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Experiment No. 4

Study of I-V Characteristics of Linear Circuits

Objective

The aim of this experiment is 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.

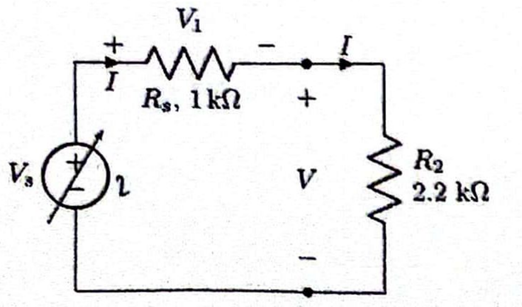
Apparatus

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

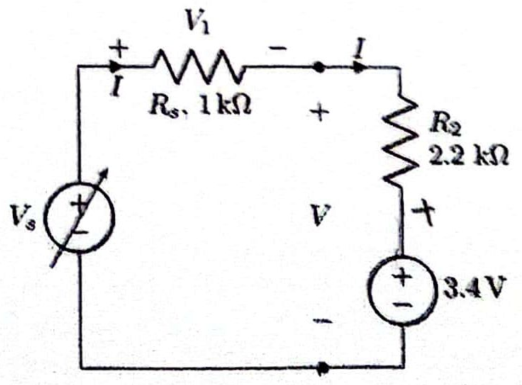
I - V

Procedures

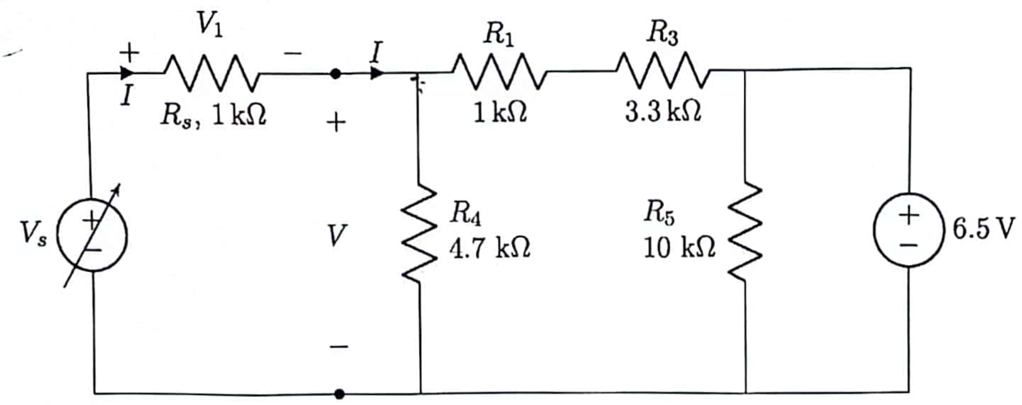
- Measure the resistances of the provided resistors and fill up the data table 1.
- Construct the following circuits on a breadboard. Try to use minimum number of jumper wires:



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: toufiqur **Date:** 10.2.24

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

Table 1: Resistance Data

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

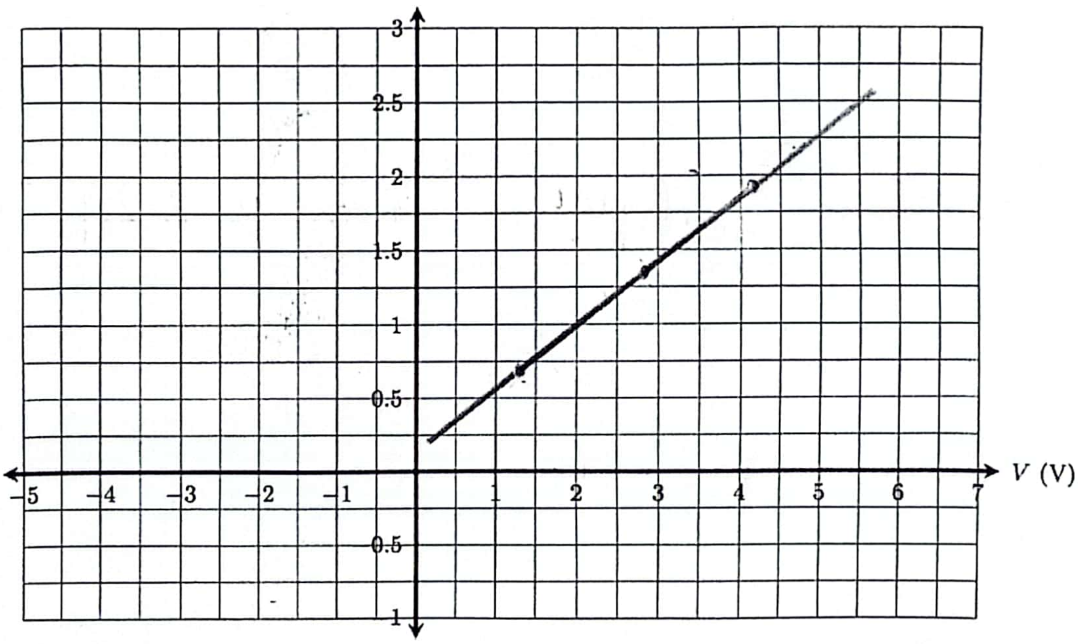
Notation	Expected Resistance	Observed Resistance (kΩ)	Notation	Expected Resistance	Observed Resistance (kΩ)
R_s	1 kΩ	0.987	R_3	3.3 kΩ	3.243
R_1	1 kΩ	0.978	R_4	4.7 kΩ	4.61
R_2	2.2 kΩ	2.160	R_5	10 kΩ	9.93

Table 2: 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	2	1.994	0.639	0.632	1.389	1.385	0.64	0.625
4.0	4	4.05	1.272	1.267	2.785	2.738	1.28	1.25
6.0	6	6.07	1.91	1.887	4.17	4.15	1.93	1.875
8.0								

$I = V/R_s$

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 = ~~[illegible]~~ ~~[illegible]~~ 0.47 $k\Omega^{-1}$

Resistance from the plot, $R_T = \frac{1}{m}$ = ~~2.181~~ ~~0.987~~ 2.13 $k\Omega$

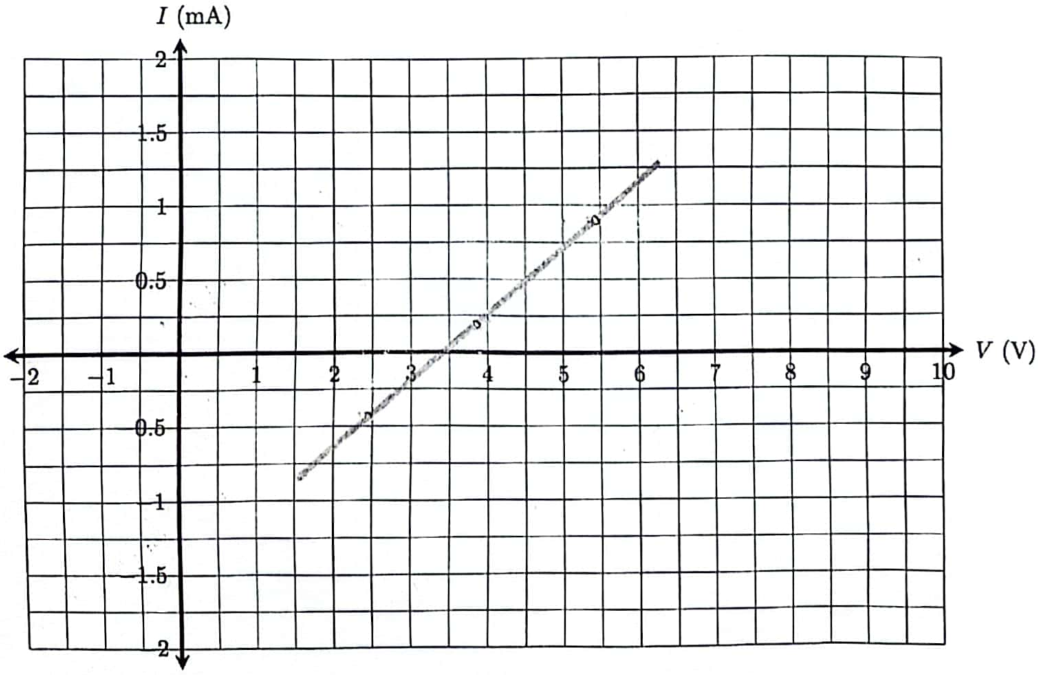
Percentage of Error $= \left|\frac{R_2 - R_T}{R_2}\right| \times 100\%$ = 1.38 ~~54.3~~ %

120 mV

Table 3: 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	2	2.07	-0.417	-0.42	2.492	2.44	-0.422	-.43
4.0	4.1	4	0.19	0.203	3.81	3.753	0.1925	0.1575
6.0	6	6.08	0.340	0.335	5.20	5.159	0.851	0.547
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 = ~~1.013~~ 0.47 $k\Omega^{-1}$

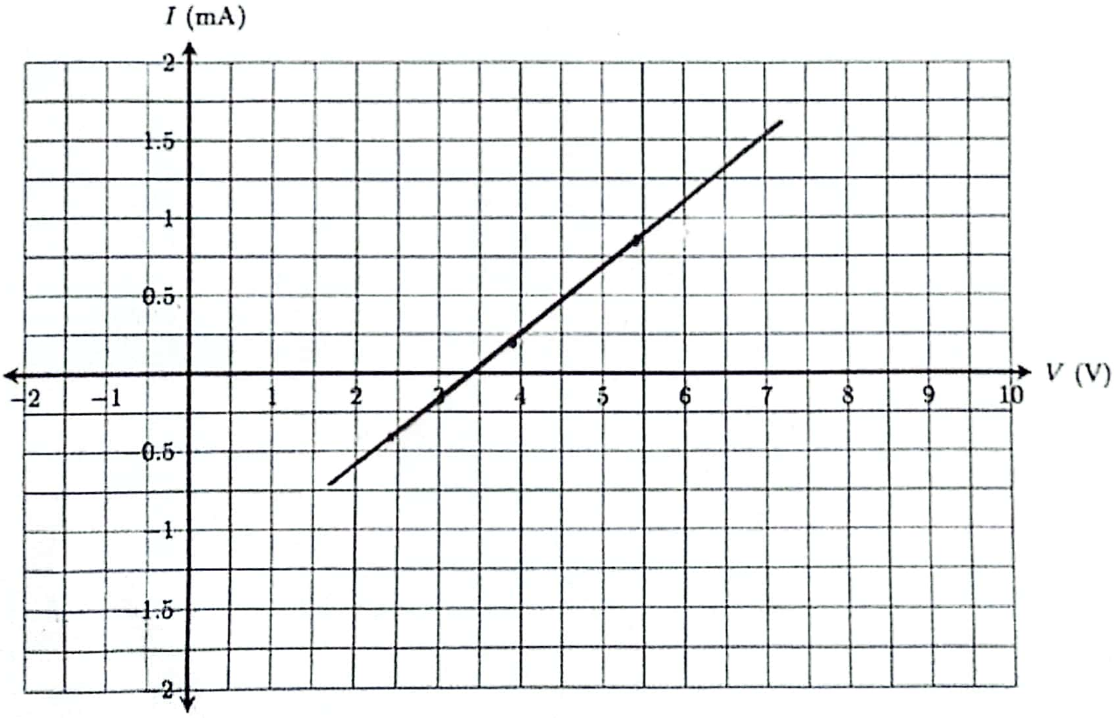
Resistance from the plot, $R_T = \frac{1}{m}$ = 2.11 $k\Omega$

The straight line intersects x-axis at, V_T = 3.4 V

Table 4: Data from Circuit 3

V_S (V)			V_1 (V)		V (V)		$I = \frac{V_1}{R_1}$ (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	2	2.073	-0.41	-0.43	2.492	2.487	-0.415	-.42
4.0	4	4.01	0.1893	0.219	3.82	3.84	0.192	0.21
6.0	6	6.02	0.808	0.8125	5.21	5.19	0.82	0.8125
8.0								

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



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

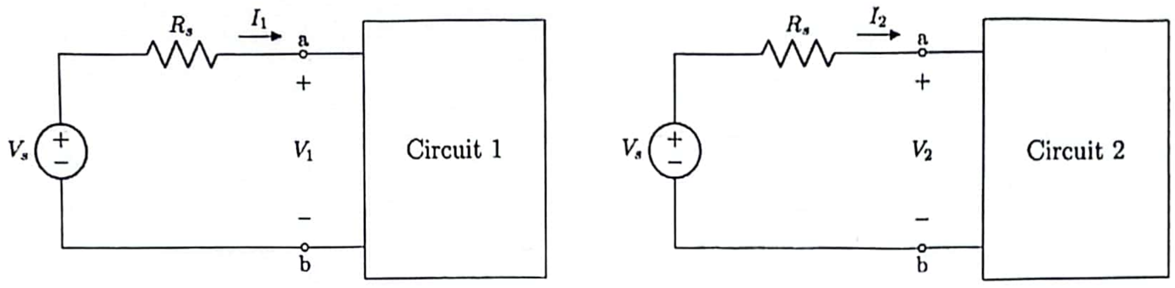
Slope of the straight line, m = 0.45 kΩ^{-1}

Resistance from the plot, $R_T = \frac{1}{m}$ = 2.21 kΩ

The straight line intersects x-axis at, V_T = 3.4 V

Questions

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



For the following two circuits to be equivalent to each other with respect to terminals a-b the condition is $I_1 = I_2$ or $V_1 = V_2$.

2.

(a) For the **Circuit 2** you constructed in the laboratory, derive a relation between I and V.

$$\frac{V-3.4}{1+2.2} = I$$

$$V-3.4 = 3.2I$$

$$V = 3.2I + 3.4$$

(b) For the **Circuit 3** you constructed in the laboratory, derive a relation between I and V.

$$\frac{V}{R_4} + \frac{V-6.5}{R_1+R_3} = I$$

$$\Rightarrow \frac{V}{4.7} + \frac{V-6.5}{1+3.3} = I$$

$$\Rightarrow \frac{V}{4.7} + \frac{V-6.5}{4.3} = I$$

$$\Rightarrow 4.3V + 4.7V - (6.5 \times 4.7) = I(4.7 \times 4.3)$$

$$\Rightarrow 9V - 30.55 = 20.21I$$

$$\Rightarrow V = 2.24I + 3.39$$

(c) Did you notice any similarity between the $I - V$ relationships in (a) and (b)?

☑ Yes ☐ No

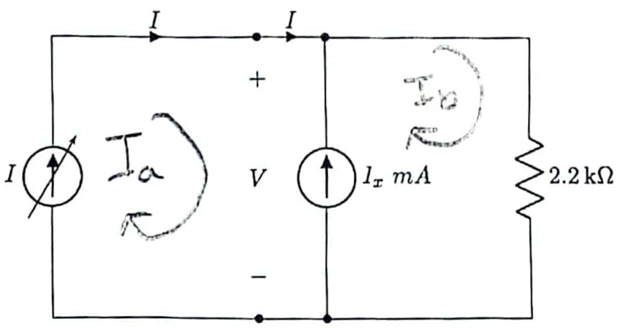
If yes, what are they?

Both have same intersont and gradient

(d) Will it have any effect if one of these two circuits is replaced with the other? Why?

No, as the I-V characteristics is same for both of the circuit.

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



KVL at loop1:

$I_a + V = 0 \ldots$ (i)

Mesh analysis at loop2:

$-V + 2.2 I_b = 0 \ldots$ (ii)

(i)+(ii)

$I_a + 22 I_b = 0$

$\therefore I_a = -2.2 I_b$

Super mesh:

$I_b - I_a = I_x$

$\Rightarrow I_x = I_b - (-2.2 I_b)$

$\therefore I_x = 3.3 I_b$

No, this circuit is not equivalent to circuit 2 and circuit 3

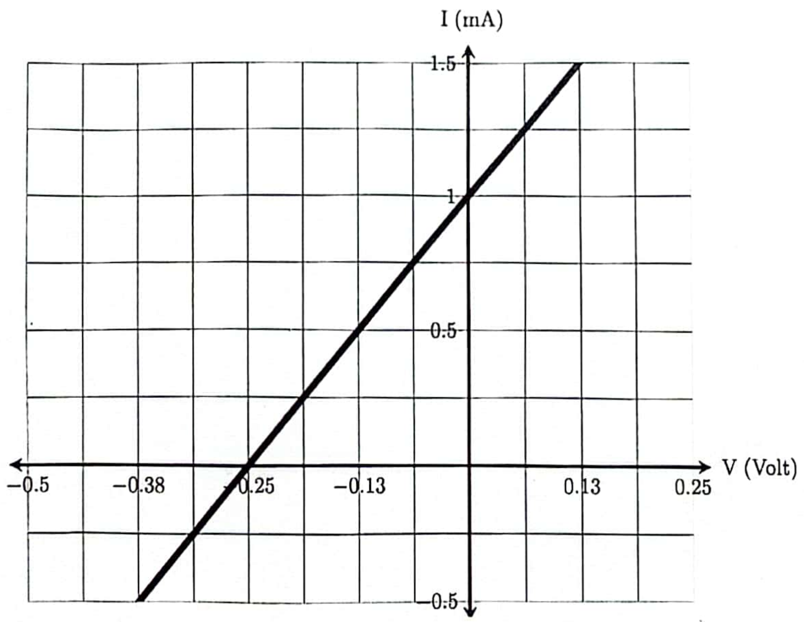
3. Can you think of any way where voltage-axis intersecting points (V_T) could be measured directly for Circuit **1** and **Circuit 2**?

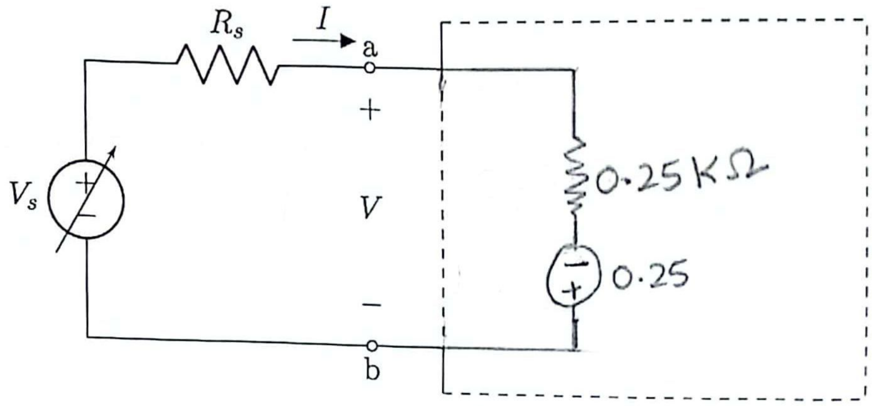
No, because it depends on line intersects x axis which I got from graph.

4. In general, what is the simplest technique to derive the $I - V$ characteristics of any linear two terminal circuit? How many minimum data points are required?

The simplest method for determining a linear two terminal circuits I-V characteristics is to take a series of measurement at various voltage levels and note the corresponding values. Ploting the I-V curve requires adjusting the voltage across the circuit and measuring the resulting current. Minimum two data points are required.

5. 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 (in the next page) a simplified version of the circuit that can give rise to the same $I - V$ as shown. Determine the corresponding parametric values of the circuit elements.





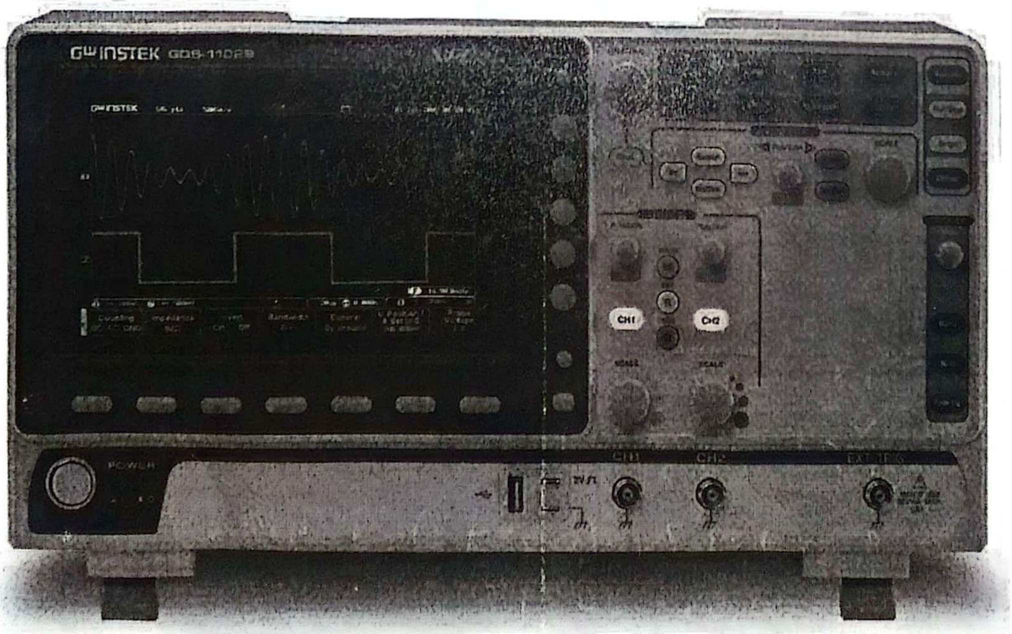
Draw inside the dashed box

Part 2: By Using Oscilloscope

Theory

Oscilloscope

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



An oscilloscope