Experiment BT-1: Ohm’s Law

Equipment Required

PC or Mac Computer

IX-TA-ROAM recorder, USB cable, power supply

A-BMET-B BMET Trainer Board

C-DIN-BB DIN to Breadboard Cable

C-BNC-BB BNC to Breadboard Cable

A-BMET-EC Electronic Components Set

Jumper Wires

Setup

1. Connect the C-DIN-BB Cable to port A5 on the TA-ROAM. Use extender cables for the yellow and brown leads.
2. Connect the C-BNC-BB Cable to the S1 (LV Stimulator) port on the TA-ROAM.

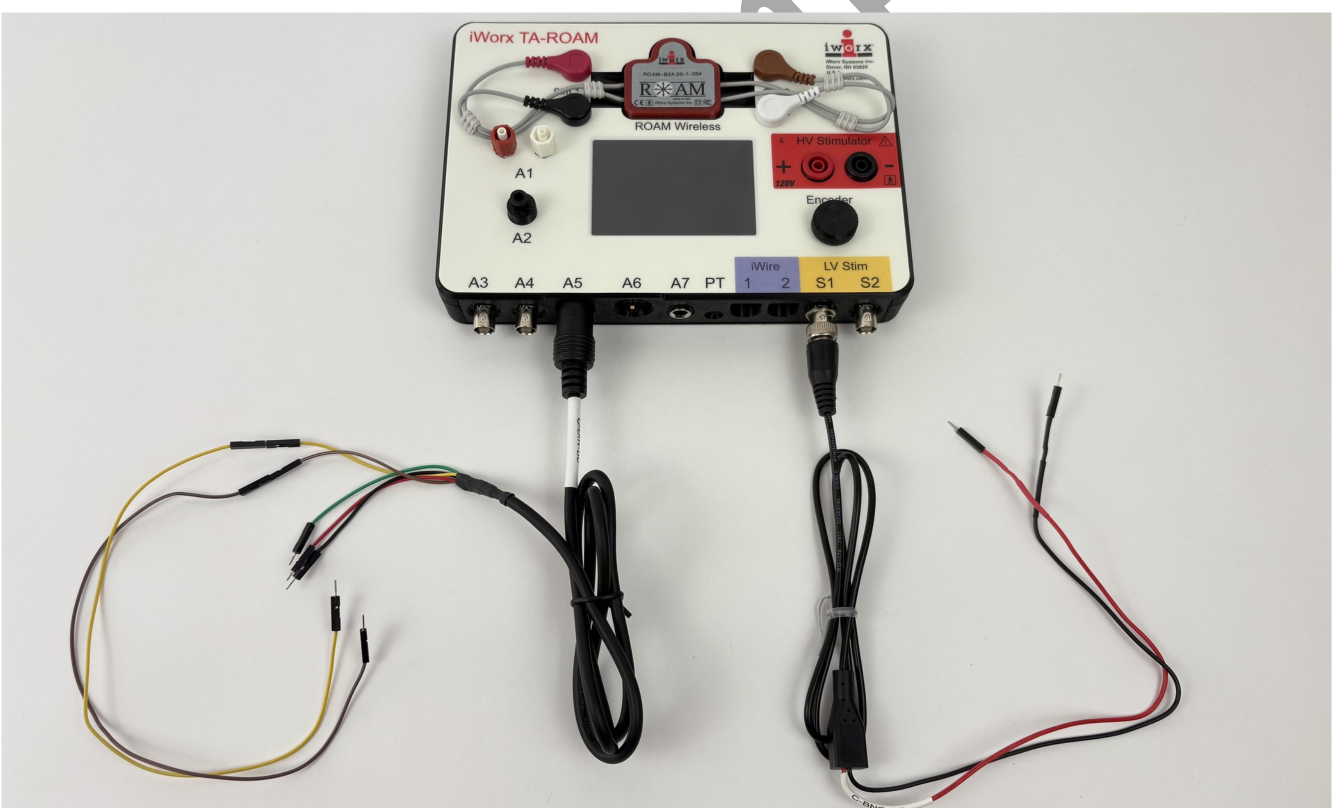

Figure BT-1-S1: IX-TA-ROAM, C-DIN-BB cable (port A5), C-BNC-BB cable (S1).

Experiment BT-1: Ohm's Law

Background

Biomedical equipment relies on electronic circuits to acquire, process, display, and store information. It is important to build an understanding of these circuits in order to make sense of more complicated biomedical instrumentation.

In this lab, students will investigate the relationship between voltage, current, and resistance. Students will also become familiar with the BMET Trainer Board and LabScribe software.

Theory

1. Loads

Loads are anything that uses energy or power in a circuit. Note that power is just the rate at which energy is transferred. It is essentially energy over time.

2. Current

Current is the flow of electrons. According to conventional current*, it flows from positive to negative. Current in a circuit can only flow when a loop is closed because it always tries to flow from one terminal of the battery to the other, which it can't do without a continuous path:

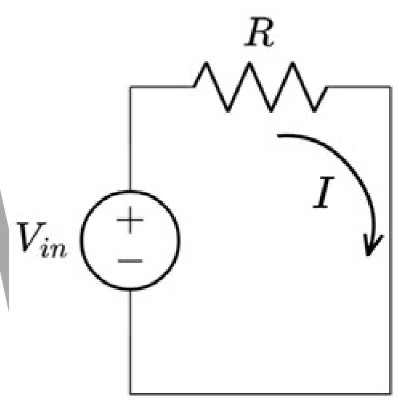

Figure 1. Simple resistor circuit

It is measured in amperes (A), how fast electrons flow through a point:

$$I = \frac{Q}{t}$$

Where I is current in amps (A), Q is the charge in coulombs (C), and t is time in seconds. One coulomb is the charge of about $6.24 * 10^{18}$ electrons.

One concept that is important to be aware of is conventional current. You may notice how in the figure above, the current flows from the positive terminal to the negative terminal of the battery. This is because we say that current flows with positive charge, which is attracted the battery's negative terminal (remember how "opposites attract").

But didn't we also say that current is the flow of electrons, which are negative, not positive? So what went wrong? It turns out that this discrepancy is simply because current was discovered before electrons. As a result, scientists at the time took a fifty-fifty guess on which way it flowed. Their guess was wrong, but by the time we figured that out, too many people were already using this convention. That is why we always use conventional current, and say that current flows from positive to negative, even though the opposite is technically true.

3. Voltage

Voltage is the electrical potential difference between two points in a circuit. Just like how gravitational potential makes objects want to fall from high elevation to low, electrical potential makes current want to flow from high charge to low.

Batteries have a high electrical potential because they use chemistry to keep a positive charge on one side and a negative charge on the other.

When electrons travel through components, resistance makes them lose some of their electric potential. This decrease in voltage is called a voltage drop.

Voltage is measured in volts (V), and represented by the equation

$$V = \frac{J}{Q}$$

where V is voltage (volts, V), J is energy (joules, J), and Q is charge (coulombs, C).

Remember that because voltage is a **difference in potential**, you always need at least **two points** to measure it. Measuring with only one voltmeter probe will give you a ghost reading, and putting both probes at the same point will give you a short circuit resulting in 0 V.

The symbol for a voltage source is depicted in Figure 2.

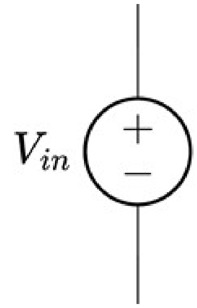

Figure 2. Voltage source symbol

4. Resistance

Everything in a circuit has resistance. It is the way components oppose the flow of current, similarly to how air resistance is the way falling objects oppose airflow. It is caused by electrons colliding with atoms inside the components. Anything with atoms has resistance, even wires. Their resistance is usually too small to matter, though.

Resistance is measured in ohms (Ω).

Resistors are intentionally used in circuits to limit current, establish voltage levels, and protect components.

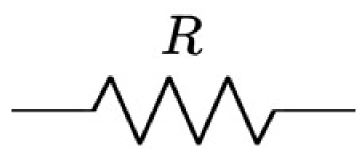

Figure 3. Resistor symbol

Resistors are commonly marked with colored bands to indicate their resistance value and tolerance. These color codes allow the resistance of a component to be identified without requiring measurement equipment. In a standard four-band resistor, the first two bands represent the significant digits, the third band represents the multiplier, and the fourth band indicates the tolerance of the resistor.

5. Ohm's Law

The relationship between voltage, current, and resistance is described by Ohm's Law,

$$V = IR$$

where V is voltage (volts, V), I is current (amperes, A), and R is resistance (ohms, Ω). This equation may be rearranged to solve for any unknown quantity:

$$I = \frac{V}{R} \text{ and } R = \frac{V}{I}$$

6. Power

Power is the rate at which energy is transferred. It is measured in Watts (W) or Kilowatts (kW). One easy way to conceptualize power is how the more power there is in a light bulb, the brighter it will be.

It can be calculated with the formula

$$P = IV$$

where P is power (W or kW), I is current (A), and V is voltage (V). By substituting for current or voltage using Ohm's Law, we can further write it as:

$$P = \frac{V^2}{R}$$

and

$$P = I^2 R$$

7. Short Circuits

A short circuit is a direct connection between nodes (a node is anywhere where two or more components connect). Short circuits have near-zero resistance. This means that a straight wire counts as a short circuit. If two nodes are connected by a short circuit, they are effectively the same node.

If a component is in parallel with a short circuit (Figure 4), all of the current will flow through the short circuit. This means that the voltage across the component will be zero.

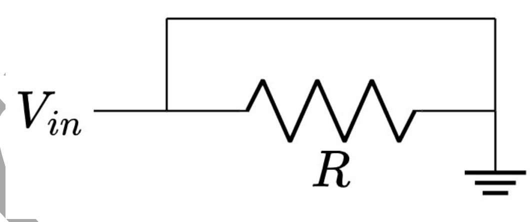

Figure 4. Shorted resistor

The opposite of a short circuit is an open circuit, where there is no connection between the given nodes.

Note on safety: Short circuits can be dangerous because they can send a massive surge of current. With a high enough input voltage this energy can melt wires, start fires, and cause electrocution. The voltages used in this lab (5-15V DC) are far too low to pose a risk, or even be felt, but when you are *working with electricity outside of this lab, it is important to be aware of short circuits.*

8. Ground

Ground functions as a common place to reference measurements to, like how you measure the height of something with respect to the physical ground. If we say an input is at 5V, it is 5V more than the ground voltage. Remember that if we measure the voltage at ground, we get 0V.

On the BMET Trainer Board, all ground connections are electrically connected together. This means that any ground point on the board can be used as the reference point for your measurements—they are all at the same electrical potential (0 V).

There are different symbols for ground (Figure 5). In these labs, we will use the first of the three.

Figure 5. Symbols for ground

Pre-Lab Questions

Complete the following questions before lab.

1. Ohm's Law

    a) Calculate the current through a 1 kΩ resistor connected to a 5 V source.

    b) Calculate the voltage across a 2 kΩ resistor carrying 3 mA.

    c) Calculate the resistance of a resistor carrying 1 mA from a 4 V source.

2. Power

    a) Calculate the power through a 4 kΩ resistor with 5 V across it.

    b) Calculate the power through a 4 kΩ resistor with 2 mA through it.

    c) Calculate the power through a resistor carrying 4 mA from a 3 V power source.

3. Why does current stop flowing when a circuit is opened?

4. Why is voltage zero across a short?

Experiment BT-1: Ohm's Law

Familiarize yourself with the BT Trainer Board (Figure BT-1-S1) by finding the following:

- Ground connections (labeled "GND")
- Resistors section
- Test points (labeled "TP")
- Jacks (labeled "J")
- Signal-conditioning sections (for future labs)

The jacks are where you will be connecting components like resistors to make your circuits work.

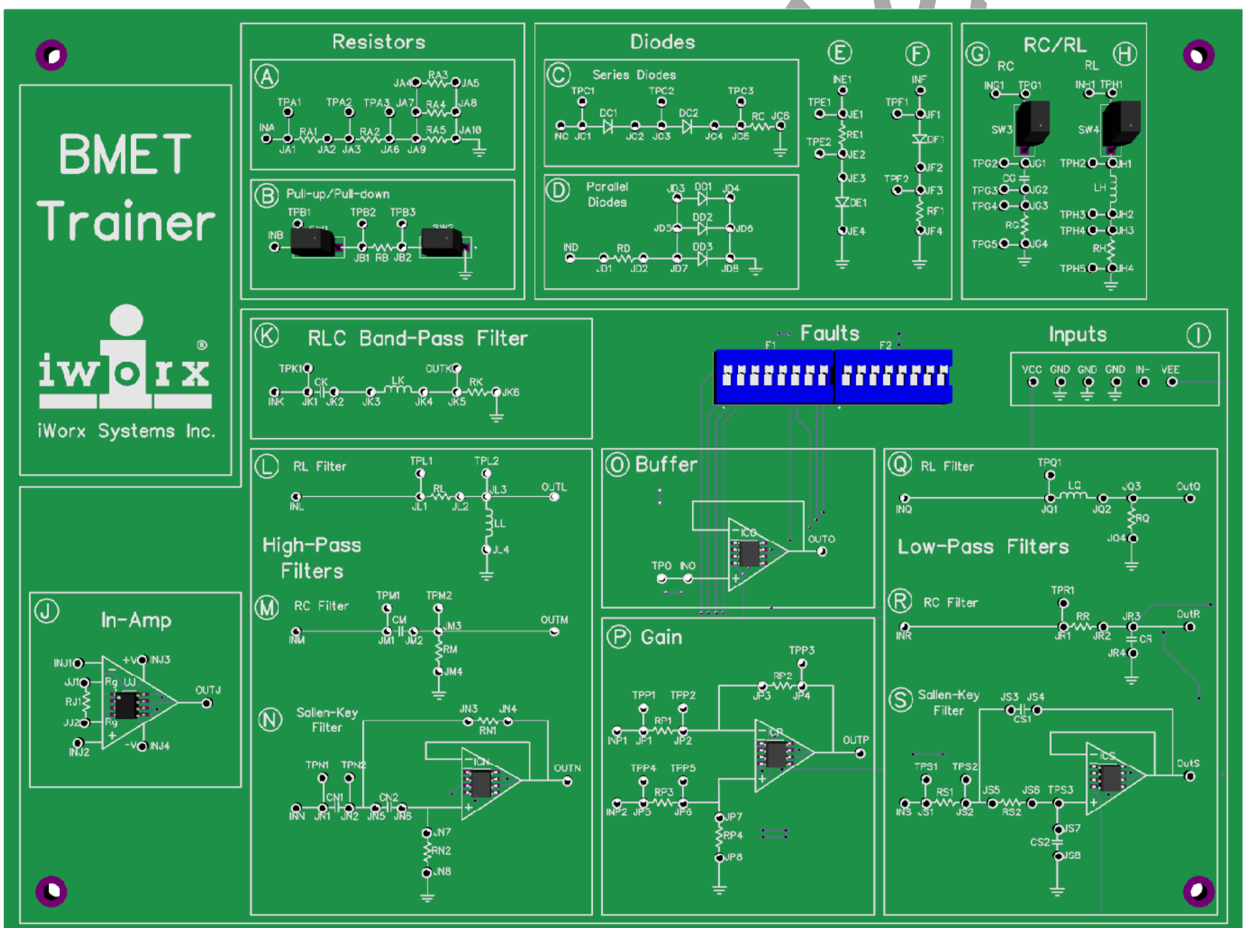

Figure BT-1-S1: The BMET Trainer Board with labeled components.

Exercise 1: Measuring Voltage Drop

Aim: To build a circuit using the BMET Trainer and measure the voltage across three different resistor values.

Approximate Time: 60 minutes

Procedure

1. Locate Circuit A in the Resistor section as shown in Figure BT-1-S2.

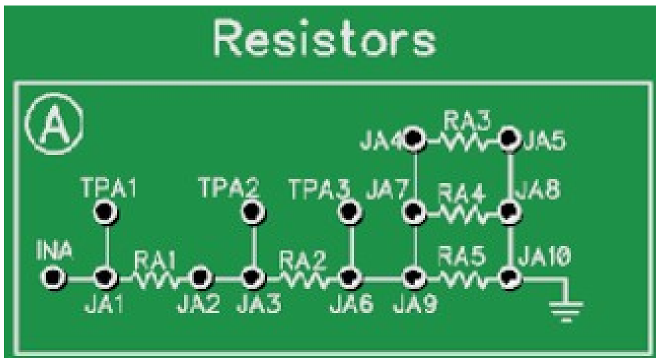

Figure BT-1-S2: Circuit A from BT Trainer Board.

2. Place a 1k ohm resistor for RA1. Place shorts for RA2 and RA5. This circuit is the same as the one in Figure BT-1-S3.

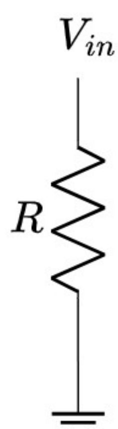

Figure BT-1-S3: Single-resistor circuit.

3. Supply power and ground to the circuit using the C-BNC-BB cable.

   a) Connect the red lead at INA.

b) Connect the black lead to one of the GND pins in the Inputs section.

Note: Power will be supplied through the S1 output on the data recorder The S1 output is set to 5V in LabScribe, when the recording button is pressed in the software.

4. Measure the voltage drop using the C-DIN-BB cable.

   a) Connect the red lead (+) to the VCC pin in the Inputs section on the right of the board.

   b) Connect the black lead (-) to the VEE pin.

   c) Connect the ground (green) to a GND pin.

   d) Remember that voltage is measured in parallel. To measure the voltage drop across RA1, place the yellow lead at TPA1 and the brown lead at TPA2.

Note: To measure the voltage at a single test point, connect the brown lead to the IN− connection. Then, connect the yellow lead to the test point on the circuit where you want to measure the voltage.

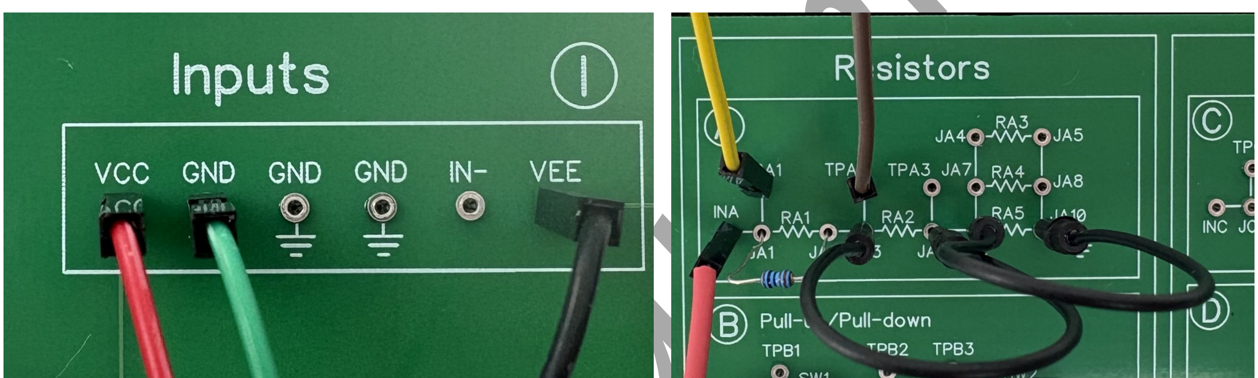

Figure BT-1-S4: Inputs Section (I): C-DIN-BB cable connections VCC (+), VEE (-), and GND. Resistors Circuit (A) connections INA, TPA1, TPA2, RA1, RA2, and RA3.

5. Press the Preview button in LabScribe (icon that resembles an eye). The preview button is primarily used to display and monitor data acquisition in real-time without actually recording or saving that data to your computer's disk. The voltage reading between TPA1 and TPA2 will be visible in the Meter dialog box to the left of the screen.

Note: If the voltage in the Meter dialog box is not ~5V, double check the resistor values.

6. Once the voltage output is as expected, press the red REC button to start the recording in LabScribe.

7. Type “1k” in the Mark box, and press the ENTER key on the computer keyboard to place a mark in the recording. The drop down arrow located to the right of the Mark button can be used to easily find marked sections of data in the recording.

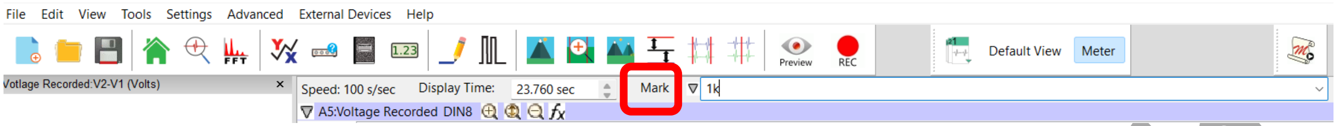

Figure BT-1-S5: Mark box, with 1k typed into the text field.

8. Record for ~10 seconds.

9. Press STOP to stop the recording.

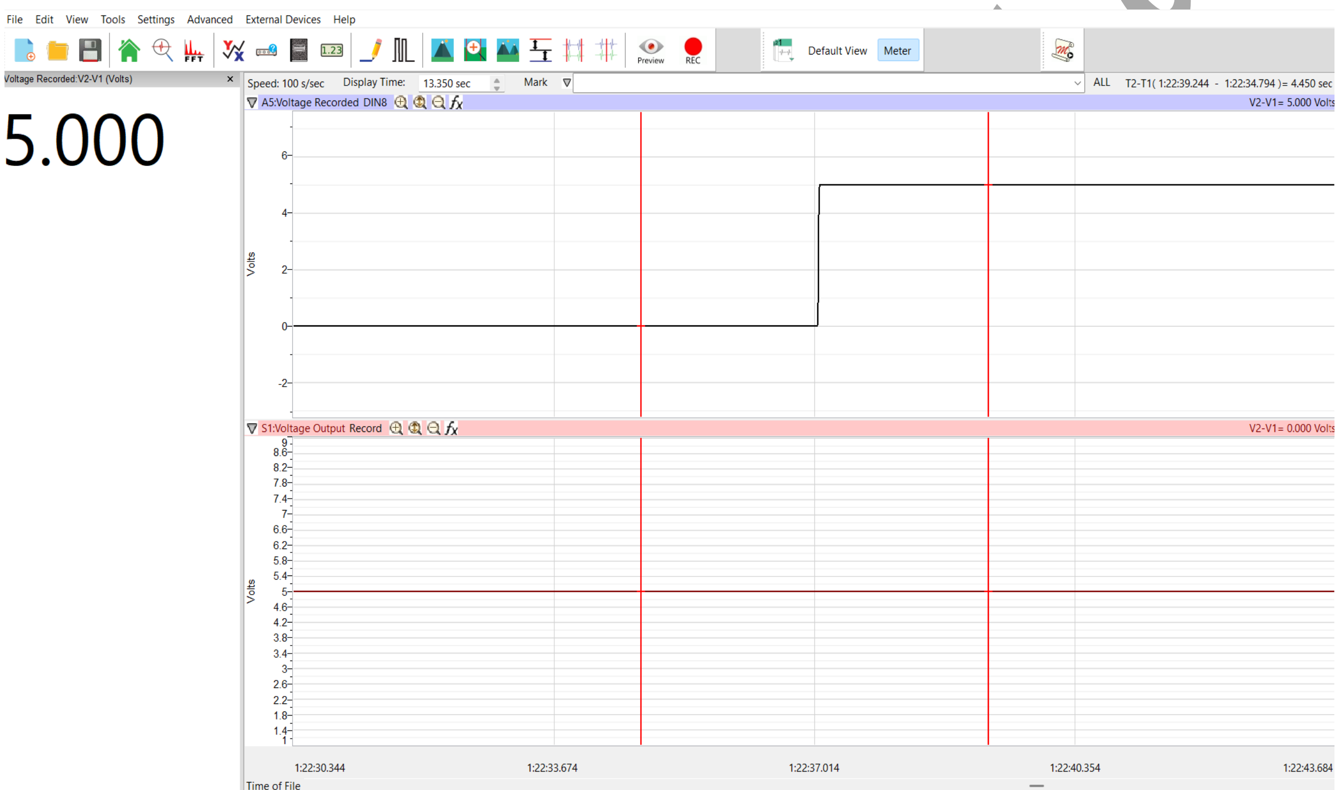

Figure BT-1-S6: Channel 1 (A5) Voltage recording in LabScribe. The Channel 2 (S1) Voltage Output is 5V.

10. Repeat the procedure for a 5 kΩ resistor, a 10 kΩ resistor, and a 100 kΩ resistor.

11. Save the data file by clicking File – Save As. Be sure to name the data file appropriately.

12. Calculate what the current should be using Ohm's Law, and record these values in Data Table BT-1-L1. Write the correct units in the table header. Calculate the percent error from the theoretical and actual values.

Table BT-1-L1: Data Table for Exercise 1 – Measuring Voltage Drop

Resistance, Voltage, and Current Values for Various Resistors					
Component	Resistance (____)	Expected Voltage (____)	Measured Voltage (____)	Current (____)	Percent Error (%)
1k					
5k					
10k					
100k					

Data Analysis

1. Scroll to the section of data recorded when the "1k" mark was made in the recording.
2. Switch into single cursor mode, by clicking on the 1 Cursor icon on the top toolbar. The 1 Cursor icon is located directly to the left of the Preview button. Drag the red cursor so it is on the 1k mark, as shown in the image below.

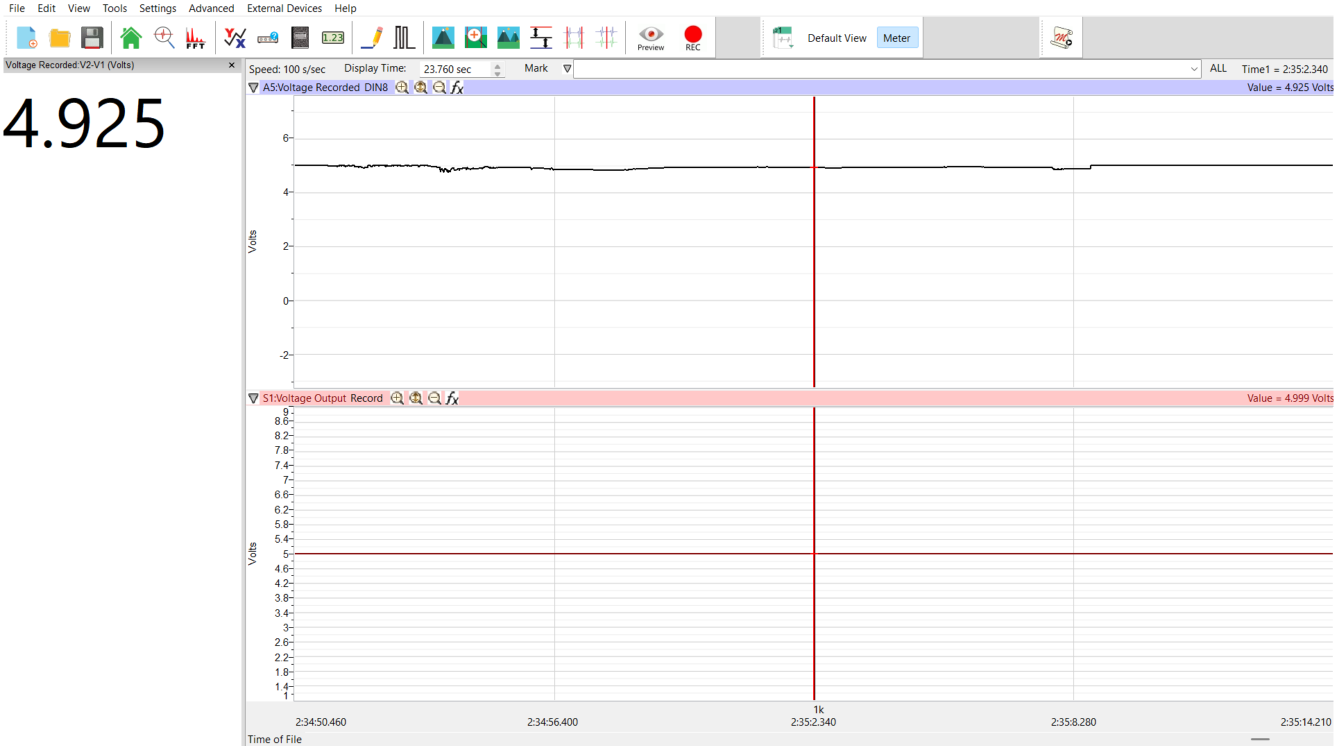

Figure BT-1-S7: Voltage recording for a 1k resistor. The 1k mark can be seen in the center of the screen.

3. Record the value displayed in the Meter dialog window in the Measured Voltage column of Data Table BT-1-L1. This value is also displayed at the right side of the screen, on the channel title.

4. Repeat steps 1-3 for the remaining resistor values.

5. Use Excel to create a Voltage vs Current plot.

Post-Lab Questions

1. Is the voltage-current relationship linear? Explain the observed behavior using concepts introduced here as evidence.

2. Explain how Ohm's Law can assist a BMET in troubleshooting medical equipment.

3. Did your measured result always match your experimental results? What are some possible sources of error in this lab?

4. Sample calculations:

   a) A medical monitor contains a 2.2 kΩ resistor connected to a 12 V supply. Calculate the current through the resistor.

b) A resistor is measured at 985 Ω. Is this value acceptable for a nominal 1 kΩ resistor with a ±5% tolerance? Show all calculations.

5. Summarize what you learned in about 2-3 sentences.