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.

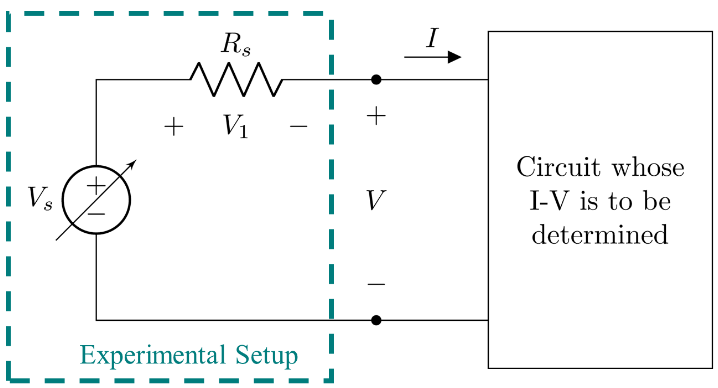
The I-V characteristic of an ideal voltage source (an ideal voltage source is a theoretical concept that maintains a constant voltage across its terminals, regardless of the current flowing through it.) is a vertical line on an I-V graph, indicating that the voltage remains constant (V) regardless of 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

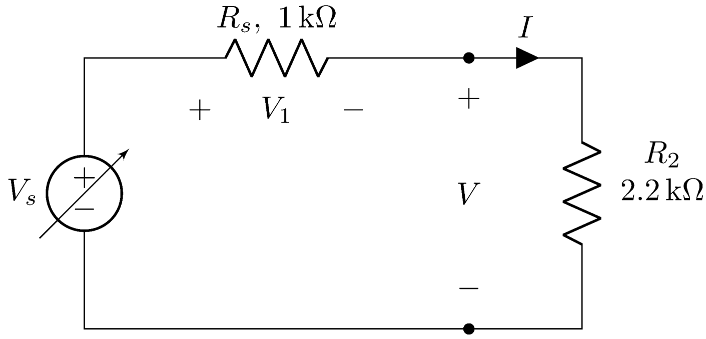
- Multimeter
- Resistors (1 kΩ x 2, 2.2 kΩ, 3.3 kΩ, 4.7 kΩ, 10 kΩ)
- DC power supply
- Breadboard
- Jumper wires

Procedures

- Measure the resistances of the provided resistors and fill in *Data 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 that is to be varied. The resistor R_s is used to facilitate the current measurement using Ohm's law as $I = V_1/R_s$. It is important to note that we are to plot $I\ vs.\ V$.



➢ We'll first investigate the I-V of a resistor. Construct the following circuit on a breadboard. Try to use as less number of jumper wires as possible.



Circuit 1

➢ 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 in *Data Table 1*.

➢ Plot the (V, I) data points from the *Data Table 1* on the grid provided and draw a best-fitting line.

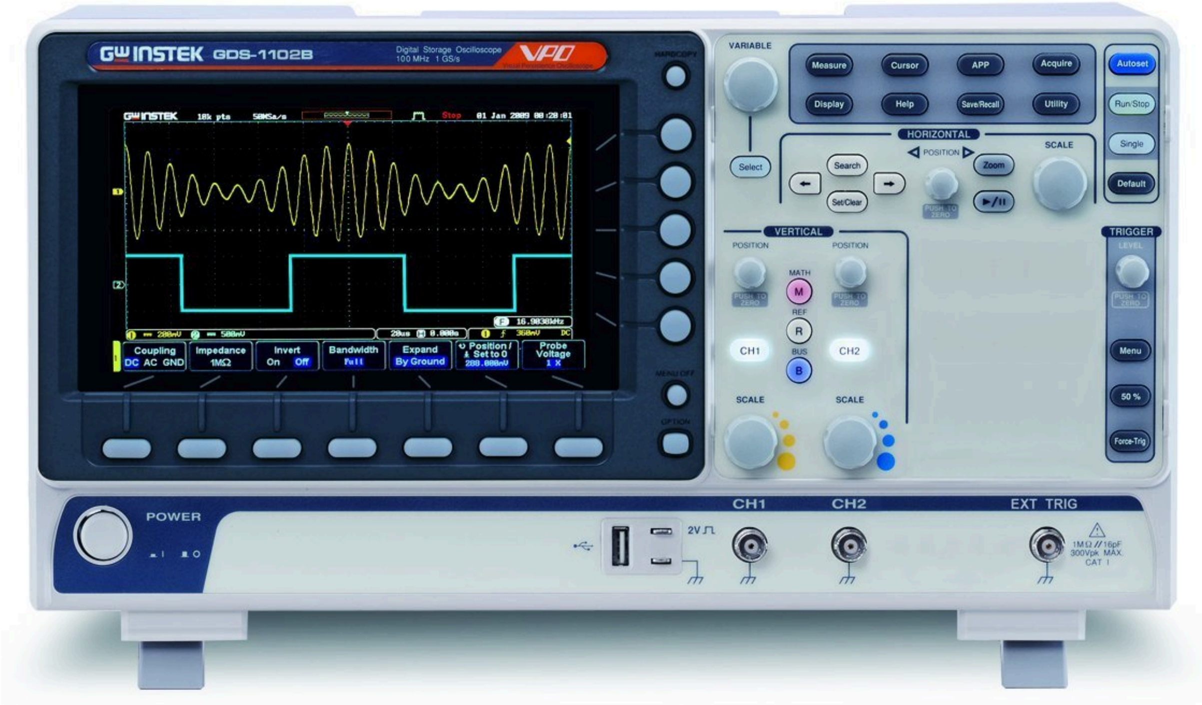
➢ Instead of manually collecting data points and plotting them, we will now automate the process using a signal generator and an oscilloscope as described in Part 2.

Part 2: 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 **time**. The y-axis for the **yellow** graph is the voltage measured at **CH1** and the **blue** graph is the voltage measured at **CH2**.

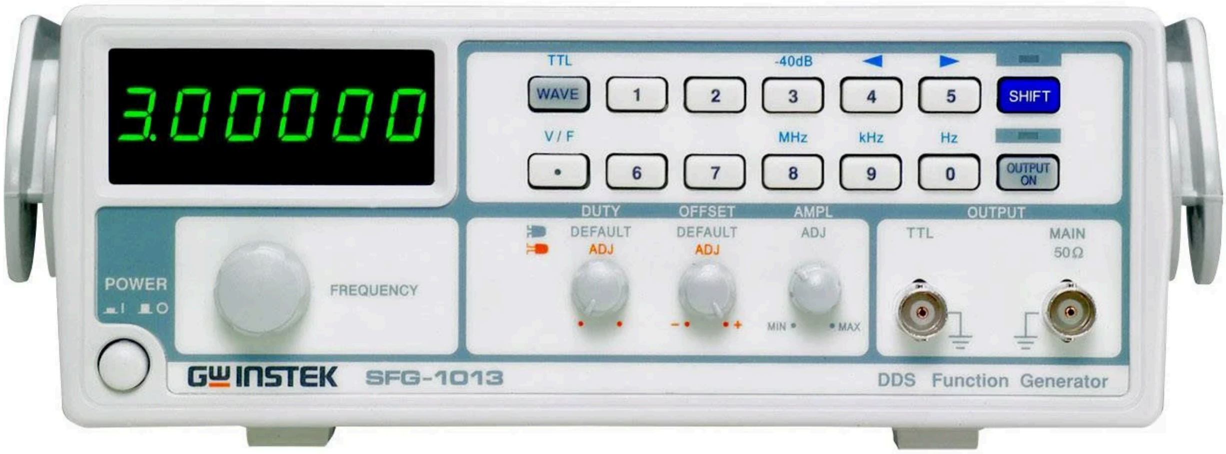
However, there is another mode called the **"XY" mode** where we can plot voltage from **CH1** on the x-axis vs voltage from **CH2** on the y-axis. This is exactly how we can plot I-V characteristics on an oscilloscope. If we connect the voltage, V across the two terminals to **CH1** and measure the 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.

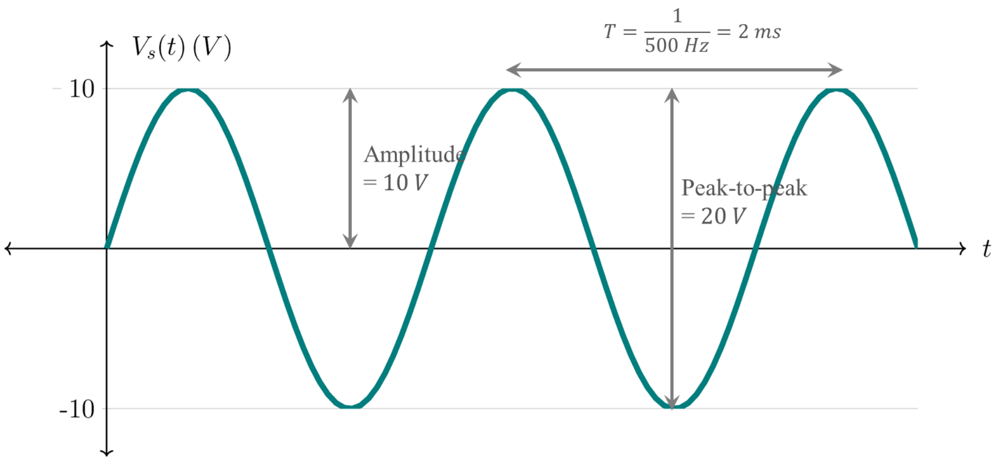
Apparatus

- Oscilloscope
- Function Generator
- DC power supply
- Resistors (1 kΩ x 2, 2.2 kΩ, 3.3 kΩ, 4.7 kΩ, 10 kΩ)
- A 100 kΩ potentiometer
- Light Dependent Resistors (LDRs)
- Breadboard
- Jumper wires

Procedures

➢ **<u>Setting up a voltage on the Function Generator</u>**

➔ Before constructing the circuit, we will configure the function generator to produce a sinusoidal, time-varying voltage signal as plotted below.

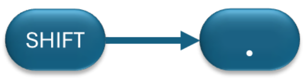


➔ Turn on the Function Generator by pushing the **POWER** button.

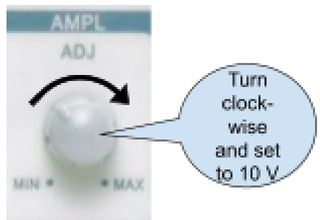
➔ Make sure the **DUTY** and **OFFSET** adjustment knobs are **<u>pushed in</u>** **(default mode).**

➔ Set the frequency to 500 Hz by pressing sequentially the following buttons.

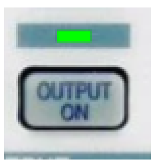
➔ Press the following buttons to change the display to show voltage.



➔ Turn the **AMPL** (amplitude) adjustment knob and set the voltage to 10 V. Note that, for a sinusoidal wave-like voltage with amplitude 10 V, the peak-to-peak value is 20 V. We always set the amplitude on the function generator.



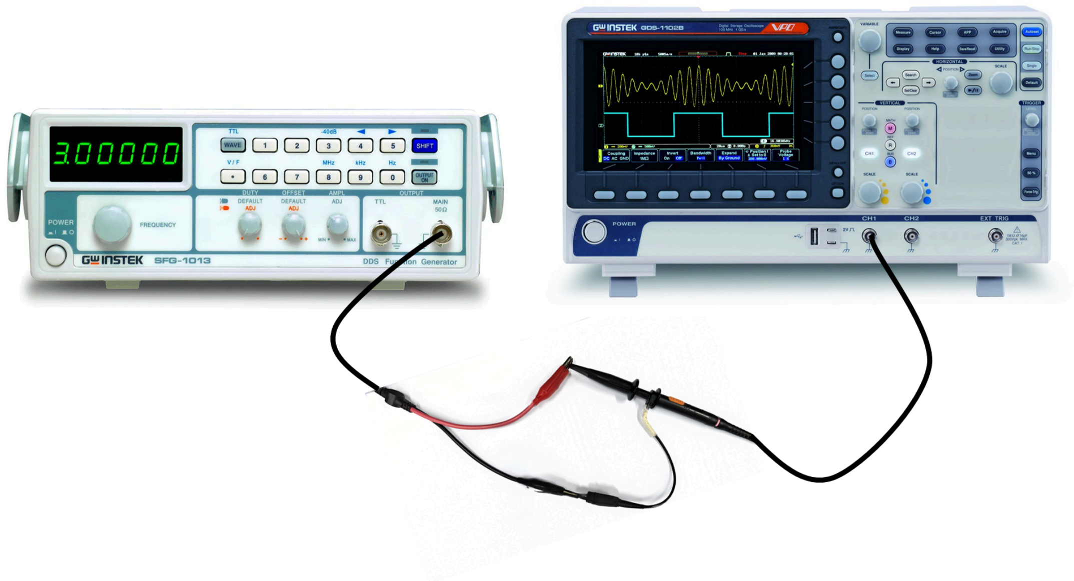
➔ Turn **<u>on</u>** the **output**.



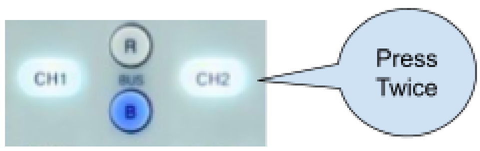
➢ <u>Setting up the oscilloscope to observe the voltage set on the Function Generator</u>

➔ Turn on the Function Generator by pushing the **POWER** button.

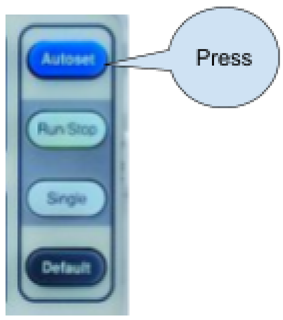
➔ Connect the probes from the function generator with any of the channels (let's say CH1) in the Oscilloscope as shown below.



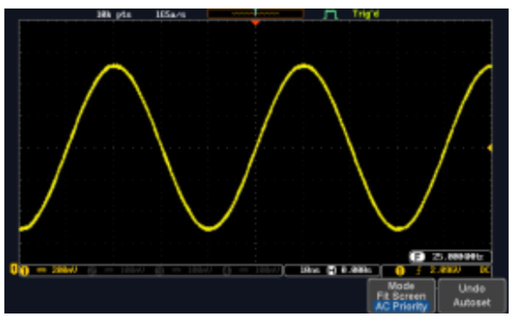
➔ If the CH2 button is glowing as shown below, press it <u>twice</u> to turn it off.



➔ Press the **Autoset** button.

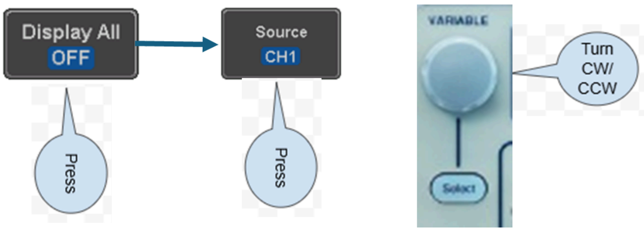


➔ You should see a yellow sine wave voltage graph as shown below.

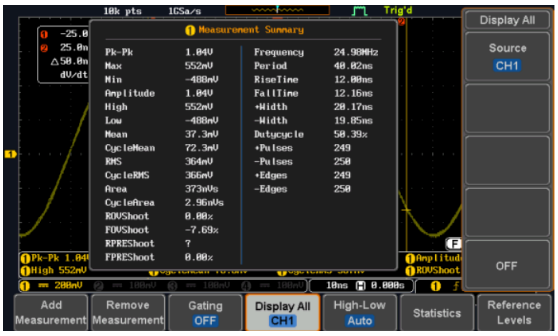


➔ Press the **Measure** button to check the peak-to-peak, maximum voltage, minimum voltage, frequency, etc.

➔ If the floating display shows "**OFF**" for the parameters of the voltage, press the following buttons.

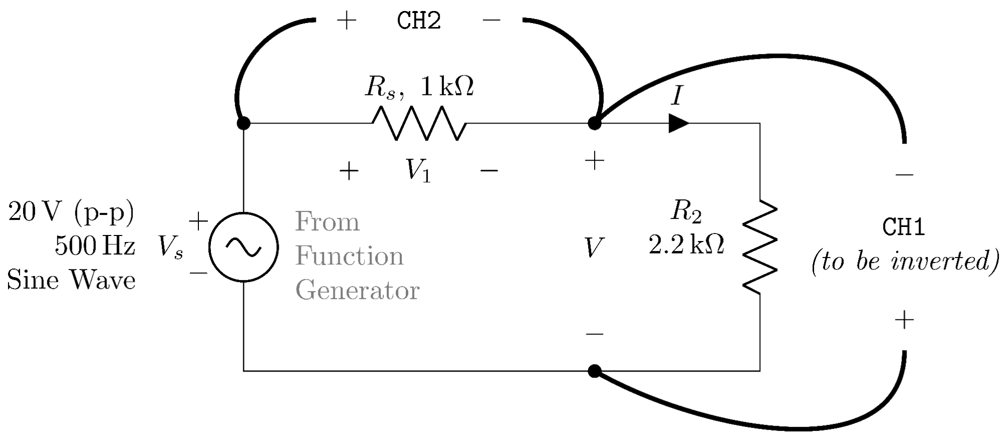


➔ You should see a window as shown below. The values for the parameters should be different than those shown in the figure.



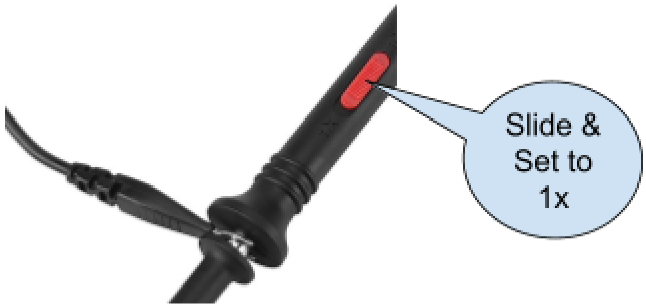
➔ Disconnect the probes of the oscilloscope and the function generator, then proceed to build the circuits and apply the input voltage.

➢ Construct the following circuit on a breadboard. It is identical to **Circuit 1**, except the **DC power supply is replaced with the voltage output from the function generator**, and the oscilloscope probes are connected to observe the I–V characteristics.

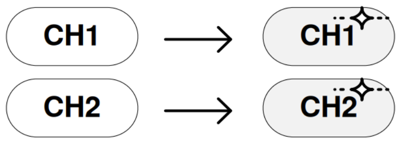


Circuit 2

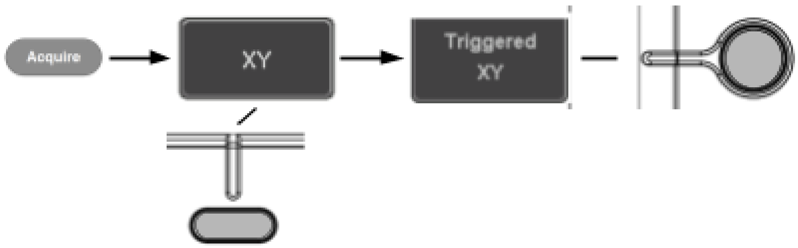
➢ Set the oscilloscope probe scaling to **<u>1x</u>** (not 10x).



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

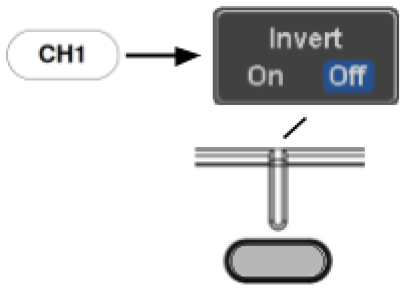


➢ Go to **<u>XY</u>** Mode:

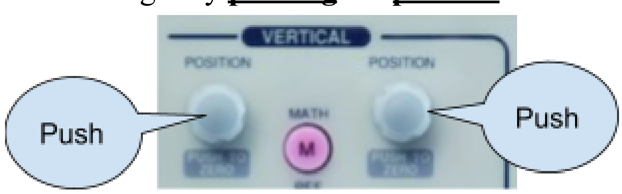


➢ **<u>Each time you observe I–V characteristics on the oscilloscope, follow these three steps</u>:**

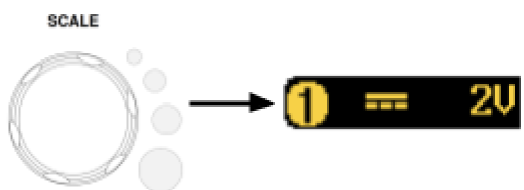
- ○ Invert **<u>`CH1`</u>** by pressing the bottom menu buttons and set it to **<u>`On`</u>**.



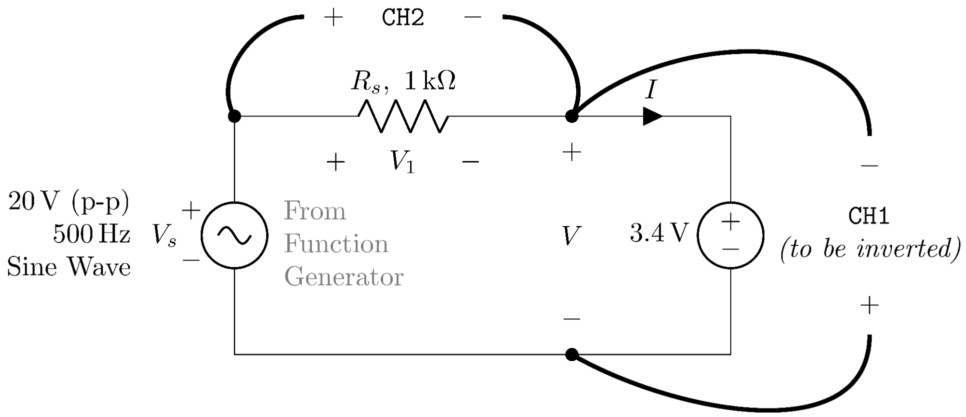
- ○ Set plot position to the origin by **<u>pushing</u>** the **<u>position</u> knobs** on each channel.



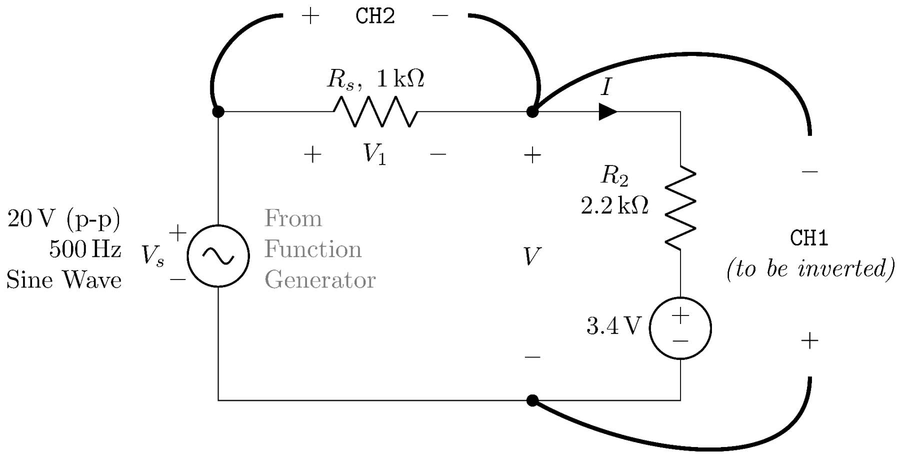
- ○ Turn both channel knobs so that the voltage resolutions are at **2V per division.**



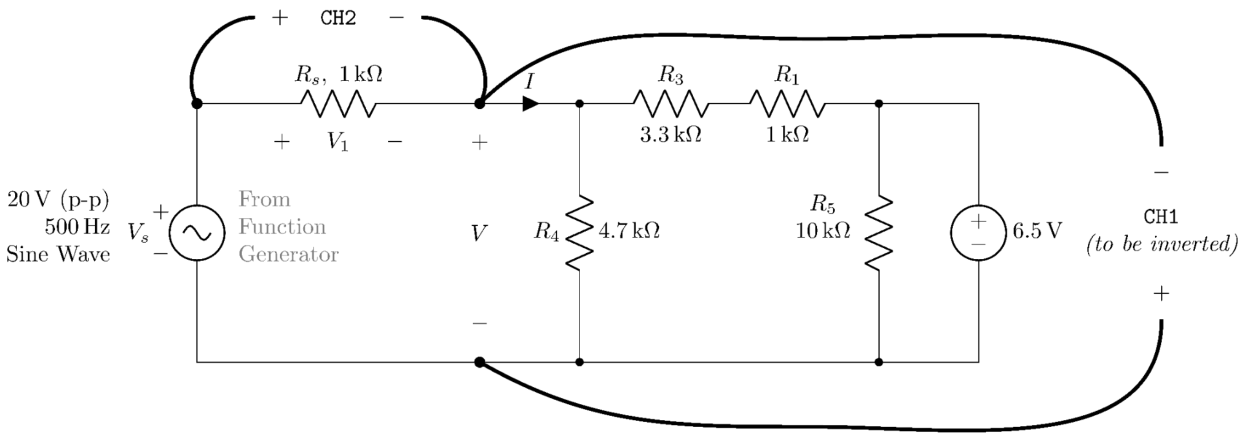
- You should observe a graph passing through the origin with a positive slope.
- Take a picture of the graph. Identify the scaling of the graph and fill in *Data Table 2*.
- In a similar manner described above, observe the I-V characteristics of **Circuit 3, Circuit 4,** and **Circuit 5** and fill in *Data Tables 3, 4,* and *5,* respectively.



Circuit 3

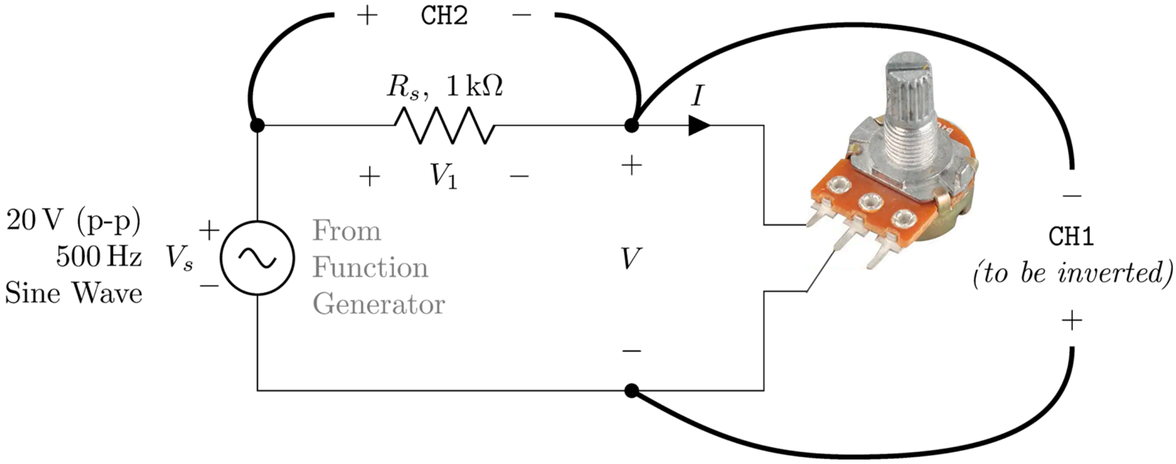


Circuit 4

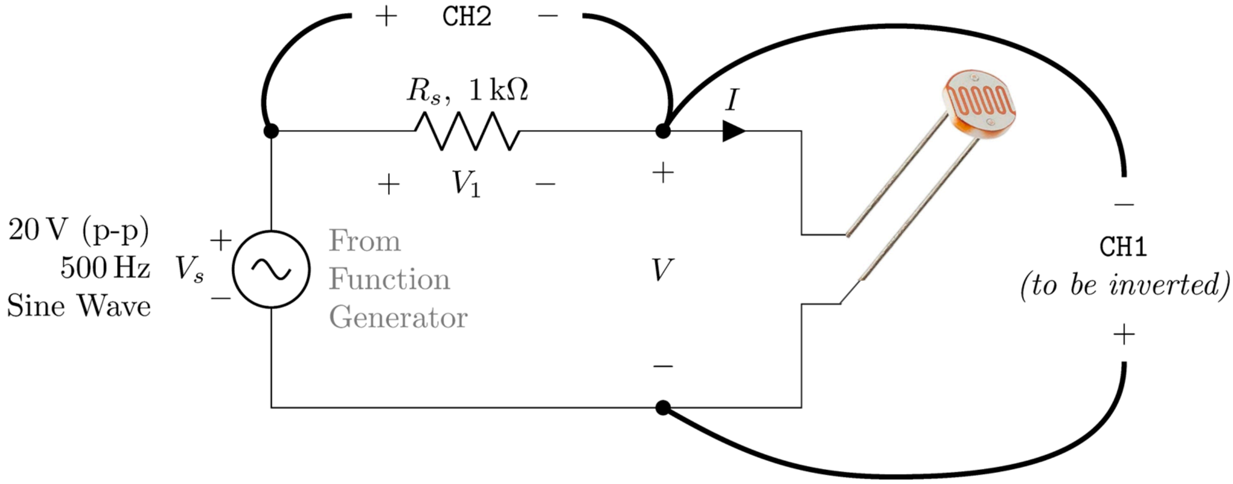


Circuit 5

➢ For **Circuits 6** and **7**, observe the I–V characteristics of the elements and record your observations in *Data Tables 6* and *7*.



Circuit 6



Circuit 7

Data Tables

Signature of Lab Faculty: **Date:**

Signature of Lab Faculty:		**Date:**	

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

Table 0: Resistance Data

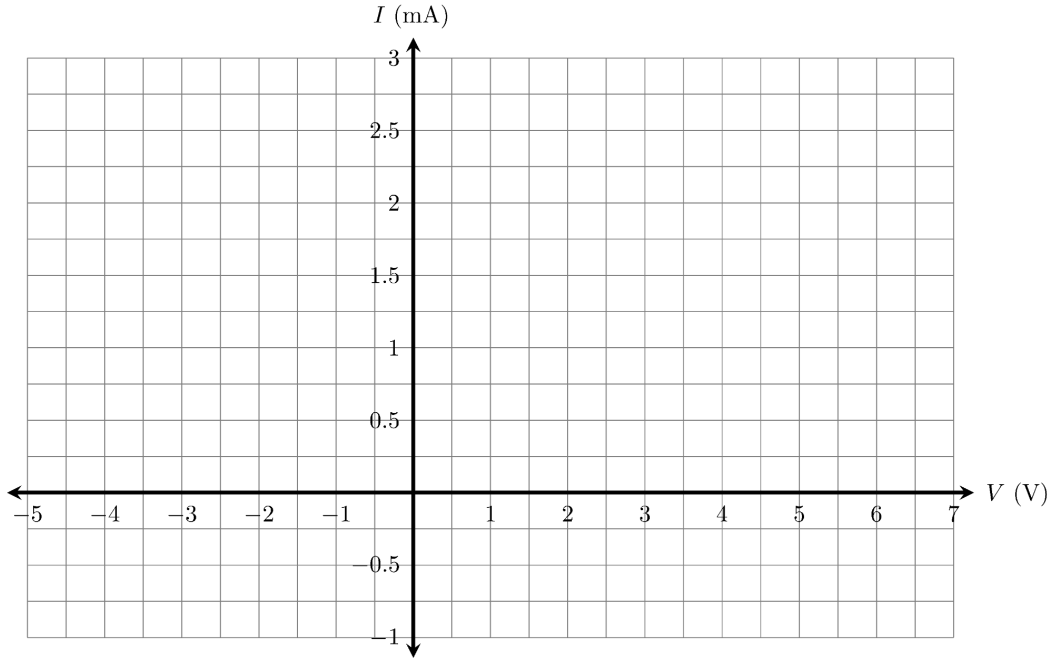
For all your future calculations, please use the observed values only **(even for theoretical calculations)**.

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								
− 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 = $\boxed{\quad}$ $k\Omega^{-1}$

Resistance from the plot, $R_{eq} = \frac{1}{m} =$ $\boxed{\quad}$ $k\Omega$

Percentage of Error $= \left|\frac{R_2 - R_{eq}}{R_2}\right| \times 100\% =$ $\boxed{\quad}$ %

Table 2: Data from Circuit 2

For the plot observed in the oscilloscope,

Does the I-V line pass through the origin? (✔ / ✗) $\boxed{\quad}$

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

Resistance from the plot, $R_{eq} = \frac{1}{m} =$ $\boxed{\quad}$ $k\Omega$

Table 3: Data from Circuit 3

For the plot observed in the oscilloscope,

Is the I-V line parallel to y-axis? (✔ / ✗) $\boxed{\quad}$

The straight line intersects the x-axis at, V_{OC} = $\boxed{\quad}$ V

Table 4: Data from Circuit 4

For the plot observed in the oscilloscope,

The I-V line intersects the x-axis at, V_{OC} =	V
The I-V line intersects the y-axis at, I_{SC} =	mA
Slope of the straight line, m =	kΩ^{-1}
Resistance from the plot, $R_{eq} = \frac{1}{m}$ =	kΩ

Table 5: Data from Circuit 5

For the plot observed in the oscilloscope,

The I-V line intersects the x-axis at, V_{OC} =	V
The I-V line intersects the y-axis at, I_{SC} =	mA
Slope of the straight line, m =	kΩ^{-1}
Resistance from the plot, $R_{eq} = \frac{1}{m}$ =	kΩ

Table 6: Observation from Circuits 6

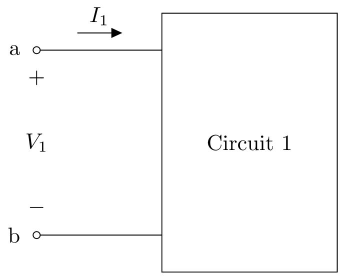
Potentiometer fully **CW** → I-V line becomes (x-axis or y-axis) -	
Potentiometer fully **CCW** → I-V line becomes (x-axis or y-axis) -	

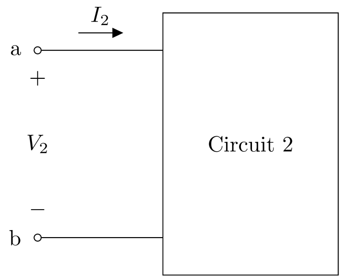
Table 7: Observation from Circuits 7

LDR is in **darkness** → its resistance (↑ or ↓) -	
LDR is **illuminated** → its resistance (↑ or ↓) -	

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 4, 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 4. Your equation cannot contain any variables other than I and V]

(b) For Circuit 5, 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 5 and try to reduce the circuit to a single loop first. Your equation cannot contain any variables other than I and V]

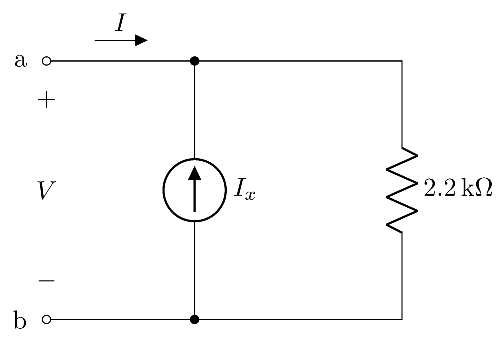
(c) Do the $I - V$ equations derived in (a) and (b) closely match?

☐ 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??

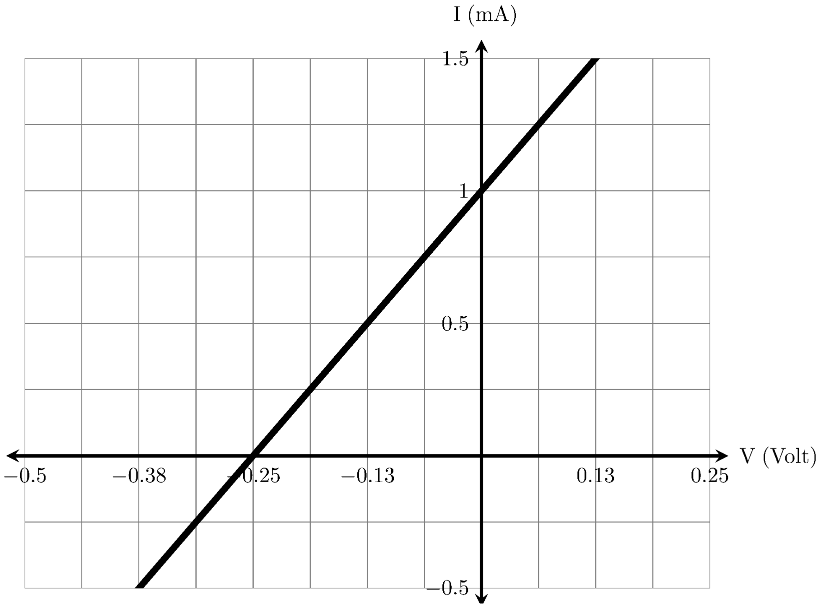
(d) Now, for the following circuit, determine the value of I_x so that the $I - V$ relation matches with those you derived in (a) or (b). Is this circuit equivalent to Circuit 4 and Circuit 5?

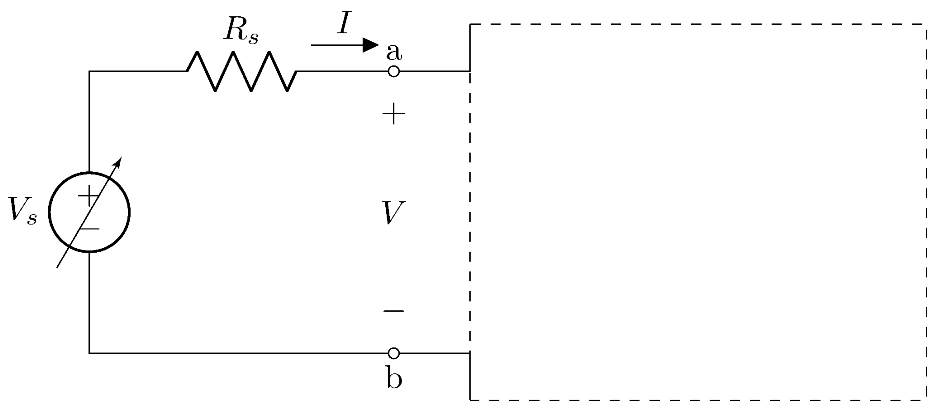
[Hint: Derive a relation between I and V from this circuit. Then compare it with that in (a) or (b) to get I_x.]



3. How can you directly measure the voltage-axis and current-axis intersecting points of the $I - V$ line of any linear circuit?

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 dashed 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.





Draw inside the dashed box

5. Refer to the illustration of an **Oscilloscope** on page 5 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 5 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 checkmarks (✔) to indicate the correct answers. The questions may have more than one answer.

(a) The I-V characteristics of which circuits went **through origin** -

☐ Circuit 2 ☐ Circuit 3 ☐ Circuit 4
☐ Circuit 5 ☐ Circuit 6 ☐ Circuit 7

(b) Circuits 6 and 7 were **equivalent to a resistor** -

☐ Voltage source ☐ Current source ☐ Resistor
☐ Short Circuit ☐ Open source

(c) When the LDR in Circuit 7 was completely **in darkness**, it was equivalent to -

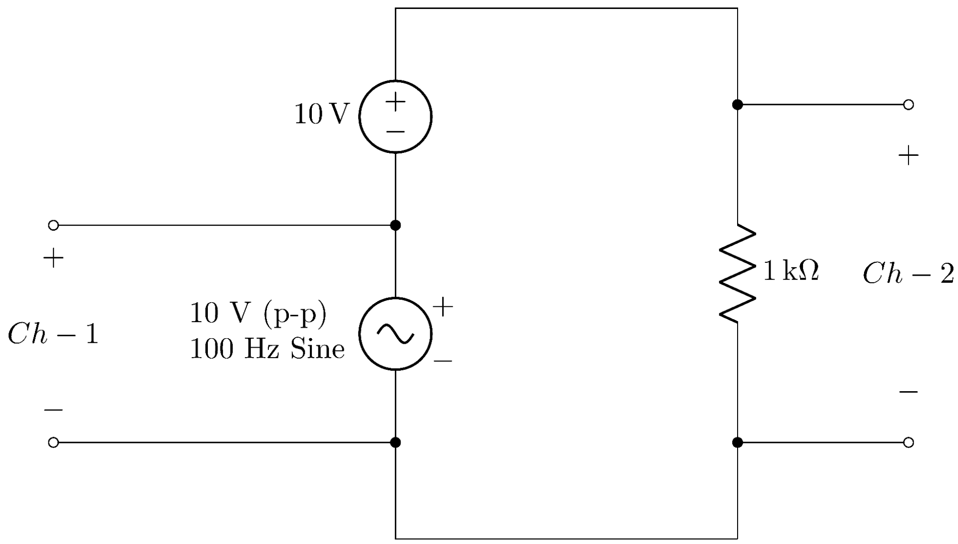
☐ short circuit ☐ open-circuit ☐ 1 kΩ resistor ☐ $0A$ current source

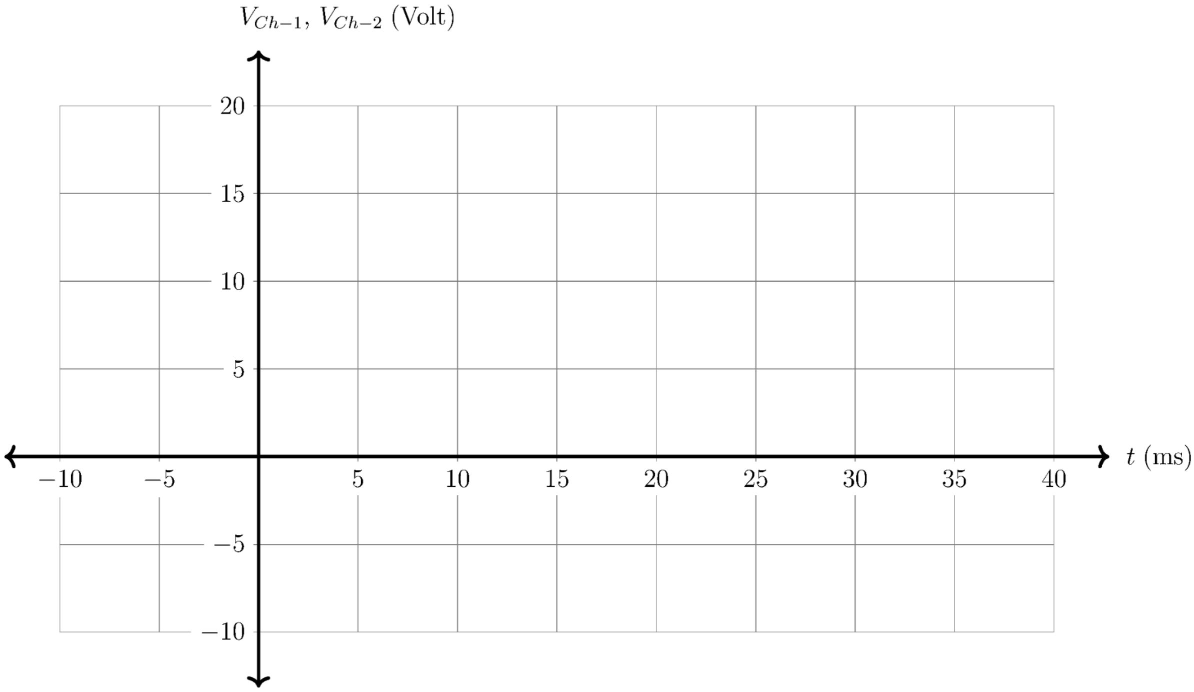
8. Why was it necessary to invert Channel 1 of the Oscilloscope?

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. Approximately 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.





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 2, 3, 4**, **5, 6,** and **7**. in the Oscilloscope. Fit all the images on a pageor two and print.
4. Discussion *[your overall experience, accuracy of the measured data, difficulties experienced, and your thoughts on those]*. Add pages if necessary.