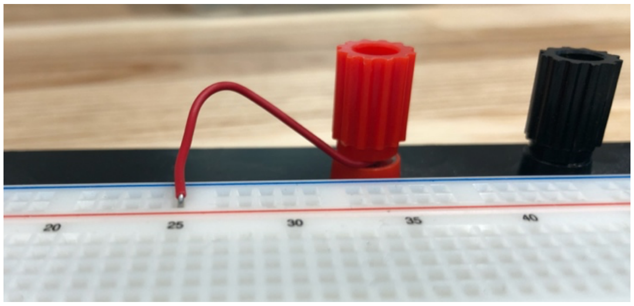
Step 2: Turn on the power supply.

Use buttons 4, 6, 7 to set the voltage output to 5 V. Then use buttons 5, 6, 7 to set the current to the limiting value calculated in the previous step.

Note: the display will show zero values until the output is set and in use. After you set your values, your set value will appear for a few seconds and then display 0.

Step 3: Use a jumper cable to connect the red binding post on your breadboard to the "+" power rail. Unscrew the top of the binding post until you see a hole in the space at the bottom. Insert one end of the jumper cable into this hole and tighten the screw of the binding post down until it is secure.

Similarly use a jumper cable to connect the ground post (green) to "–" power rail.



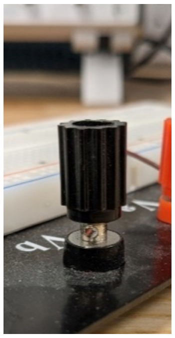


Figure 7: Left: a wire connects the red post to the power rail. Right: the hole for connecting a wire to the posts.

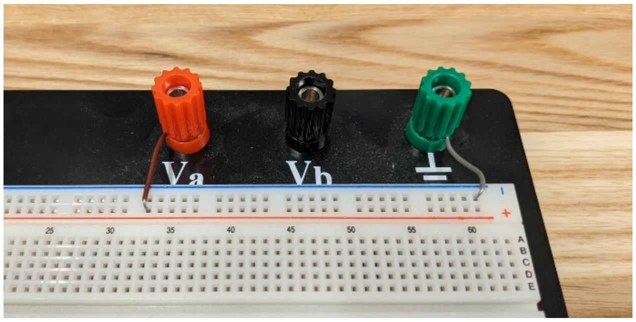


Figure 8: red and green posts connected to the power rails.

Step 4: Ensure the output of the power supply is off. The output icon on the display should look like:

If not, press button 8 until the icon shows the power supply is off.

Once the output is off, connect the positive, red terminal of the power supply to the red binding post of your breadboard using a banana cable. Connect the negative, black terminal of the power supply to the black binding post.

(Make sure you understand and remember the setup in steps 1 – 4 above. The current limit was given to you here, but in later labs you may be asked to determine it yourself, either by doing calculations or looking up values in data sheets.)

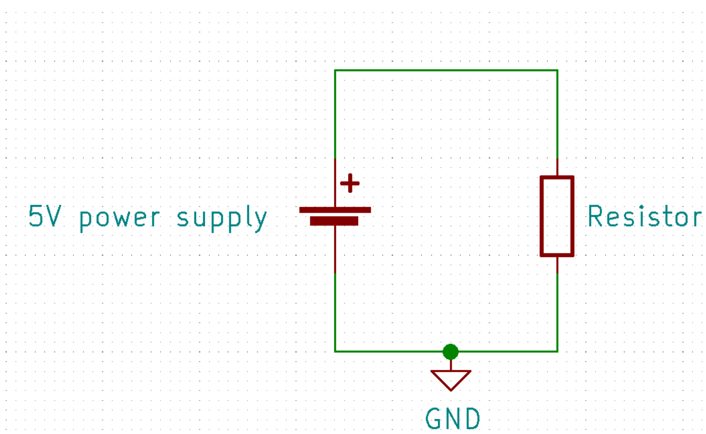
Step 5: A RadioShack digital multimeter (DMM) will be used to measure the current output because the power supply's monitoring will not be sufficiently accurate for this experiment.

To use a multimeter as an ammeter it must be in series with the circuit within which you want to measure current. To do this:

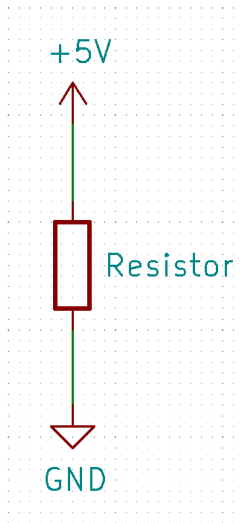
- remove the banana cable from the red binding post of your breadboard. Connect this cable to the 200 mA port of the multimeter.
- Take a new banana cable and attach the red binding post to the "COM" port of the multimeter.
- Set the multimeter to 200 mA DC current by rotating the central dial. (There is also a button to toggle between DC and AC measurements.)

Figure 9: Left: RadioShack Digital Multimeter. Right: The experimental set up for Step 5.

Step 6: Now you will build the first circuit using the breadboard. The circuit you are building corresponds to the following diagram:



Note the use of the GND symbol. This is short for "Ground" and is where the circuit designer wants to set a reference for 0 V. This allows circuit schematics to be greatly simplified to reference power sources. Using these methods the diagram above can be changed to:



For a simple circuit, this method does not significantly simplify the diagram. However, there will be circuits that need power sent to many different locations. In these cases, the value of drawing circuits in this manner will be more obvious.

To begin with, build the circuit using a 200 Ω resistor. If you need a reminder about how to read resistor bands and values, you can use an internet search engine to find resources. There are a variety of online resistor value calculators, such as the one by Digikey [here](#).

There are many ways to make this circuit on your breadboard. The photo below shows one example:

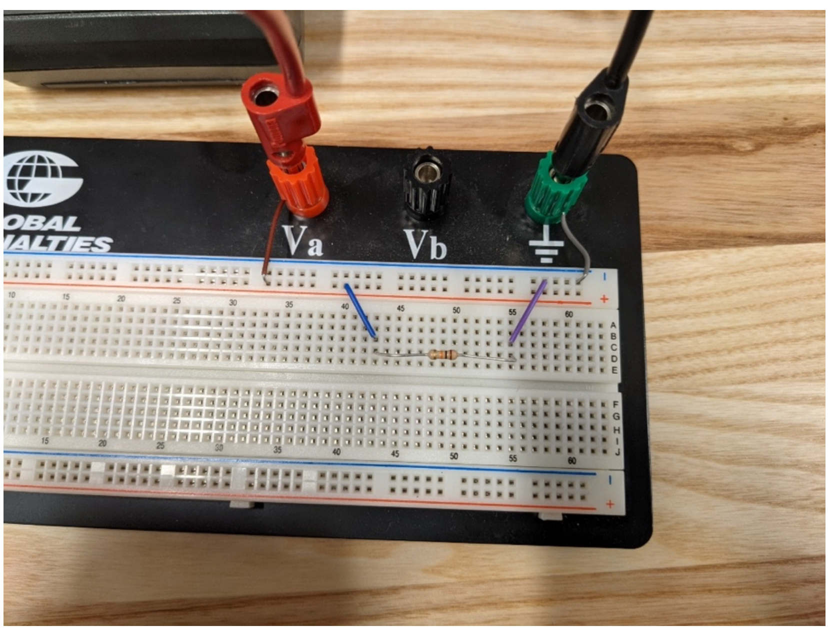


Figure 10: The circuit for Step 6, except the resistor should be 200 Ω.

Step 7: Turn on the output of the power supply using button 8. Record the voltage displayed by the power supply and the current measured using the multimeter.

Step 8: Repeat steps 6 and 7 with these resistors: 300 Ω, 430 Ω, and 510 Ω.

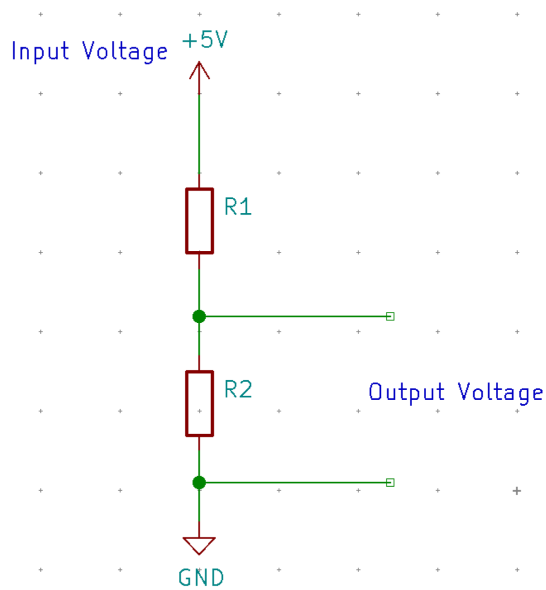
Question 1 [3 points]

Take a photo of your resistor circuit.

Calculate the true value of each resistor from your observed voltage and current values. Do your resistors obey Ohm's law? Are the values you calculated within the tolerances listed on the resistors' bands?

Exercise 2: Voltage Dividers

Voltage dividers are a common circuit element. They are found within most electronic devices. A voltage divider consists of two or more resistors in series. They have a simple purpose: take an input of one voltage and convert it to a different output voltage. Here is an example:



The output voltage is simply the voltage drop across the 2nd resistor. We can calculate this voltage, starting with Ohm's law:

$$V_{input} = IR_{Total} = I(R_1 + R_2) \text{ [1]}$$

$$V_{output} = IR_2 \text{ [2]}$$

Solving [1] for I and substituting into [2] yields:

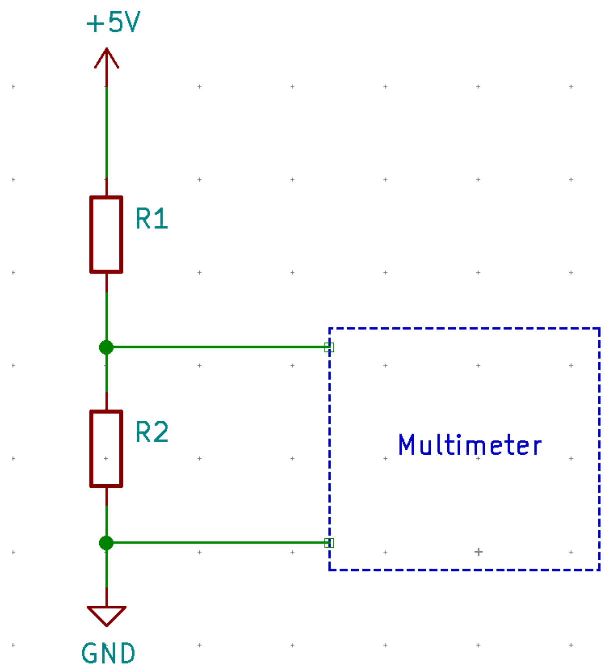
$$V_{output} = V_{input}\frac{R_2}{(R_1 + R_2)}$$

Question 2 [1 point]

Using equation [3] calculate the output of a voltage divider with R_1 and R_2 as 10 MΩ with an input voltage of 5 V.

Step 1: Using your breadboard, power supply, multimeter and two 10 MΩ resistors build the following circuit:

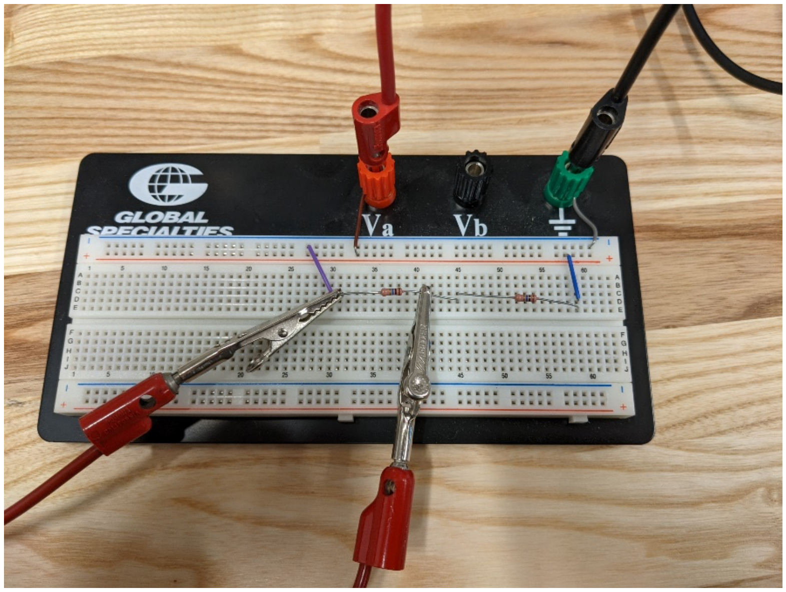
Remember to set your power supply to 5 V. What is an appropriate current limit considering the current limit of 10 MΩ resistors is ¼ W?

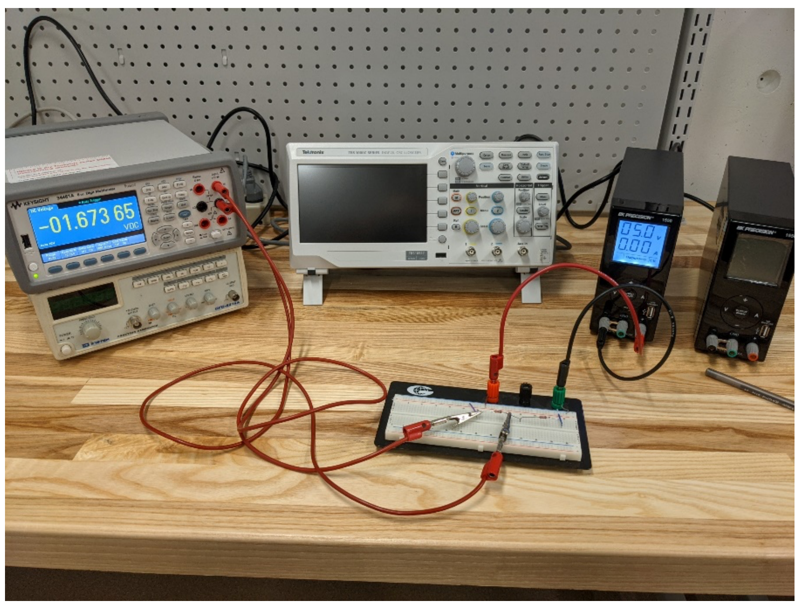


In this exercise use the Agilent multimeter. It has higher accuracy and precision.

To attach the multimeter, insert banana plugs into the voltage measurement outlets on the front of the device and use alligator clips to attach the multimeter across the 2nd resistor. Then turn on the power supply and multimeter. To measure the output voltage press the "DCV" button on the multimeter. Record the voltage.

These photos illustrate the set up at this step:





Step 2: Did your measured voltage match the predicted voltage in Question 2?

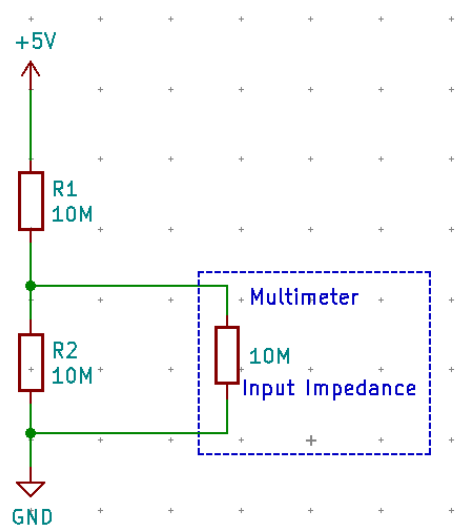
The next part continues directly from this question.

Exercise 3: Input Impedance

In the previous exercise, you built a voltage divider circuit and measured the voltage using a multimeter. However, the multimeter is also a circuit. It is a complicated circuit, but the impact of complicated devices is summarized with a simple concept called "input impedance". In the same way you can analyze a network of resistors and calculate a single equivalent resistor, complicated devices can be analyzed and a single equivalent input impedance calculated. When speaking about DC circuits, impedance and resistance are the same. However, this distinction is more complicated with AC circuits.

For the Agilent DMM, the input impedance can be found on page 21 of its data sheet. You can find the manual on the course website. Its listed input impedance is 10 MΩ, the same as the voltage divider.

With this information you can create a new model of the circuit in Exercise 2 but including the multimeter into the circuit.



Question 3 [2 points]

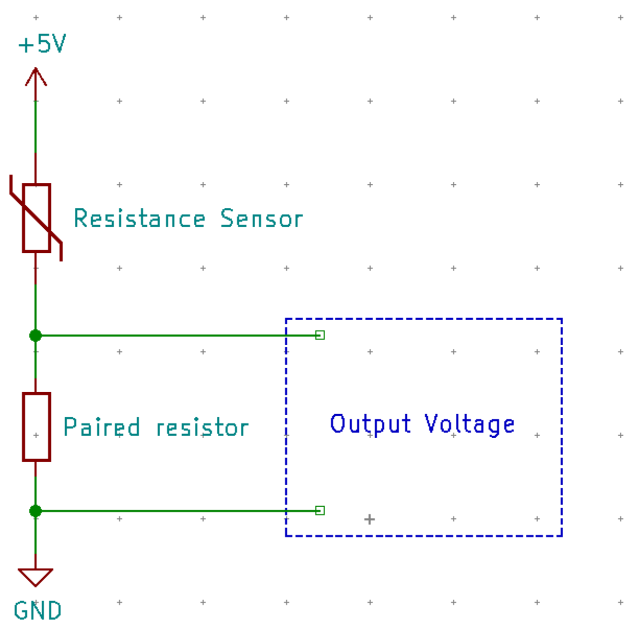
Using your knowledge of parallel and series resistor calculate the expected voltage drop across R_2 including the input impedance of the multimeter. Does this match the voltage measured in Exercise 2?

Exercise 4: Resistance Sensors

A resistance sensor is a device that changes its resistance due to an external stimulus. There are many kinds of resistance sensors, including:

- Photoresistor: resistance changes due to intensity of light on the sensor.
- Thermistor: Resistance changes due to external temperature.
- Strain Gauge: resistance change due to applied load (mechanical force).

Resistance sensors are used in a voltage divider circuit to produce an output voltage that can be converted to measurement through an equation[1] that describes the behaviour of the sensor. Here is an example:



Using a voltage divider with a resistance sensor provides two practical benefits:

(1) The voltage drop across a lone resistance sensor would be constant; the current would change. Voltage is much easier to measure and requires less power. This is good for any battery-powered device. A voltage divider allows a measurement of voltage instead of current.

(2) The paired resistor can be chosen to minimize error from the input resistance, e.g., as seen in the previous exercise. The value of the paired resistor is also important; it maximizes the range of possible voltages, based on the properties of the resistance sensor.

[1] The code provided for this experiment to interpret the thermistor data uses the Steinhart-Hart equation. See Steinhart and Hart, 1968: DOI:10.1016/0011-7471(68)90057-0.

In this exercise you will build a temperature sensor using an Arduino and a NTC thermistor.

A NTC thermistor is a "Negative Temperature Coefficient" resistor. Its resistance decreases when the external temperature increases. Our basic circuit will be a voltage divider. The voltage measurement will be taken using the Analog to Digital converter (ADC) on the Arduino chip, which converts the voltage to a 10-bit binary number. The microprocessor on the Arduino will then perform the calculation to convert that number to a temperature measurement.

Before building the circuit there are a few things we need to determine:

1. the properties of the NTC thermistor and
2. the input impedance of the ADC on the Arduino.

Everything we need to know is given to us by the manufacturer of these components in their data sheets. Data sheets are typically found on the internet by searching for part number. Make sure you get the data sheet directly from the manufacturer or a site dedicated to archiving these sheets. For now, you can find the relevant data sheets in the folder for this lab on Quercus.

Starting with the Thermistor, the component we are using today is the Cantherm MF52A2103J3470. All the information we need is in the part number and the data sheet allows us to decipher it. On page 4 of the data sheet you'll find:

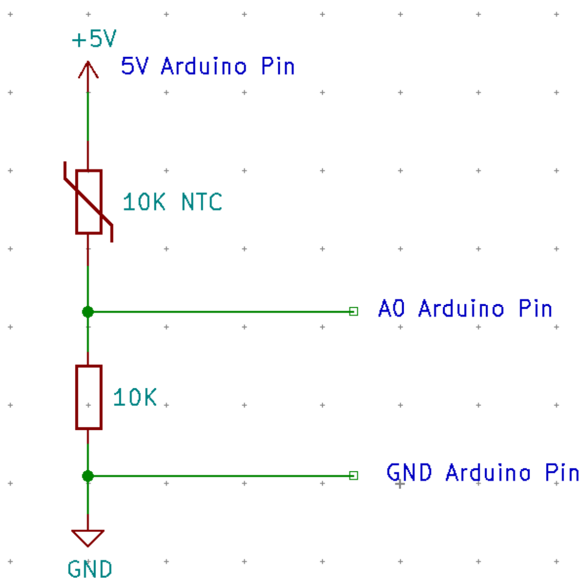
- "MF52" is the part series
- "A2" is the package type
- "103" is the resistance at 25C, for our part 10^3 or 10k
- "J" is the tolerance, for our part ±5%
- "3470" is the temperature coefficient or "B value"

Next let's take a look at the data sheet for the Arduino which is based on the Amtel ATmega328P microprocessor. As you can see this is a big data sheet. At 294 pages it is more like a data book! This is because microprocessors are very complicated devices. Most of the sheet deals with the operation of the processor core. We do not need to worry about this because it will be taken care of for us by the Arduino board. We are only interested in the input impedance of the ADC. On Page 262, it lists the input impedance of the ADC as 100 MΩ. However, on page 212 it says:

> *"The ADC is optimized for analog signals with an output impedance of approximately 10 kΩ or less. If such a source is used, the sampling error will be negligible."*

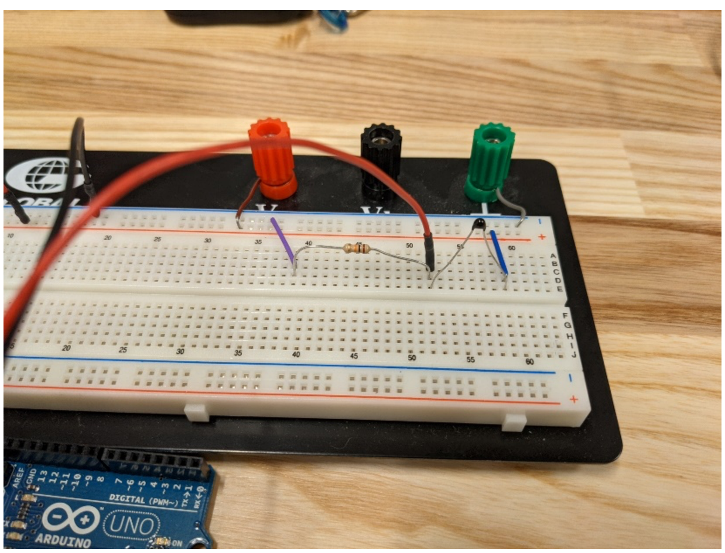
The output impedance is a similar concept as the input impedance. The data sheet is telling us the paired resistor should be 10 kΩ or less to reduce error. Our thermistor is 10 kΩ at room temperature, so it is appropriate for this experiment. The sampling error will be negligible. In addition, the 10 kΩ resistor will maximize the range of our thermometer. The output voltage at room temperature will be 2.5 V, which is in the middle of 0 – 5 V range of the voltage divider. This will provide the most range to measure either increases or decreases in temperature.

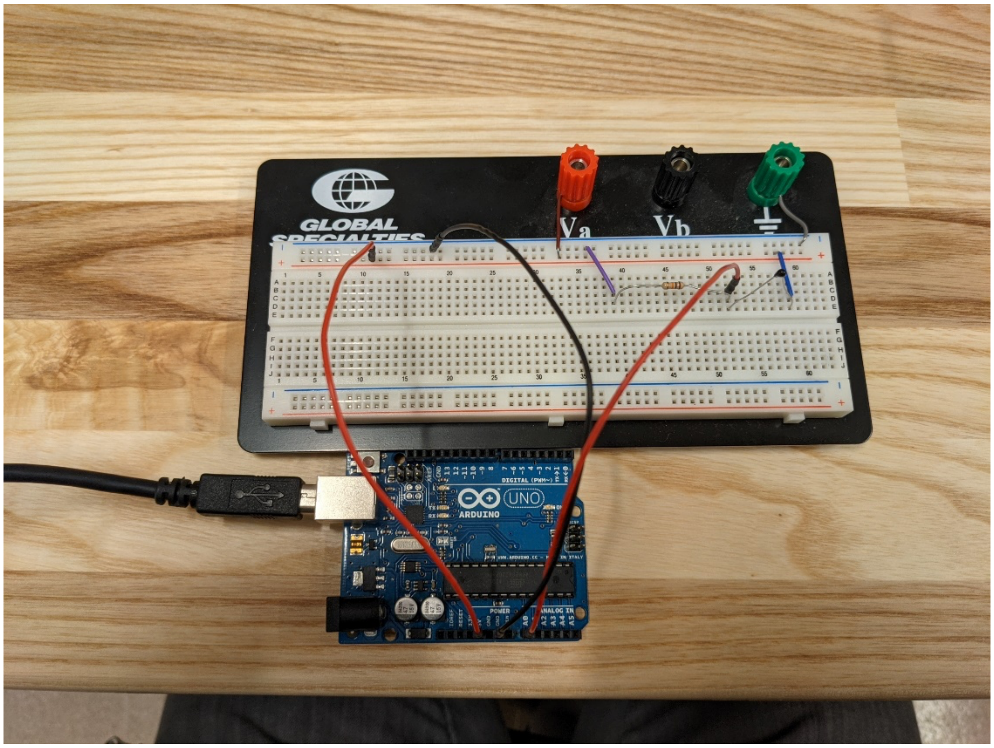
Build the following circuit:



Step 1: For this circuit you will not be using the BK Precision power supply. Remove the banana plugs from the binding posts of your breadboard. (You can leave the jumper cables.) Instead use a jumper cable from the 5 V pin of the Arduino to the "+" power rail and the GND pin to the "–" power rail.

Step 2: Build the voltage divider with the 10 kΩ NTC and a 10 kΩ resistor. Connect a jumper cable from the 10 kΩ resistor to the A0 pin of the Arduino. While there are 5 ADC pin inputs on the Arduino the program will only work if it is connected to the A0 pin.





Step 3: Download the Arduino sketch “Lab1_themometer” from Quercus and then upload to the Arduino. Open the serial monitor from the “Tools” menu (shortcut CTRL + SHIFT + M).

Note: More details about this step is provided in Appendix A.

Step 4: Test your thermometer by holding the thermistor with your thumb and index finger. Does the measurement in the serial monitor temperature go up? When ready, notify the lab tech to get a canister of compressed air. Be cautious when using compressed air: It is cold enough to cause serious injury to your skin, i.e., frostbite.

Question 4 [4 points]

Plot your temperature data. Note when/where specific changes occur – e.g., steady room temperature, cooled by compressed air.

Appendix A: Connecting the Arduino and Taking Measurements

Get the Arduino IDE Software

Begin by using a web browser to navigate to the Arduino web site page:
https://www.arduino.cc/en/Guide

From here, download the Arduino IDE version that is appropriate for your computer's operating system.

Note: if you are using a computer in the physics labs, this is not necessary. The Arduino software should already be installed.

Get & Load the Code

Download the Arduino code for this experiment from the course Quercus page. Load the code into the Arduino IDE by opening the file. You will likely get a message saying that it needs to be within a folder named the same as the file: simply say ok. This folder will be created and the file will be moved automatically.

Collect Data

Now that the code is loaded in the Arduino IDE, you can try collecting data:

- Connect the Arduino to the computer using the USB cable.
- Upload the code to the Arduino by going to the Sketch toolbar and choosing "upload". This might ask you to confirm a port.
- Note that there is a variable called measure_INT at the top of the code. This is the time interval between measurements, in milliseconds. The default is set to 500 ms. Keep this value to start.
- Navigate to the Tools menu bar and select "Serial Monitor". This will tell your computer, using the Arduino code, to listen to the data being sent by the Arduino, which is monitoring the circuit with the thermistor.

You should see a data window pop up with multiple columns of data being output. The columns are:

- milliseconds since the data collection began,
- resistance of the resistor,
- measured voltage, and
- the calculated temperature.

The temperature value output by the thermistor sensor has been compared to highly accurate measurements when both instruments were measuring the room temperature. The values output by the thermistor sensor appeared to agree with the highly accurate instrument within 1°C.

You can now try a variety of ways to change the measured temperature, e.g., hold it with your fingers should raise the temperature by a degree or two; blowing on it (through a mask) can raise the temperature by several degrees.

To lower the temperature of the thermistor, ask the lab technician for access to a canister of compressed air. Please be cautious when using the compressed air. The gas can be very cold and cause injury. The canister will also cool down rapidly (why does this happen? Hint: physics is involved).

Ending & Saving Measurements

To end the measurement collection, unplug the USB cable connection.

The data in the window can be copied and pasted from the Arduino window into a text file editor or Excel to save as a CSV file.

Now you can plot the data from the CSV file. Microsoft Excel is accepted as a way to plot the data; however, python is preferred.

Note about Re-starting Measurements

If you simply close the data output window of the Arduino IDE, the measurements continue but you will not be collecting that data. If you reopen the data window, i.e., by again selecting "Serial Monitor" from Tools, you will again collect measurements, but the time will not begin at zero. You will not be able to recover any measurements you missed.

To restart measurements, you must disconnect the USB connection between the Arduino/circuit and the computer. This can be done while the data output window is open or closed. However, you will need to close the data output window before re-starting data collection.