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### 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.

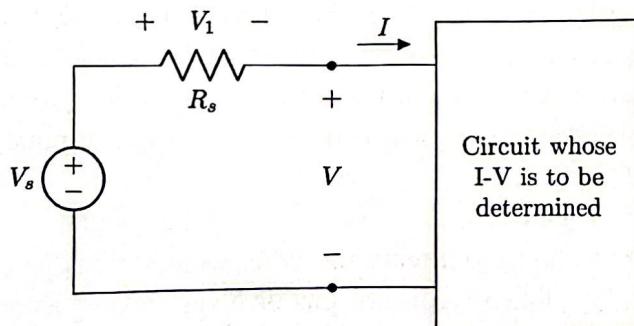
The I-V characteristic of an ideal voltage source (an ideal voltage source is a theoretical concept that maintains a constant voltage across its terminals, regardless of the current flowing through it.) is a vertical line on an I-V graph, indicating that the voltage remains constant ( $V$ ) regardless of the current ( $I$ ). Mathematically, it can be represented as  $V = \text{constant}$ . 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

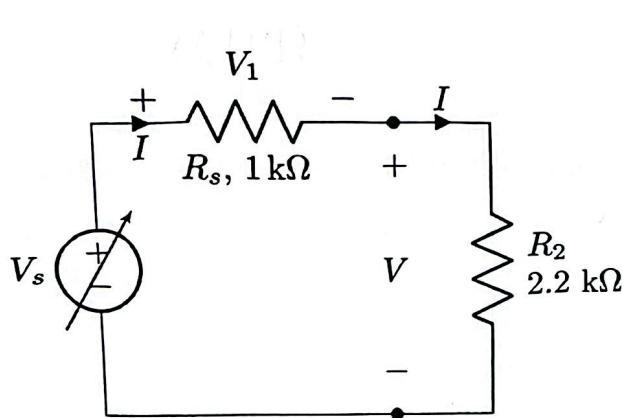
- Multimeter
- Resistors (1 k $\Omega$  x 2, 2.2 k $\Omega$ , 3.3 k $\Omega$ , 4.7 k $\Omega$ , 10 k $\Omega$ )
- DC power supply
- Breadboard
- Jumper wires

## Procedures

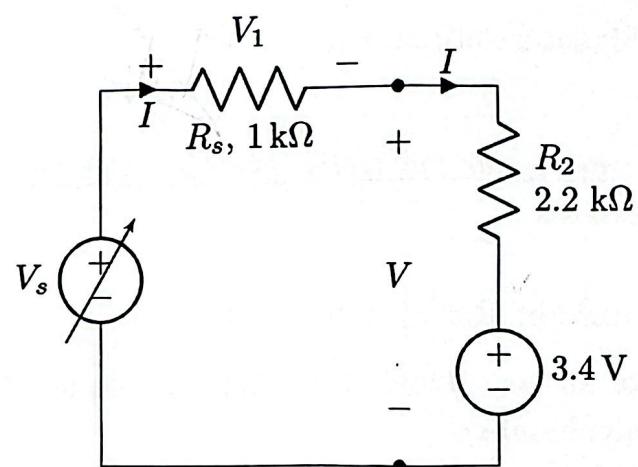
- Measure the resistances of the provided resistors and fill up Table 0.
- The following is the experimental setup we'll follow to derive  $I - V$  characteristics of any circuit. Here,  $V_s$  is the applied voltage which is to be varied. The resistor  $R_s$  is used to facilitate the current measurement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



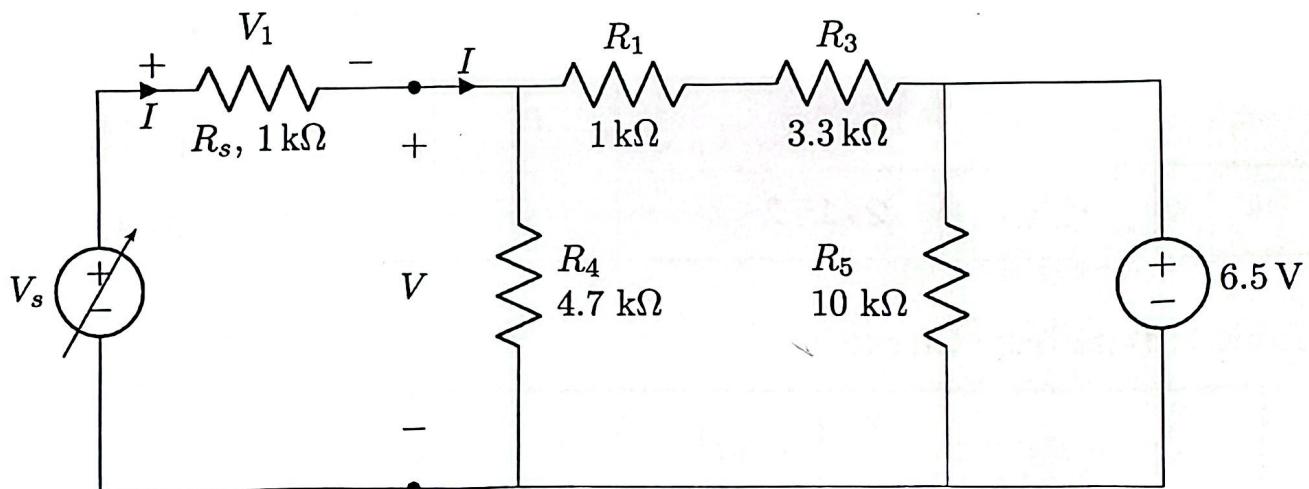
- Construct the following circuits on a breadboard. Try to use as less number of jumper wires as possible.



**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  $1\text{ k}\Omega$  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:

8/4/28

**\*\* 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**

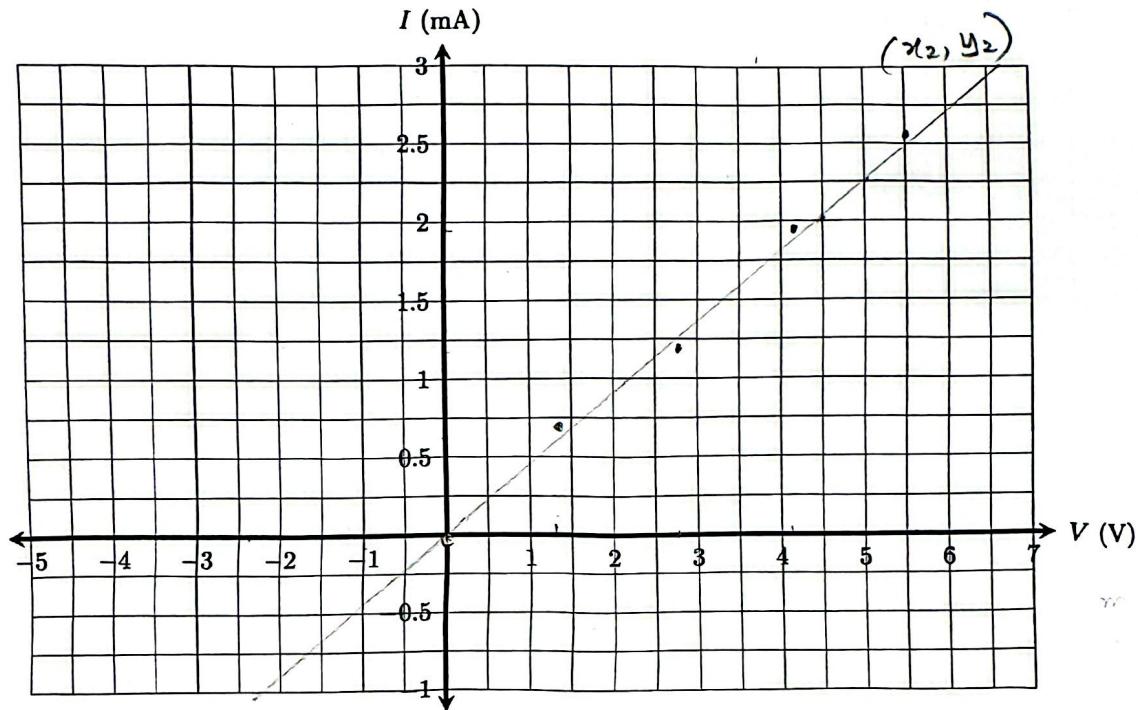
For all your future calculations, please use the observed values only (even for theoretical calculations).

Notation	Expected Resistance	Observed Resistance (kΩ)	Notation	Expected Resistance	Observed Resistance (kΩ)
$R_s$	1 kΩ	0.983	$R_3$	3.3 kΩ	3.25
$R_1$	1 kΩ	0.98	$R_4$	4.7 kΩ	4.65
$R_2$	2.2 kΩ	2.172	$R_5$	10 kΩ	9.99

**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	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
0.0	0	-0.0036	-0.001	-0.0011	-0.0024	-0.0025	-0.001	-0.0011
2.0	2.0	2.033	0.632	0.631	1.398	1.402	0.643	0.641
4.0	4.0	4.01	1.253	1.246	2.77	2.764	1.274	1.267
6.0	6.0	6.07	1.894	1.887	4.17	4.183	1.926	1.919
8.0	8.0	8.05	2.516	2.502	5.54	5.548	2.56	2.545

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



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

$$\text{Slope of the straight line, } m = \boxed{0.462 \text{ k}\Omega^{-1}}$$

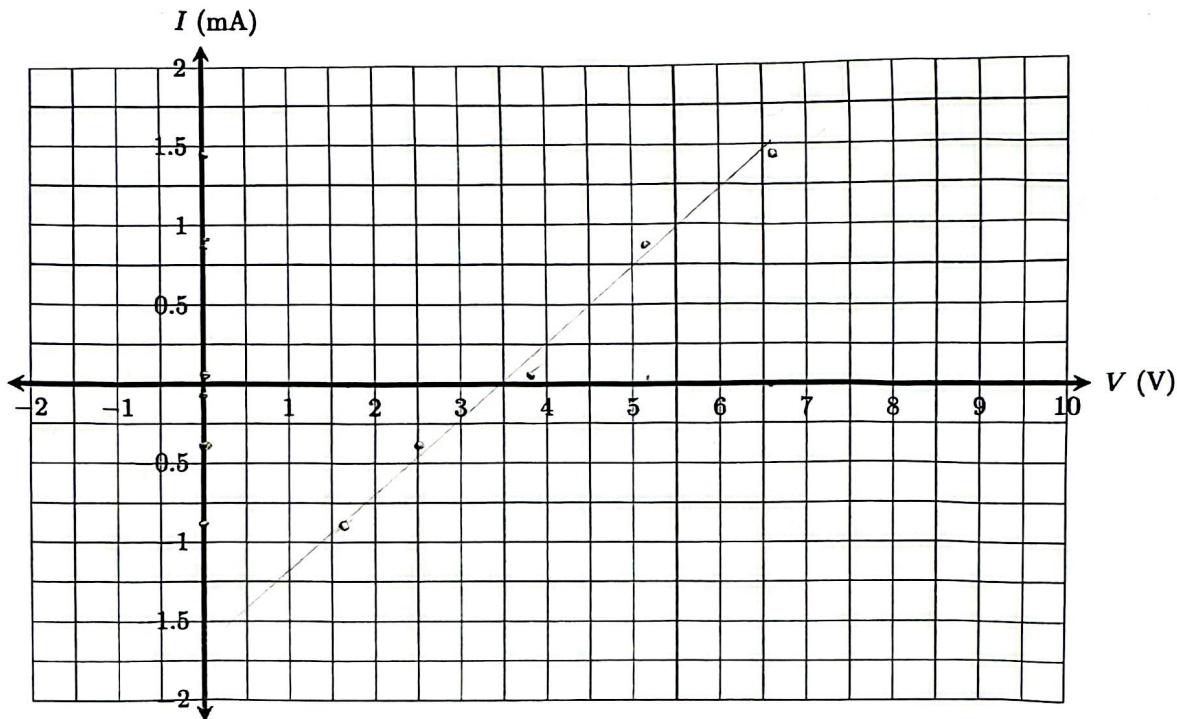
$$\text{Resistance from the plot, } R_T = \frac{1}{m} = \boxed{2.164 \text{ k}\Omega}$$

$$\text{Percentage of Error} = \left| \frac{R_2 - R_T}{R_2} \right| \times 100\% = \boxed{0.3683 \%}$$

**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 multimeter	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
0.0	0.8	0.784	-0.816	-0.813	1.602	1.597	-0.83	-0.827
2.0	2.0	2.087	-0.411	-0.408	2.498	2.495	-0.42	-0.415
4.0	4.0	4.06	0.208	0.205	3.86	3.855	0.211	0.208
6.0	6.0	6.04	0.826	0.821	5.22	5.219	0.84	0.835
8.0	8.0	8.02	1.441	1.436	6.58	6.584	1.466	1.461

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



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

$$\text{Slope of the straight line, } m = \boxed{0.462 \text{ k}\Omega^{-1}}$$

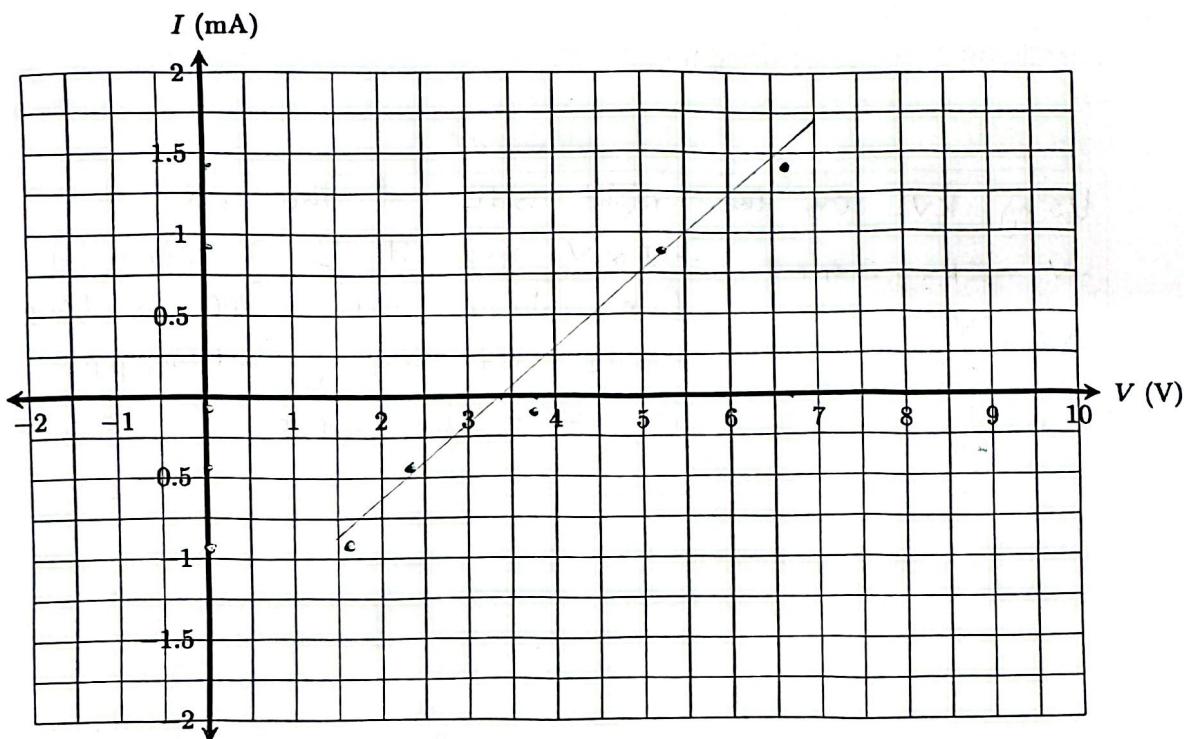
$$\text{Resistance from the plot, } R_T = \frac{1}{m} = \boxed{2.167 \text{ k}\Omega}$$

$$\text{The straight line intersects x-axis at, } V_T = \boxed{3.409 \text{ V}}$$

**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 multimeter	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
0.0	0.7	0.779	-0.811	-0.809	1.591	1.582	-0.825	-0.822
2.0	2.0	2.022	-0.432	-0.428	2.455	2.453	-0.439	-0.435
4.0	4.0	4.0	0.178	0.183	3.837	3.841	-0.181	-0.179
6.0	6.0	6.02	0.8	0.783	5.22	5.27	0.813	0.796
8.0	8.0	8.03	1.418	1.414	6.62	6.58	1.44	1.438

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



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

$$\text{Slope of the straight line, } m =$$

$$0.4528 \text{ k}\Omega^{-1}$$

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

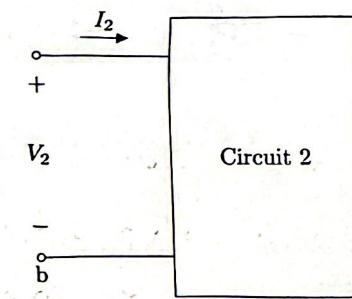
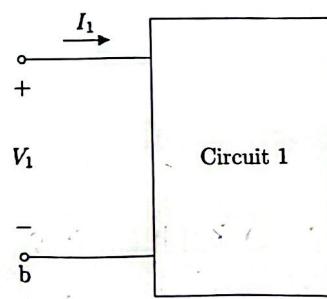
$$2.208 \text{ k}\Omega$$

$$\text{The straight line intersects x-axis at, } V_T =$$

$$3.433 \text{ V}$$

## 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 two circuits to be equivalent at their terminals for any applied  $V_1$  and  $V_2$  voltages the resulting currents  $I_1$  and  $I_2$  must be identical.

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  $V$ ]

Using KVL on the right side of the circuit,

$$-V + IR_2 + 3.4 = 0 \quad \therefore I \propto V \text{ and it is a straight line where the slope is } \frac{1}{2.2}$$

$$\Rightarrow I = \frac{V - 3.4}{2.2} \quad = 0.45 \text{ and the y intercept}$$

$$\Rightarrow I = \frac{1}{2.2} \cdot V - \frac{3.4}{2.2} \quad \text{is } -\frac{3.4}{2.2} = -1.5$$

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

[Hint: The  $10\text{k}\Omega$  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  $V$ ]

By ignoring the  $10\text{k}\Omega$  resistor the circuit will look like below,

Now using KVL on the loop we get,

$$-V + (3.3 + 1)I + 6.5 = 0$$

By applying KCL in node  $a$ ,

$$I = I_1 + I_2 \Rightarrow 4.3I - \left(\frac{4.3}{4.7}\right)V - V + 6.5 = 0$$

$$\Rightarrow I_2 = \frac{\left[\left(\frac{4.3}{4.7}\right) + 1\right]V}{4.3} - \frac{6.5}{4.3}$$

$$\Rightarrow I_2 = 0.495V - 1.5$$

$\therefore I \propto V$  and it is a straight line where the slope is 0.45 and the y intercept

is  $-\frac{3.4}{2.2} = -1.5$ .

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

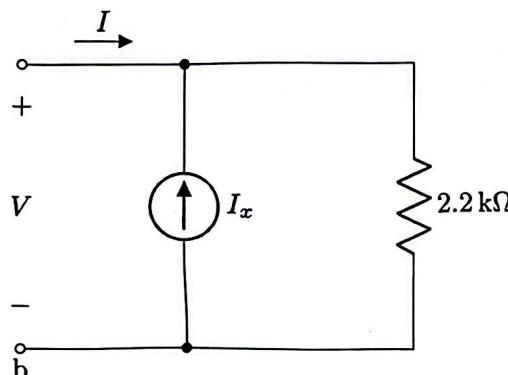
Yes       No

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??

Both of the equations are the same and they both have the same slope and y-intercept. There will be no effect if one of them is replaced with the other.

- (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  $i_x$ .]



By using KVL we get, So, by comparing eqn ①  
 $-V + (I + I_m)(2.2) = 0$  with them we get  
 $\Rightarrow -V + 2.2I + 2.2I_m = 0$  the y intercept is  
 $\therefore I = \frac{V}{2.2} - I_m - ①$  equal to  $I_m$ .

Since the equations  $\therefore I_m = -1.5$   
 we got from (a) and  $\therefore I_m$  must be  $\underline{\underline{-1.5}}$ .  
 (b) are identical.

3. Can you think of any way to measure 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?

To find the voltage axis intercept we have to remove all the external components from the circuit to create an open circuit. The voltage measured across the terminals is the voltage axis intercept. Then we have to short the circuit and measure the current flowing in the wire to get the current axis intercept.

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.

