Student ID:		Lab Section:	
Name:		Lab Group:	

Experiment No. 4

Study of I-V Characteristics of Linear Circuits

Objective

This experiment aims to acquaint students with the concept of I-V characteristics. They will find I-V characteristics of some linear components and some circuits consisting linear combinations of them.

Part 1: By Using Multimeter

Theory

I-V characteristics, also known as current-voltage characteristics, describe the relationship between the current flowing through a device/circuitry and the corresponding potential difference (voltage) across it. This concept is commonly used in the field of electronics and electrical engineering to analyze the behavior of various components such as resistors, diodes, transistors, and in general, circuits.

I-V characteristics provide a way to understand how current and voltage interact in electrical and electronic components and circuits. By analyzing these characteristics, circuits/devices can be designed and optimized, appropriate components can be selected, and the behavior of devices under different operating conditions can be predicted.

In hardware labs, studying the I-V characteristics of an element/circuitry can be done in some simple steps. After building the circuit using hardware tools (such as Breadboards, Power Supply), a multimeter or other measuring instruments can be used to measure the voltage and current at specified terminals in the circuit. The multimeter probes can be placed across the component or along the desired path (specified by the terminals) to measure the voltage difference and current flow. To determine the I-V characteristics, the voltage or current across the circuit or specific components must be varied. This can be done by adjusting the power supply voltage, using variable resistors, or changing the values of other circuit parameters. As the voltage or current is varied and the corresponding values are measured, the data can be recorded in a table. The voltage and current values for each point of interest in the circuit should be noted.

Once we have the values of currents and voltages at various points in the circuit, the I-V characteristics can be plotted. Typically, this involves creating a graph with current (I) on the y-axis and voltage (V) on the x-axis.

A circuit is linear if its I-V characteristic is linear, represented by a straight line in an I versus V plot. A circuit composed of linear components (resistors, voltage sources, current sources) has a straight-line I-V characteristic.

For a simple resistor, the I-V characteristics follow Ohm's Law, which states that the current passing through a resistor is directly proportional to the voltage applied across it. Mathematically, this relationship can be expressed as $I = \frac{V}{R}$, where I is the current, V is the voltage, and R is the resistance. The characteristic line passes through the origin.

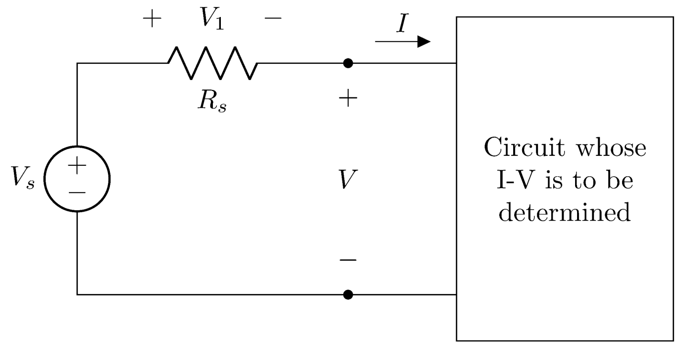
The I-V characteristic of an ideal voltage source (an ideal voltage source is a theoretical concept that maintains a constant voltage across its terminals, regardless of the current flowing through it.) is a vertical line on an I-V graph, indicating that the voltage remains constant (V) regardless of the current (I). Mathematically, it can be represented as $V = constant$. Real-life voltage sources (for example, DC power supply in our labs) do not exactly behave this way, but should closely resemble an ideal voltage source. Similarly, an ideal current source has an I-V line parallel to the voltage axis since it supplies a constant current with theoretically any voltages across.

Apparatus

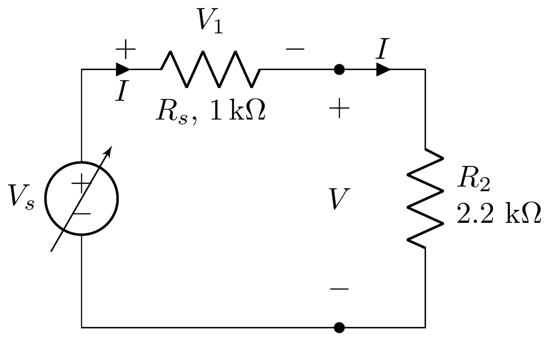
- Multimeter
- Resistors (1 kΩ x 2, 2.2 kΩ, 3.3 kΩ, 4.7 kΩ, 10 kΩ)
- DC power supply
- Breadboard
- Jumper wires

Procedures

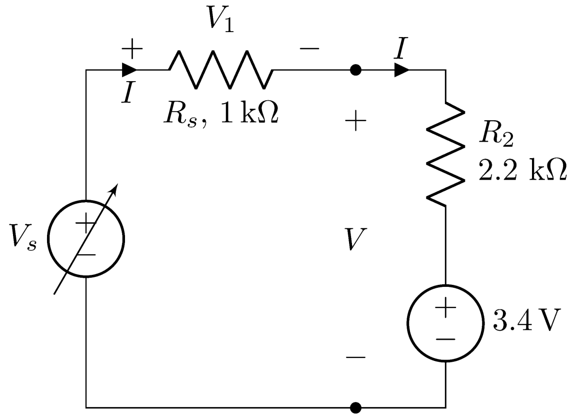
- Measure the resistances of the provided resistors and fill up Table 0.
- The following is the experimental setup we'll follow to derive $I - V$ characteristics of any circuit. Here, V_s is the applied voltage which is to be varied. The resistor R_s is used to facilitate the current measurement using Ohm's law as $I = \frac{V_1}{R_s}$. It is important to note that we have to plot $I\ vs.\ V$.



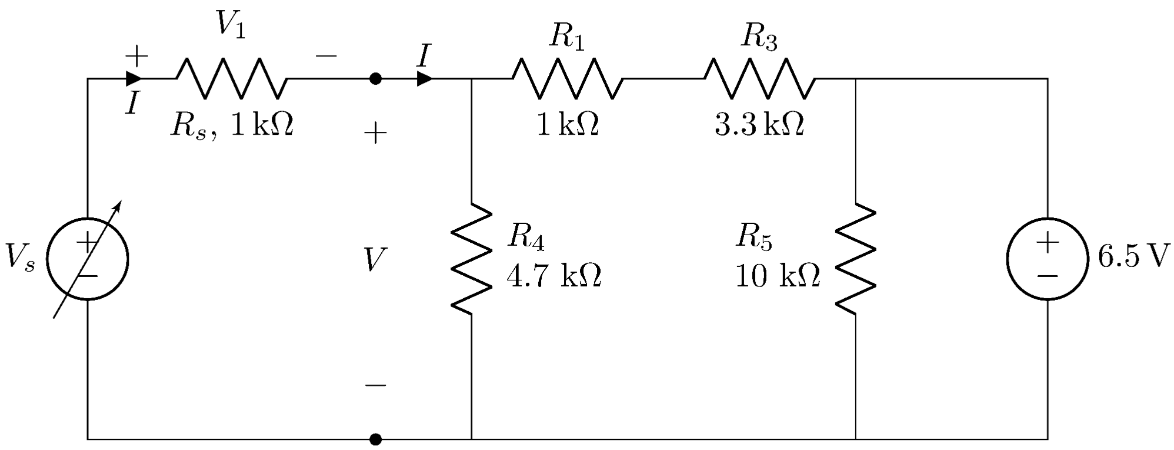
- Construct the following circuits on a breadboard. Try to use as less number of jumper wires as possible.



Circuit 1



Circuit 2



Circuit 3

- For each of these circuits, apply the specified supply voltages (from the first column of their respective data tables) using the DC power supply.
- Measure the voltage, V_1 across the 1 kΩ resistor using the multimeter and use Ohm's law to calculate the current I through the two terminals (denoted by • in the circuits).
- Measure the voltage, V across the two terminals (denoted by • in the circuits) using the multimeter, and fill up the data tables.

Data Tables

Signature of Lab Faculty: | | **Date:** | |

** ***<u>For all the data tables, take data up to three decimal places, round to two, and then enter into the table.</u>***

Table 0: Resistance Data

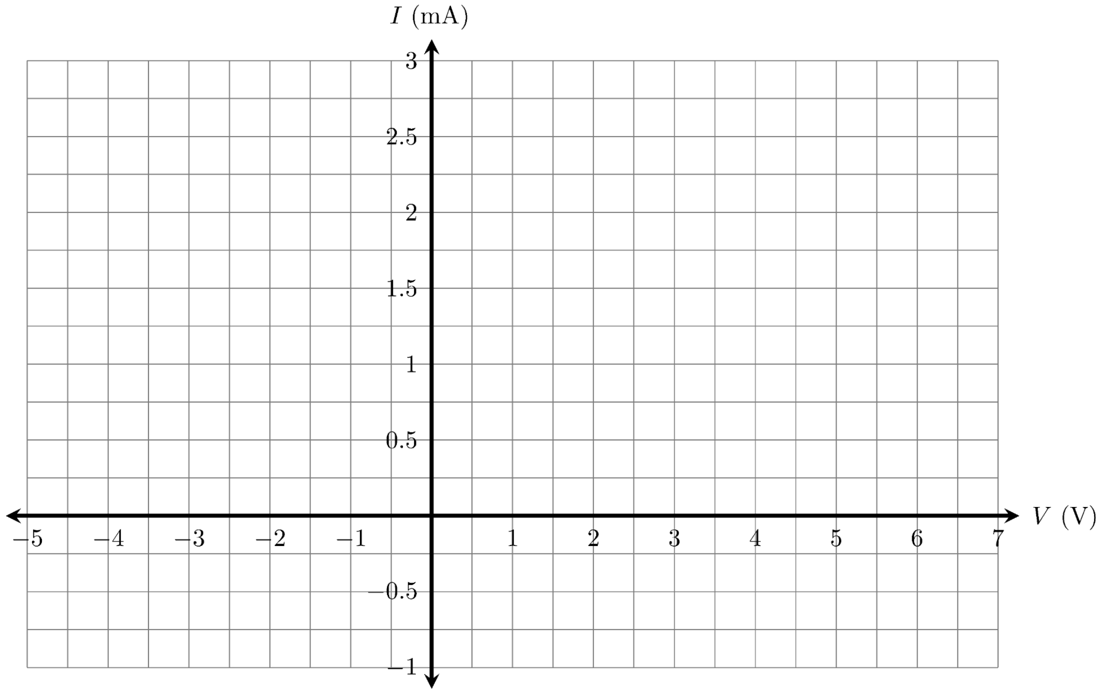
For all your future calculations, please use the observed values only **(even for theoretical calculations)**.

Notation	**Expected Resistance**	**Observed Resistance (kΩ)**	**Notation**	**Expected Resistance**	**Observed Resistance (kΩ)**
R_s	1 kΩ		R_3	3.3 kΩ	
R_1	1 kΩ		R_4	4.7 kΩ	
R_2	2.2 kΩ		R_5	10 kΩ	

Table 1: Data from Circuit 1

V_S (V)			V_1 (V)		V (V)		$I = \frac{V_1}{R_s}$ (mA)	
Expected Voltage	From DC power supply	Using multi-meter	Experi-mental	Theo-retical	Experi-mental	Theo-retical	Experi-mental	Theo-retical
0.0								
2.0								
4.0								
6.0								
8.0								

Plot the values of I and V from the above table.



Draw the best-fitting straight line through all the data points.

Slope of the straight line, m = [ ] $k\Omega^{-1}$

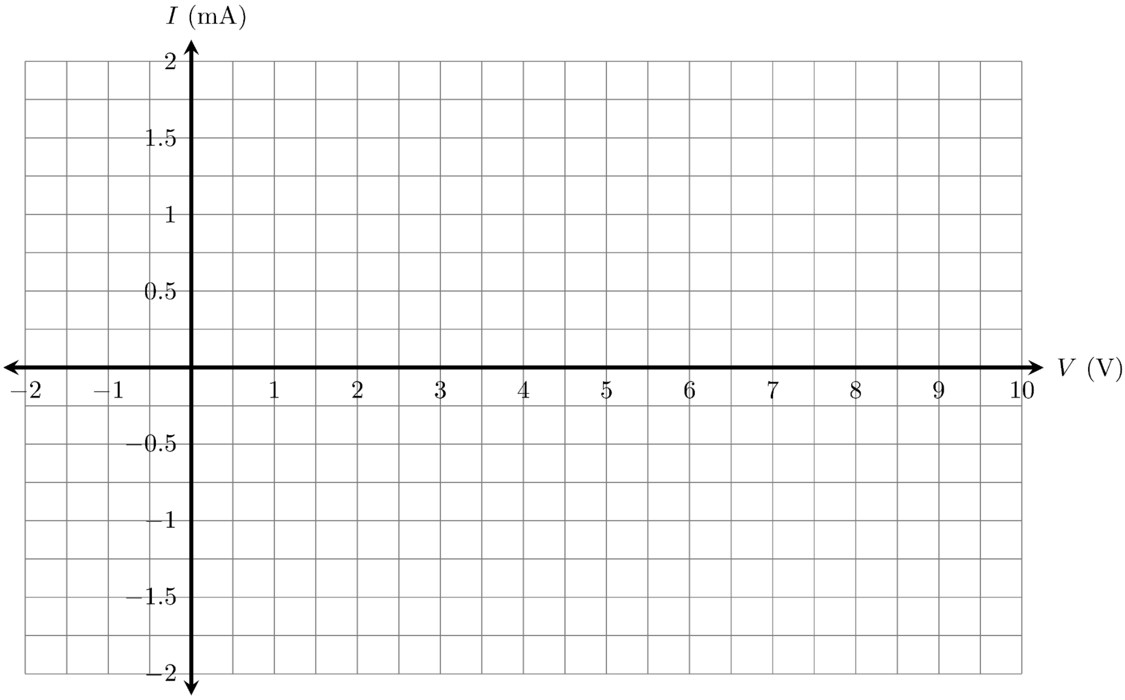
Resistance from the plot, $R_T = \frac{1}{m}$ = [ ] $k\Omega$

Percentage of Error $= \left|\frac{R_2 - R_T}{R_2}\right| \times 100\%$ = [ ] %

Table 2: Data from Circuit 2

V_S (V)			V_1 (V)		V (V)		$I = \frac{V_1}{R_s}$ (mA)	
Expected Voltage	From DC power supply	Using multi-meter	Experi-mental	Theo-retical	Experi-mental	Theo-retical	Experi-mental	Theo-retical
0.0								
2.0								
4.0								
6.0								
8.0								

Plot the values of I and V from the above table.



Draw the best-fitting straight line through all the data points.

Slope of the straight line, m = ______ $k\Omega^{-1}$

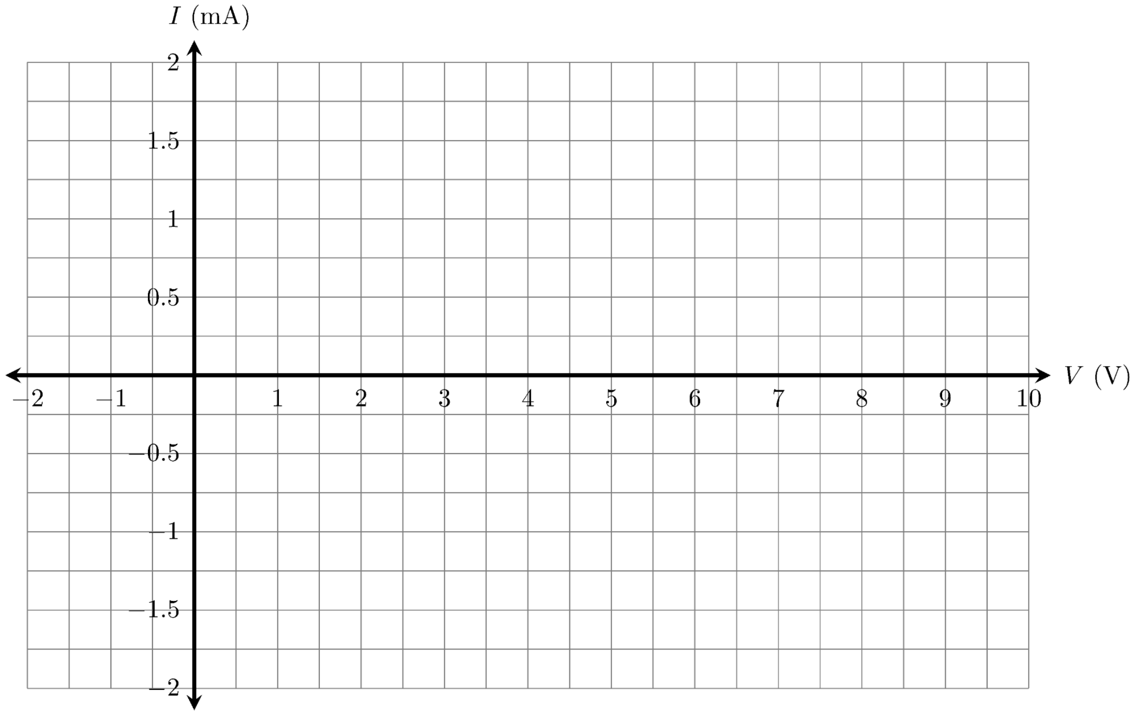
Resistance from the plot, $R_T = \frac{1}{m}$ = ______ $k\Omega$

The straight line intersects x-axis at, V_T = ______ V

Table 3: Data from Circuit 3

V_S (V)			V_1 (V)		V (V)		$I = \frac{V_1}{R_s}$ (mA)	
Expected Voltage	From DC power supply	Using multi-meter	Experi-mental	Theo-retical	Experi-mental	Theo-retical	Experi-mental	Theo-retical
0.0								
2.0								
4.0								
6.0								
8.0								

Plot the values of I and V from the above table.



Draw the best-fitting straight line through all the data points.

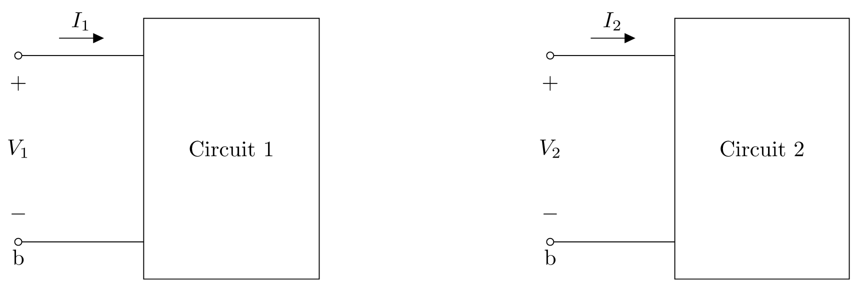
Slope of the straight line, m = [kΩ^{-1}]

Resistance from the plot, $R_T = \frac{1}{m}$ = [kΩ]

The straight line intersects x-axis at, V_T = [V]

Questions

1. What conditions must exist for the following two circuits to be equivalent to each other with respect to terminals $a - b$?



2.

(a) For Circuit 2, you constructed it in the laboratory, derive a relation between I and V.
[Hint: Exclude the experimental setup part (left side of V) in Circuit 2. Your equation cannot contain any variables other than I and V]

(b) For Circuit 3, you constructed it in the laboratory, derive a relation between I and V.
[Hint: The $10\ k\Omega$ resistor can be ignored as it is parallel to a voltage source. Exclude the experimental setup part (left side of V) in Circuit 3 and try to reduce the circuit to a single loop first. Your equation cannot contain any variables other than I and V]

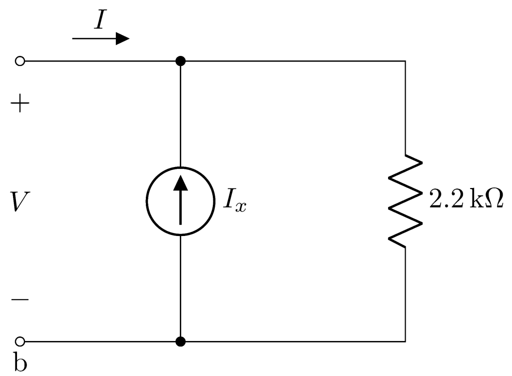
(c) Do the $I - V$ equations derived in (a) and (b) closely match?

☐ Yes ☐ No

If yes, what conclusion can you draw from this, and will it have any effect if one of these two circuits is replaced with the other? Why??

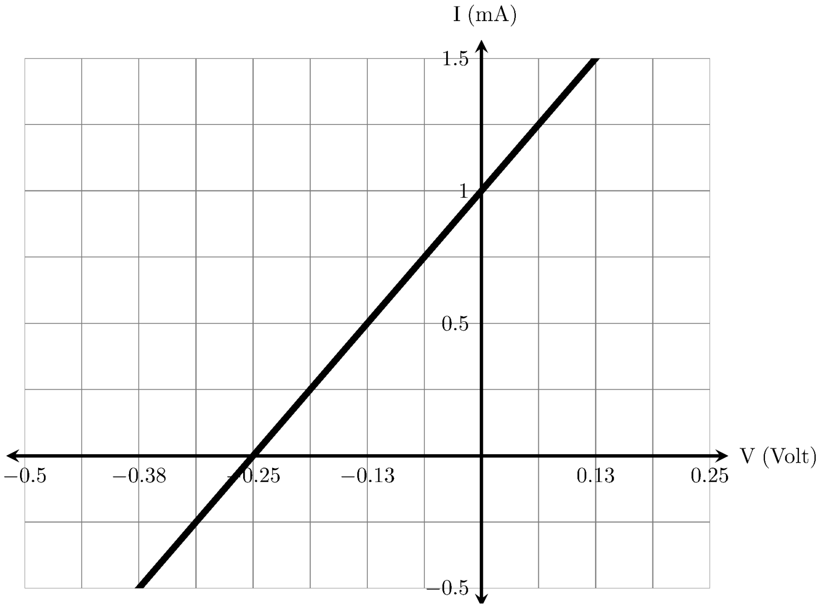
(d) Now, for the following circuit, determine the value of I_x so that the $I - V$ relation matches with those you derived in (a) or (b). Is this circuit equivalent to Circuit 2 and Circuit 3?

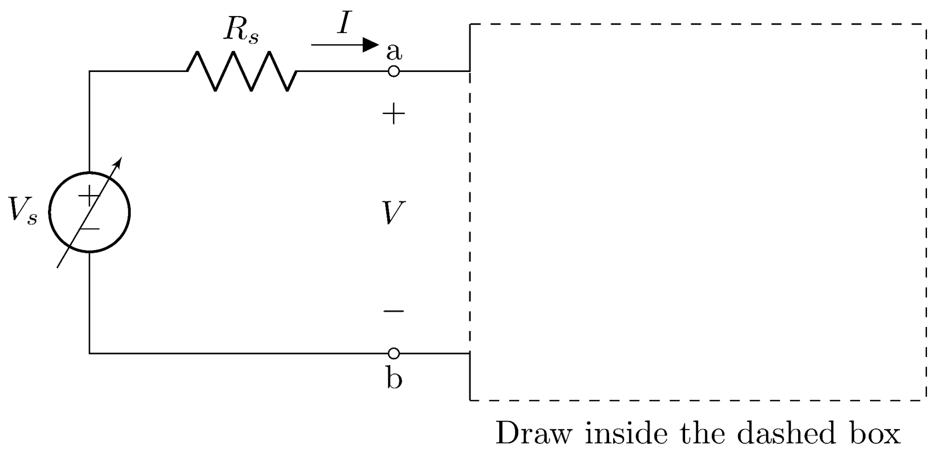
[Hint: Derive a relation between I and V from this circuit. Then compare it with that in (a) or (b) to get i_x*.]*



3. Can you think of any way to <u>measure</u> the voltage-axis and current-axis intersecting points of the $I - V$ line of any linear circuit directly without even plotting the $I - V$ line?

4. A linear two-terminal circuit has the following $I - V$ relationship at the terminals $a - b$ measured in a laboratory with the setup shown below. Draw (inside the box) a simplified version of the circuit that can give rise to the same $I - V$ as shown. Also, write the corresponding values of the circuit elements.



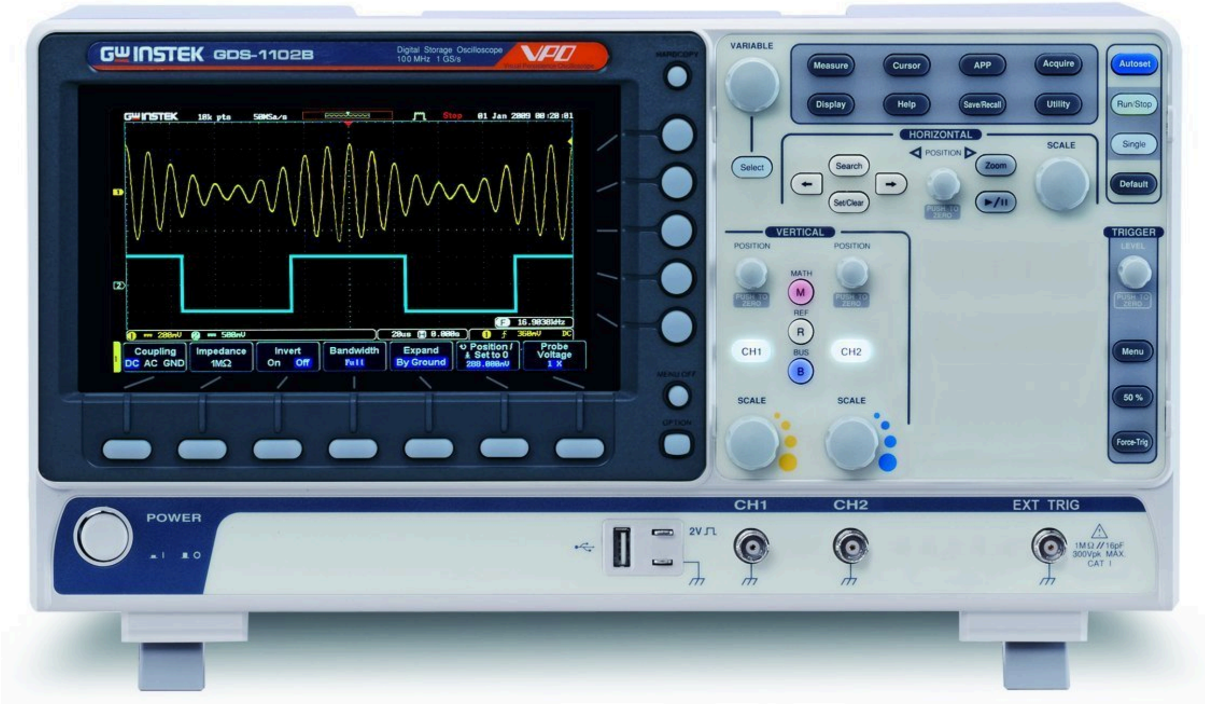


Part 2: By Using Oscilloscope

Theory

Oscilloscope

An oscilloscope is a device that can measure a sequence of voltages over time and can display that information by plotting those on a screen. In fact, oscilloscopes available at our labs are dual channel (**`CH1`** and **`CH2`**), meaning, they can simultaneously show voltage vs time graphs across two separate sets of nodes.



An oscilloscope

In the default mode, an oscilloscope can show 2 separate graphs (yellow and blue) where the common x-axis for both of the graphs is <u>**time**</u>. The y-axis for the <u>**yellow**</u> graph is the voltage measured at <u>**`CH1`**</u> and the <u>**blue**</u> graph is the voltage measured at <u>**`CH2`**</u>.

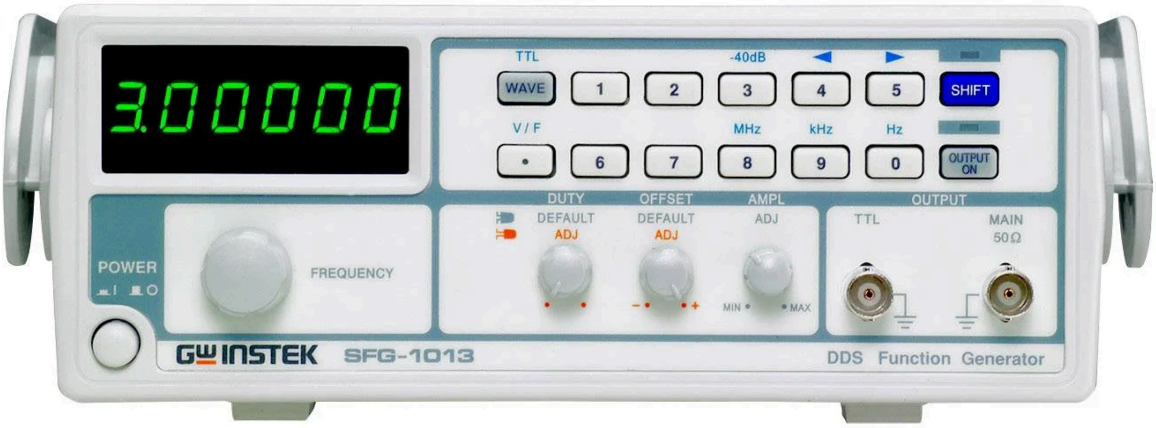
However, there is another mode called the **"`XY`" mode** where we can plot voltage from **`CH1`** on the x-axis vs voltage from **`CH2`** on the y-axis. This is exactly how we can plot I-V characteristics on an oscilloscope. If we connect the voltage, V across the two terminals to **`CH1`** and measure the current I on **`CH2`**, we could plot the I-V characteristics. However, oscilloscopes can only measure voltages. This can easily be done using a 1 kΩ resistor since the voltage (in volts) across a 1 kΩ resistor is equivalent to the current (in milliamperes) through that resistor.

There is another hurdle to overcome regarding the negative terminals of the two oscilloscope channels. Although they seem separate, in actuality, **the two negative terminals are**

internally shorted. Hence, we need to connect both the channels in such a way that there negative terminals are connected at the same node. In fact, connecting only one of the negative terminals at that node is enough. But this is a challenge since we may want the inverted voltages. This can be easily done through the GUI by pressing the channel buttons. For example, if we want to invert **`CH1`**, it can be done by pressing the glowing **`CH1`** button and then turning **`On`** "**`Invert`**" mode (detailed procedures are discussed later).

Function Generator

A function generator is a device that can generate various shapes of electrical waveforms. We can produce signals of different frequencies, amplitudes, and wave shapes, such as sine waves, square waves, triangular waves, etc.



A Function Generator

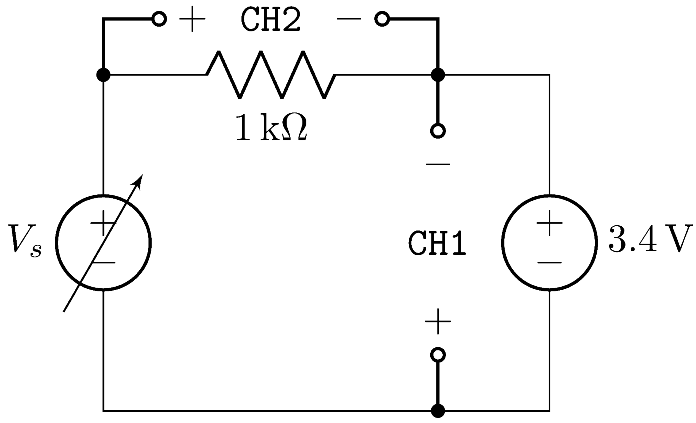
In the previous part, we collected data using a multimeter, and the supply voltage was changed with a knob on the DC power supply. However, an oscilloscope samples thousands to millions of data points per second. So, manually adjusting the supply voltage is not possible. However, for that, we may use a function generator that creates a 1 kHz signal of the maximum amplitude (10 V) as the supply voltage V_S.

Apparatus

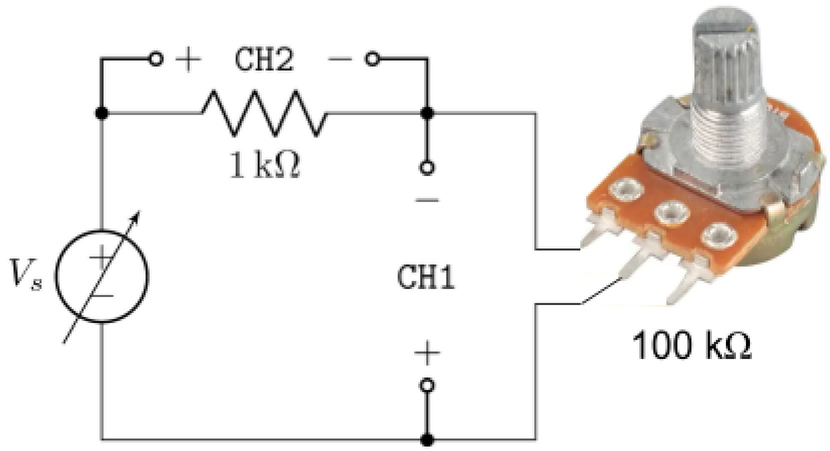
- Oscilloscope
- Function Generator
- DC power supply
- A 100 kΩ potentiometer
- Light Dependent Resistors (LDRs)
- Breadboard
- Jumper wires

Procedures

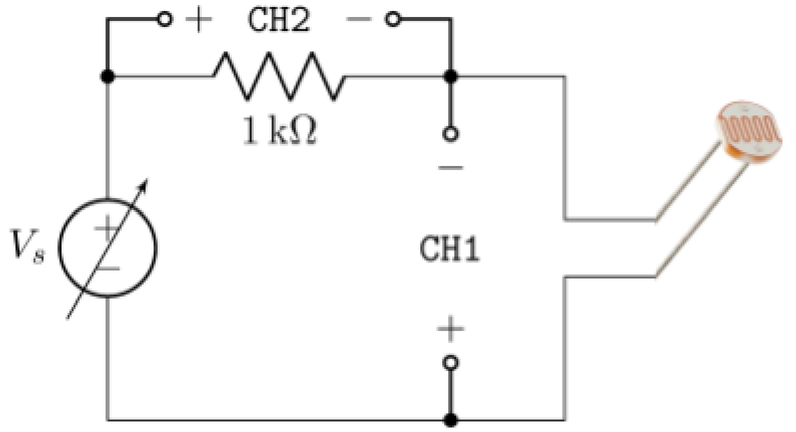
- Construct the following circuits on a breadboard. Try to minimize the number of jumper wires in your circuit:



Circuit 4 (DC Voltage Source)



Circuit 5 (Potentiometer)

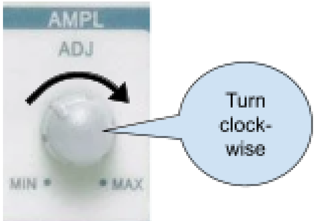


Circuit 6 (LDR)

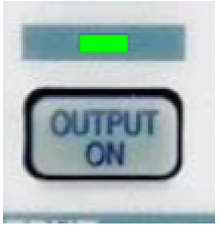
➢ Setup the **function generator**:

- ➢ Connect the positive and negative terminals of the function generator according to the positives and negatives of the supply voltage V_S.
- ➢ Make sure the **`DUTY`** and **`OFFSET`** adjustment knobs are **<u>pushed in</u> (default mode).**

- ➢ Set the **`AMPL`** (amplitude) adjustment knob to the **`MAX`** position.

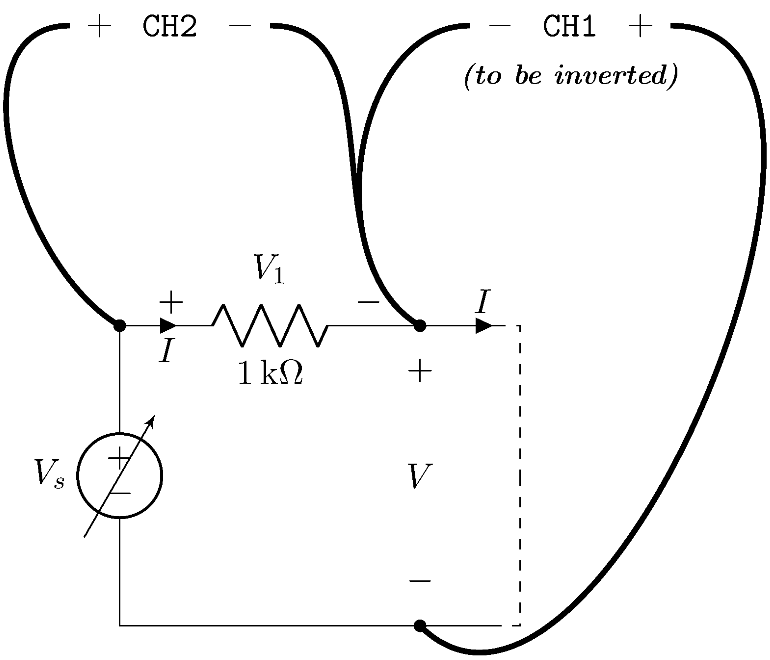


- ➢ Turn **<u>on</u>** the **output**.



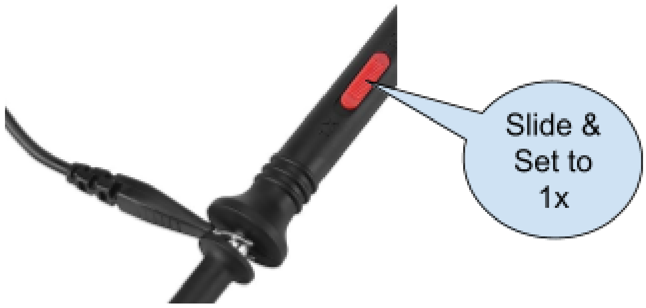
➢ Setup the **oscilloscope**:

- ➢ Connect the channels of the oscilloscope as demonstrated in this figure:

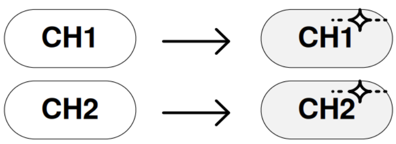


Connecting oscilloscope channels

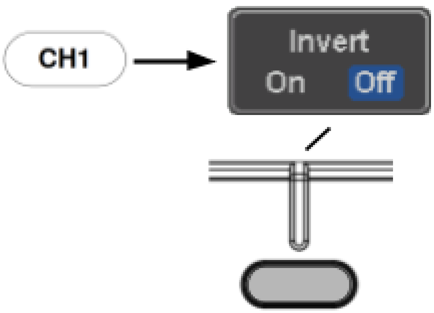
➢ Set the oscilloscope probe scaling to **<u>1x</u>** (not 10x).



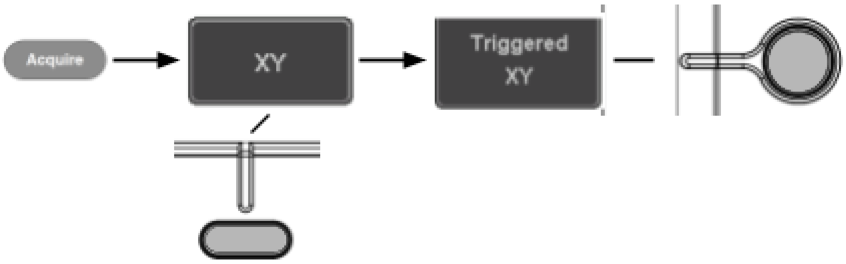
➢ Make sure both channels are turned on. These buttons should be glowing:



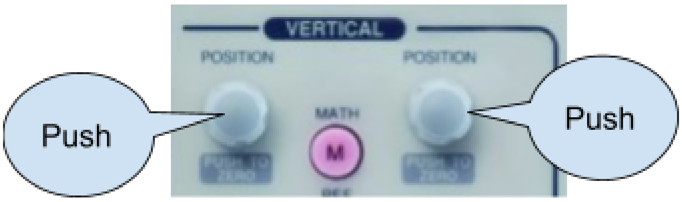
➢ Invert **<u>CH1</u>** by pressing the bottom menu buttons and set it to **<u>On</u>**.



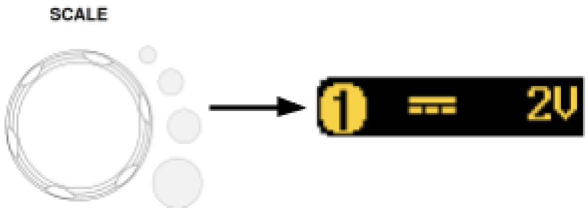
➢ Go to **<u>XY</u>** Mode:



➢ Set position to origin by **<u>pushing</u>** the **<u>position</u> knobs** on each channel.



➢ Turn both channel knobs so that the voltage resolutions are at **2V per division.**



Questions

5. Refer to the illustration of an **Oscilloscope** on page 11 to answer the following questions–

(a) In the normal mode of operation, an oscilloscope always plots–

☐ voltage as a function of time ☐ current as a function of time

(b) In the X-Y mode of operation, an oscilloscope plots Channel-1 along the -

☐ x-axis ☐ y-axis

(c) What is the function of the button "**Measure**"?

☐ It measures the total resistance of the circuit.

☐ It adds the voltage waveforms fed to the channels.

☐ It displays the properties of the voltage waveforms fed to the channels.

(d) Is there any way to observe the one you haven't selected in (a)?

6. Refer to the illustration of a **Function Generator** on page 11 to answer the following questions:

(a) If you are asked to set a sinusoidal voltage with a dc offset $v(t) = 5 + 5sin(2\pi 100t)\ (Volt)$ in a **Function Generator**, specify the values of the following parameters. On the rightmost boxes, put a checkmark ✔ to indicate the ones that need to be set on the Function Generator.

• Amplitude of the voltage =	V	☐
• Peak to peak of the voltage =	V	☐
• Natural Frequency, f =	Hz	☐
• Angular Frequency, ω =	$rads^{-1}$	☐
• Initial Phase, ϕ =	^{o}	☐
• DC Offset =	V	☐

(b) List the buttons you need to press sequentially to set a frequency equal to $1.23\ kHz$. Add boxes if necessary.

Power On	→		→		→		→		→		→	

(c) Turning the "**AMPL**" knob clockwise or counterclockwise will change the–
☐ Frequency of the voltage waveform
☐ Amplitude of the voltage waveform
☐ Phase of the voltage waveform

(d) What is the function of the button "**WAVE**"?
☐ It converts a voltage waveform into a current waveform
☐ It sets everything to default.
☐ It changes the types of voltage waveforms.

7. Put a checkmark ✔ beside the correct answers:

(a) The I-V characteristics of the following circuits were **straight lines** -
☐ Circuit 4 ☐ Circuit 5 ☐ Circuit 6

(b) The I-V characteristics of the following circuits went **through origin** -
☐ Circuit 4 ☐ Circuit 5 ☐ Circuit 6

(c) The following circuits were **equivalent to a resistor** -
☐ Circuit 4 ☐ Circuit 5 ☐ Circuit 6

(d) When the LDR was completely **in darkness**, the I-V characteristic line was -
☐ y-axis ☐ x-axis ☐ parallel to x-axis but shifted upwards

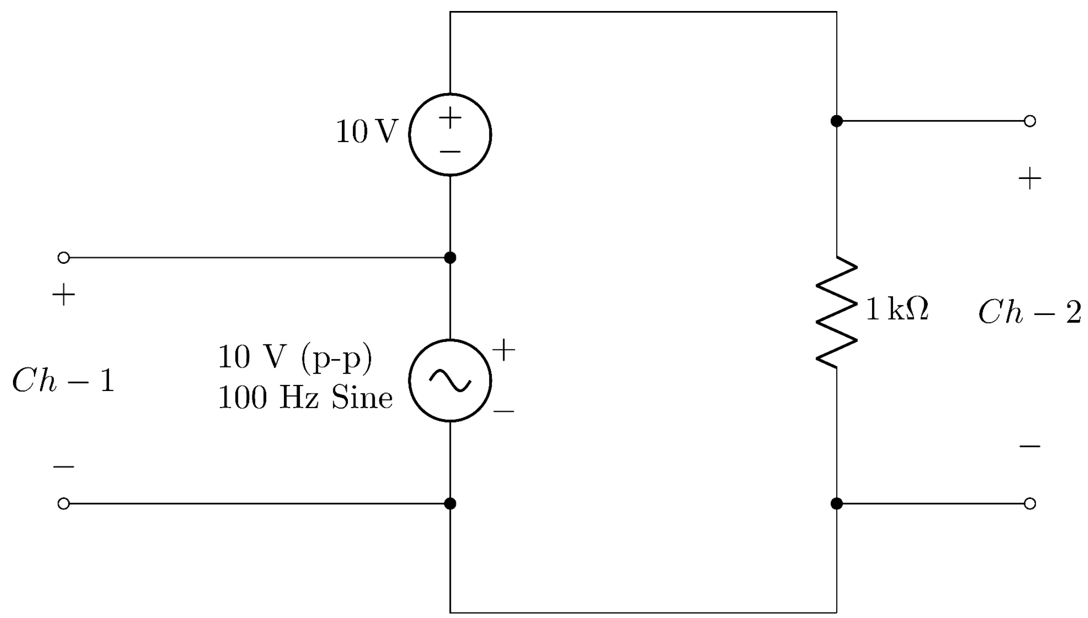
(e) When the LDR was completely **in darkness**, it was equivalent to -
☐ short circuit ☐ open-circuit ☐ 1 kΩ resistor ☐ $0A$ current source

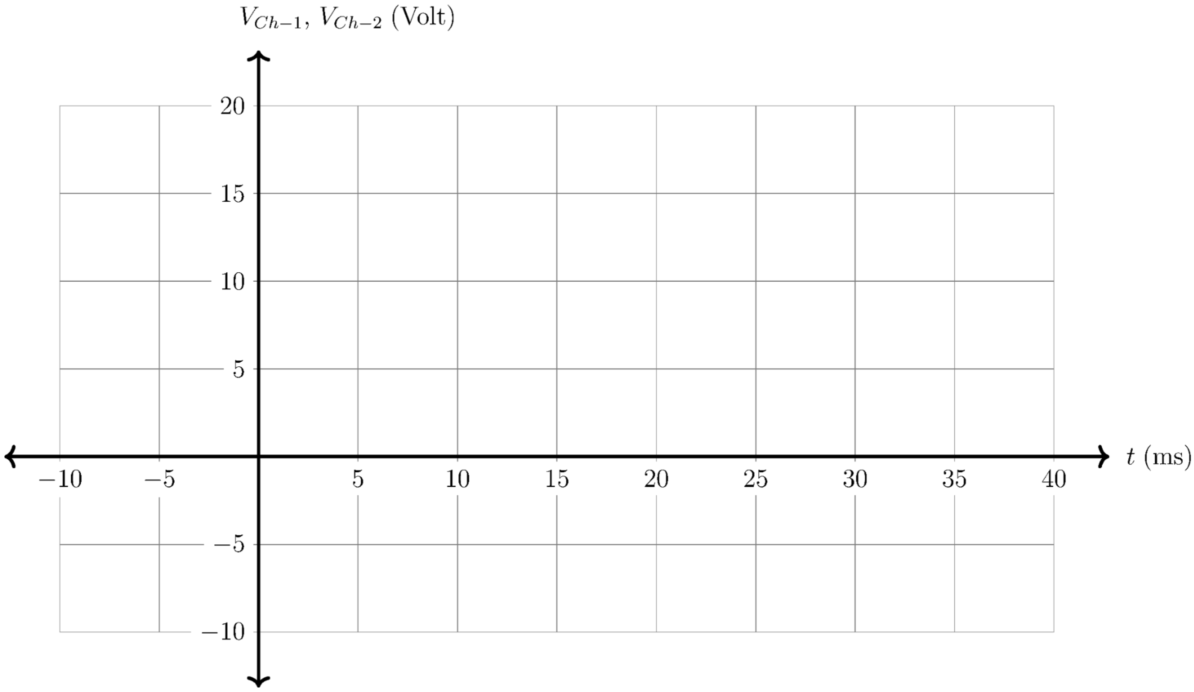
8. Why was it necessary to invert Channel 1 of the Oscilloscope to visualize the $I\ vs.\ V$ plot of **Circuits 4, 5,** and **6**?

9. Compared to the expected one, how the observed $I - V$ plot would be if we didn't invert the Channel-1 on the Oscilloscope?

- ☐ The $I - V$ plot would mirror with respect to the y-axis.
- ☐ The $I - V$ plot would mirror with respect to the x-axis.
- ☐ The $I - V$ plot would still be the expected one.
- ☐ We wouldn't observe any graph.

10. Draw the waveforms that should be observed in Channel-1 and Channel-2 of an oscilloscope when both the channels are ON and are connected in a setup shown below. Draw both plots in the same template given below. Mark the waveforms according to their visualizing channel.





11. Write two significance/importance of I-V characteristics.

Report

1. Fill up the theoretical parts of all the data tables.
2. Answers to the questions.
3. Attach the captured images of the $I - V$ plot observed for **Circuits 4**, **5**, and **6**. in the Oscilloscope. Fit all the images on a single page and print.
4. Discussion *[your overall experience, accuracy of the measured data, difficulties experienced, and your thoughts on those]*. Add pages if necessary.