CSE251: Electronic Devices and Circuits

Diodes - 1

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Outline

- **Linear** IV characteristics.
- **Non-linear** IV characteristics
- **Piecewise Linear Approximation** of **Non-linear** circuit elements
  - Example 1
  - Example 2
- Solving Circuits with Non-Linear elements: **Method of Assumed States**
  - Example 3
  - Example 4

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 element.

- The Current-Voltage (I-V) characteristics are found by evaluating the **response** of a device/element under different **excitation** conditions. The behavior of a device depends on the **applied excitation** and can change if the excitation changes.

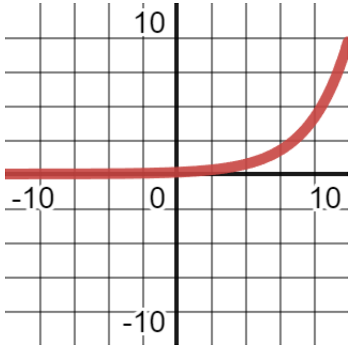
Type of (I-V) Characteristics

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:

$$I = kV$$

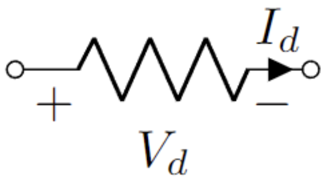
2. Non-Linear Devices/Elements: The Current-Voltage relationship is Non-linear i.e., the current through the element is a **nonlinear function** of the applied voltage across it.

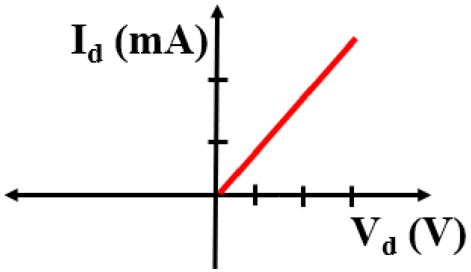
$$I = k\sqrt{V}$$
$$I = kV^2$$
$$I = kV^3$$



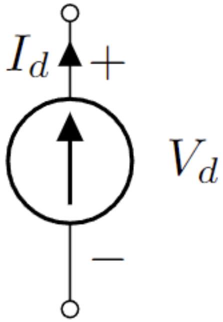
Linear IV Char.

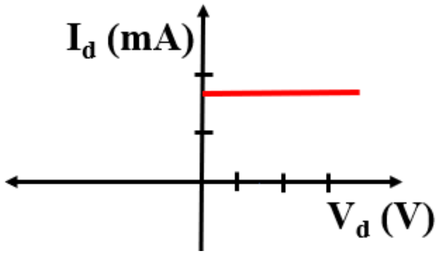
- Resistors



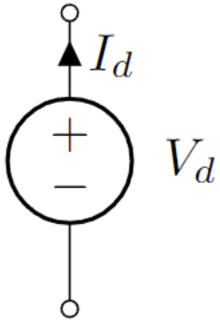


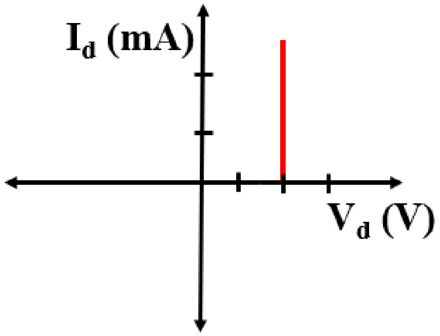
- Current Source





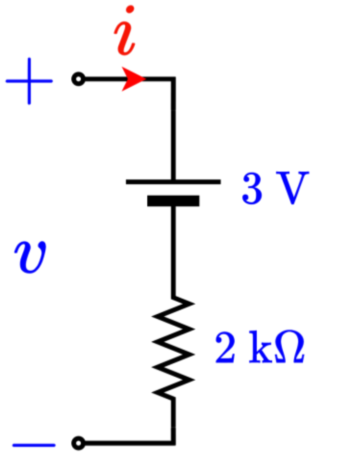
- Voltage Source

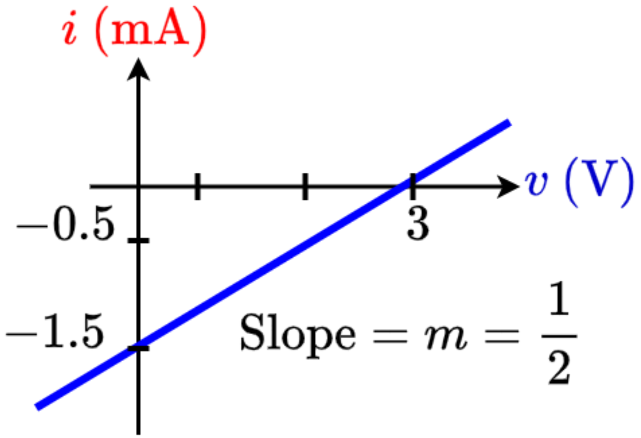




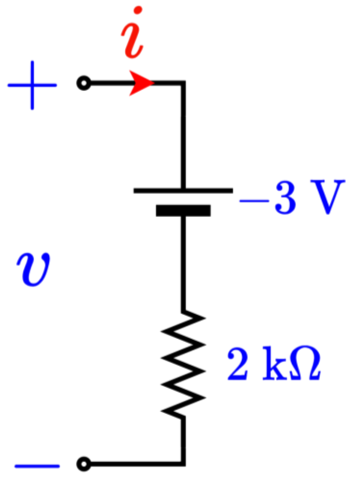
Linear IV Char.

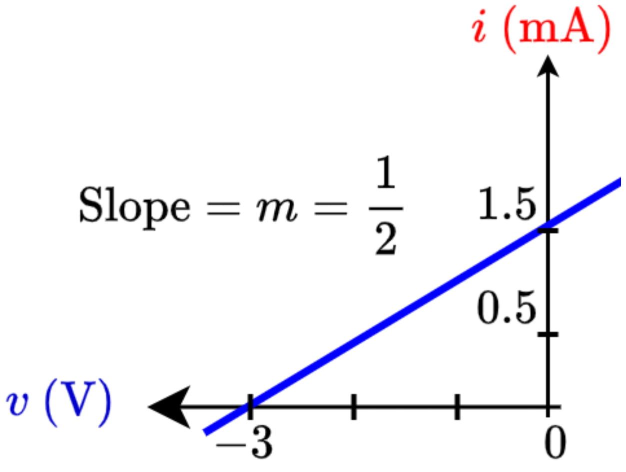
Voltage source in series with a resistor





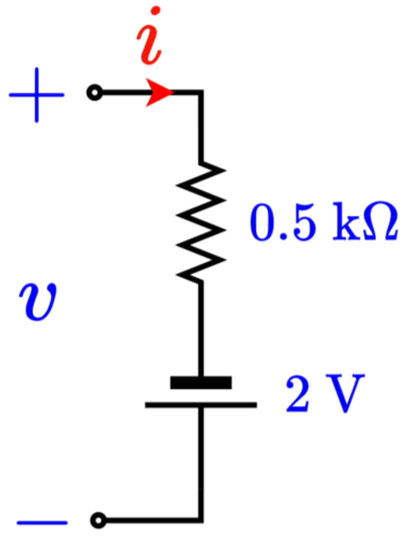
Voltage source in series with a resistor

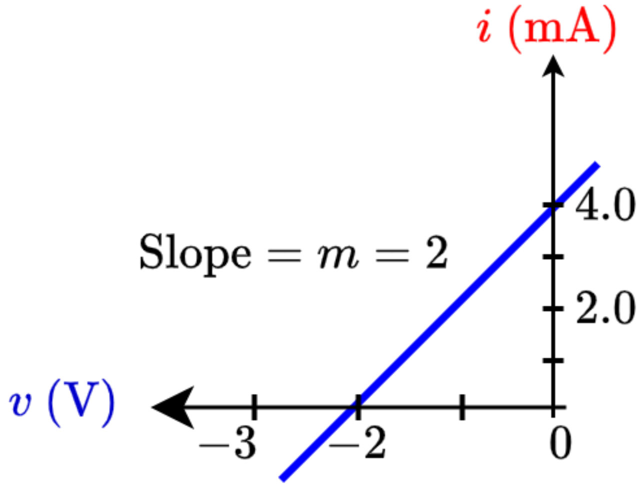




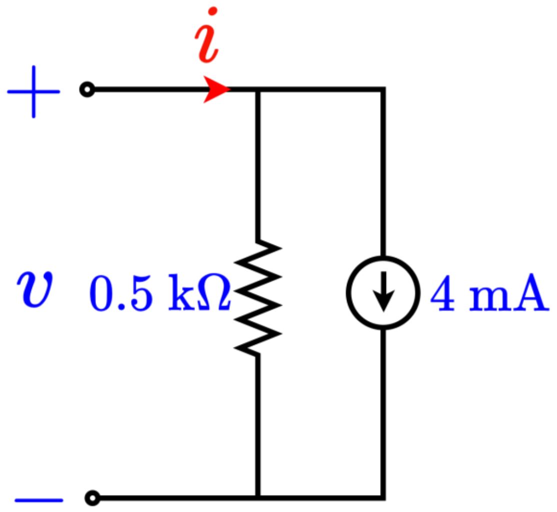
Linear IV Char.

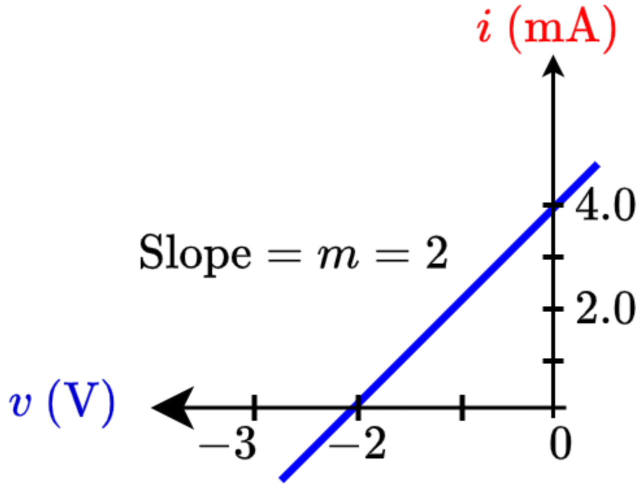
Voltage source in series with a resistor





Current source parallel to a resistor

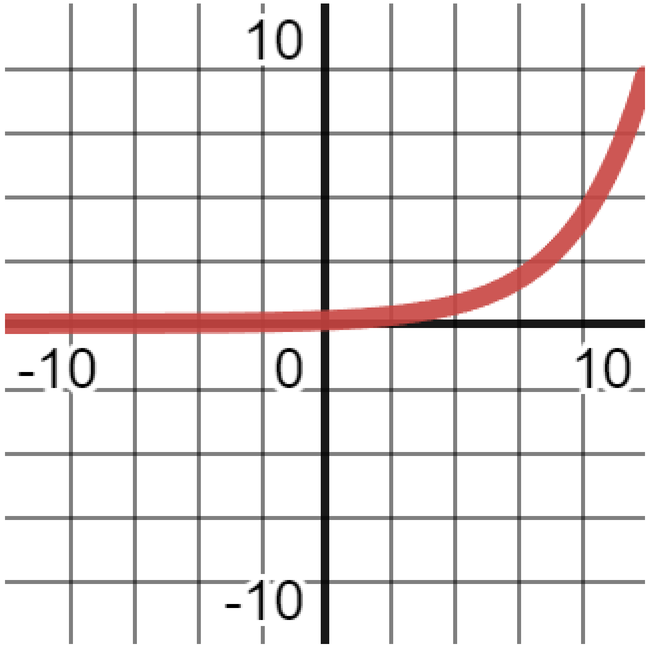




Non-Linear I-V Char.

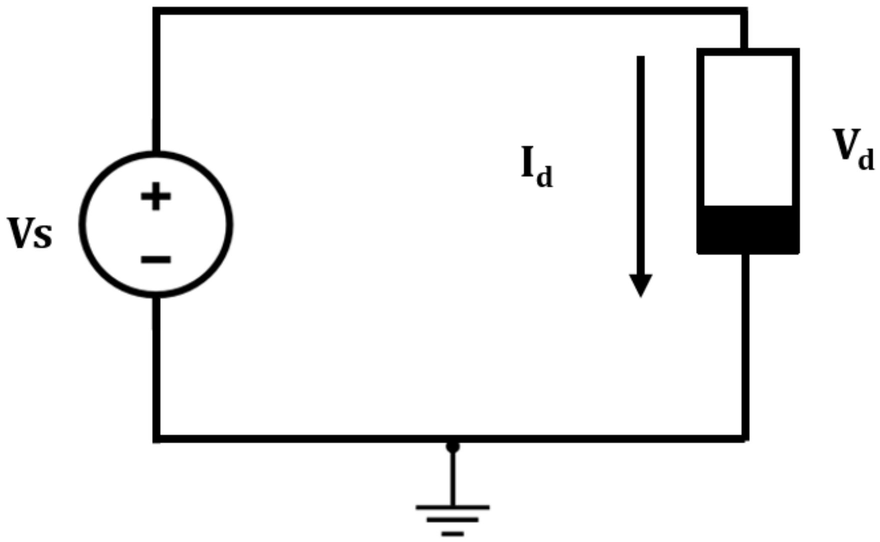
$I = kV$ $\qquad$ $I = kV^2$ $\qquad$ $I = \mathrm{A} \cdot \exp(\frac{V}{b})$

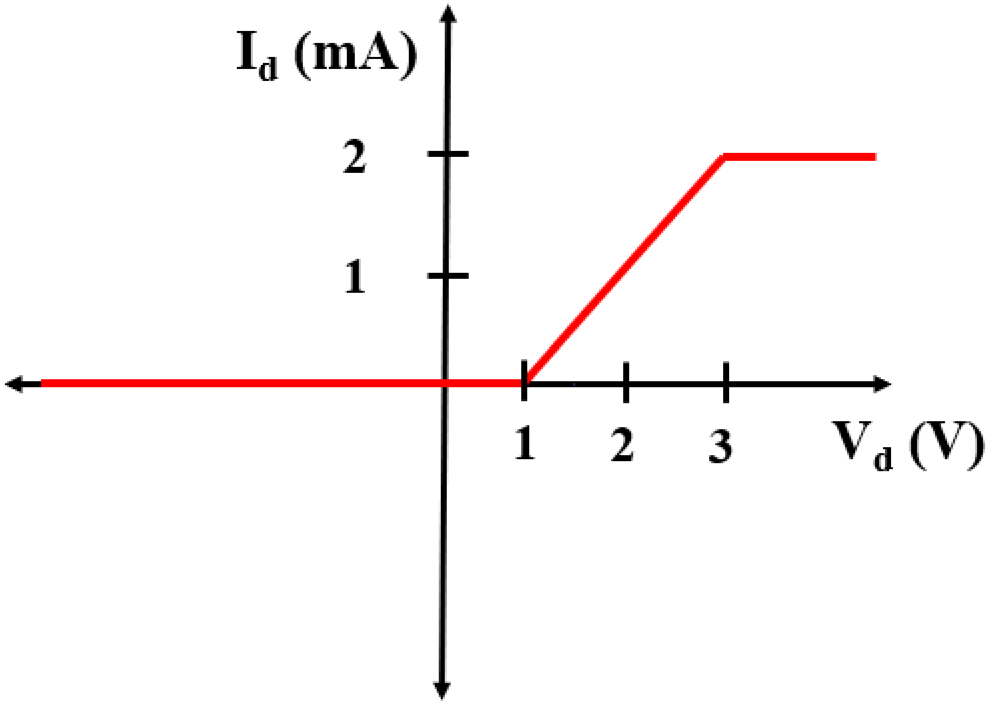
$y = mx$ $\qquad$ $y = ax^2$ $\qquad$ $y = \mathrm{A} \cdot \exp(\frac{x}{b})$



Non-Linear I-V Char.

Example:

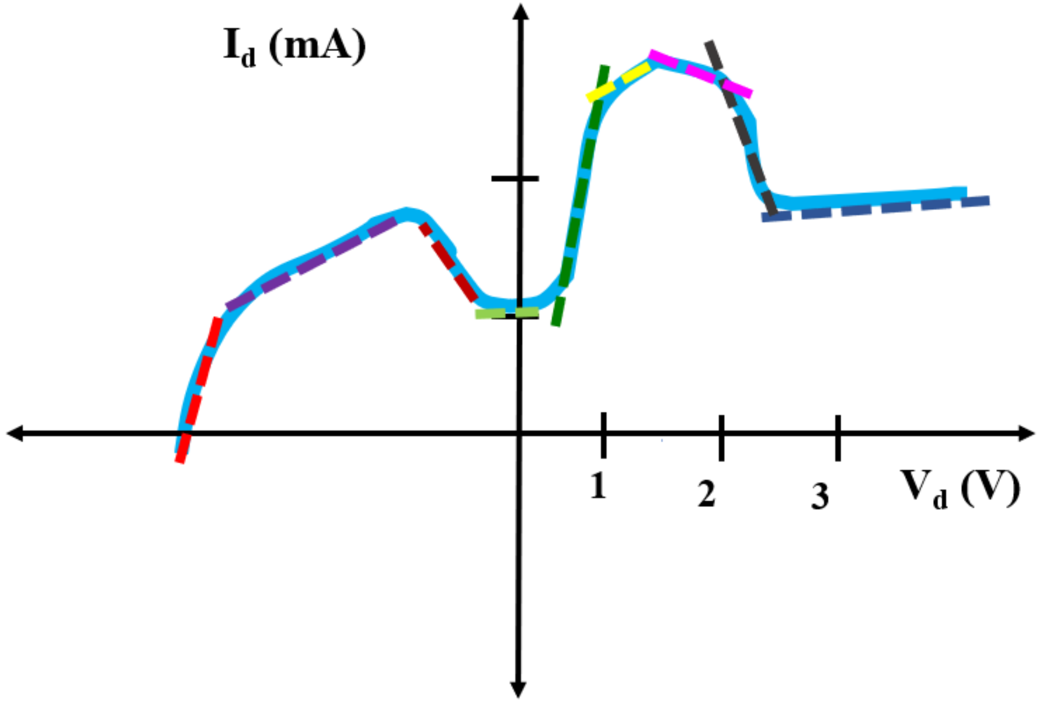




Piecewise linear function is a **Non-linear** function.

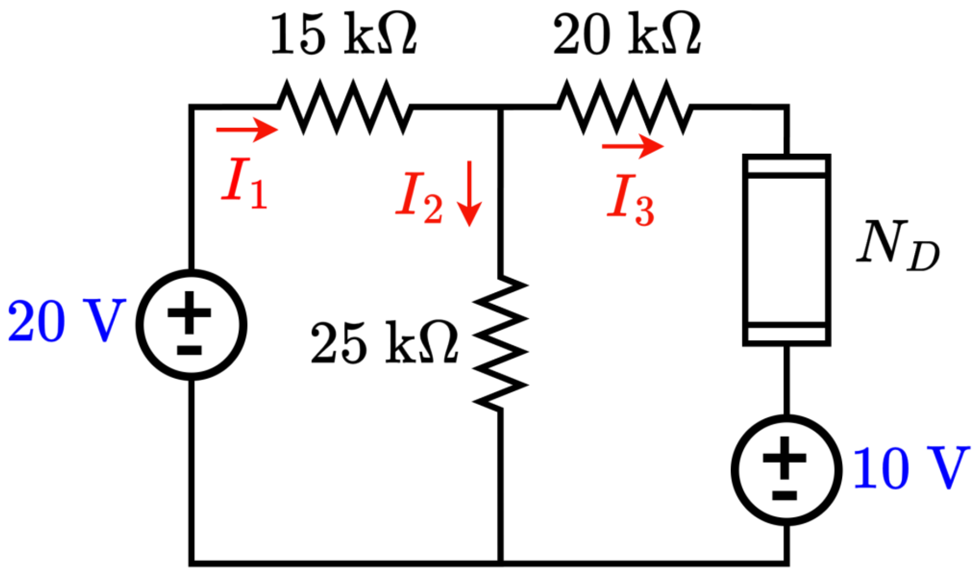
Non-Linear I-V Char.: Piecewise Linear Model

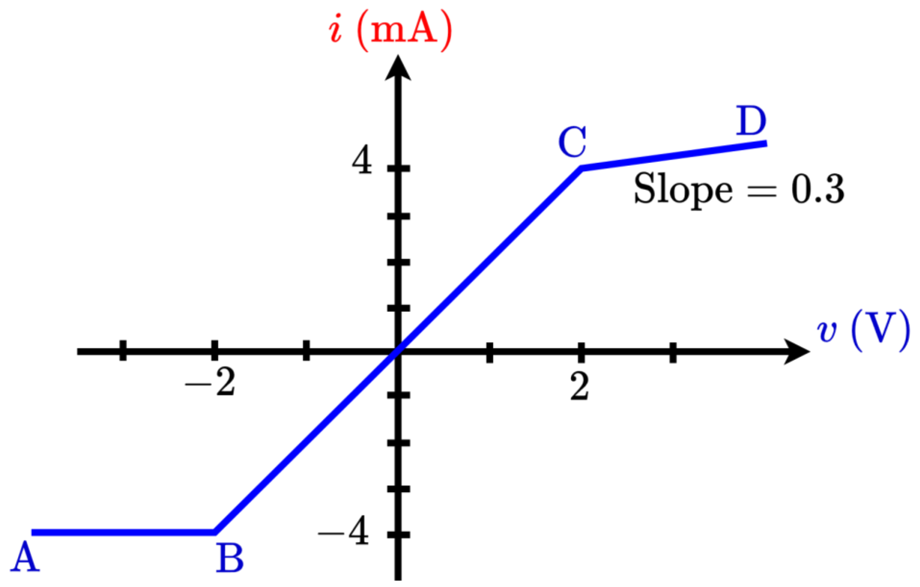
- Simplifying non-linear IV characteristics by piecewise linear parts.
- Non-linear functions are usually approximated by a series of linear segments that follow the tangent of the non-linear segment as can be seen from the following figure.



NL I-V Char.: PL Model Example 1

- **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 (right) and calculate the model parameters.





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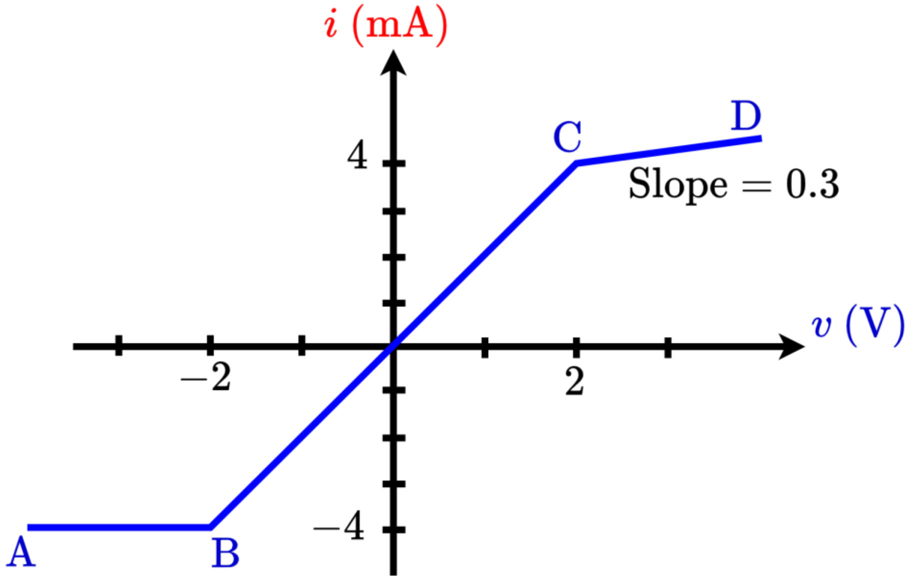
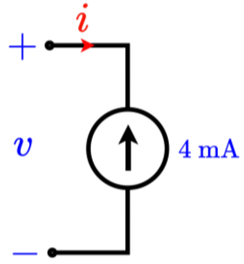
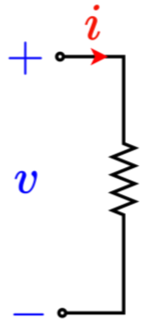


Solution:

AB : $-\mathbf{4\ mA}$ Current Source



BC : $\mathbf{0.5\ k\Omega}$ resistor



NL I-V Char.: PL Model Example 1

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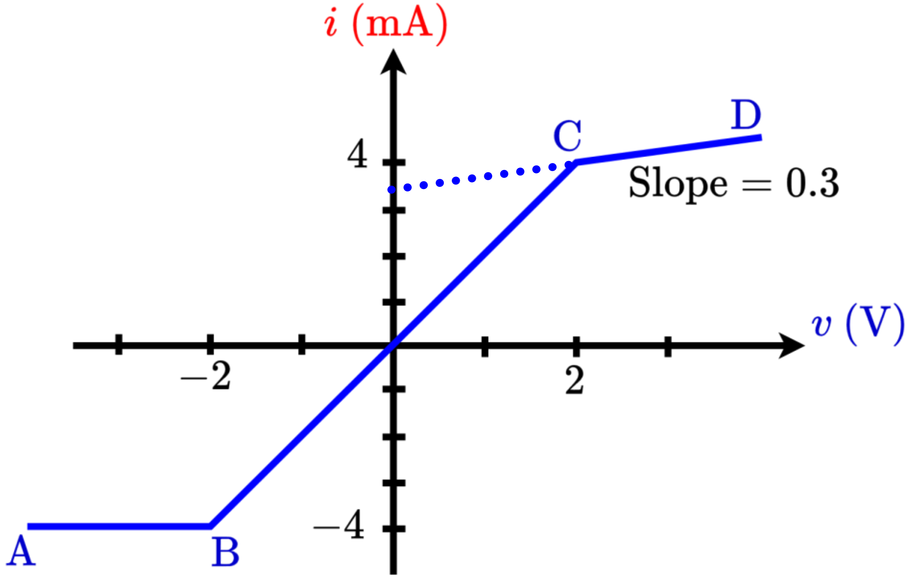


Solution:

CD : At C, $\boldsymbol{i} = \mathbf{4}, \boldsymbol{v} = \mathbf{2}$ and $R = \frac{1}{\text{Slope}} = \frac{10}{3}$

Expressing the equivalent circuit as

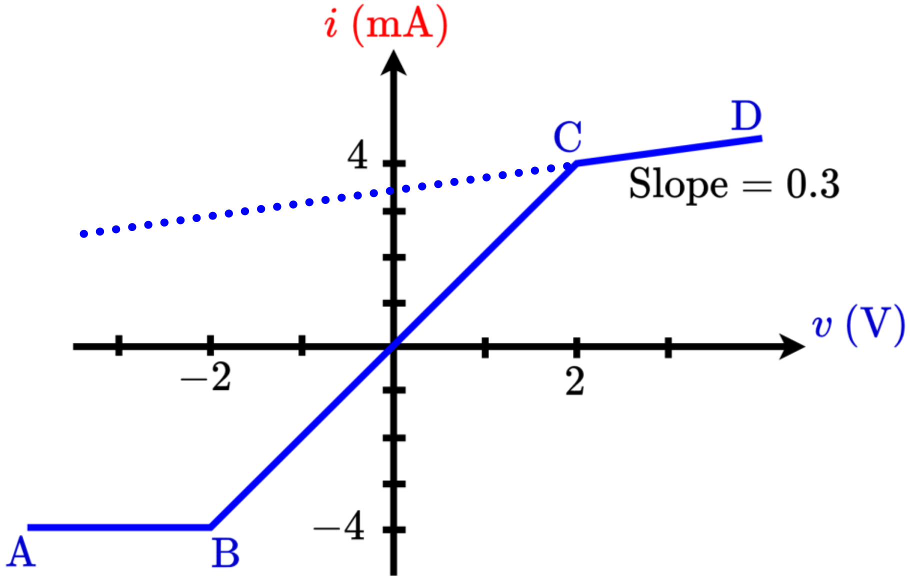
$$\boldsymbol{i} = \frac{\boldsymbol{v}}{R} + \boldsymbol{I_O}$$

and putting the values of $\boldsymbol{i}, \boldsymbol{v}$ and $\boldsymbol{R}$, we get

$$\boldsymbol{I_O} = \boldsymbol{i} - \frac{\boldsymbol{v}}{R} = 4 - \frac{2 \times 3}{10} = 3.4\ \mathbf{mA}$$

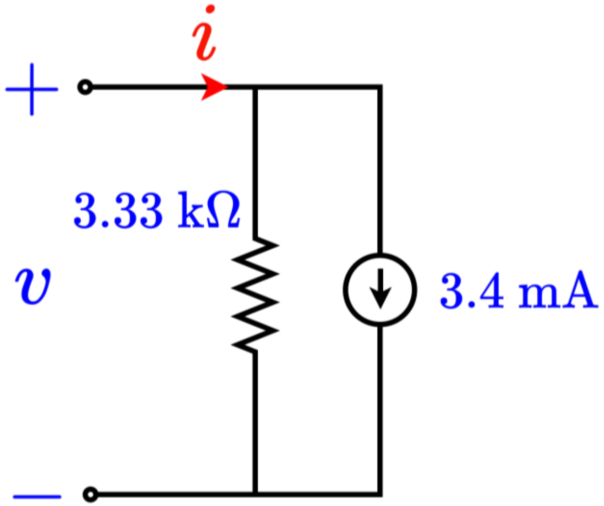
NL I-V Char.: PL Model Example 1

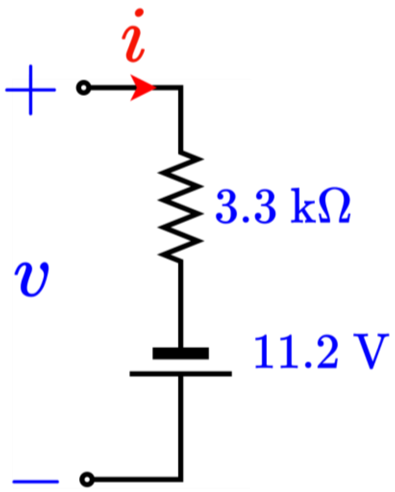
- **Identify** the equivalent linear circuit models for the 3 linear regions (AB, BC, CD) shown in the **IV** characteristics of the non-linear device N_D (right) and calculate the model parameters.



Solution:

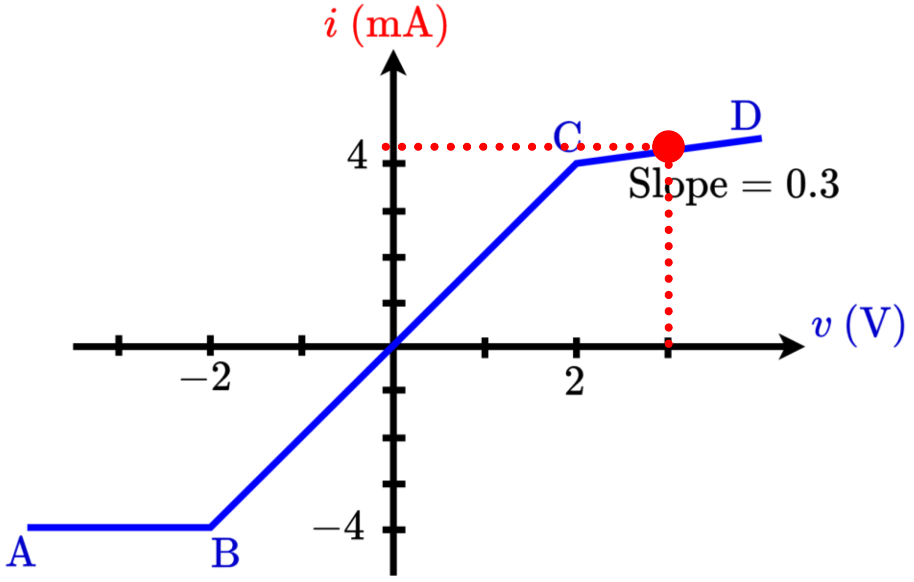
CD : $$i = \frac{v}{3.33} + \mathbf{3.4}$$





NL I-V Char.: PL Model Example 2

- **Detect** the operating region for the device when $\boldsymbol{v} = \mathbf{3\ V}$ and calculate the current through the device, $\boldsymbol{i}$, for this voltage (hint: use the IV graph and answers from previous part).



Solution:

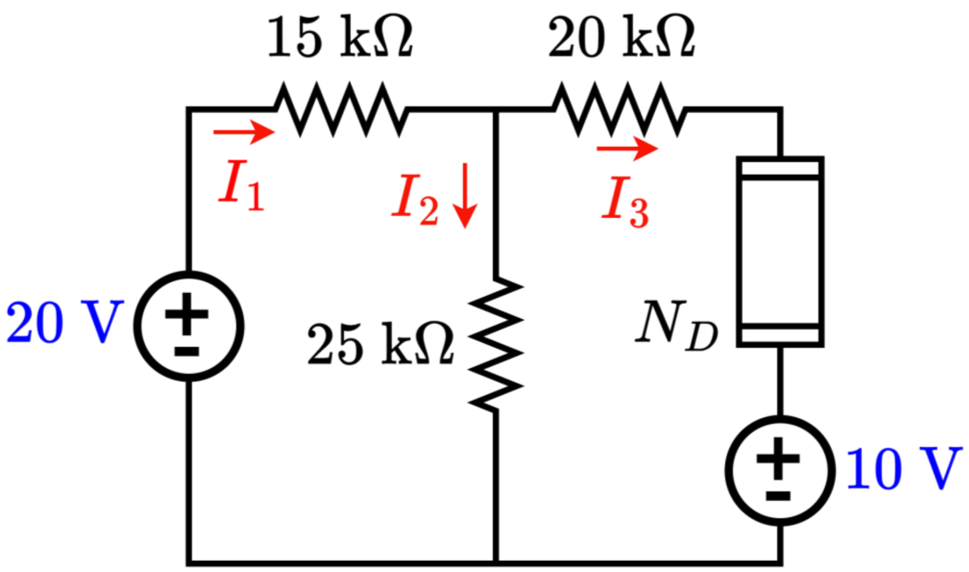
Operating region → CD :

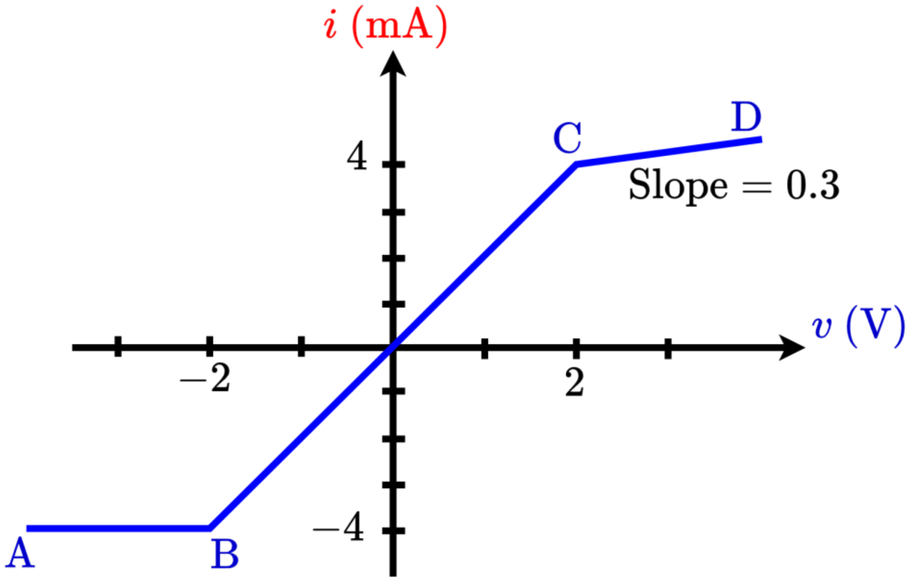
$$\boldsymbol{i} = \frac{\boldsymbol{v}}{3.33} + \mathbf{3.4}$$

$$\boldsymbol{i} = \frac{\mathbf{3}}{3.33} + \mathbf{3.4} = \mathbf{4.3\ mA}$$

NL I-V Char.: PL Model Example 3

- **Solve** the circuit on the left, to find the currents $\boldsymbol{I_1, I_2}$ and $\boldsymbol{I_3}$. Additionally, determine the voltage across $\boldsymbol{N_D}$.



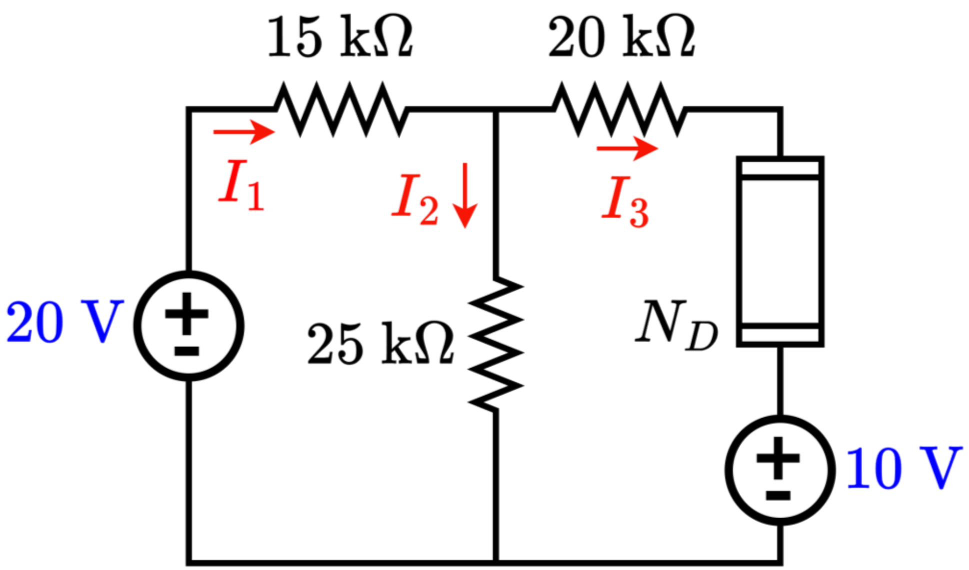


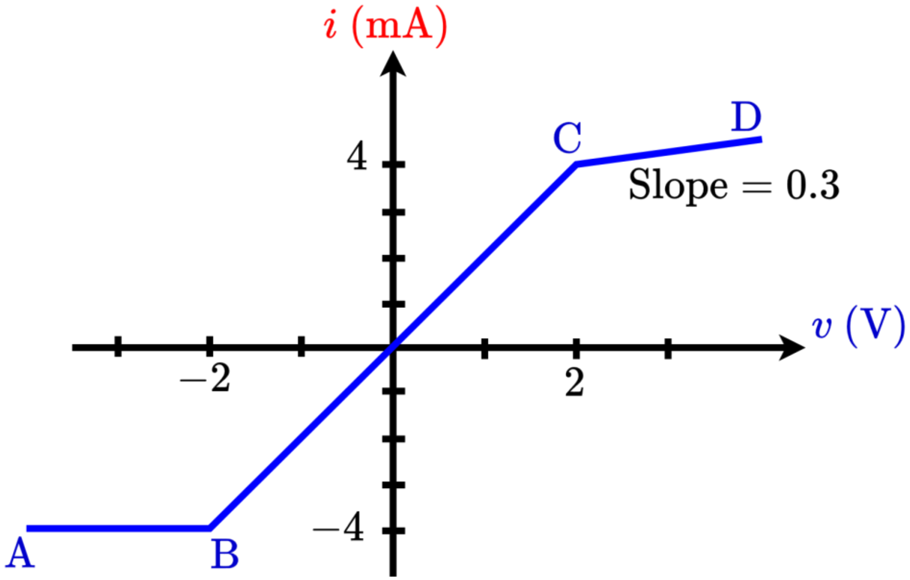
Solving Circuits with Non-Linear elements

- Use **Method of Assumed State**!
- Three steps:
  - **Assume**: One of the operating modes (**AB**, **BC**, **CD**)
  - **Solve**: Use corresponding equation with any circuit analysis tool
  - **Verify**: Check if the conditions of the NL device are satisfied. If not, repeat.

NL I-V Char.: PL Model Example 3

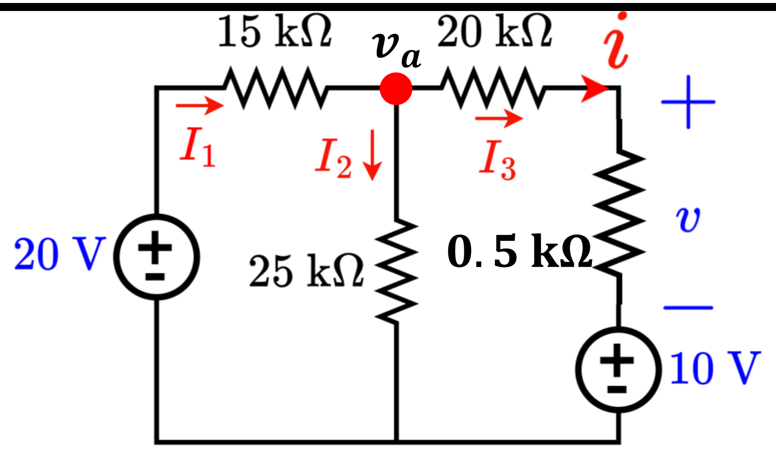
Solve the circuit on the left, to find the currents $\boldsymbol{I_1}, \boldsymbol{I_2}$ and $\boldsymbol{I_3}$. Additionally, determine the voltage across $\boldsymbol{N_D}$.





Method of Assumed State: Example 3

Solve the circuit on the right, to find the currents $\boldsymbol{I_1, I_2}$ and $\boldsymbol{I_3}$. Additionally, determine the voltage across $\boldsymbol{N_D}$.



Assume:

Let $\boldsymbol{N_D}$ be in **BC** mode: $\mathbf{0.5\ k\Omega}$ resistor where,

$$-2 < v \leq 2\ \mathrm{V}$$

$$-4 < i (= I_3) \leq 4\ \mathbf{mA}$$

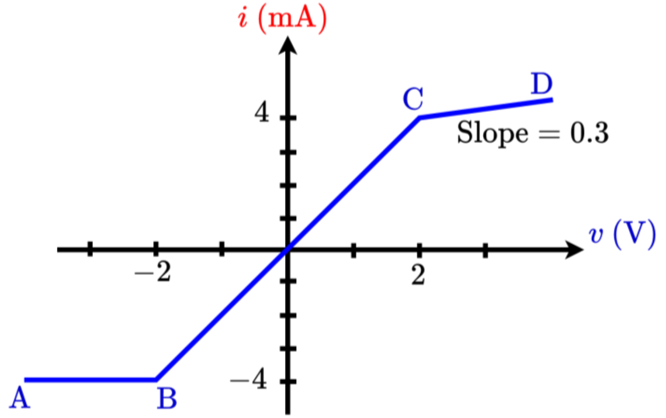
Solve:

Equations: $$v_a\left(\frac{1}{15} + \frac{1}{25} + \frac{1}{20+0.5}\right) = 20\left(\frac{1}{15}\right) + 10\left(\frac{1}{20+0.5}\right)$$

$$v_a = \mathbf{11.7155\ V}$$

$$\Rightarrow v = \frac{0.5}{0.5+20} \cdot (v_a - 10) = \mathbf{0.0418\ V}$$

$$\Rightarrow I_3 = \frac{v_a - 10}{20+0.5} = \mathbf{0.0837\ mA} = i$$



Method of Assumed State: Example 3

Solve the circuit on the right, to find the currents $\boldsymbol{I_1, I_2}$ and $\boldsymbol{I_3}$. Additionally, determine the voltage across $\boldsymbol{N_D}$.

Assumption:

$\boldsymbol{N_D}$ is in **BC** region: A $\mathbf{0.5\ k\Omega}$ resistor where,

$$-2 < \boldsymbol{v} \leq 2\ \mathrm{V}$$
$$-4 < \boldsymbol{i}(= \boldsymbol{I_3}) \leq 4\ \mathbf{mA}$$

Solution:

$$\boxed{\boldsymbol{v} = \mathbf{0.0418\ V}}$$

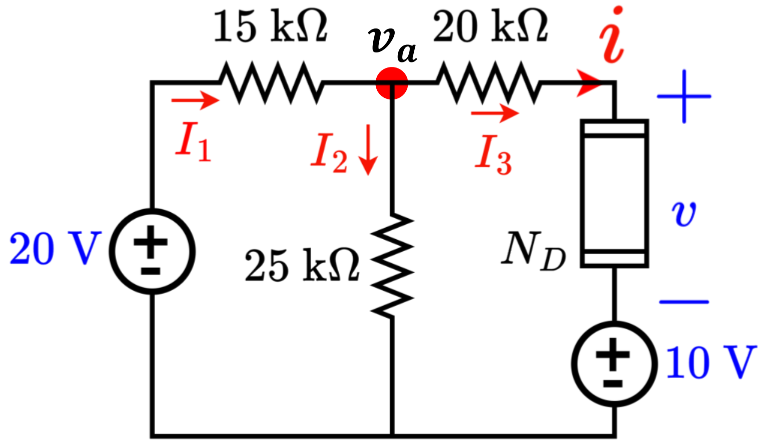
$$\boxed{\boldsymbol{I_3} = \mathbf{0.0837\ mA}}$$

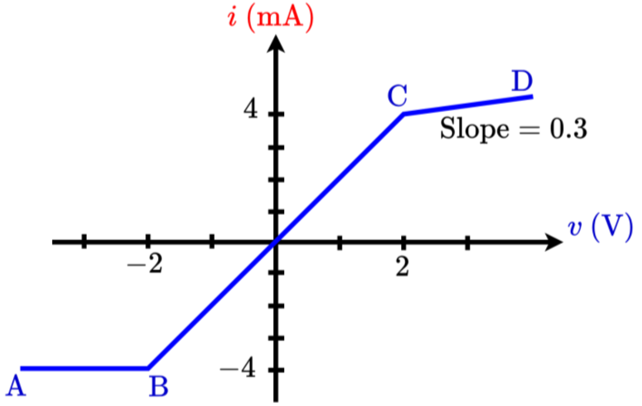
Verify: For **BC** mode $\rightarrow$ $-2 < \boldsymbol{v} \leq 2\ \mathrm{V}$

$$-4 < \boldsymbol{I_3} \leq 4\ \mathbf{mA}$$

Here, both conditions are fulfilled. **Assumption is Correct!**

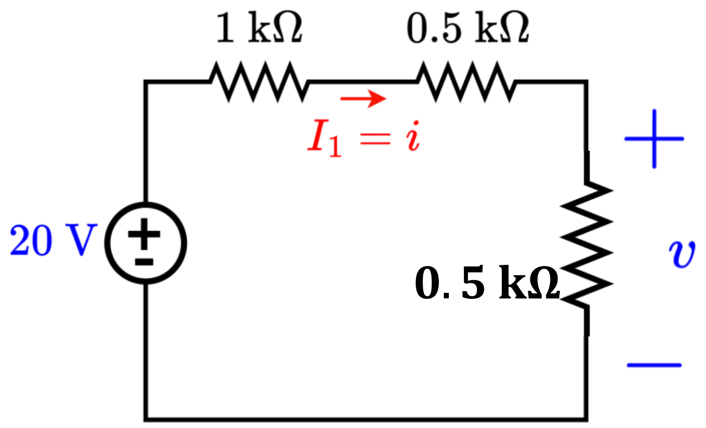
$$\boldsymbol{I_1} = \frac{\mathbf{20} - \boldsymbol{v_a}}{\mathbf{15}}$$
$$\boldsymbol{I_2} = \boldsymbol{I_1} - \boldsymbol{I_3}$$





Method of Assumed State: Example 4

Solve the circuit on the right, to find the currents $\boldsymbol{I_1}$. Additionally, determine the voltage across $\boldsymbol{N_D}$.



Assume:

Let N_D be in **BC** mode: $\mathbf{0.5\ k\Omega}$ resistor where,

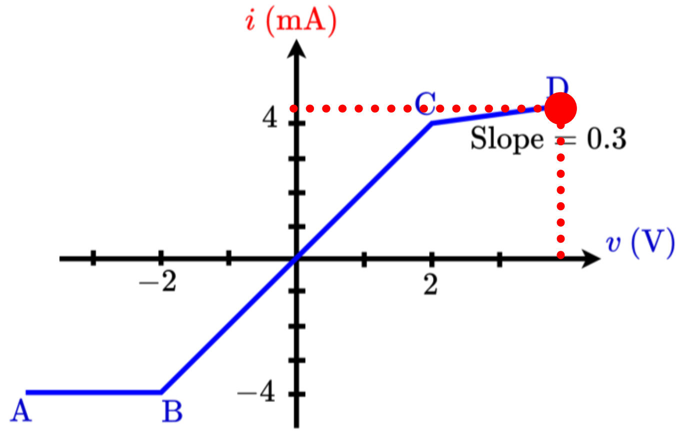
$$-2 < v \leq 2\ \text{V}$$

$$-4 < i(= I_3) \leq 4\ \mathbf{mA}$$

Solve:

Equation: $$v = \frac{0.5}{0.5+0.5+1} \cdot 20 = \mathbf{5\ V}$$

$$I_1 = \frac{\mathbf{20}}{\mathbf{1+0.5+0.5}} = \mathbf{10\ mA} = i$$



Verify:

For **BC** mode $\rightarrow$ $-2 < v \leq 2\ \text{V}$

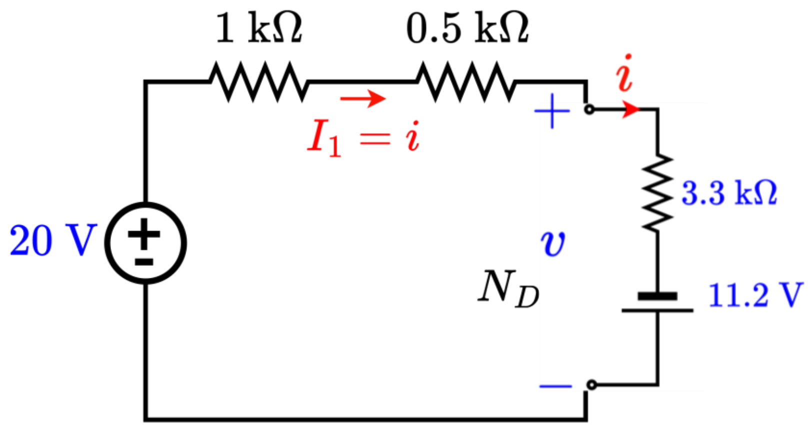
$-4 < I_3 \leq 4\ \mathbf{mA}$

Here, NONE of the conditions are fulfilled.

Assumption is INCORRECT!

Method of Assumed State: Example 4

Solve the circuit on the right, to find the currents $\boldsymbol{I_1}$**.** Additionally, determine the voltage across $\boldsymbol{N_D}$**.**



Assume:

Let N_D be in **CD** mode: $\mathbf{3.3\ k\Omega}$ resistor in series with a $-\mathbf{11.2\ V}$ DC voltage source where,

$$v > 2\ \mathrm{V}$$

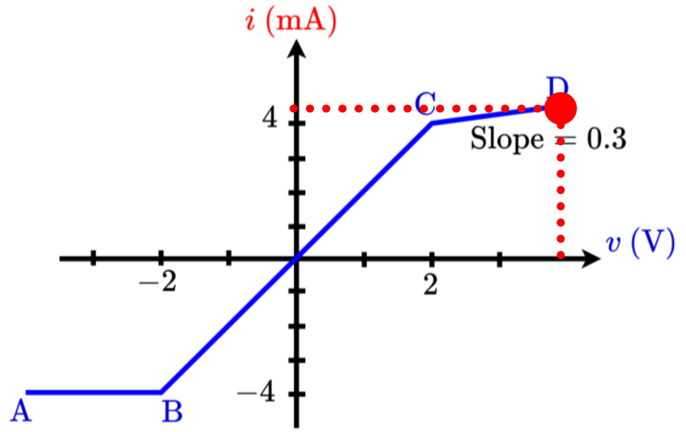
$$i(= I_1) > 4\ \mathrm{mA}$$

Solve:

Equation:

$$I_1 = \frac{20-(-11.2)}{1+0.5+3.3} = \boxed{6.5\ \mathrm{mA} = i}$$

$$v = 3.3i - 11.2 = \boxed{10.25\ \mathrm{V}}$$



Verify: For **BC** mode → $v > 2\ \mathrm{V}$

$i(= I_1) > 4\ \mathrm{mA}$

Here, both conditions are fulfilled.

Assumption is Correct!

Part 1 ends here

Outline

- Semiconductor Materials
  - n-type
  - p-type
- Semiconductor Devices: pn junction Diode
  - Physical Characteristics
  - Modes of Operation

Semiconductor Materials

- Semiconductors are special class of materials (as opposed to conductors and insulators) that fall **between conductors and insulators** in terms of their electrical conductivity.

- By making simple material changes, such as **doping**, these materials can achieve remarkably precise control over electron flow.

- This ability to **control electron flow** makes semiconductors the optimal candidate for building non-linear electrical devices, where electron (current) flow is not always just proportional to the applied voltage.

- As these non-linear devices offer exceptional control over electron flow, the class of devices and circuits are branched under the umbrella term **"Electronics"**

Semiconductor Materials

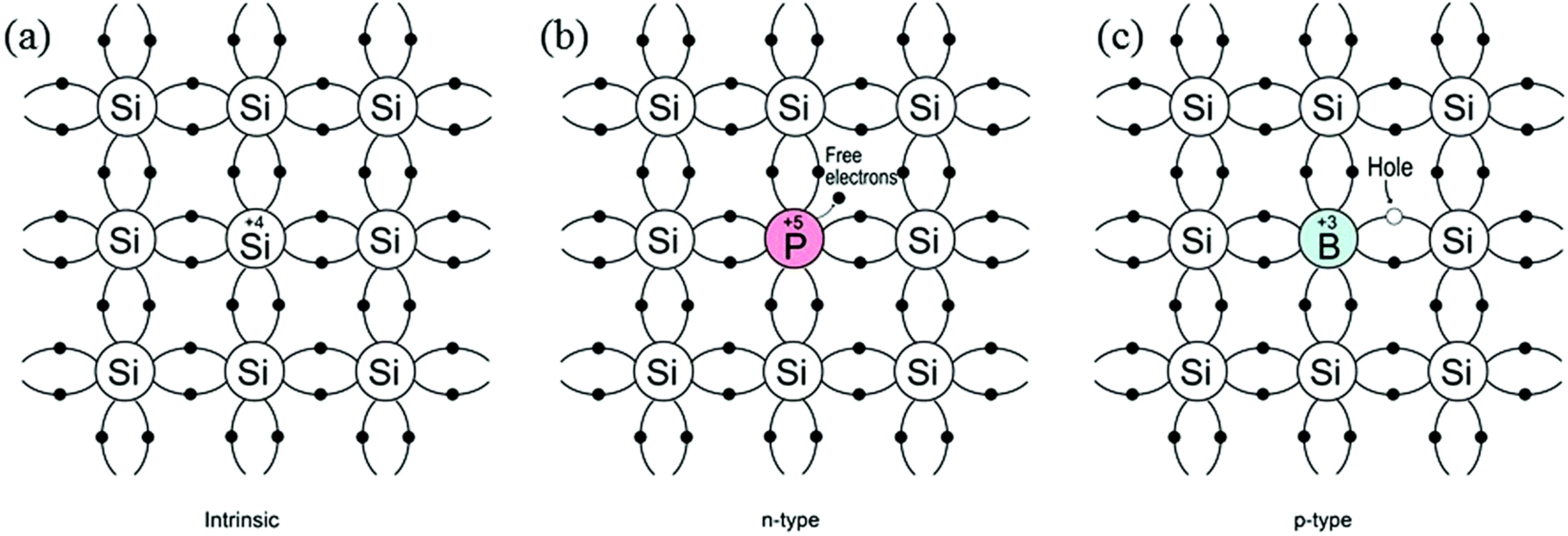
What is doping?

Doping is to deliberately inject atomic level "impurities" into a material (such as an "intrinsic" or **pure semiconductor** such as **Silicon**. These atoms are called dopants.

Usually, the concentration of the "dopant" atoms is much less than the actual concentration of the host material.

Since the atoms being injected are different from the actual material atom, they are considered impurities. A doped semiconductor is also known as "**Extrinsic**" semiconductor.

Semiconductor Materials

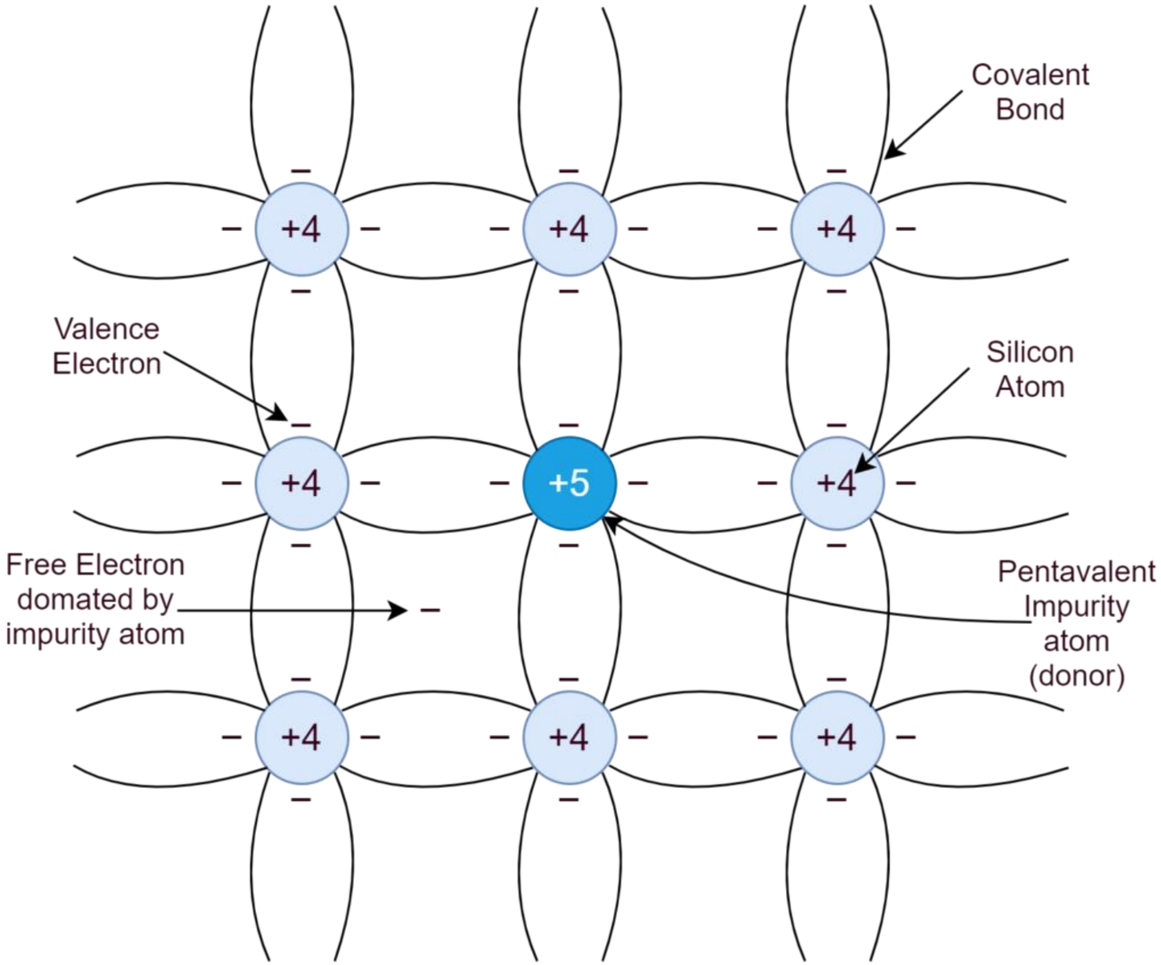


$\boldsymbol{n}$ **−type doped** → Si lattice is riddled with **pentavalent atoms**

$\boldsymbol{p}$ **−type doped** → Si lattice is riddled with **trivalent atoms**

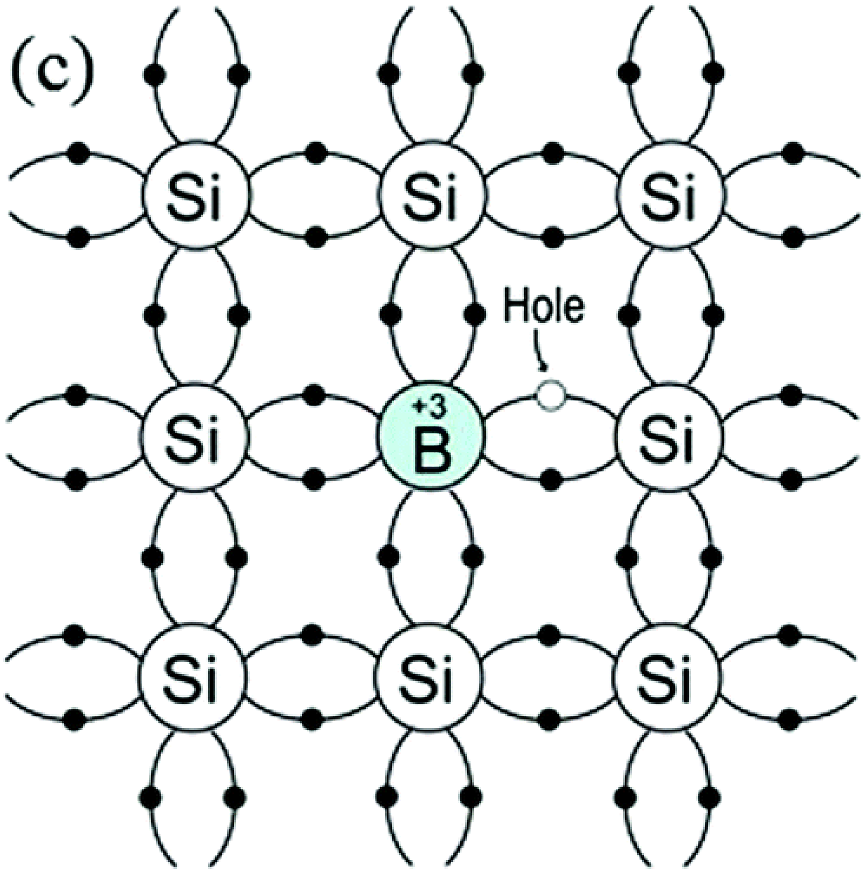
n-type doping

- n-type materials are doped with pentavalent atoms.
- Pentavalent atoms have one more electron than the surrounding tetravalent **Si** atoms.
- This lone extra electron acts as a **mobile electron** that can flow easily as it is not bonded to any atom.



p-type doping

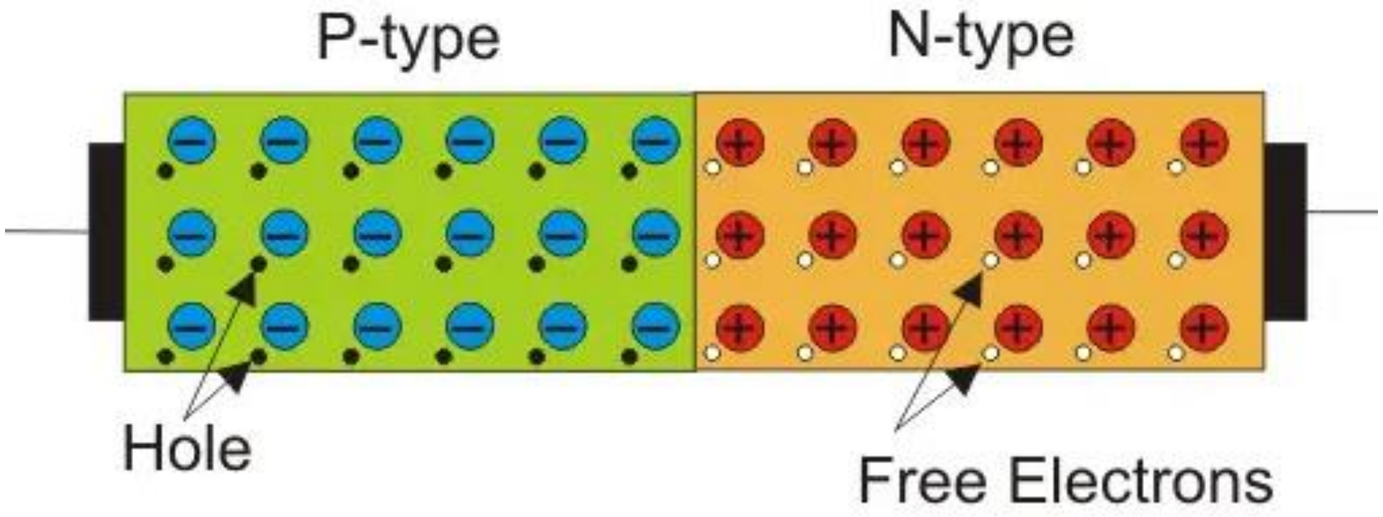
- p-type materials are doped with trivalent atoms.
- Trivalent atoms have one less electron than the surrounding tetravalent Si atoms.
- This absence of an electron (termed as a hole) acts as can flow easily from atom to atom across the material as it is not bonded to any atom. The flow of holes is opposite to the actual flow of electrons.



p-type

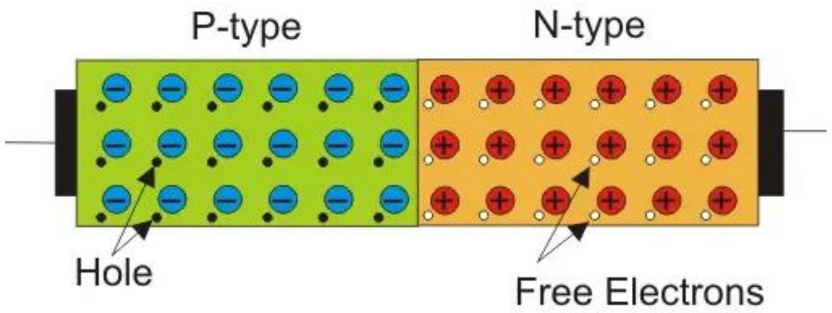
Semiconductor Devices: Diode

- **Diode** is the most basic semiconductor device.
- It is made by doping an intrinsic semiconductor (**Si**) half as **p-type** and the other half as **n-type**.



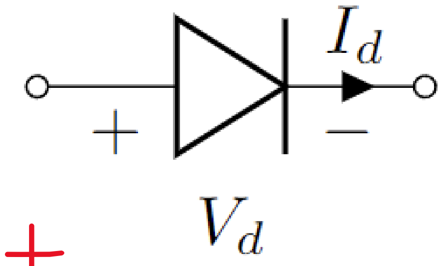
The **pn** junction diode: Physical characteristics

Internal Structure



Circuit Schematic

Anode



Cathode

+ −

Real device image

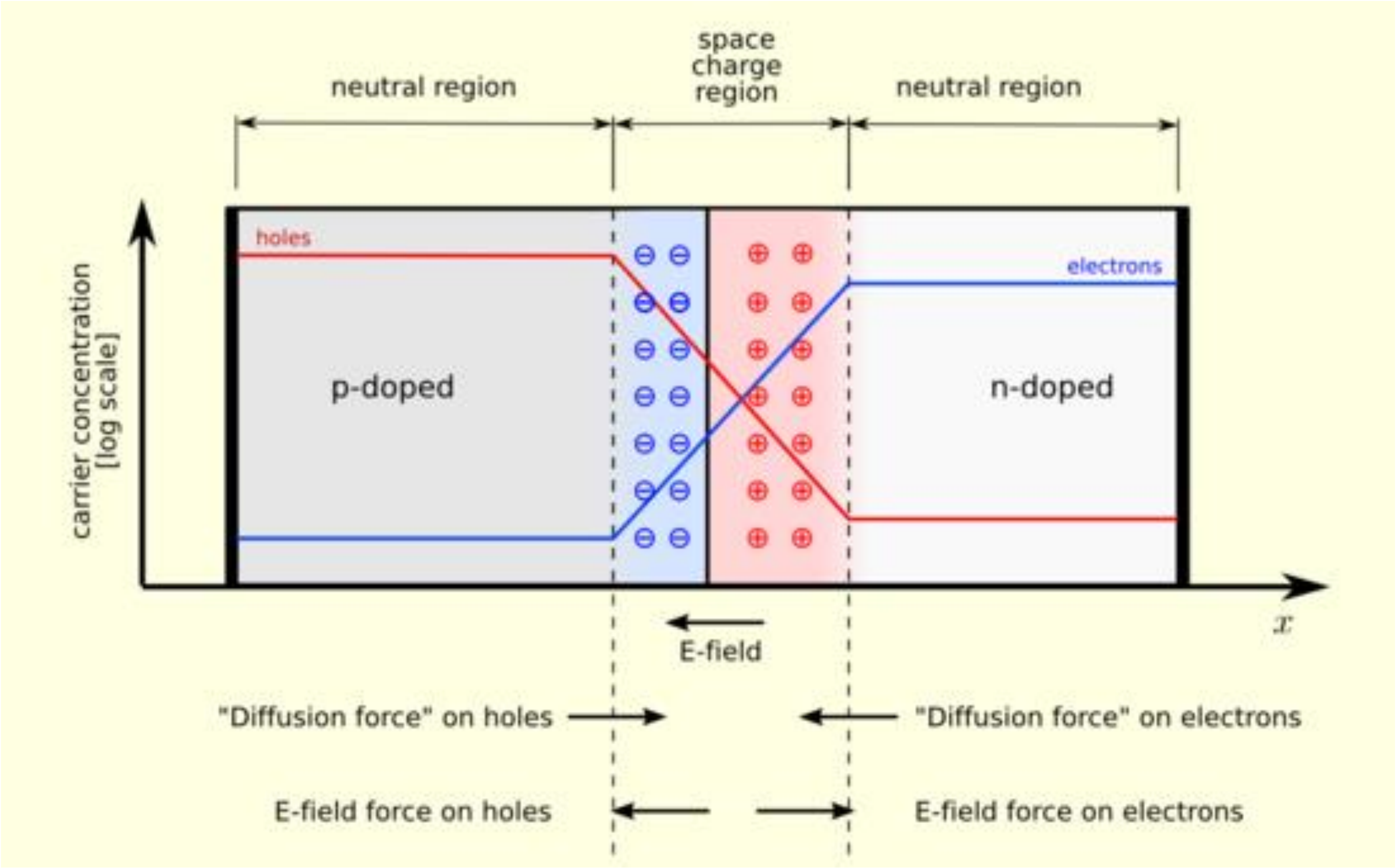
The **pn** junction diode: Physical characteristics

The depletion region:

This is the region in a **pn-**junction device sandwiched between the *n-doped* and *p-doped* regions.

In n-doped region, mobile electrons dominate charge flow. In p-type, holes dominate.

In a pn-junction depletion regions form naturally, as charge carriers (holes in p-type and electrons in n-type) near the pn junction boundary seep into each other.



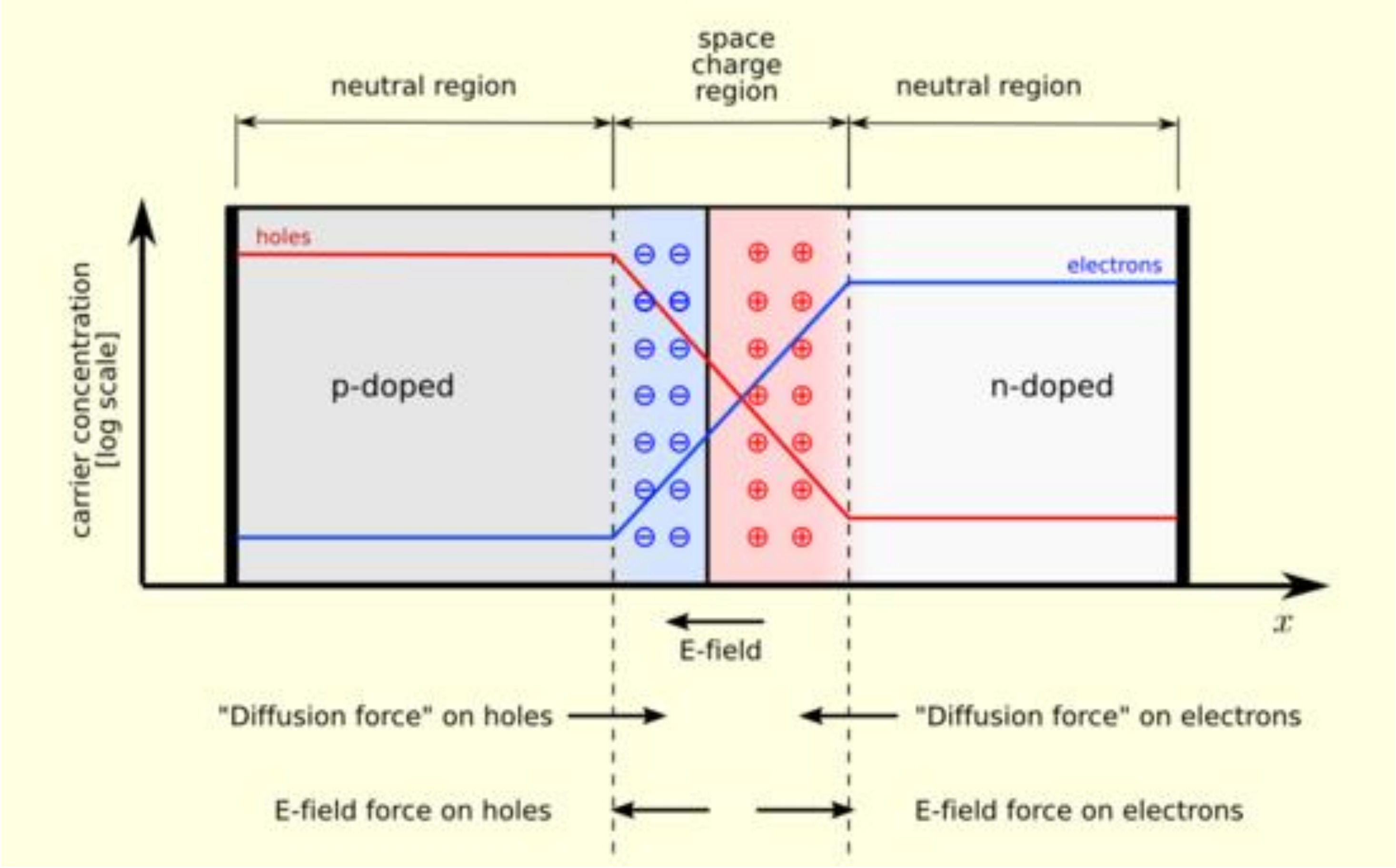
The **pn** junction diode: Physical characteristics

The depletion region:

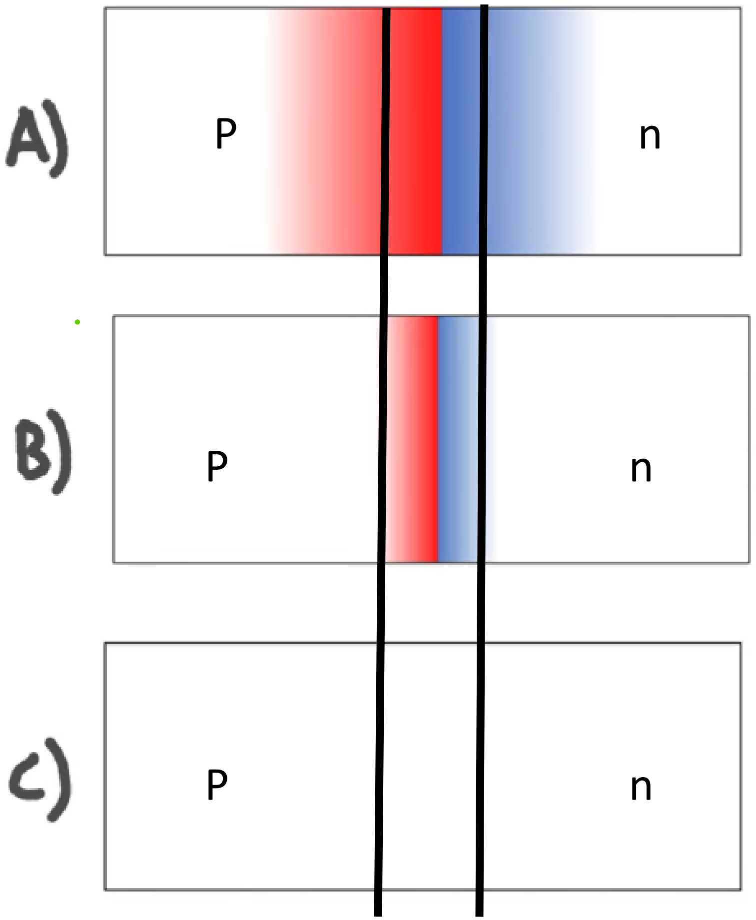
In a pn-junction depletion regions form naturally, as charge carriers (holes in p-type and electrons in n-type) near the pn junction boundary seep into each other.

Electrons from n-type region flow into p-type region while holes flow into n-type region from p-type region.

This mutual overflow into the opposite region, creates a space charge barrier, (like that in a capacitor).

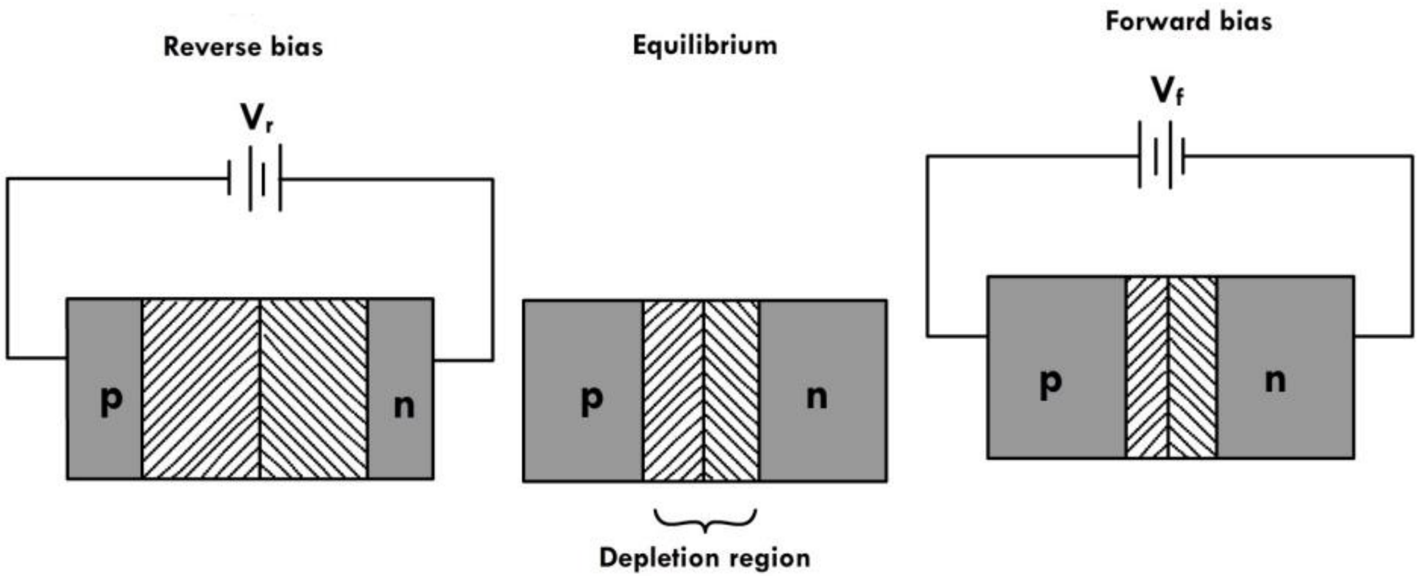


The **pn** junction diode: Modes of operation



Depletion Region

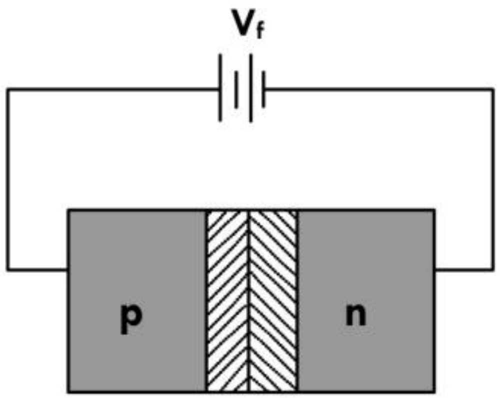
A) Reverse Bias
B) No Bias
C) Forward Bias



The **pn** junction diode: 2 Modes of operation

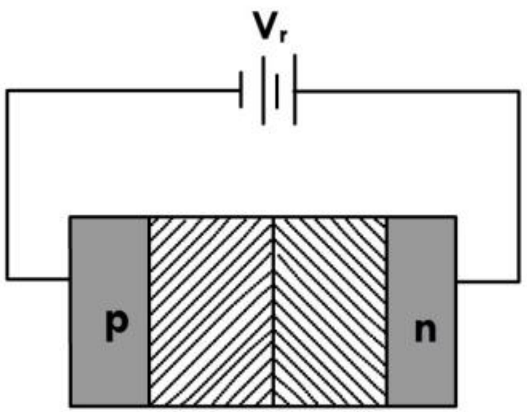
1. Forward Bias (FB):
   - Depletion Region is **constricted**.
   - ***Allow*** electrons to flow through the junction
   - Ideally acts as a **short circuit**

Forward bias



2. Reverse Bias (RB):
   - Depletion Region is **expanded**.
   - Bars / does not allow electron flow through the junction.
   - Ideally acts as an **open circuit**

Reverse bias



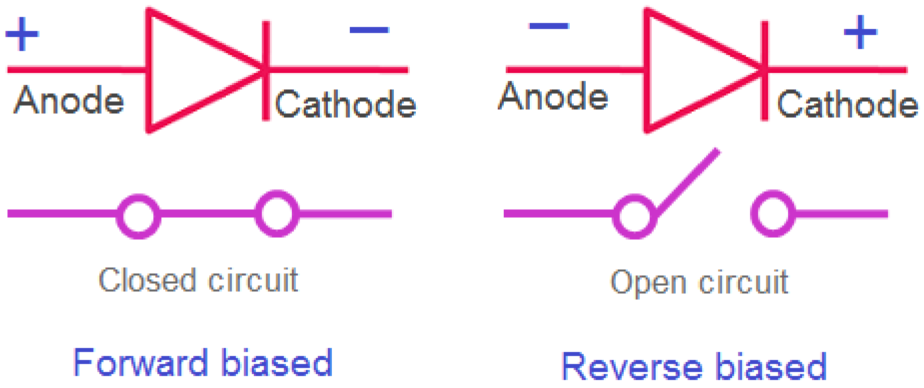
Part 2 ends here

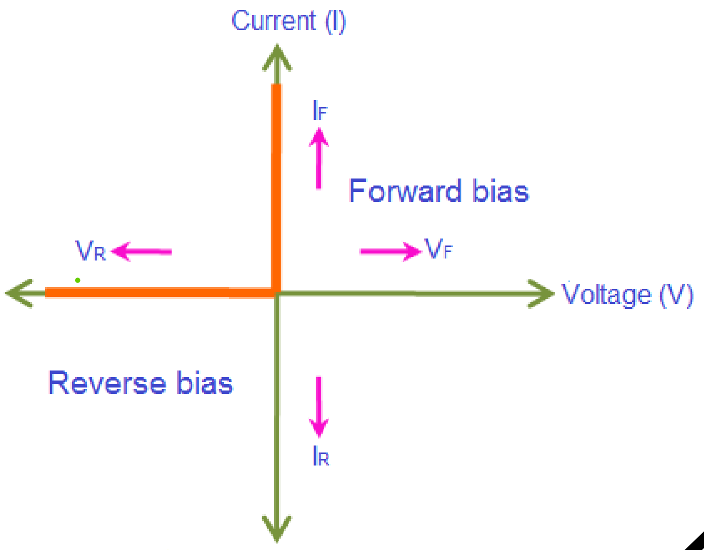
Outline

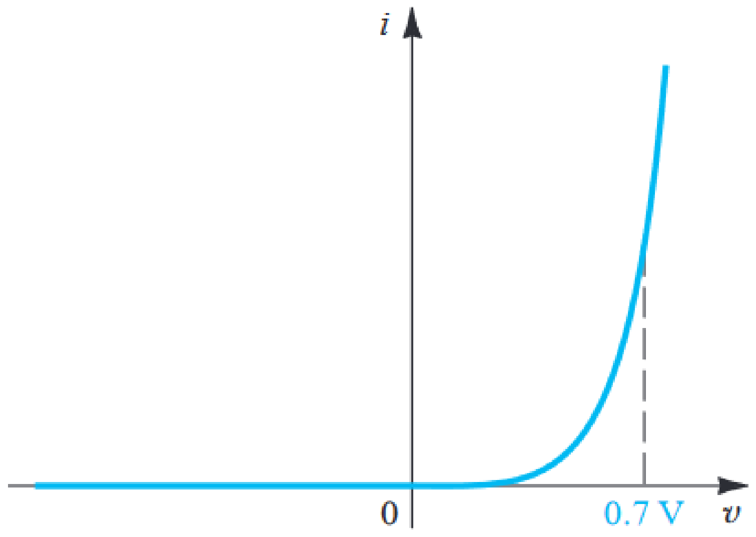
- **pn** junction Diode IV Characteristics: Circuit Model
  - Ideal Diode Model:
  - Constant Voltage Drop (CVD) Model:
  - Constant Voltage Drop with Resistor (CVD+R) Model
  - Exponential Model (Shockley Model):
- Examples: 6

Diode Circuit Models

Ideal *Versus* Real Diode







Constant Voltage Drop
(CVD) Model

Ideal Model → **Real / Shockley** Model

Low Accuracy

Simple

CVD with resistance
(CVD+R) Model

Increased Accuracy

More Complex

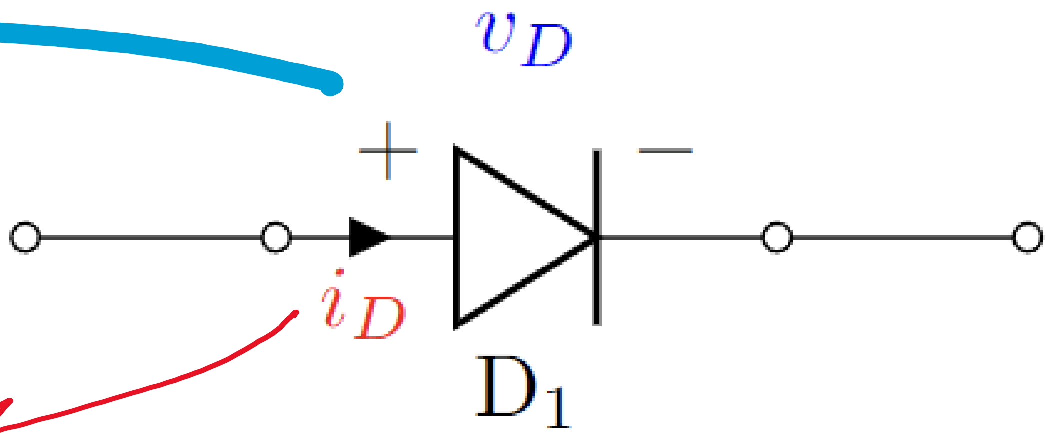
Diode Circuit Models

1. **Ideal Diode** Model:
2. **Constant Voltage Drop (CVD)** Model:
3. **Constant Voltage Drop with Resistor (CVD+R)** Model
4. **Exponential** Model (Shockley Model):

Piecewise Linear IV Models

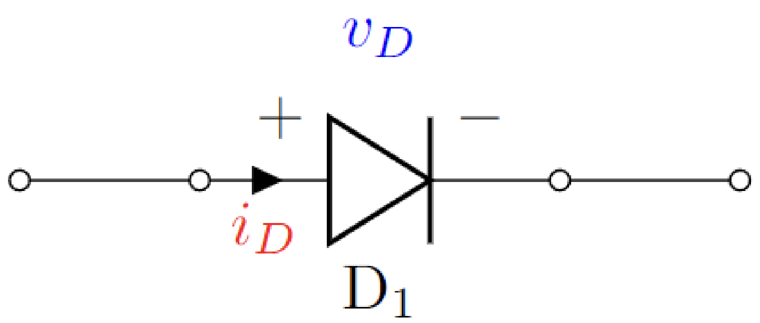
v_D: Total Voltage Across diode
v_d: AC component of the Voltage
V_d: DC component of Voltage

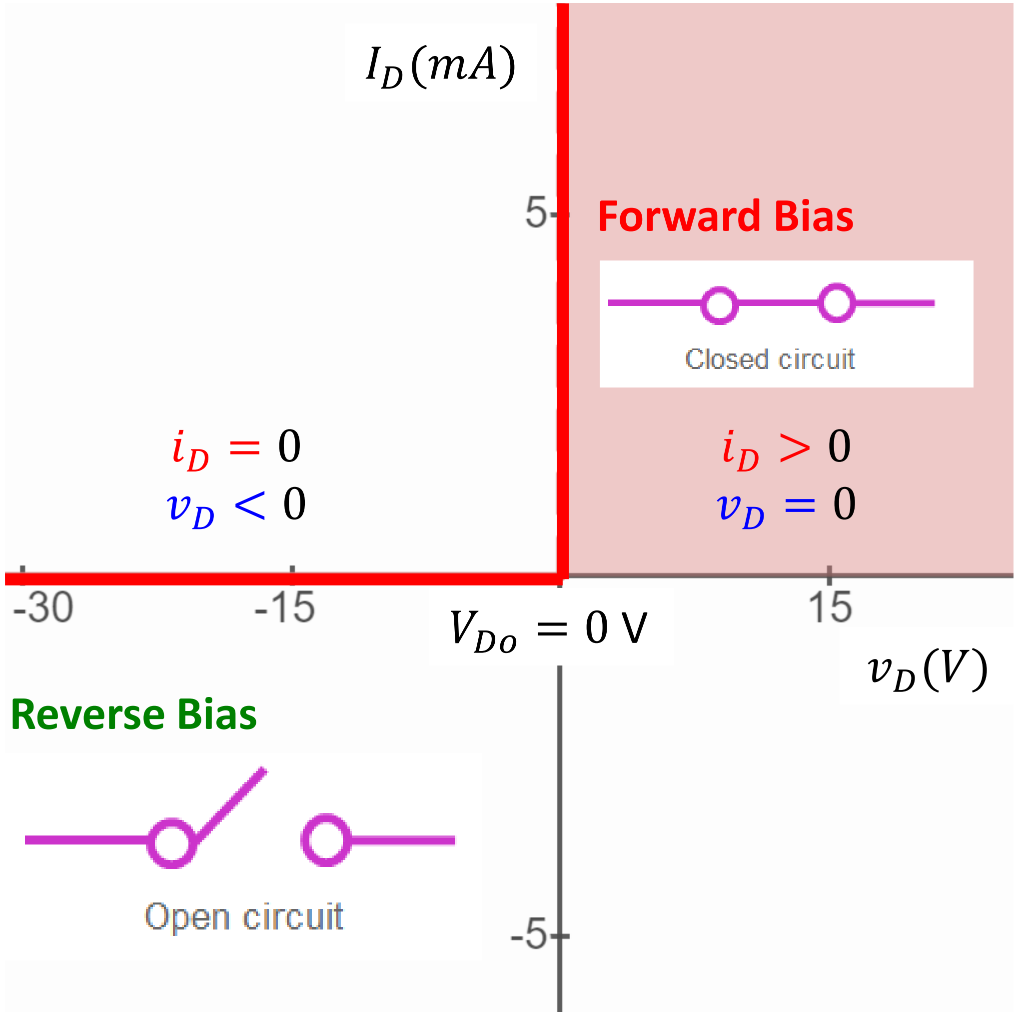
V_{Do}: Diode Cut-off voltage
----
i_D: Total current through diode (Anode to Cathode)



Diode Models

1. Ideal Diode Model:





Solving Circuits with Diodes

- Use **Method of Assumed State**!
- Three steps:
  - **Assume**: One of the **two** operating modes (**Forward Biased** – **FB** or **Reverse Biased - RB**)

    *Correct assumptions will make solving circuit easier.

  - **Solve**: Use corresponding equation and KCL/KVL or any circuit analysis tool of your choice.

  - **Verify**: Check if the conditions of the diodes in the chosen region **(FB or RB)** are satisfied. If not, one can be sure that the other operating mode is correct.

Example Problems (Ideal Diode)

Example 1: $R_L = 2.5\ \mathbf{k\Omega}$

Assume:

Diode is in **FB:** A short circuit,

$v_d = 0\ \mathrm{V}$

$I > 0\ \mathbf{mA}$

Solve:

$$v_O = v_{IN} = \mathbf{5\ V}$$

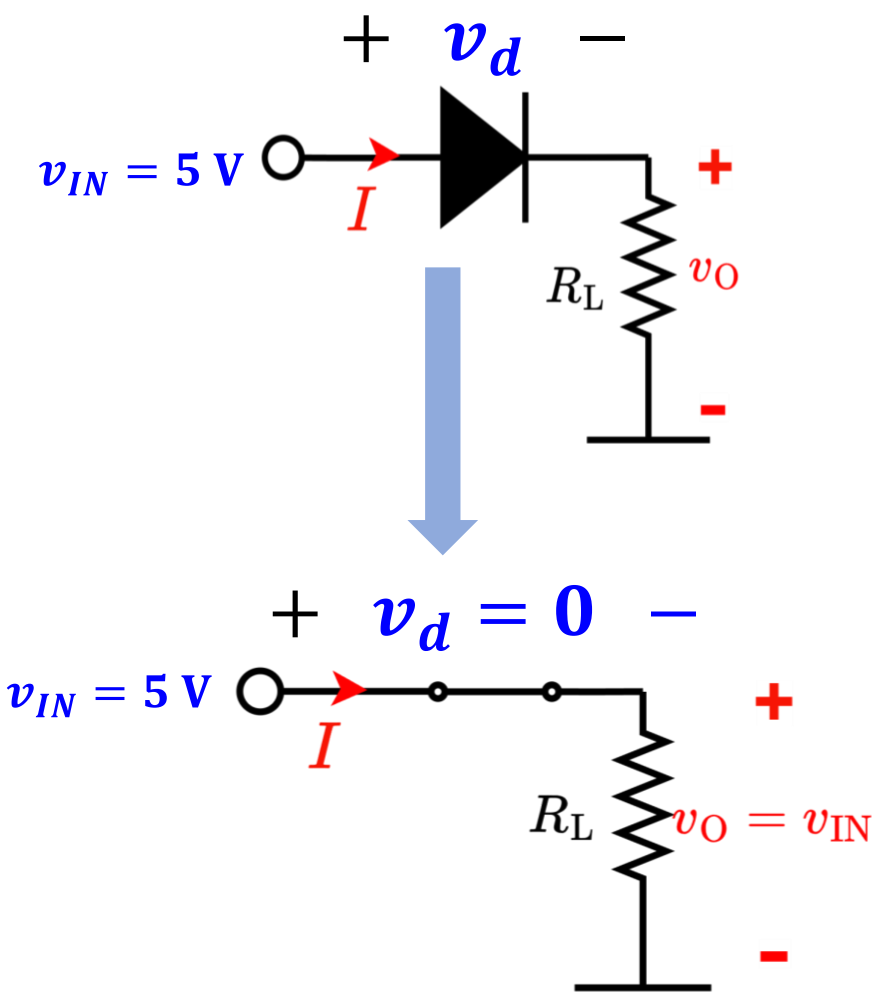
$$\boxed{\boldsymbol{v_d = v_{IN} - v_O = 0\ \mathrm{V}}}$$

$$I = \frac{v_O}{R_L} = \frac{5\ \mathrm{V}}{2.5\ \mathrm{k\Omega}} = \boxed{\mathbf{2\ mA > 0}}$$

Verify: For **FB** $\rightarrow$ $v_d = 0\ \mathrm{V}$

$I > 0\ \mathbf{mA}$

Here, both conditions are fulfilled. **Assumption is Correct!**



Example Problems (Ideal Diode)

Example 2: $R_L = 2.5\ \mathbf{k\Omega}$

Assume:

Diode is in **FB:** A short circuit,

$$v_d = 0\ \text{V}$$
$$I > 0\ \mathbf{mA}$$

Solve:

$$v_O = v_{IN} = \mathbf{5\ V}$$

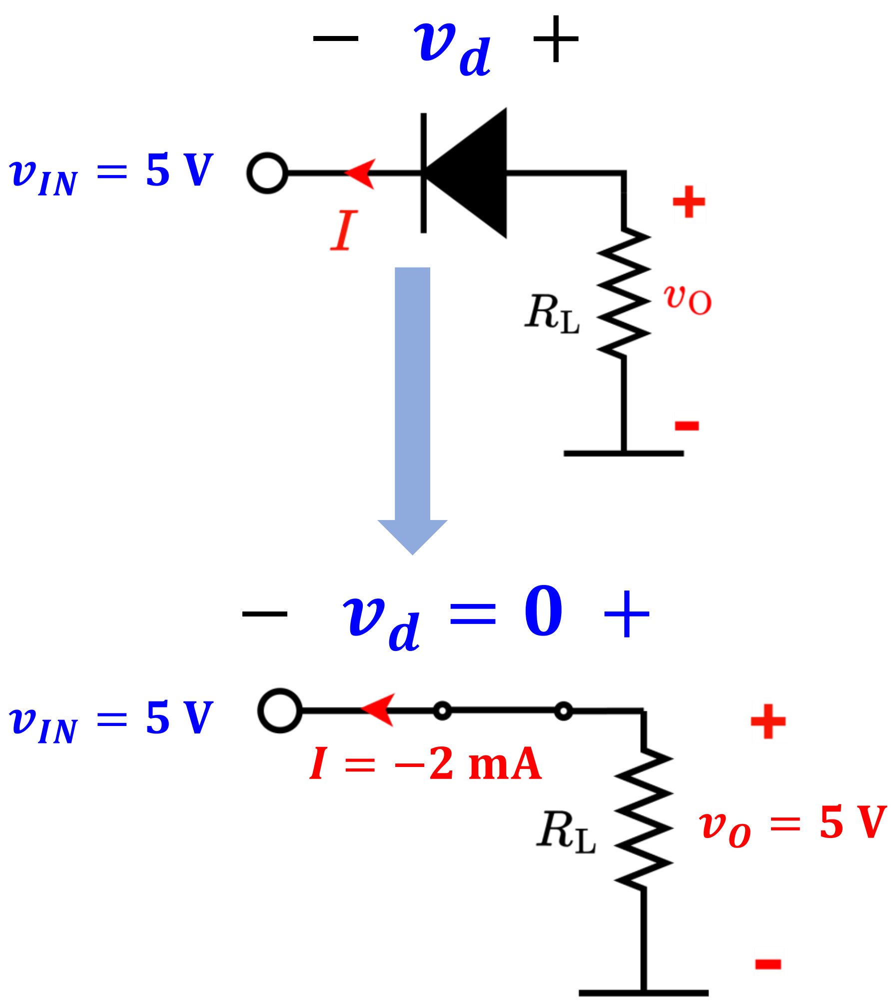
$$v_d = v_O - v_{IN} = \mathbf{0\ V}$$

$$I = -\frac{v_O}{R_L} = -\frac{5\ \text{V}}{2.5\ \text{k}\Omega} = \boxed{-\mathbf{2\ mA} < \mathbf{0}}$$

Verify: For **FB** $\rightarrow$ $v_d = 0\ \text{V}$

$I > 0\ \mathbf{mA}$

Here, $I < 0\ \mathbf{mA}$. **Assumption is INCORRECT!**



Example Problems (Ideal Diode)

Example 2: $R_L = 2.5\ \mathbf{k\Omega}$

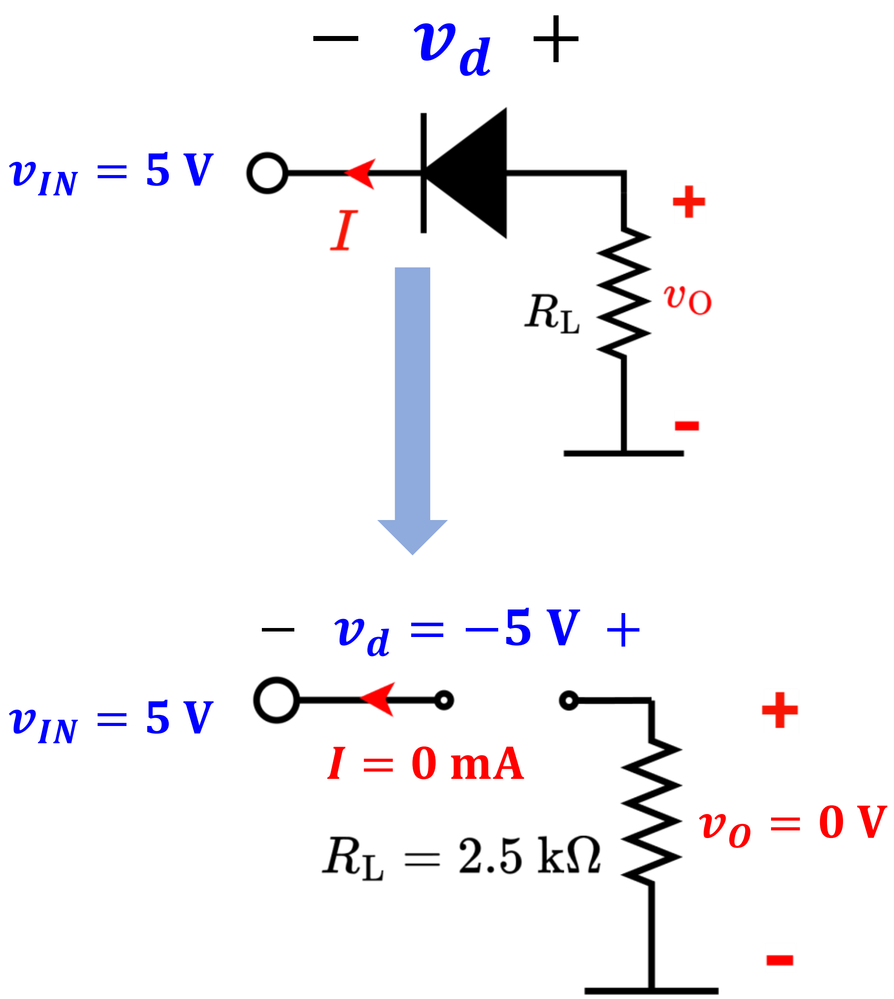
~~**Assume:**~~

Diode is in **RB:** An open circuit,

$$v_d < 0\ \mathrm{V}$$
$$I = 0\ \mathbf{mA}$$

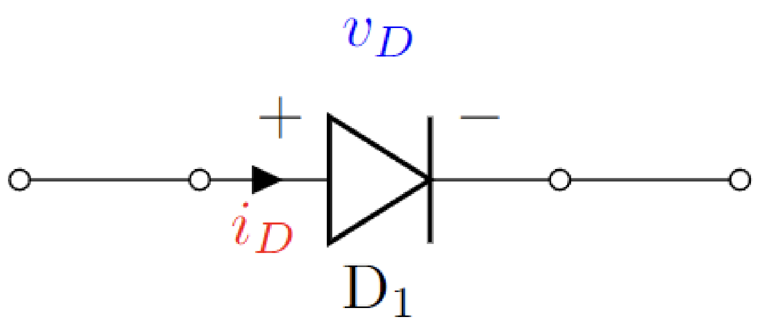
Solve:

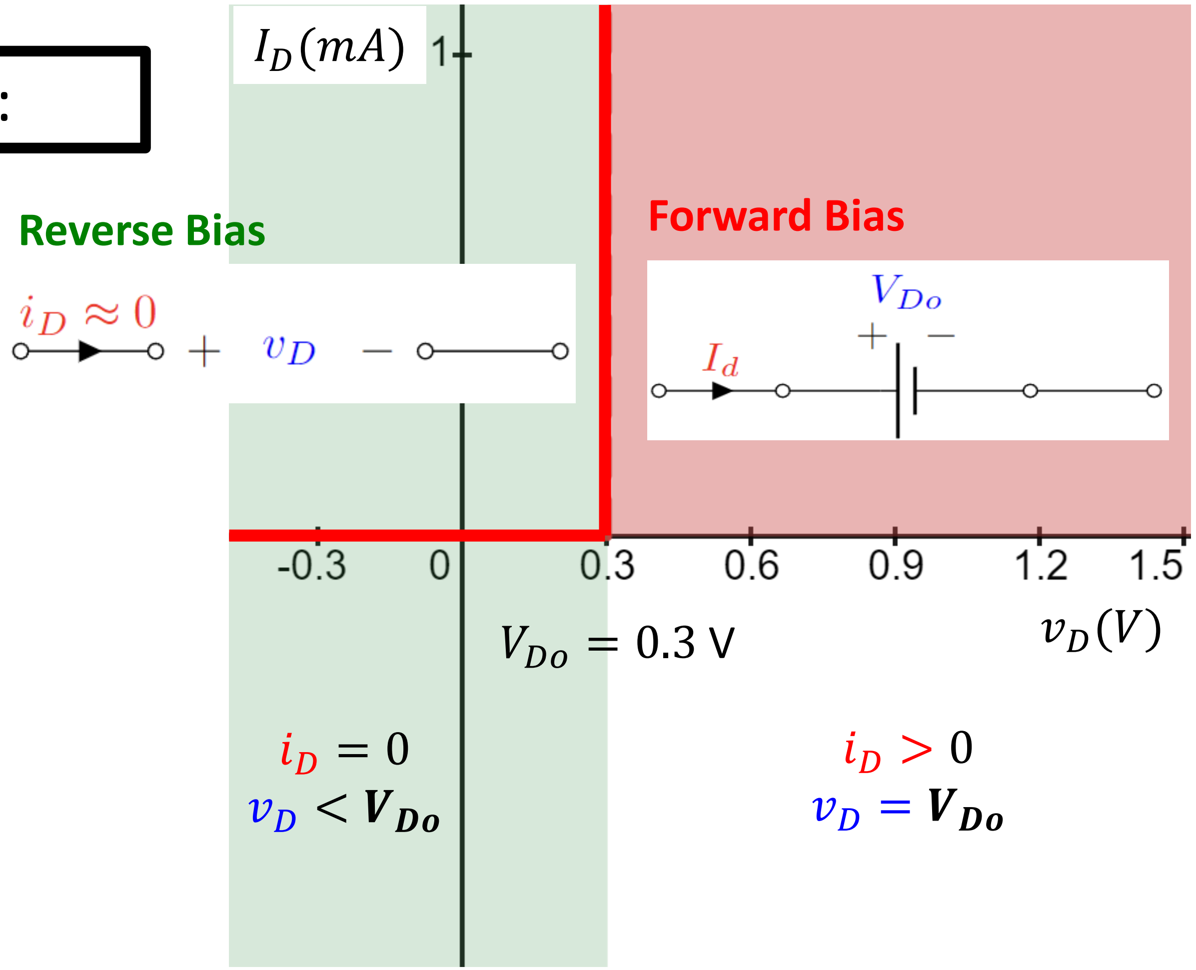
$$v_O = \mathbf{0\ V}$$
$$v_d = v_O - v_{IN} = -\mathbf{5\ V} < \mathbf{0\ V}$$
$$I = 0\ \mathbf{mA}$$



Diode Models

2. Constant Voltage Drop (CVD) Model:





v_D: Total Voltage Across diode

V_{Do}: Diode Cut-off voltage (0.3 V here)

Example Problems (CVD Diode)

Example 3: $R_L = 2.5\ \mathbf{k\Omega}$

Assume:

Diode is in **FB:** A constant voltage source of $\boldsymbol{V_{DO}}$ voltage,

$$\boldsymbol{v_d} = \boldsymbol{V_{DO}} = 0.7\ \mathbf{V}$$

$$\boldsymbol{I} > 0\ \mathbf{mA}$$

Solve:

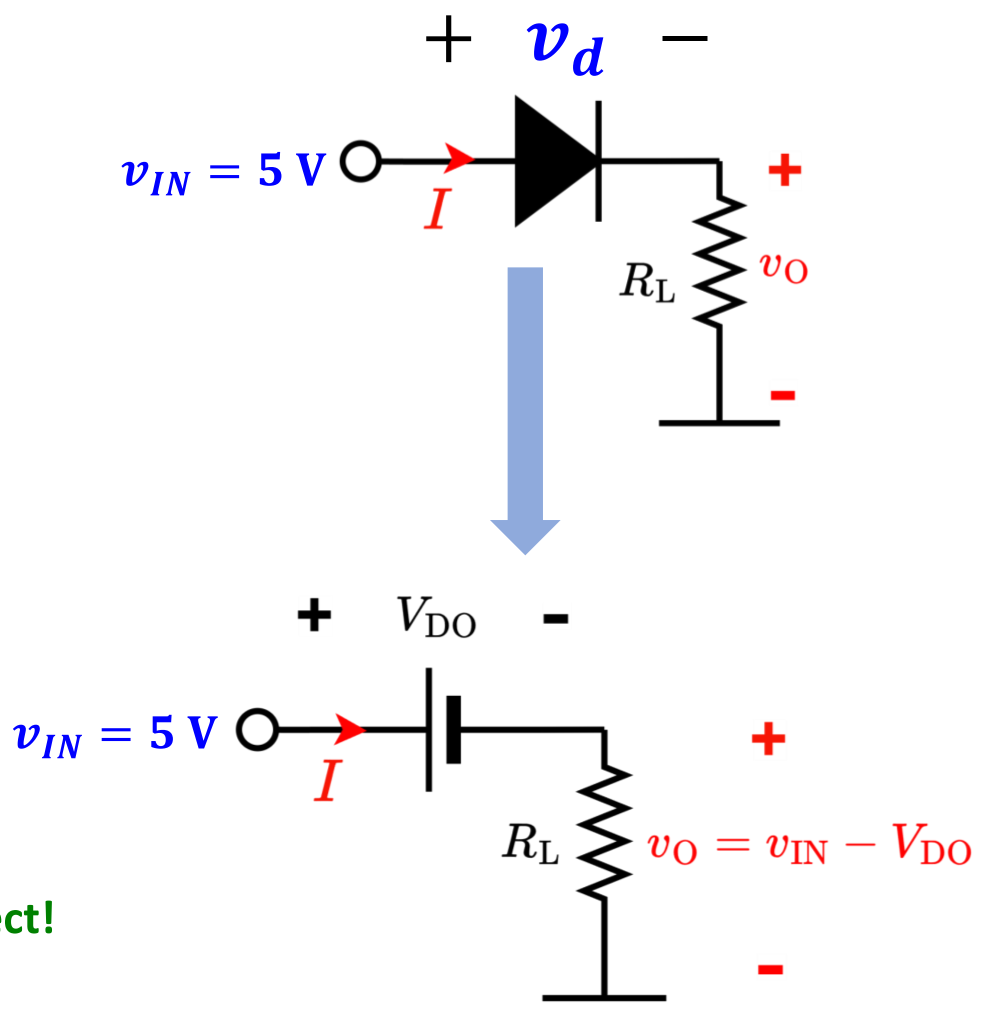
$$\boldsymbol{v_O} = \boldsymbol{v_{IN}} - \boldsymbol{V_{DO}} = 5 - 0.7\ \text{V} = 4.3\ \text{V}$$

$$\boxed{\boldsymbol{v_d} = \boldsymbol{V_{DO}} = \mathbf{0.7\ V}}$$

$$\boldsymbol{I} = \frac{v_{IN} - V_{DO}}{R_L} = \frac{4.3\ \text{V}}{2.5\ \text{k}\Omega} = \boxed{1.72\ \text{mA} > \mathbf{0}}$$

Verify: For **FB** → $\boldsymbol{I} > 0\ \mathbf{mA}$

Here, both conditions are fulfilled. **Assumption is Correct!**



Example Problems (CVD Diode)

Example 4: $R_L = 2.5\ \mathbf{k\Omega}$

Assume:

Diode is in **FB:** A **constant voltage source of** $\boldsymbol{V_{DO}}$ voltage,

$$\boldsymbol{v_d} = \boldsymbol{V_{DO}} = 0.7\ \mathbf{V}$$

$$\boldsymbol{I} > 0\ \mathbf{mA}$$

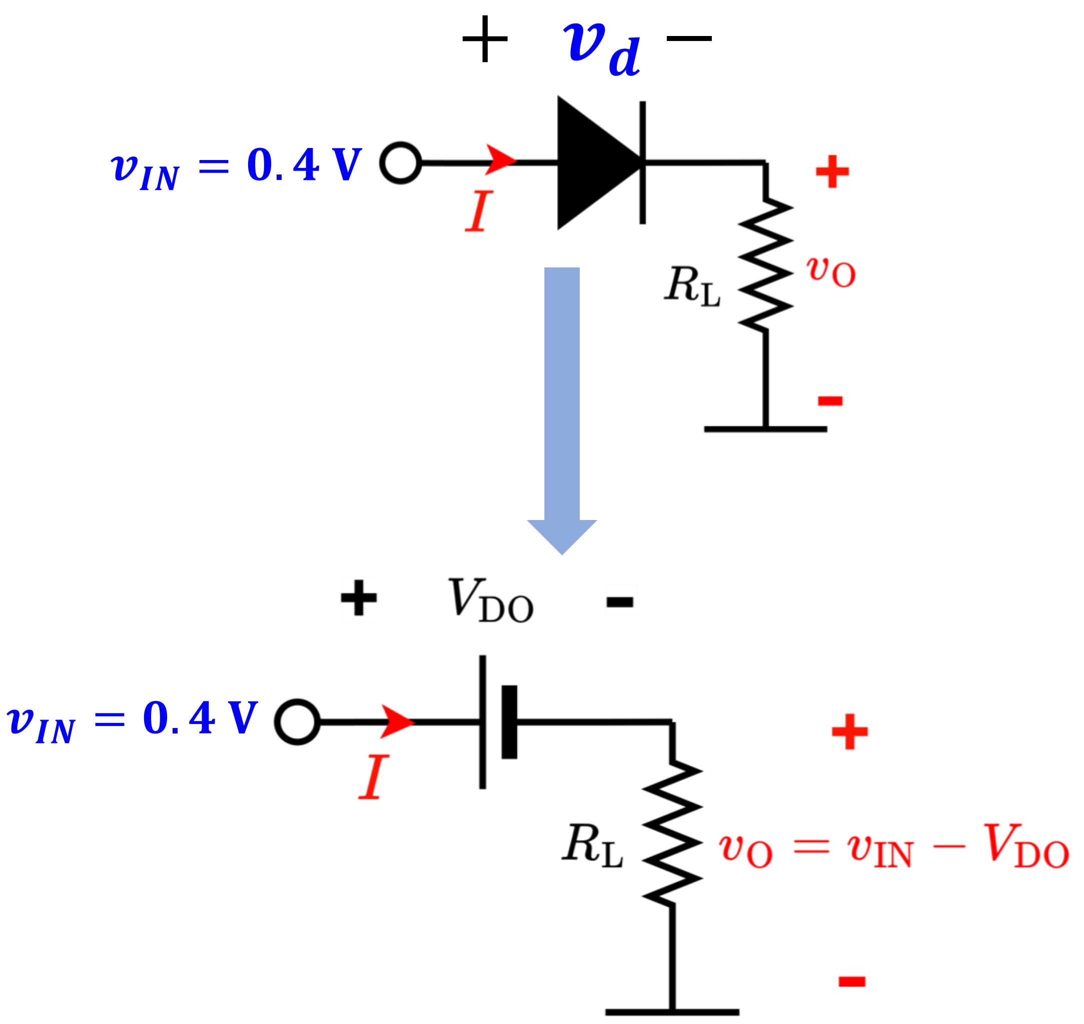
Solve:

$$\boldsymbol{v_O} = v_{IN} - V_{DO} = 0.4 - 0.7\ \text{V} = -0.3\ \text{V}$$

$$\boldsymbol{I} = \frac{v_O}{R_L} = \frac{-0.3\ \text{V}}{2.5\ \text{k}\Omega} = \boxed{-0.12\ \mathbf{mA} < \mathbf{0}}$$

Verify: For **FB** $\rightarrow$ $\boldsymbol{I} > 0\ \mathbf{mA}$

Here, $\boldsymbol{I} < 0\ \mathbf{mA}$. **Assumption is INCORRECT!**



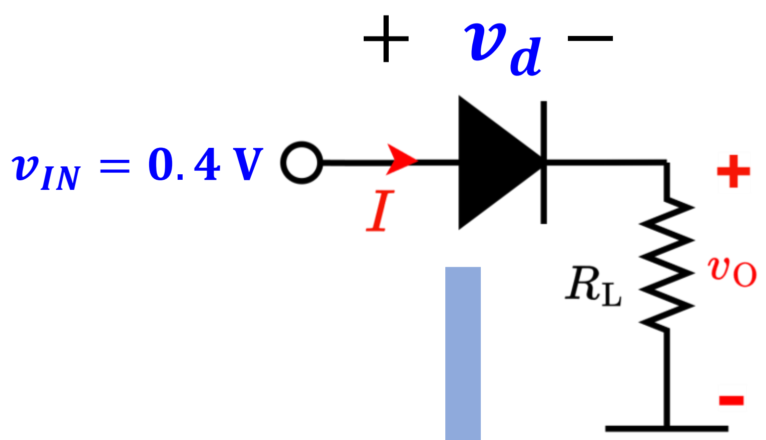
Example Problems (Ideal Diode)

Example 4: $R_L = 2.5\ \mathbf{k\Omega}$

~~**Assume:**~~

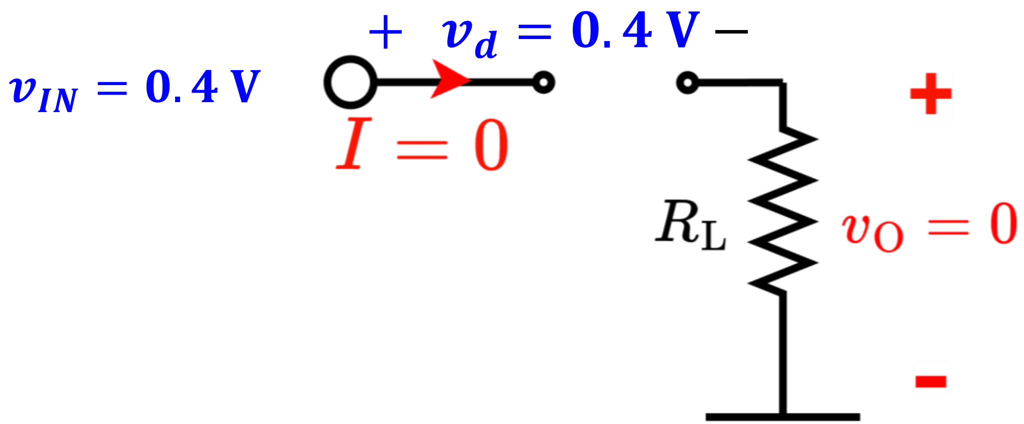
Diode is in **RB:** An open circuit,

$$v_d < V_{DO} = 0.7\ \text{V}$$
$$I = 0\ \mathbf{mA}$$



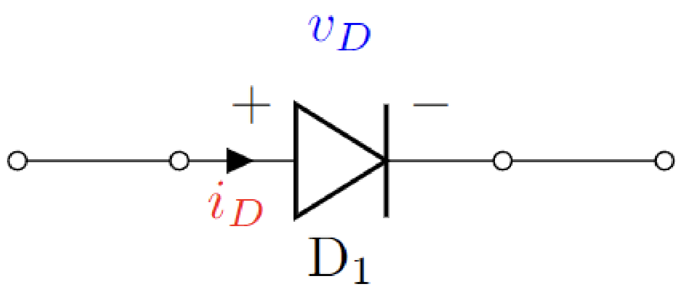
Solve:

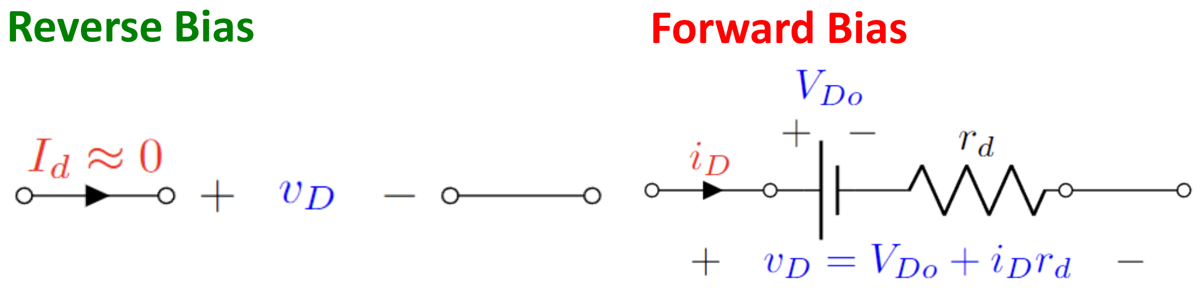
$$I = 0\ \mathbf{mA}$$
$$v_O = \mathbf{0\ V}$$
$$v_d = v_{IN} - v_O = \mathbf{0.4\ V < 0.7\ V}$$

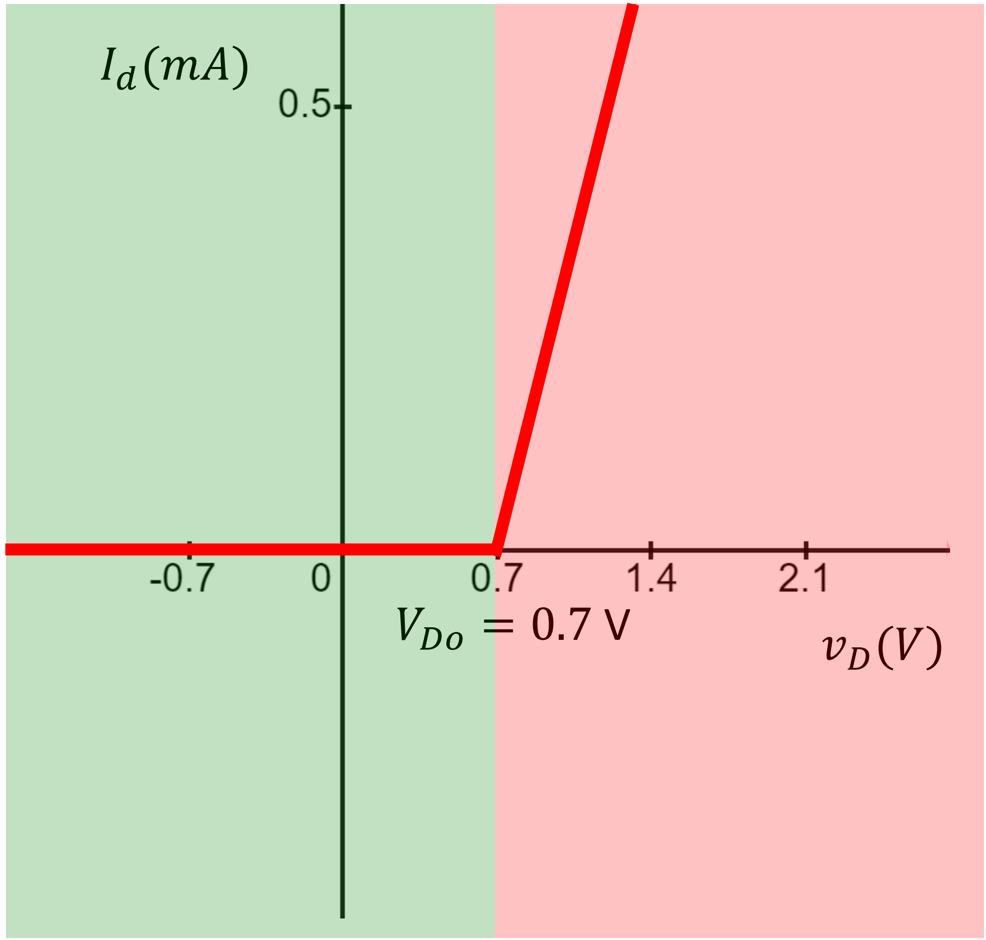


Diode Models

3. CVD+R Model:





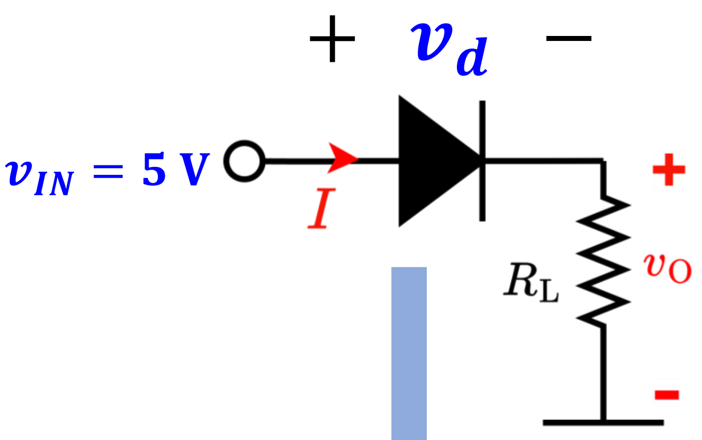


v_D: Total Voltage Across diode

V_{Do}: Diode Cut-off voltage (0.7 V)

Example Problems (CVD+R Diode)

Example 5: $R_L = 2.5\ \mathbf{k\Omega}$, $\boldsymbol{V_{DO} = 0.7\ \mathrm{V},\ r_d = 50\ \Omega}$



Assume:

Diode is in **FB:** A constant voltage drop in series with a resistor,

$V_{DO} = 0.7\ \mathrm{V}, \quad r_d = 50\ \Omega$

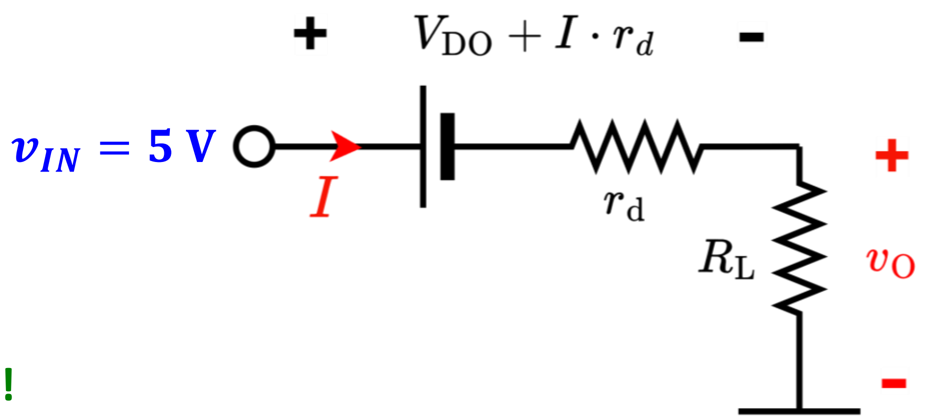
$\boldsymbol{v_d} = V_{DO} + Ir_d$

$\boldsymbol{I} > 0\ \mathbf{mA}$

Solve:

$$\boldsymbol{I} = \frac{v_O - V_{DO}}{R_L + r_d} = \frac{4.3\ \mathrm{V}}{2.5\ \mathrm{k\Omega} + 0.05\ \mathrm{k\Omega}} \boxed{= 1.70\ \mathrm{mA}}$$

$$\boldsymbol{v_O} = \boldsymbol{I}R_L = 1.70 \times 2.5\ \mathrm{V} = \mathbf{4.25\ V}$$



Verify: For **FB** → $\boldsymbol{I} > 0\ \mathbf{mA}$

Here, the condition is fulfilled. **Assumption is Correct!**

Example Problems (CVD+R Diode)

Example 6: $R_L = 2.5\ \mathbf{k\Omega}$, $\boldsymbol{V_{DO} = 0.7\ \mathrm{V}}$, $\boldsymbol{r_d = 50\ \Omega}$

Assume:

Diode is in **RB:** An open circuit,

$$v_d < V_{DO}$$
$$I = 0\ \mathrm{mA}$$

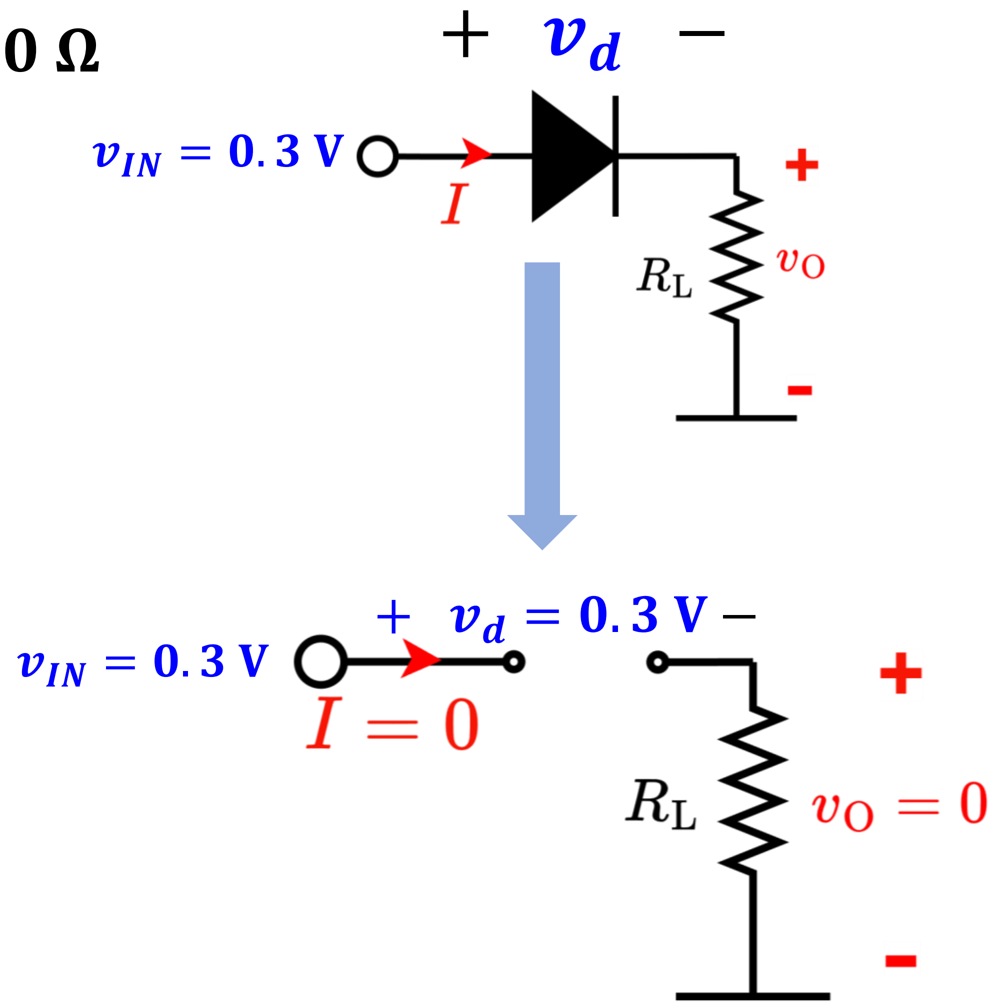
Solve:

$$v_O = 0\ \mathrm{V}$$

$$v_d = v_{IN} - v_O \boxed{= 0.3\ \mathrm{V}}$$

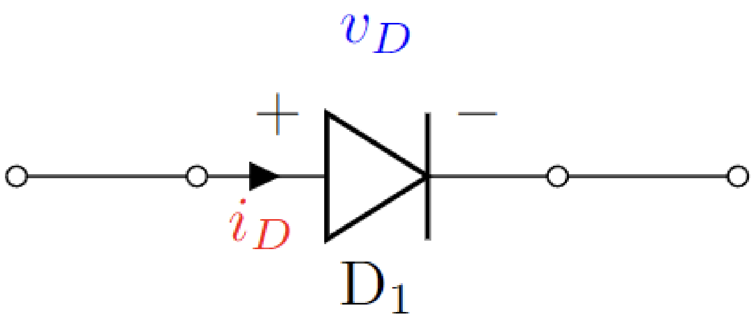
Verify: For **FB** $\rightarrow$ $v_d < V_{DO}$

Here, the condition is fulfilled. **Assumption is Correct!**



Diode Models

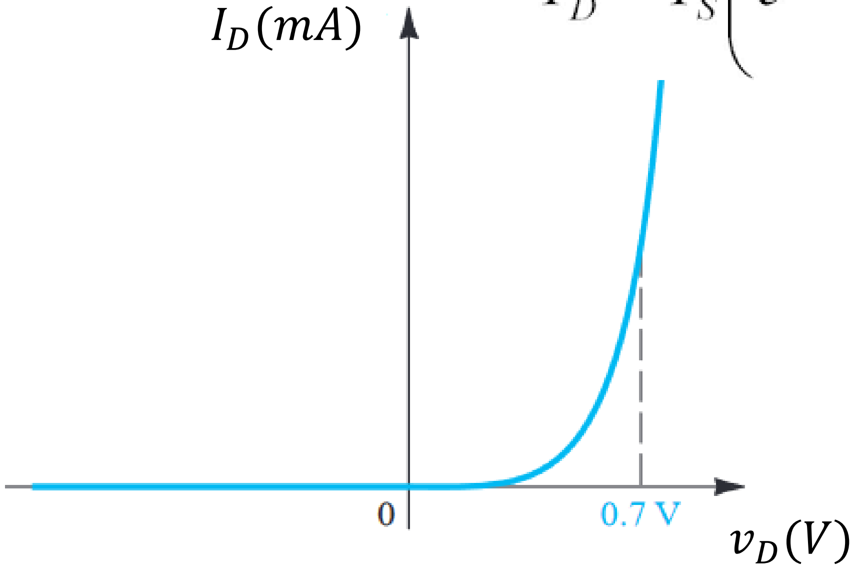
4. Shockley Diode Equation Model:



$$i_D = I_s\left[\exp\left(\frac{v_D}{nV_T}\right) - 1\right] \qquad V_T = \frac{kT}{q}$$

k = 1.38 × 10^{-23} J/K is Boltzmann's constant and q = 1.60 × 10^{-19} C is the magnitude of the electrical charge of an electron. At a temperature of 300 K, we have $V_T \simeq 26\,\text{mV}$

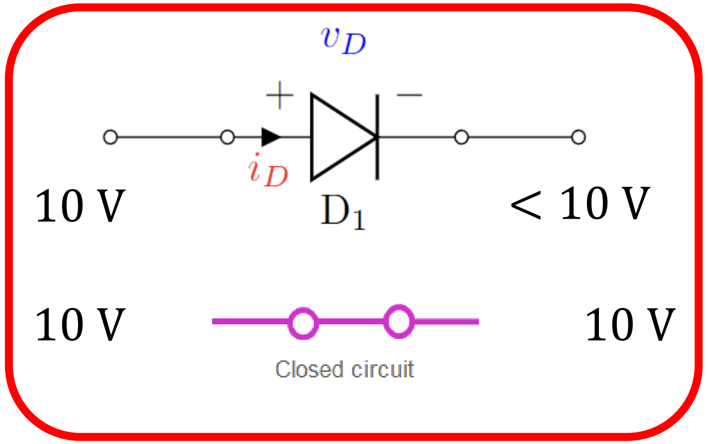
$$I_D = I_S\left(e^{\frac{qV_D}{nkT}} - 1\right)$$

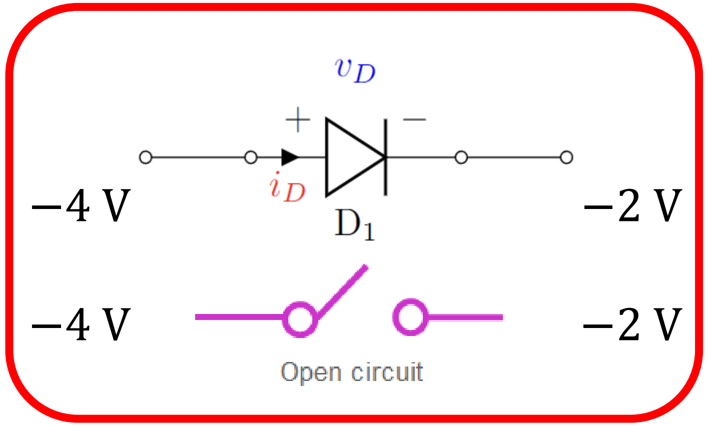


Where I_S is reverse saturation current

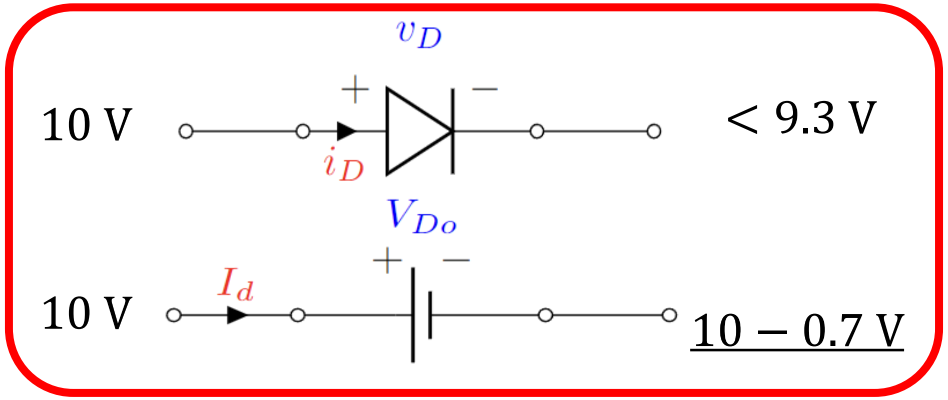
Diode Models: Summary

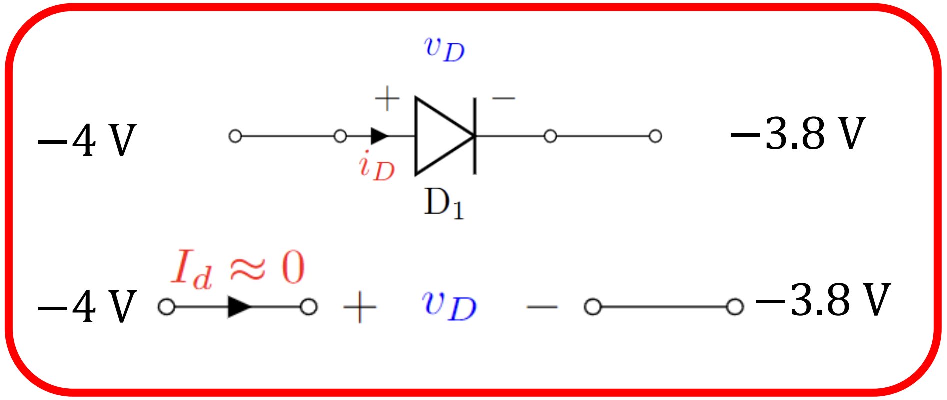
Ideal Diode





CVD Diode

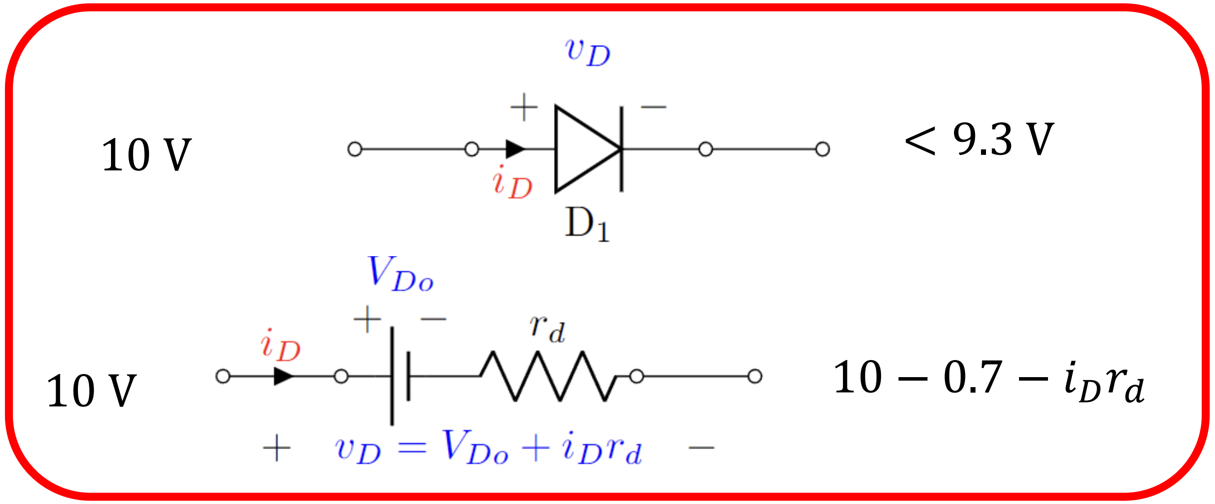


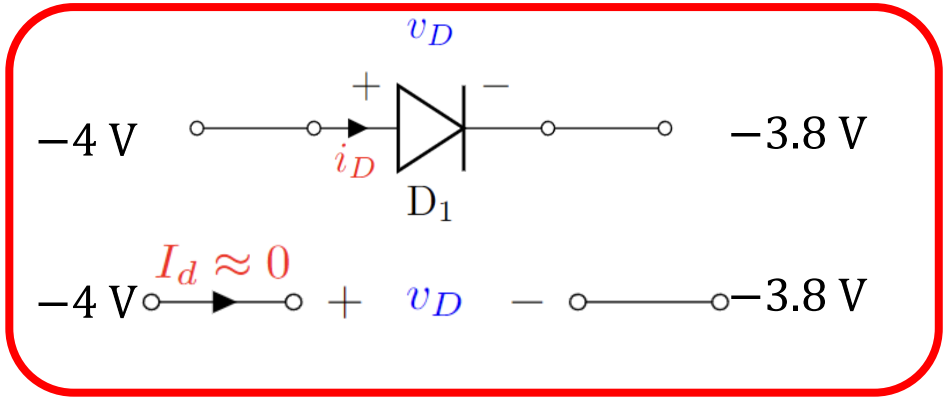


$$V_{Do} = 0.7 \text{ V}$$

Diode Models: Summary

CVD+R Diode





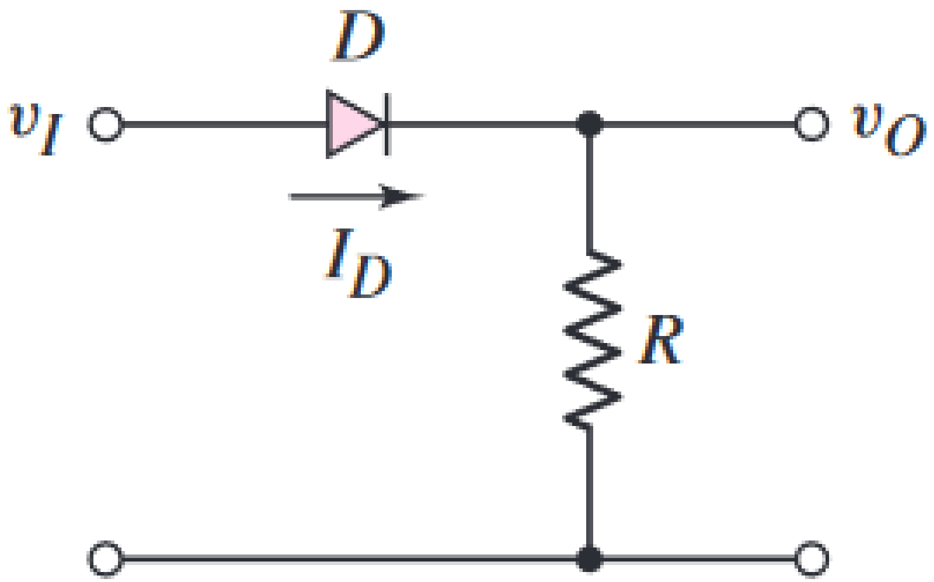
$V_{Do} = 0.7$ V

Part 3 ends here

Outline

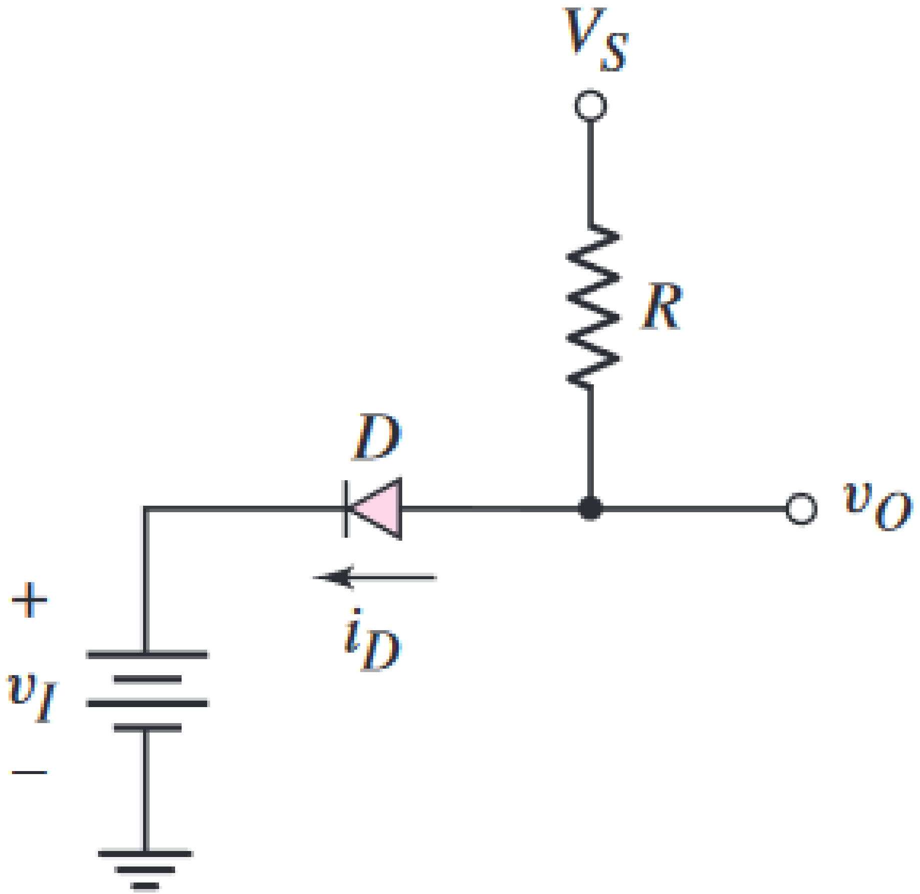
- **Practice Problems**

Solving Circuits with diodes (7)



If $v_I = 5$ V and $V_{DO} = 0.7$ V, find $\boldsymbol{v_O}$

Solving Circuits with diodes (7)

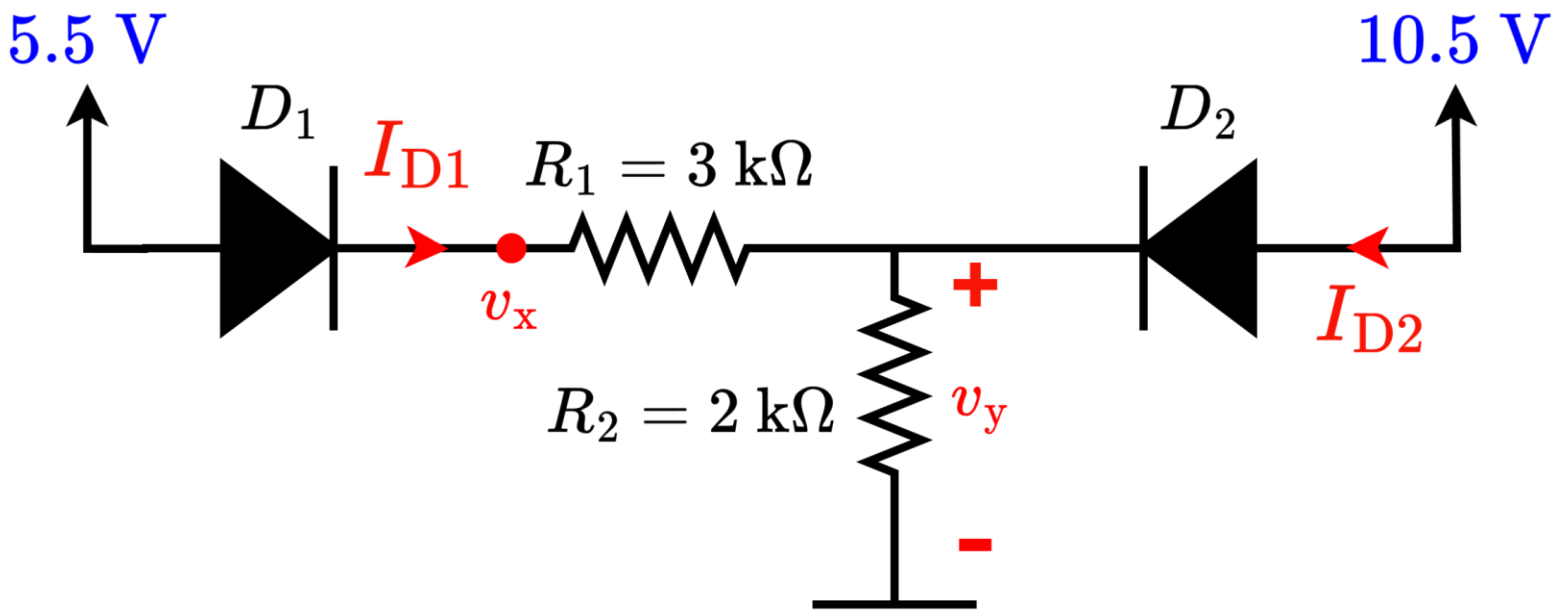


i) If $v_I = 5\ \mathrm{V}$, $V_S = 10\ \mathrm{V}$ and $V_{DO} = 0.7\ \mathrm{V}$, find $\boldsymbol{v_O}$

ii) If $v_I = 11\ \mathrm{V}$, $V_S = 10\ \mathrm{V}$ and $V_{DO} = 0.7\ \mathrm{V}$, find $\boldsymbol{v_O}$

iii) If $v_I = 0\ \mathrm{V}$, $V_S = 10\ \mathrm{V}$ and $V_{DO} = 0.7\ \mathrm{V}$, find $\boldsymbol{v_O}$

Solving Circuits with diodes (9)

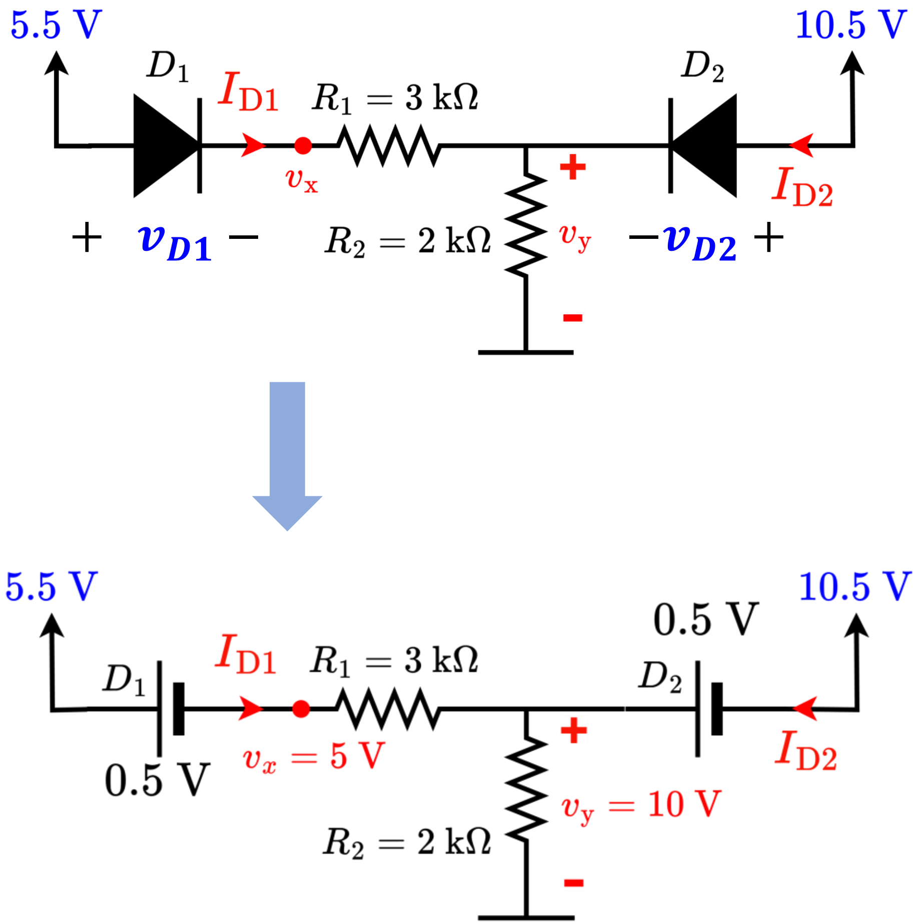


Example 9: Analyze the circuit to find I_{D1}, I_{D2}, v_x and v_y. Consider $\boldsymbol{V_{DO} = 0.5\ \mathrm{V}}$.
[Validate Assumptions]

Solving Circuits with diodes (9)

Example 9: Analyze the circuit to find I_{D1}, I_{D2}, v_x and v_y. Consider $\boldsymbol{V_{DO} = 0.5\ V}$.

[Validate Assumptions]



Assume:

D1, D2 are in **FB**: A **constant voltage source of** V_{DO} voltage,

$v_{D1} = 0.5\ \mathbf{V}$, || $v_{D2} = 0.5\ \mathbf{V}$

$I_{D1} > 0\ \mathbf{mA}$, || $I_{D2} > 0\ \mathbf{mA}$

Solve:

$$v_x = 5.5 - v_{D1} = 5\ \mathbf{V}$$

$$v_y = 10.5 - v_{D2} = 10\ \mathbf{V}$$

$$I_{D1} = \frac{v_x - v_y}{R_1} = \frac{-5\ \text{V}}{3\ \text{k}\Omega} \boxed{= -1.66\ \mathbf{mA} < \mathbf{0}}$$

$$I_{D2} = \frac{v_y}{R_1} - I_{D1} = \frac{10}{2} - \frac{-5}{3} \boxed{= \frac{20}{3}\ \mathbf{mA} > \mathbf{0}}$$

Verify: $I_{D1} > 0\ \mathbf{mA}$, || $I_{D2} > 0\ \mathbf{mA}$

Here, $I_{D1} < 0\ \mathbf{mA}$. **Assumption is INCORRECT!**

Solving Circuits with diodes (9)

Example 9: Analyze the circuit to find I_{D1}, I_{D2}, v_x and v_y. Consider $\boldsymbol{V_{DO} = 0.5\ V}$.

[Validate Assumptions]

Assume:

D1 in **RB**		**D2** are in **FB**
$I_{D1} = 0\ \mathbf{mA}$,	||	$v_{D2} = 0.5\ \mathbf{V}$
$v_{D1} < 0.5\ \mathbf{V}$,	||	$I_{D2} > 0\ \mathbf{mA}$

Solve:

$$v_y = 10.5 - v_{D2} = 10\ \mathbf{V}$$

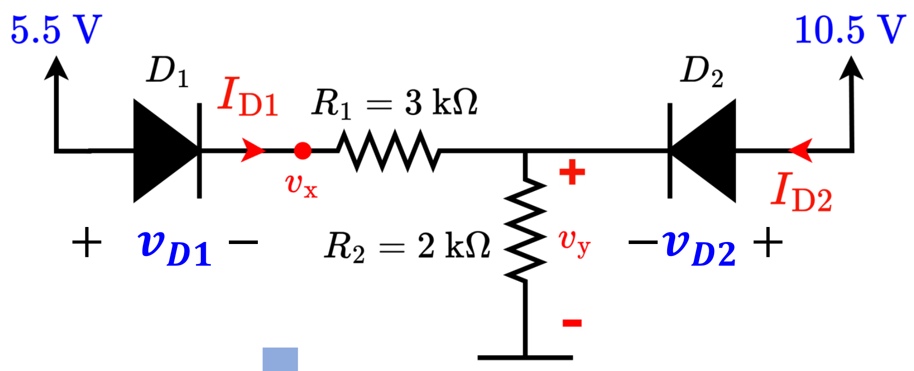
$$v_x = v_y = \mathbf{10\ V}, \text{as } I_{D1} = 0$$

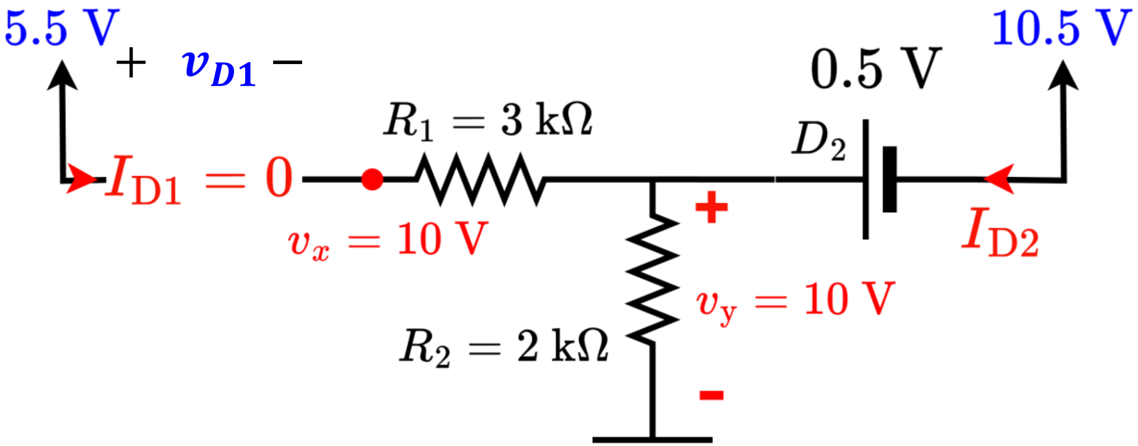
$$v_{D1} = 5.5 - v_x \boxed{= -4.5\ \mathrm{V} < 0.5\ \mathrm{V}}$$

$$I_{D2} = \frac{v_y}{R_1} = \frac{10}{2} = \boxed{5\ \mathrm{mA} > 0}$$

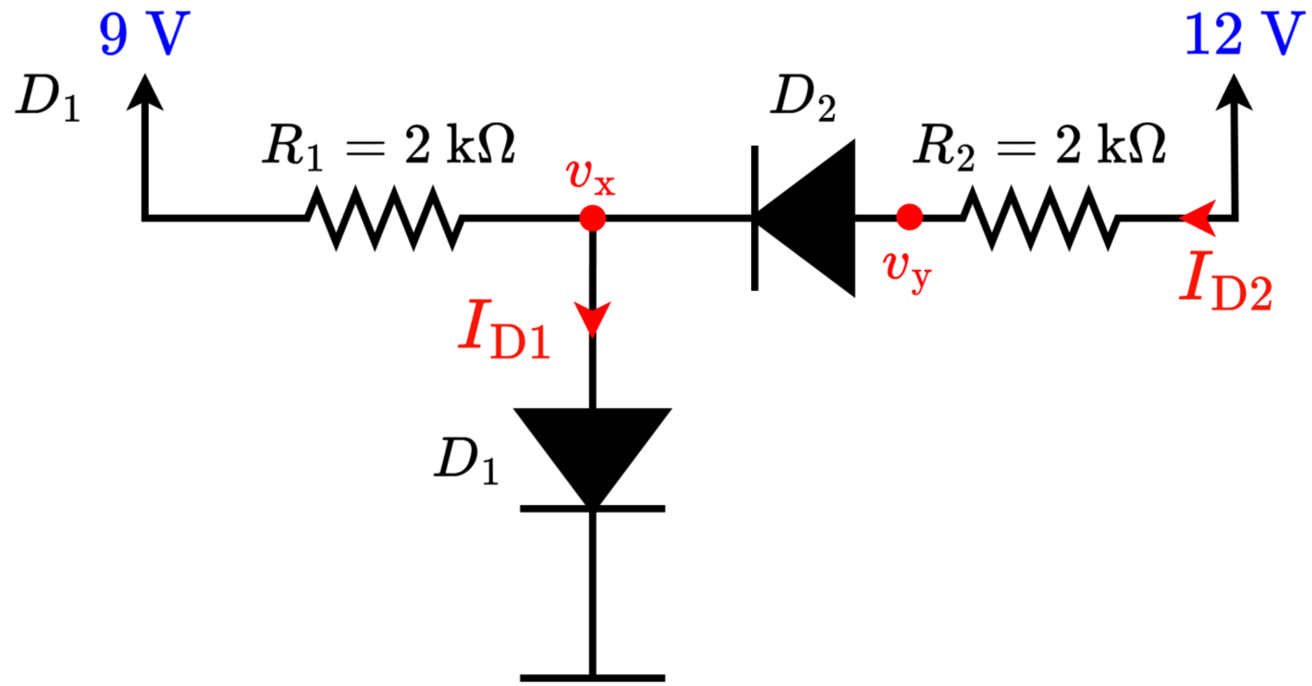
Verify: $v_{D1} < 0.5\ \mathbf{V}$, || $I_{D2} > 0\ \mathbf{mA}$

Assumption is Correct!





Solving Circuits with diodes (10)



Example 10: Analyze the circuit to find I_{D1}, I_{D2}, v_x and v_y. Consider $\boldsymbol{V_{DO} = 1\ \text{V}}$. **[Validate Assumptions].** Are the diodes consuming power or delivering power?

Solving Circuits with diodes (11)

Example 10: Analyze the circuit to find I_{D1}, I_{D2}, v_x and v_y. Consider $\boldsymbol{V_{DO} = 1\ \mathrm{V}}$. [Validate Assumptions]. Are the diodes consuming power or delivering power?

Assume:

D1, D2 are in **FB**: A **constant voltage source of** V_{DO} voltage,

$v_{D1} = 1\ \mathbf{V}$, || $v_{D2} = 1\ \mathbf{V}$

$I_{D1} > 0\ \mathbf{mA}$, || $I_{D2} > 0\ \mathbf{mA}$

Solve:

$$v_x = v_{D1} = 1\ \mathbf{V}$$

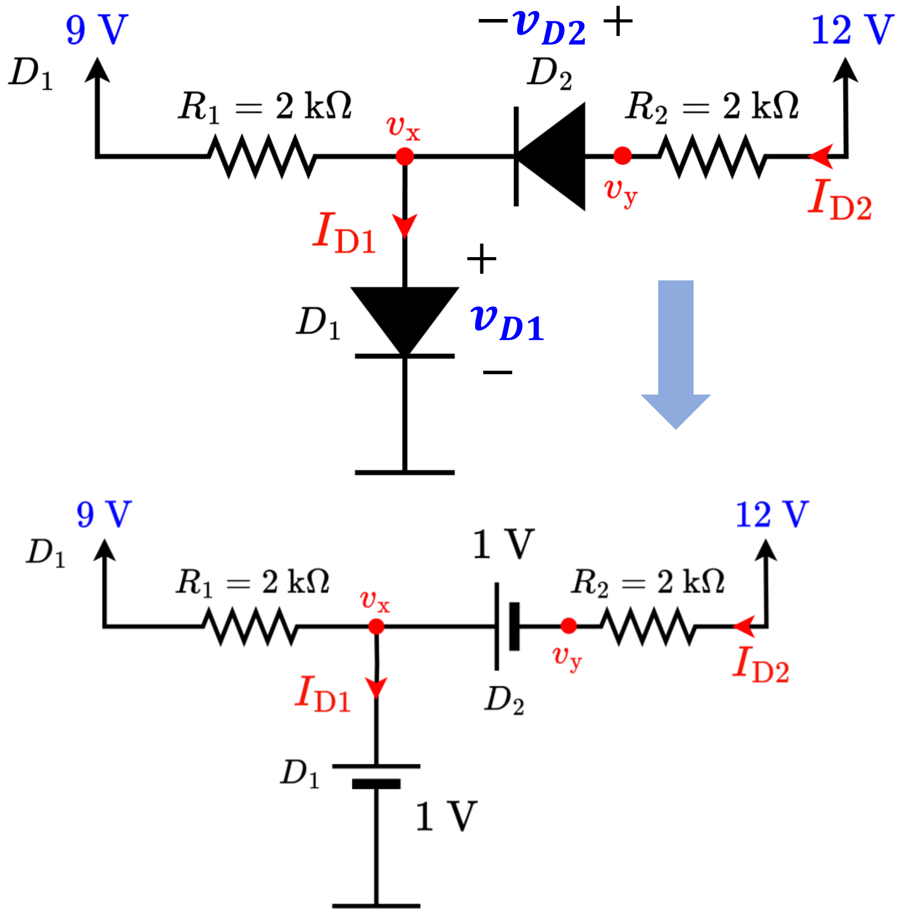
$$v_y = v_x + v_{D2} = 2\ \mathbf{V}$$

$$I_{D2} = \frac{\mathbf{12} - v_y}{R_2} = \frac{10}{2} \boxed{= 5\ \mathbf{mA} > \mathbf{0}}$$

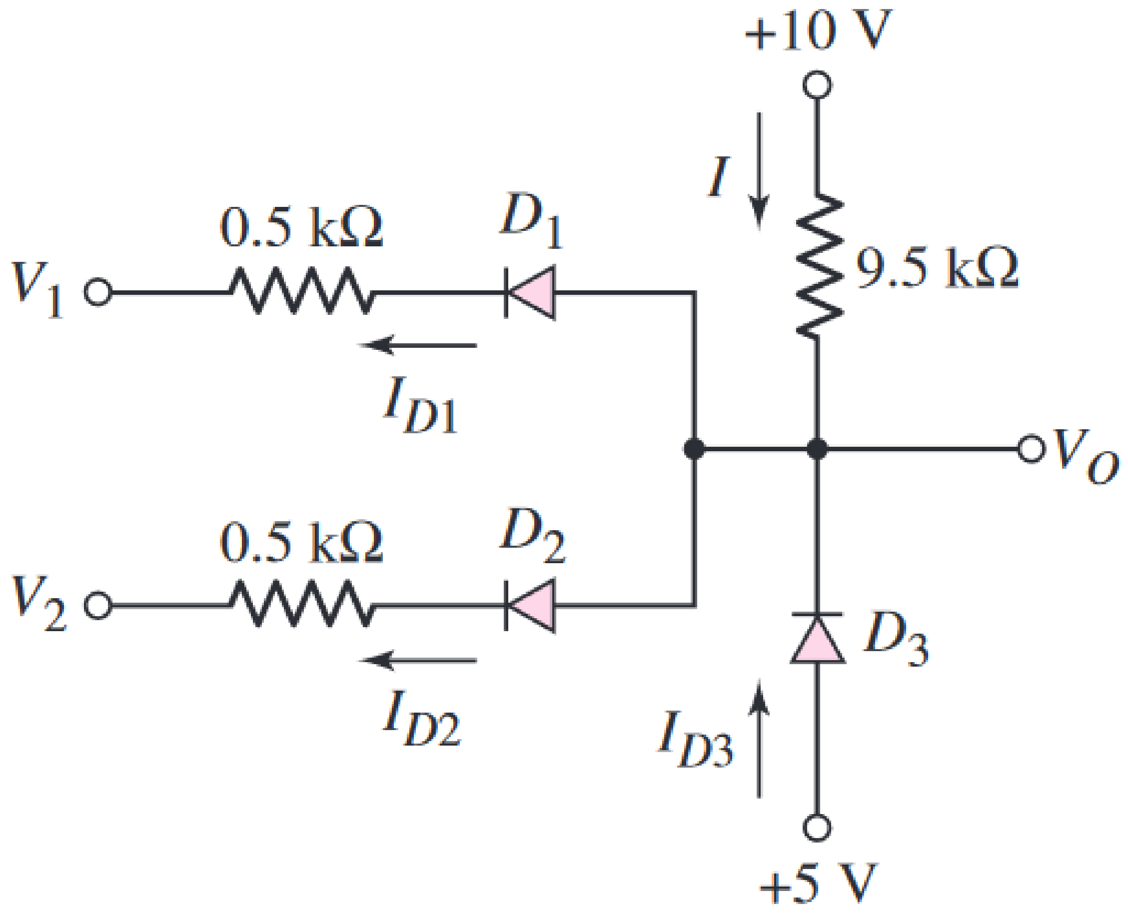
$$I_{D1} = I_{D2} + \frac{\mathbf{9} - v_x}{R_1} = 5 + \frac{8}{2} \boxed{= 9\ \mathbf{mA} > \mathbf{0}}$$

Verify: $I_{D1} > 0\ \mathbf{mA}$, || $I_{D2} > 0\ \mathbf{mA}$

Assumption is Correct!



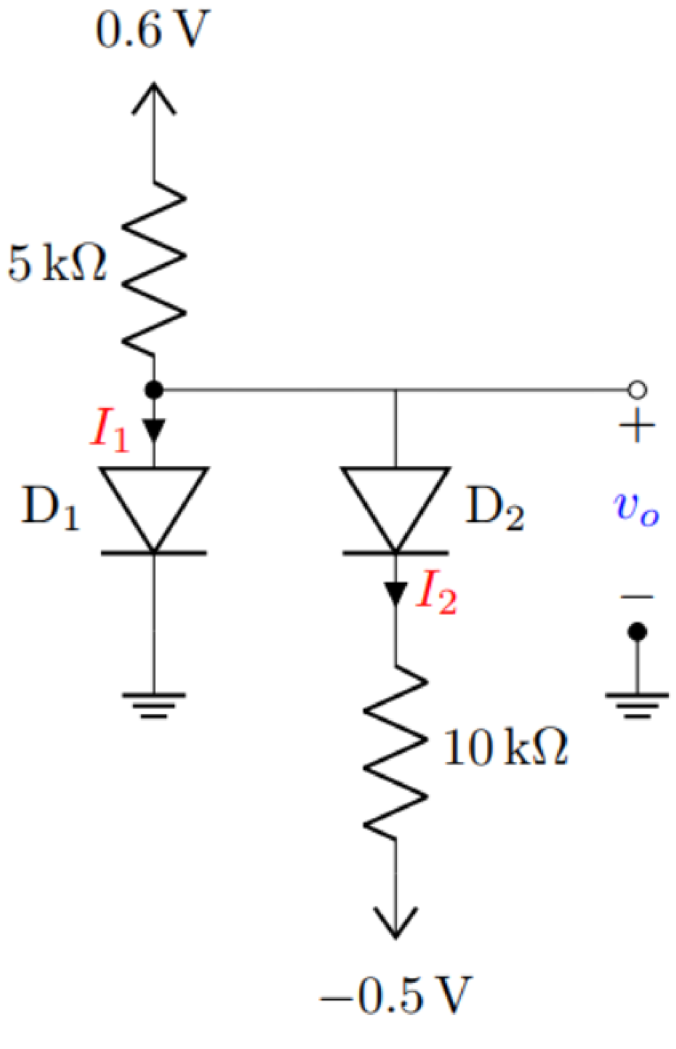
Solving Circuits with diodes (12)



Analyze the circuit to find I_{D1}, I_{D2}, I_{D3} and I for the following cases: Consider $\boldsymbol{V_{DO} = 0.6\ \mathrm{V}}$. **[Validate Assumptions]**

$$\boldsymbol{V_1 = V_2 = 0\ \mathrm{V}}$$
$$\boldsymbol{V_1 = V_2 = 5\ \mathrm{V}}$$
$$\boldsymbol{V_1 = 5\ \mathrm{V}, \qquad V_2 = 0\ \mathrm{V}}$$
$$\boldsymbol{V_1 = 0\ \mathrm{V}, \qquad V_2 = 2\ \mathrm{V}}$$

Solving Circuits with diodes (13)



Analyze the circuit to find I_1, I_2, and $\boldsymbol{v_O}$ for

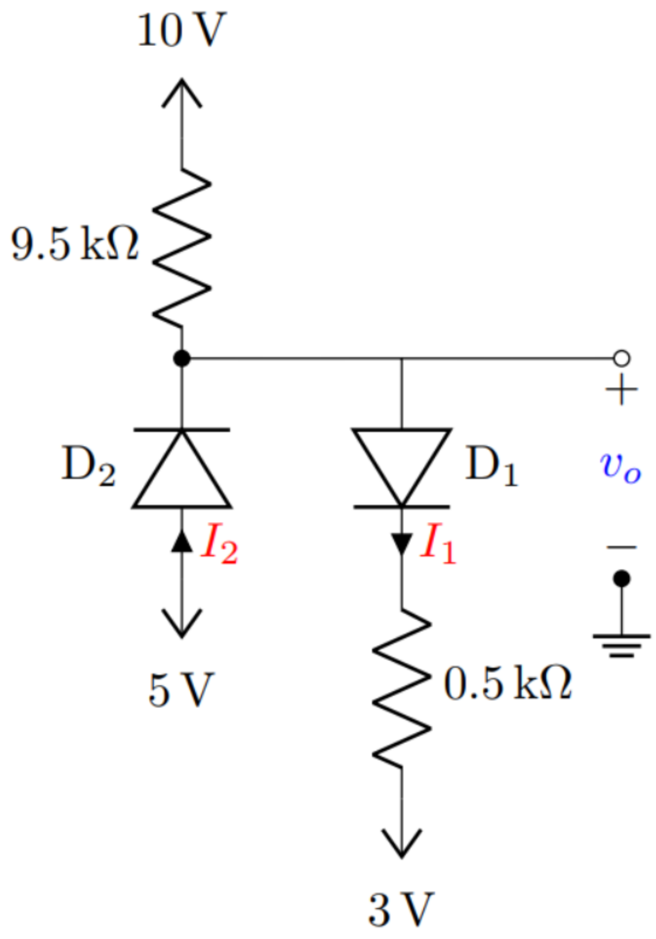
i. Assuming all diodes as ideal

ii. Consider $\boldsymbol{V_{D1} = 0.5\ \mathrm{V}}$ and $\boldsymbol{V_{D2} = 0.7\ \mathrm{V}}$**. (CVD model)**

iii. Consider $\boldsymbol{V_{DO} = 0.6\ \mathrm{V}}$ and $\boldsymbol{r_d = 50\ \Omega}$**. (CVD+R model)**

[Validate Assumptions]

Solving Circuits with diodes (14)



Analyze the circuit to find I_1, I_2, and $\boldsymbol{v_O}$ for

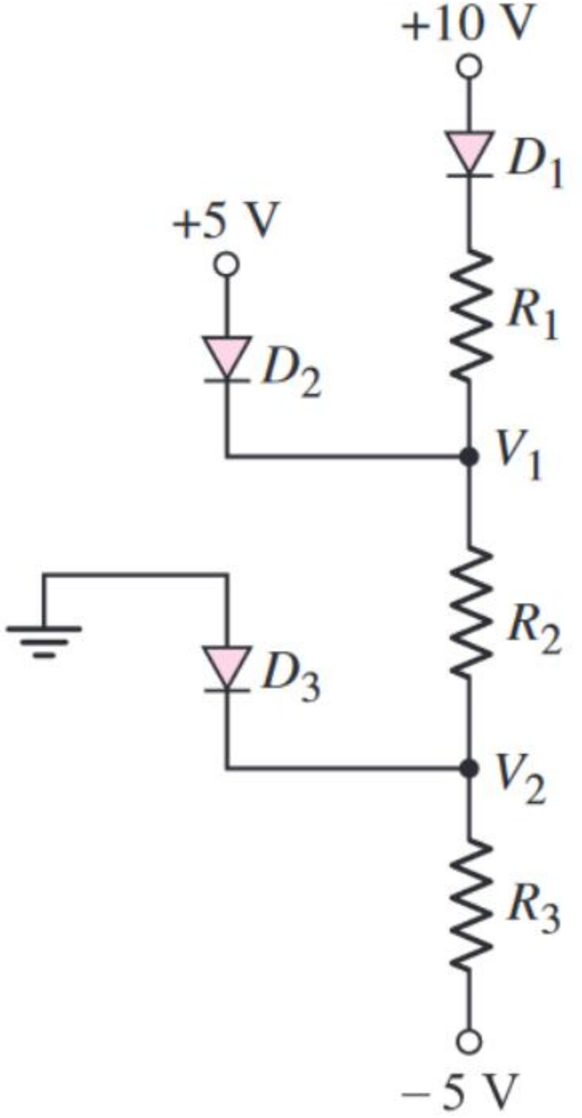
i. Assuming all diodes as ideal

ii. **Consider $\boldsymbol{V_{DO} = 0.6\ \mathrm{V}}$. (CVD model)**

iii. **Consider $\boldsymbol{V_{DO} = 0.6\ \mathrm{V}}$** and **$\boldsymbol{r_d = 50\ \Omega}$. (CVD+R model)**

[Validate Assumptions]

Solving Circuits with diodes (15)



a. Determine $\boldsymbol{R_1}, \boldsymbol{R_2}$ and $\boldsymbol{R_3}$ such that

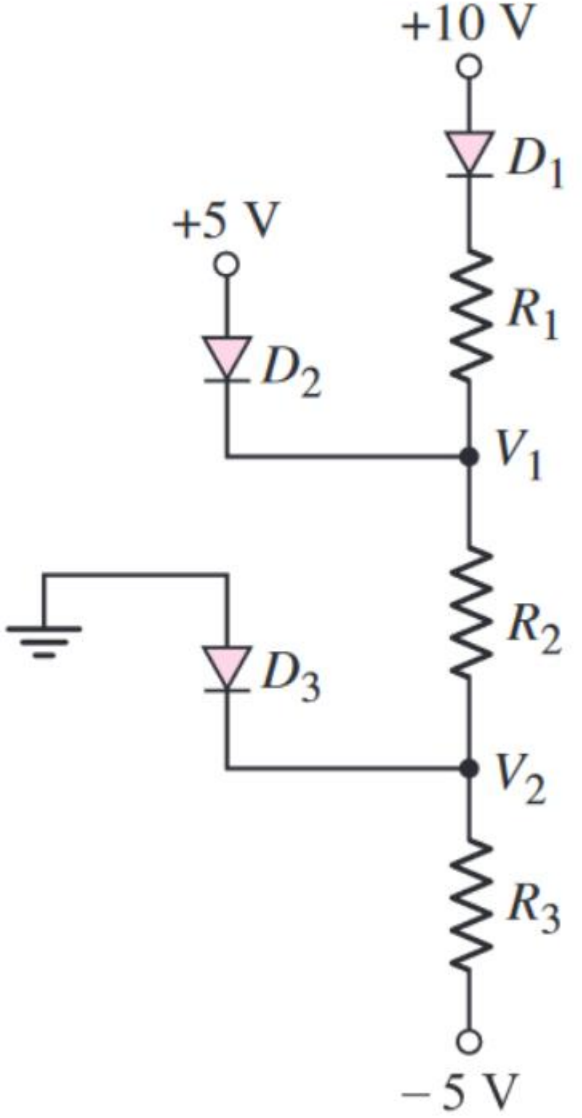
$$I_{D1} = 0.2 \text{ mA},$$
$$I_{D2} = 0.3 \text{ mA}$$
$$I_{D3} = 0.5 \text{ mA}$$

b. Find $\boldsymbol{V_1}, \boldsymbol{V_2}$ and each diode current for

$$R_1 = 10 \text{ k}\Omega$$
$$R_2 = 4 \text{ k}\Omega$$
$$R_3 = 2.2 \text{ k}\Omega$$

Consider $\boldsymbol{V_{DO} = 0.6}$ **V. [Validate Assumptions]**

Solving Circuits with diodes (16)



a. Find $\boldsymbol{V_1}, \boldsymbol{V_2}$ and each diode current for

$$R_1 = 3\ \mathrm{k\Omega}$$
$$R_2 = 6\ \mathrm{k\Omega}$$
$$R_3 = 2.5\ \mathrm{k\Omega}$$

b. Find $\boldsymbol{V_1}, \boldsymbol{V_2}$ and each diode current for

$$R_1 = 6\ \mathrm{k\Omega}$$
$$R_2 = 3\ \mathrm{k\Omega}$$
$$R_3 = 6\ \mathrm{k\Omega}$$

Consider $\boldsymbol{V_{DO} = 0.6\ \mathrm{V}}$. **[Validate Assumptions]**

Thank You!