Lecture-3

I-V characteristics

Current-Voltage (I-V) Characteristics

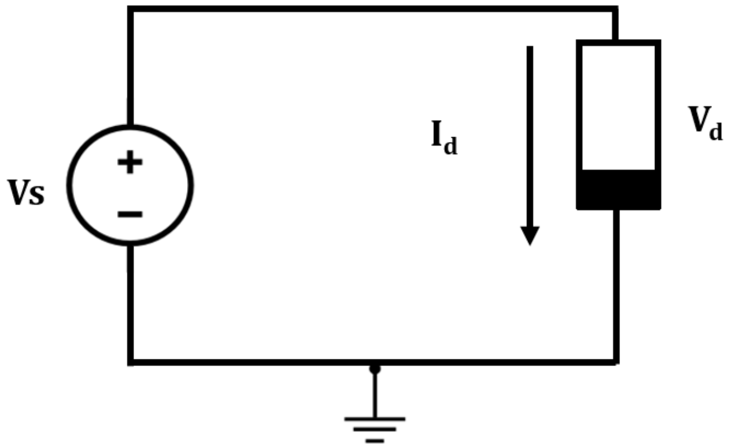
- I-V characteristic defines the relationship between the **current flow (through), I** and **voltage (across), V** an electronic device or element.

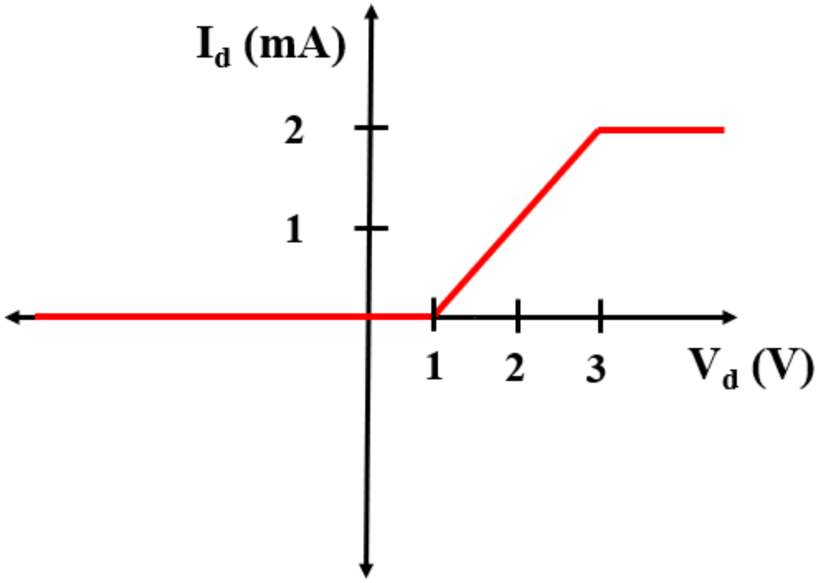
- A tool for understanding the operation of the circuit.

- The Current-Voltage (I-V) characteristics are found by evaluating the **response** of a device/element under different conditions. The behavior of a device depends on the **applied excitation** and can change if the excitation changes. For example, a device may act as an "open circuit" under certain input conditions and as "current source" in another. A diode acts as an open circuit below a specific threshold voltage and acts differently after that.

Current-Voltage (I-V) Characteristics

Example:

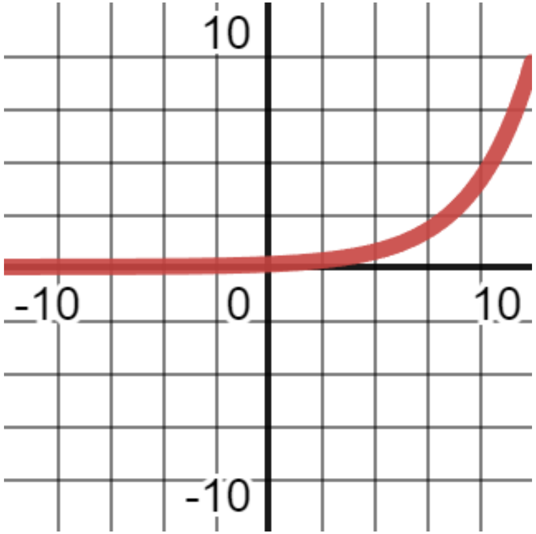




Current-Voltage (I-V) Characteristics

$$I = kV \qquad I = kV^2 \qquad I = \mathrm{A} \cdot \exp(\frac{V}{b})$$

$$y = mx \qquad y = ax^2 \qquad y = \mathrm{A} \cdot \exp(\frac{x}{b})$$



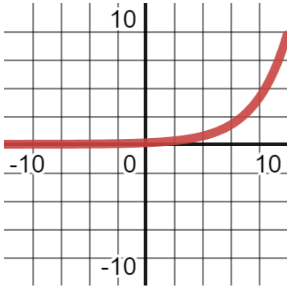
Type of (I-V) Characteristics

1. Linear Devices/Elements: The Current-Voltage relationship is linear i.e. the current through the element is a linear function of the applied voltage across it. The relationship can be characterized by:

$$I = kV$$

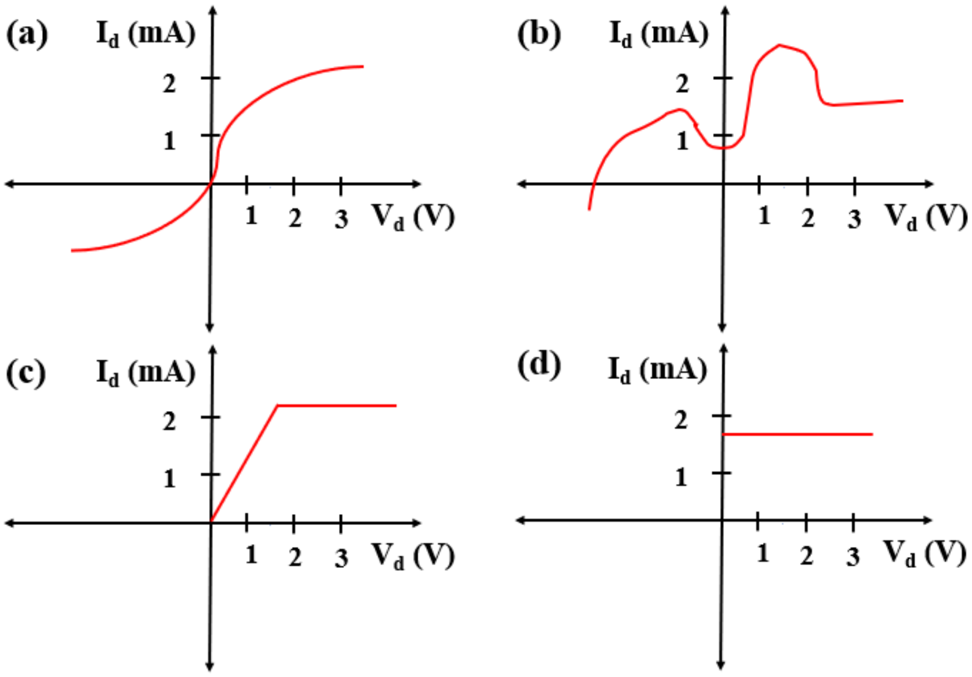
2. Non-Linear Devices/Elements: The Current-Voltage relationship is Non-linear i.e., the current through the element is a nonlinear function of the applied voltage across it.

$$I = k\sqrt{V}$$
$$I = kV^2$$
$$I = kV^3$$



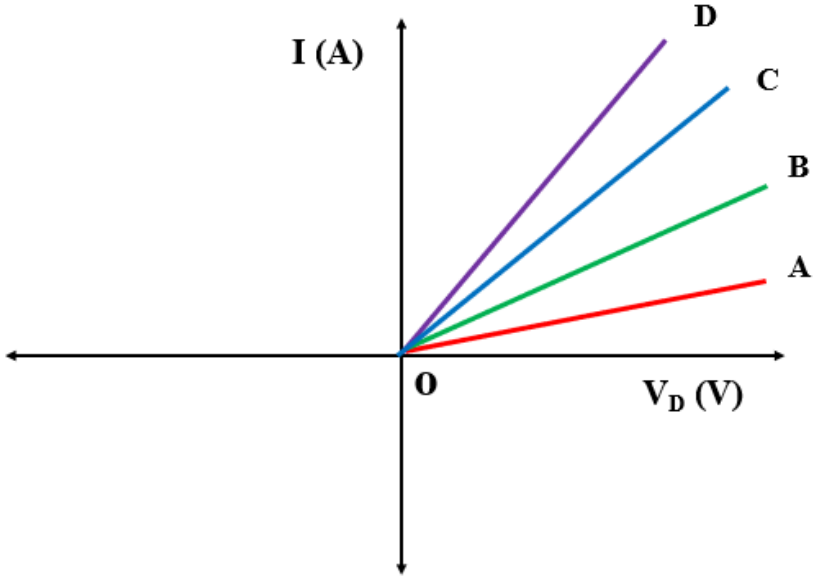
Type of (I-V) Characteristics

- Identify which of these I-V curves are Linear and which are Nonlinear



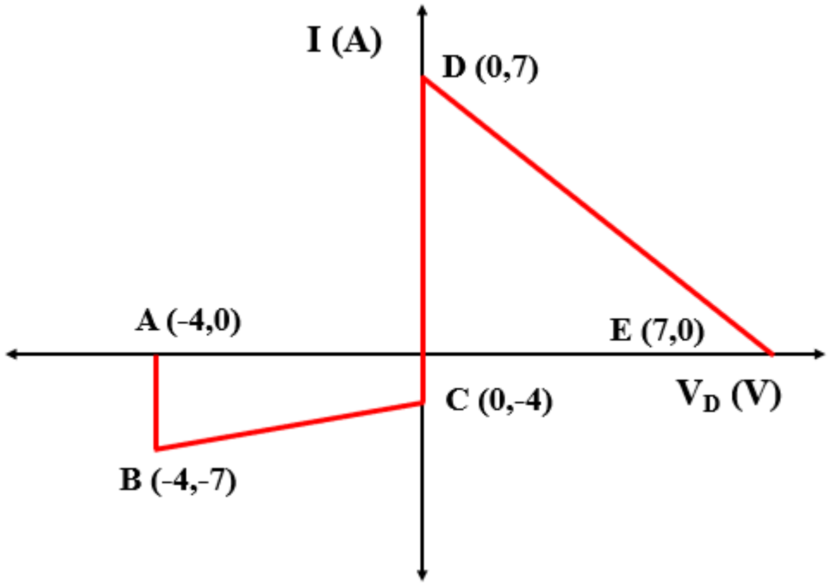
Linear Devices/Elements

- Write down the slopes of these following regions in ascending order (you do not need to calculate the slopes)



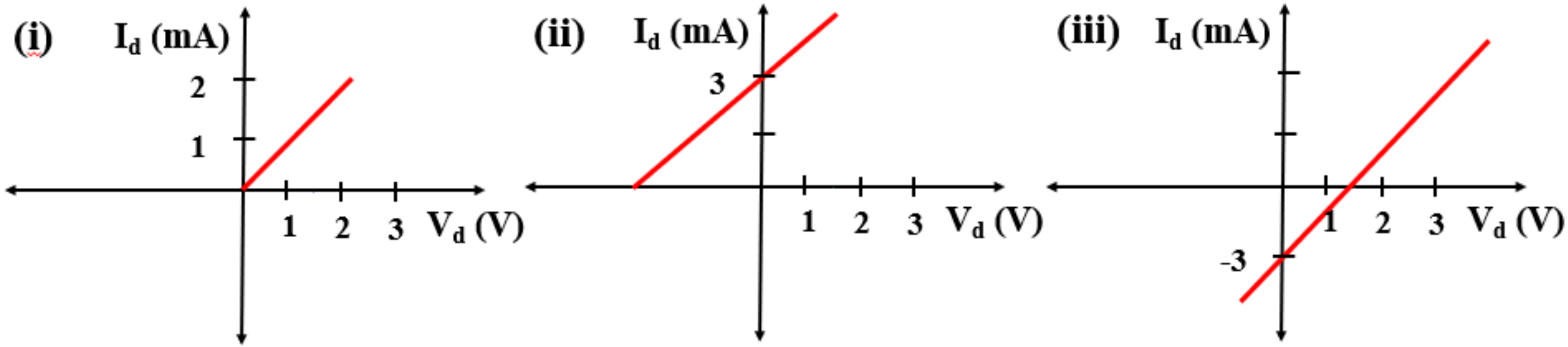
Linear Devices/Elements

- Find out the slope of the following curves



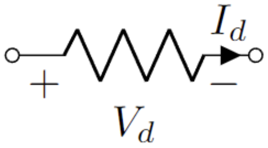
Linear Devices/Elements

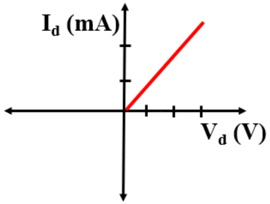
- For the lines represented by $y = mx + c$ what is the value of c in the following figures [Figure (i), (ii) and (iii)]



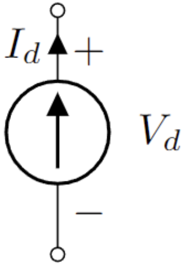
Linear Devices/Elements:

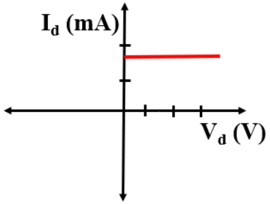
- Resistors



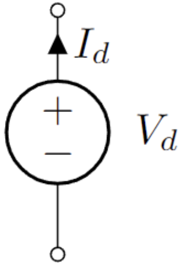


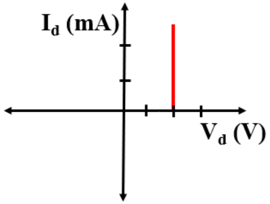
- Current Source





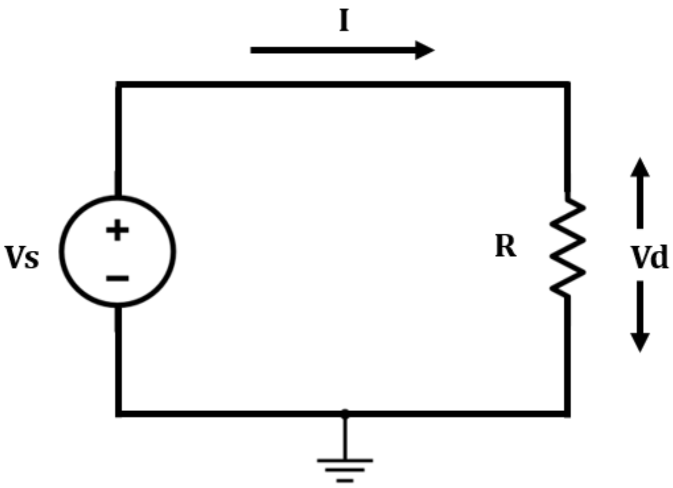
- Voltage Source





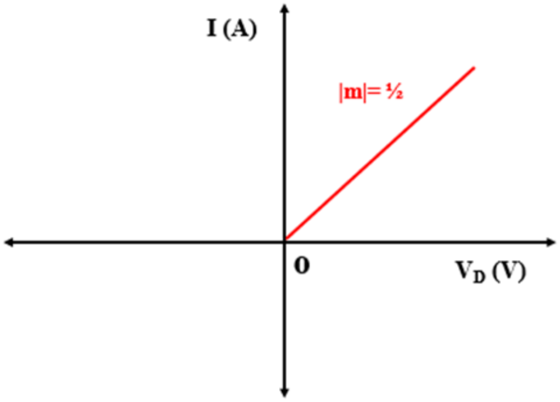
Resistor

- The relationship between current, $\boldsymbol{I}$ and voltage, $\boldsymbol{V_d}$ in a resistor of value '**R**' is defined by the "**<u>Ohm's law</u>**":



$$V_d = IR$$
$$\Rightarrow I = \frac{V_d}{R}$$
$$\Rightarrow I = \frac{1}{R} \cdot V + 0$$

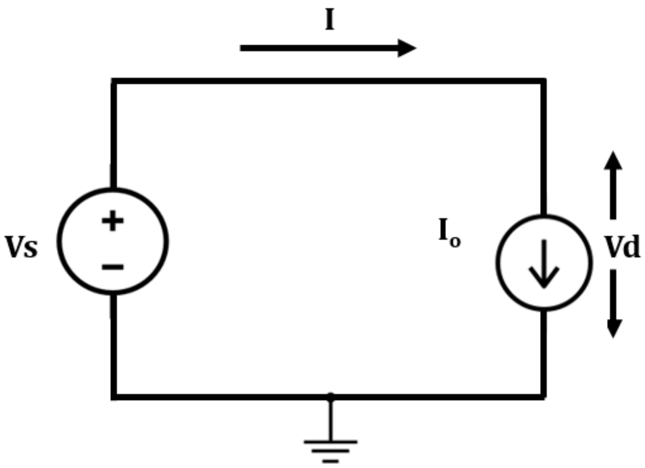
$$\boldsymbol{y = m \cdot x + c}$$



I-V curve of a 2Ω resistor

Current Source

- The value of current flow through a current source is **FIXED** and thus does not change with voltage. The equation is as follows



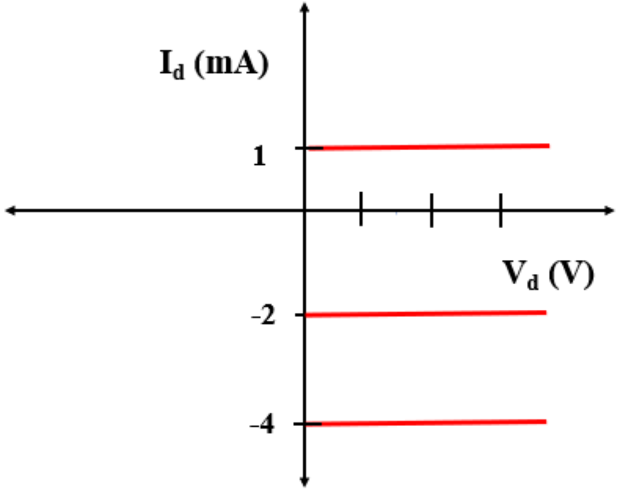
$$I = I_0$$

$$\boldsymbol{y = c}$$

$$I = 0 \cdot V_d + I_0$$

$$\boldsymbol{y = m \cdot x + c}$$

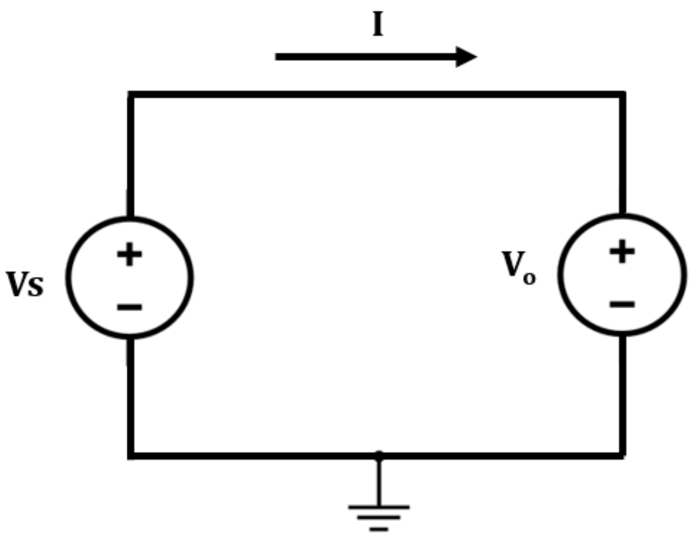
Slope: $\boldsymbol{m = 0}$



This curve intersects the y axis at $\boldsymbol{I = I_0}$.

Voltage Source

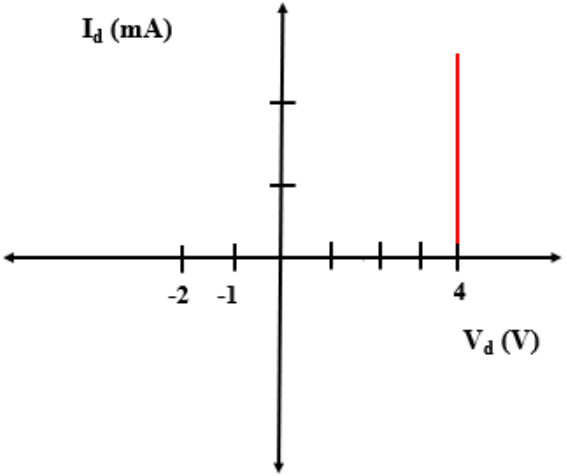
- The value of *voltage across a voltage source* is **FIXED** and thus does not change even if the current through the branch changes.



$V = V_0$

$\boldsymbol{x = c}$

Slope: $\boldsymbol{m} = \infty$

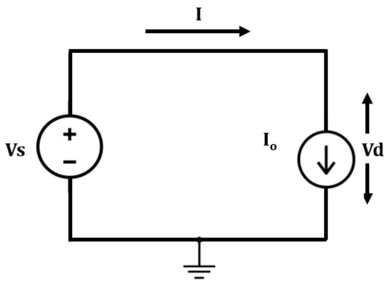


This curve intersects the x axis at $\boldsymbol{V_d = V_o}$.

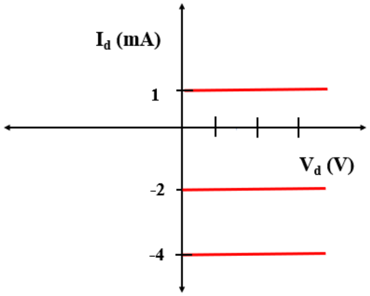
Electrical Sources

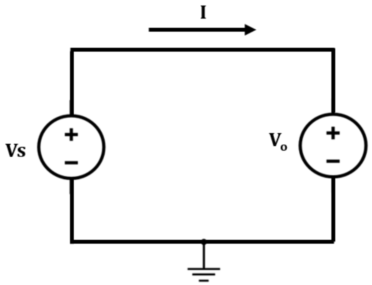
Ideally, internal resistance of a **CURRENT SOURCE** is **infinite (undefined)**

That of a **VOLTAGE SOURCE** is **zero**

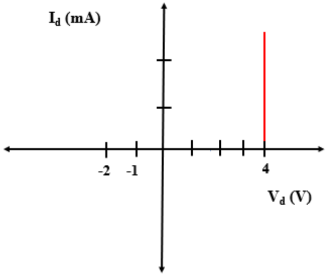


Resistance: ∞



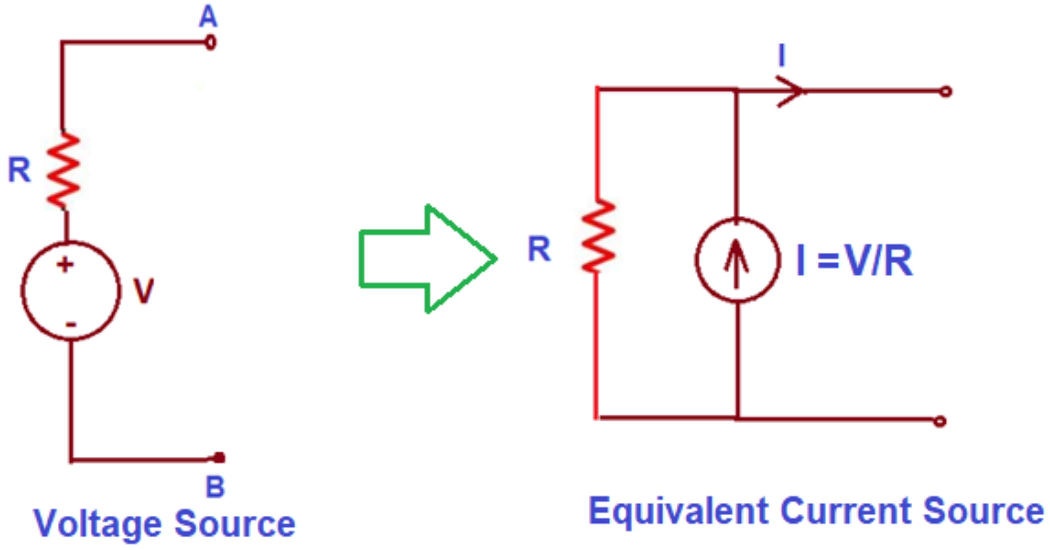


Resistance: 0

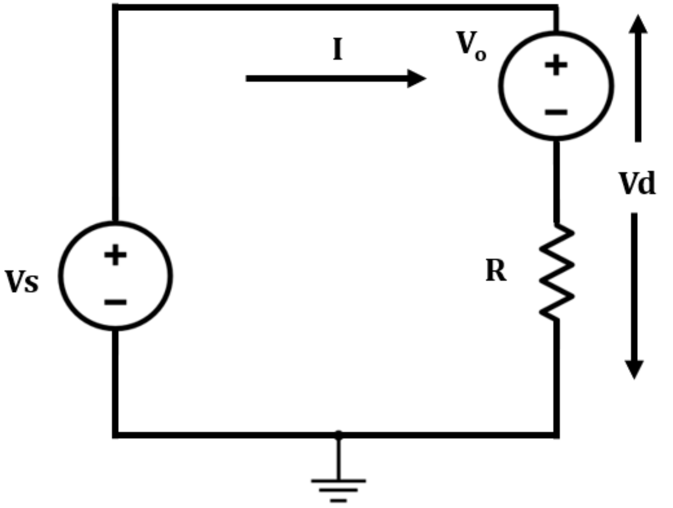


Hybrid/ Compound Linear Circuits

- Voltage Source in Series with a Resistor
- Current source in Parallel with a Resistor



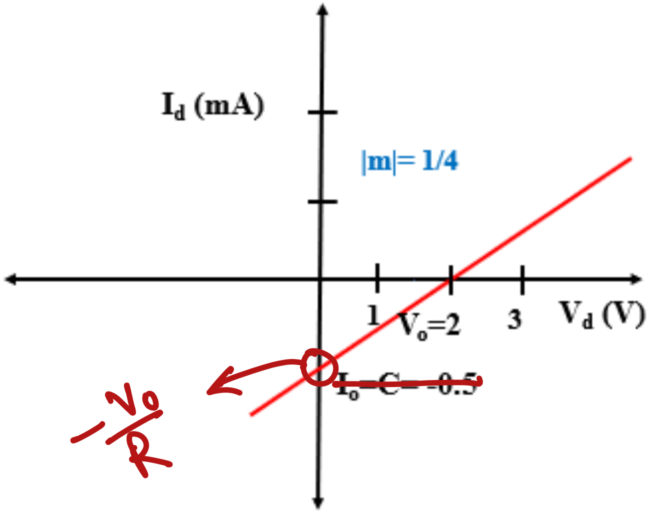
Voltage Source in Series with a Resistor



$$V_d - V_o = IR$$
$$\Rightarrow I = \frac{V_d - V_o}{R}$$
$$\Rightarrow I = \frac{1}{R} \cdot V_d - \frac{Vo}{R}$$

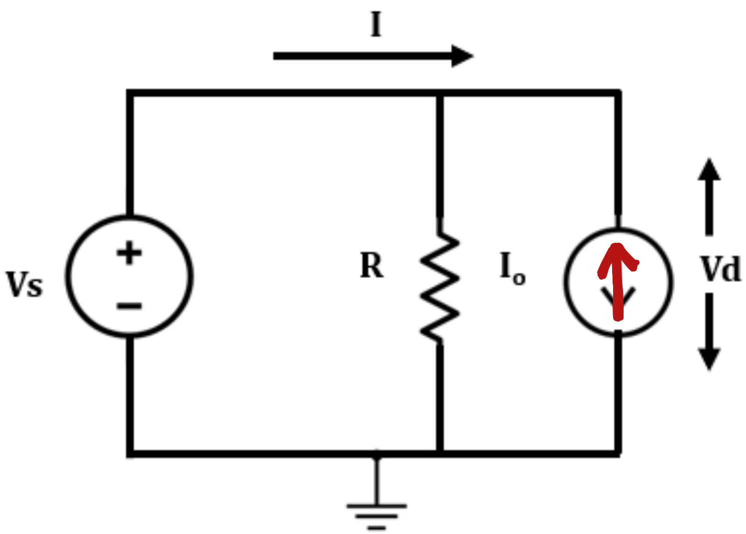
$$\boldsymbol{y = mx + c}$$

$$\boldsymbol{m = \frac{1}{R}}$$
$$\boldsymbol{c = -\frac{V_0}{R}}$$



I-V curve of a **4 *k*Ω** resistor in series with a **2 V** voltage source

Current source in Parallel with a Resistor



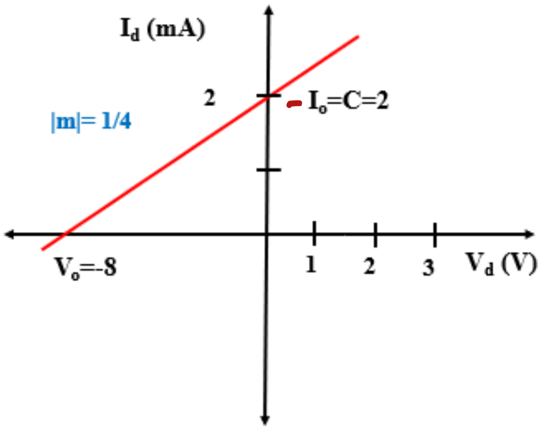
$$I = \frac{V_d}{R} + I_0$$

$$\Rightarrow I = \frac{1}{R} \cdot V_d \cancel{+} - I_0$$

$$\boldsymbol{y = mx + c}$$

$$\boldsymbol{m = \frac{1}{R}}$$

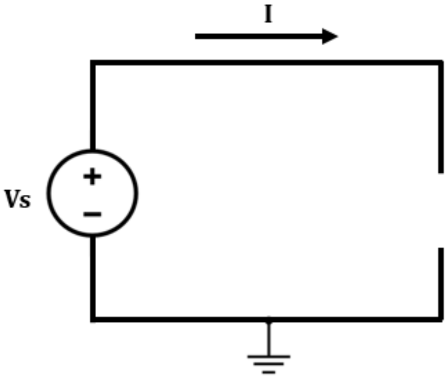
$$\boldsymbol{c = -I_0}$$



The value of a resistor CAN NOT be Negative!

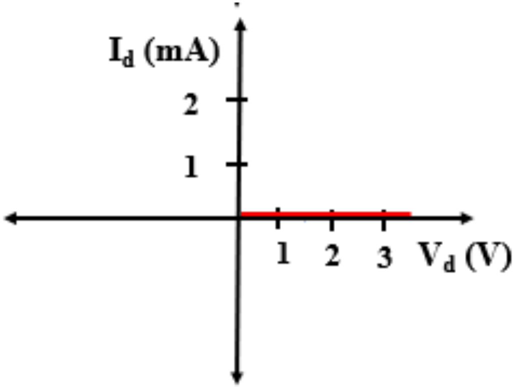
Degenerate Linear Elements

- Open Circuit

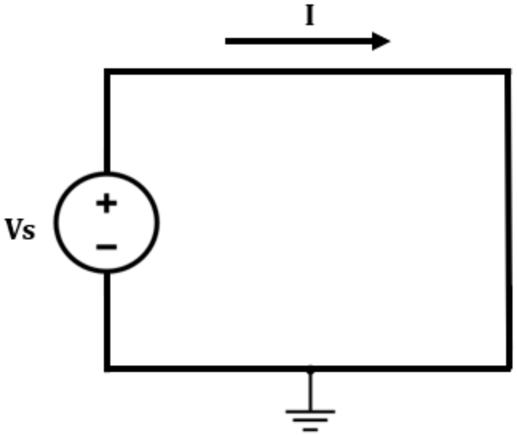


$$I_d = I_0 = 0$$

$$\boldsymbol{y = c = 0}$$

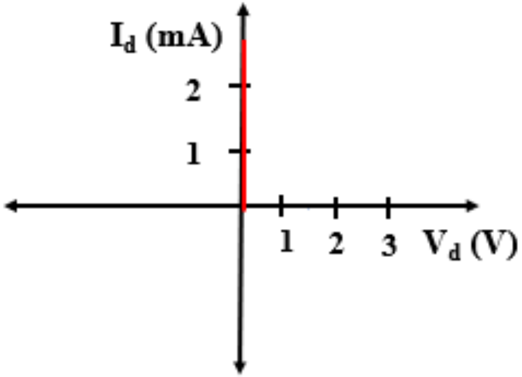


- Short Circuit



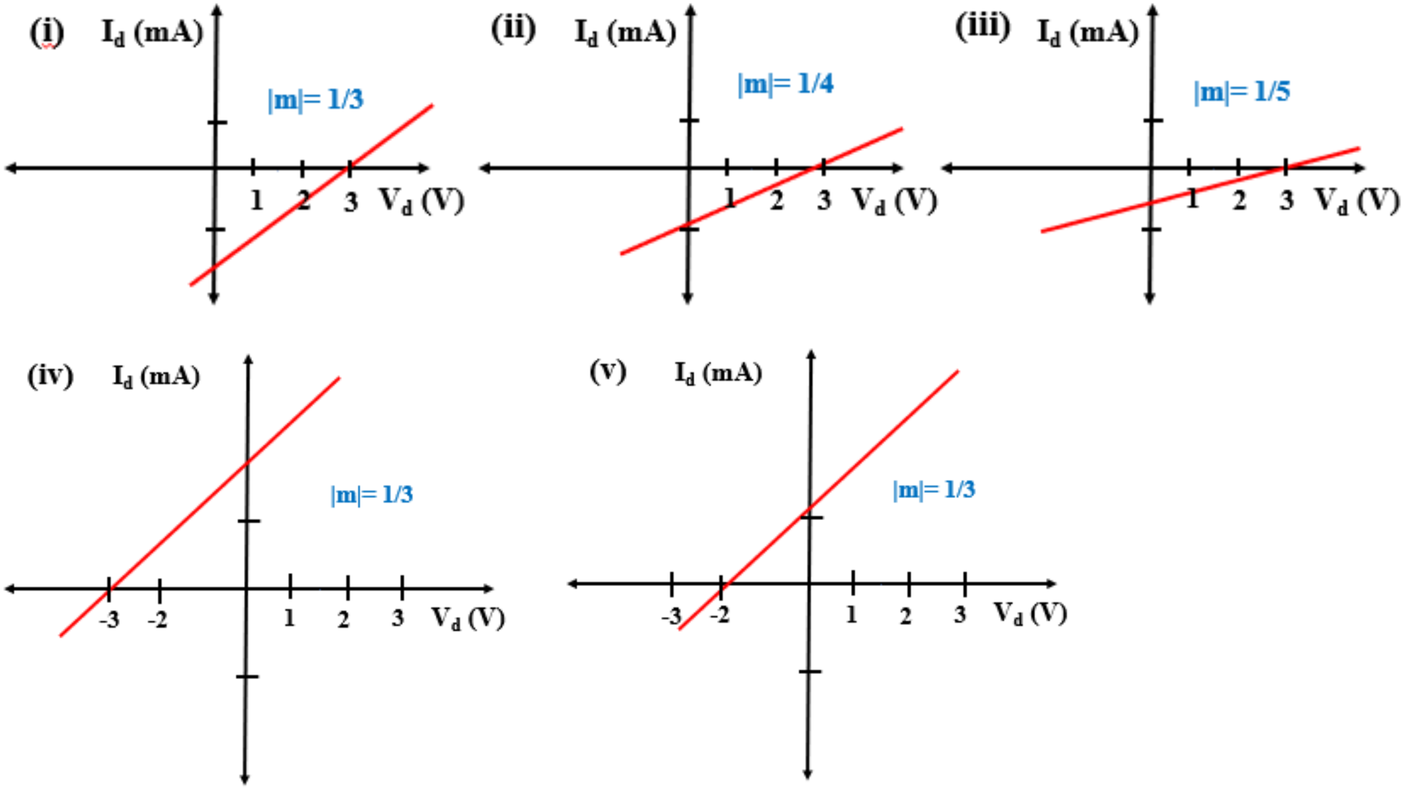
$$V = V_0 = 0$$

$$\boldsymbol{x = c = 0}$$



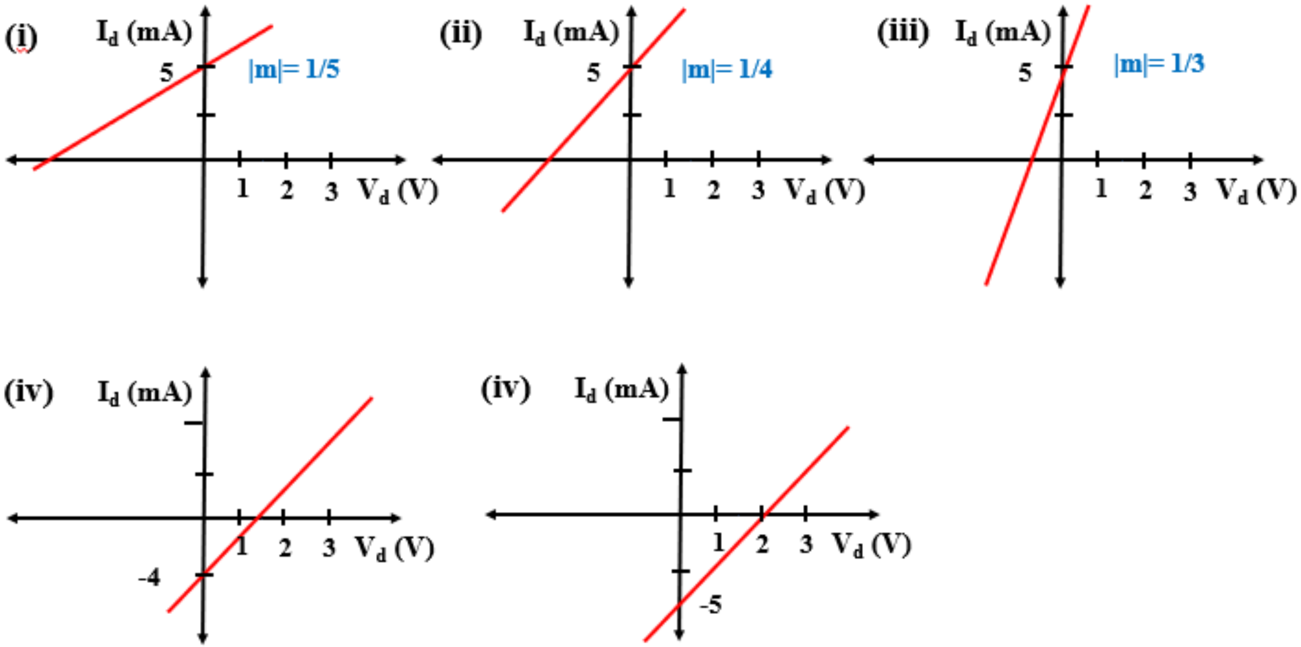
Voltage Source in Series with a Resistor

- Find the circuit



Current source in Parallel with a Resistor

Find the circuit

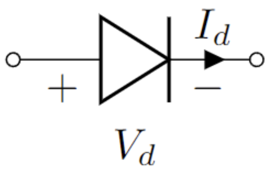


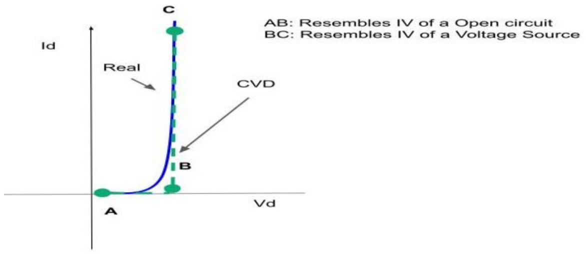
Practice Problems

1. A Voltage Source, $V_o = -10$ V in series with a resistor of $R = 3$ kΩ.
   i. Write down the equation representing this curve
   ii. Determine the unknown parameters
   iii. Label the I-V curve
2. A Current Source, $I_o = -5$ mA in parallel with a resistor of $R = 5$ kΩ.
   i. Write down the equation representing this curve
   ii. Determine the unknown parameters
   iii. Label the I-V curve
3. A Current Source, $I_o = 5$ mA in parallel with a resistor. The slope of the curve is, $m = -5\ k\Omega^{-1}$.
   i. Write down the equation representing this curve
   ii. Determine the unknown parameters
   iii. Label the I-V curve

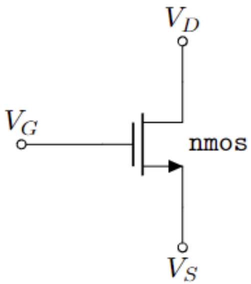
Non-Linear Devices/Elements

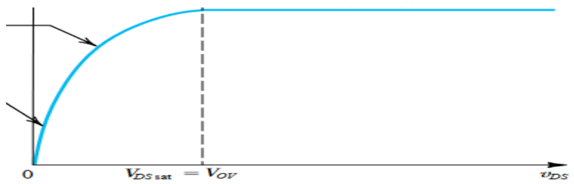
- Diode



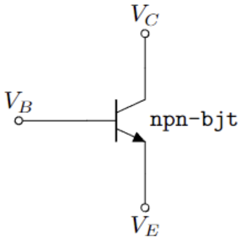


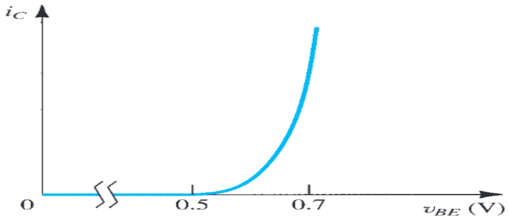
- MOSFET





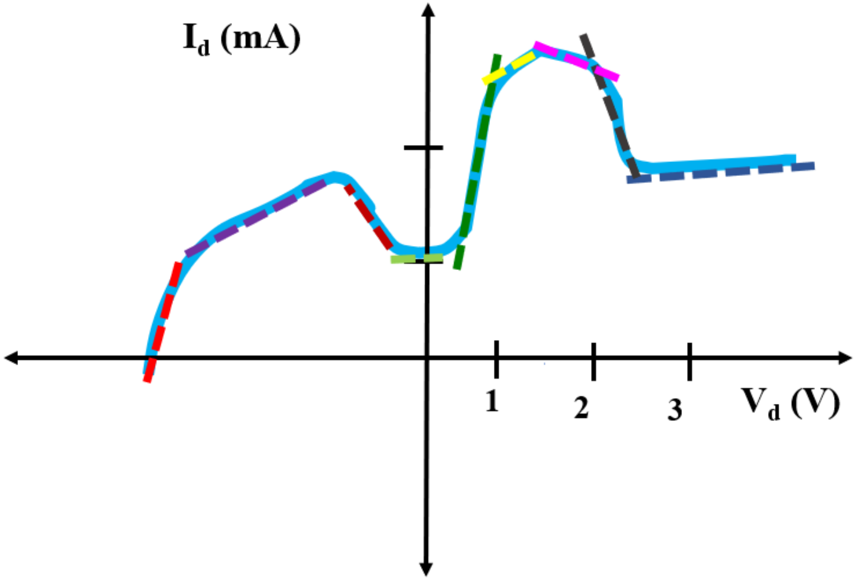
- BJT





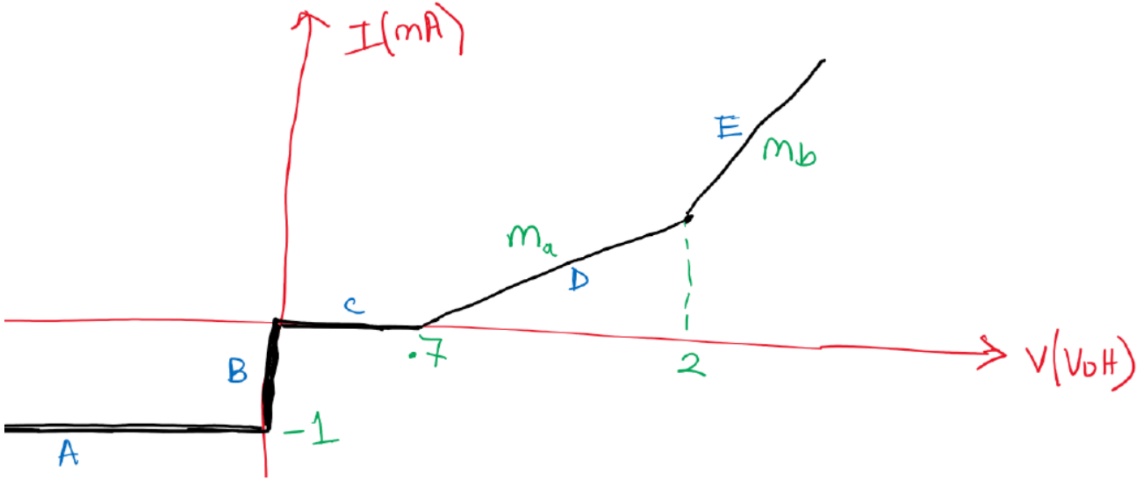
Piecewise Linear Approximation for NL devices

- Simplifying non-linear IV characteristics by piecewise linear parts.
- Non-linear functions are usually approximated by a series of linear segments that follow the tangent of the non-linear segment as can be seen from the following figure.



Piecewise Linear Approximation for NL devices

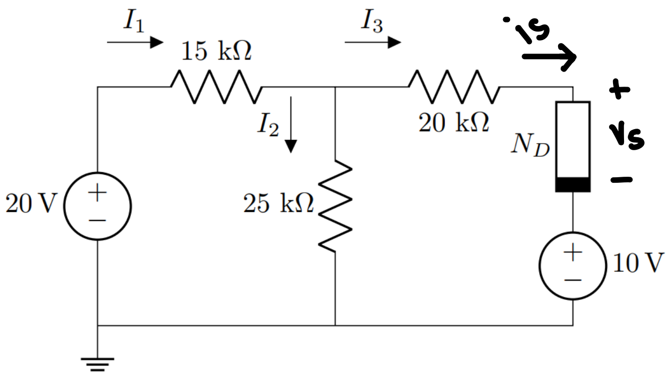
I-V curve of a hypothetical piecewise linear device is shown below.



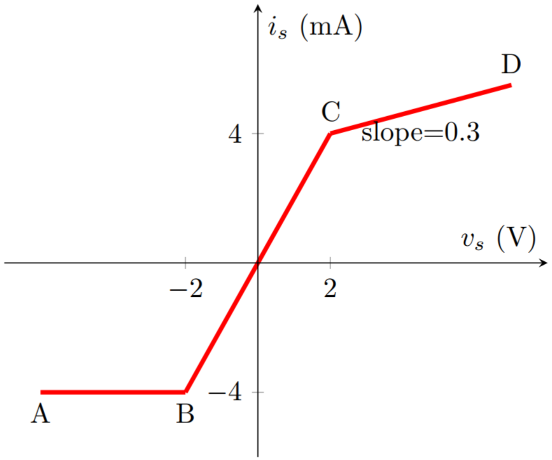
Here, P & Q that will come from your student id. For example, if the last 4 digits of your student id is 1234, then P=12, Q=34. In the graph, m_a = P and m_b = Q

What is the device model and parameter for the regions A, B, C, D, E? If the voltage across the device is 2.1v, what will be the operating region? What is the current flowing through it?

Piecewise Linear Approximation for NL devices



(a) A circuit with a non-linear device N_D



(b) IV Characteristics of the non-linear device N_D

(a) **Identify** the equivalent linear circuit models for the 3 linear regions (AB, BC, CD) shown in the IV characteristics of the non-linear device N_D (Figure (b)) and **calculate** the model parameters. [3]

(b) **Detect** the operating region for the device when $v_s = 3$ V and **calculate** the current through the device, i_s, for this voltage (hint: use Figure (b) and answers from previous part). [1+1]

(c) **Show** the alternative representation of the circuit in Figure (a). [1.5]

(d) Assume that the non-linear device N_D has been replaced with its equivalent linear device of segment BC. **Draw** the alternative representation of the circuit again by replacing N_D. [0.5]

(e) **Apply** KVL and KCL on the circuit of part (d) to calculate the values of I_1, I_2, and I_3. [3]