Lecture-4

Diodes

Semiconductor Devices

- 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

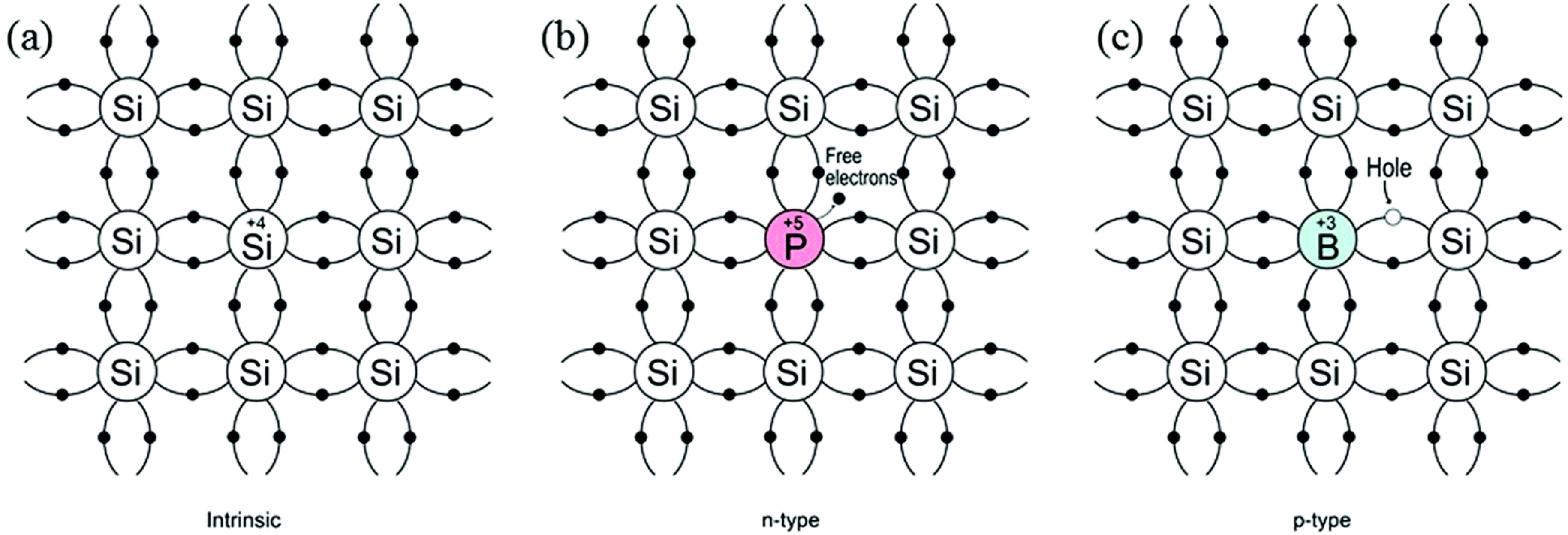
What is doping?

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

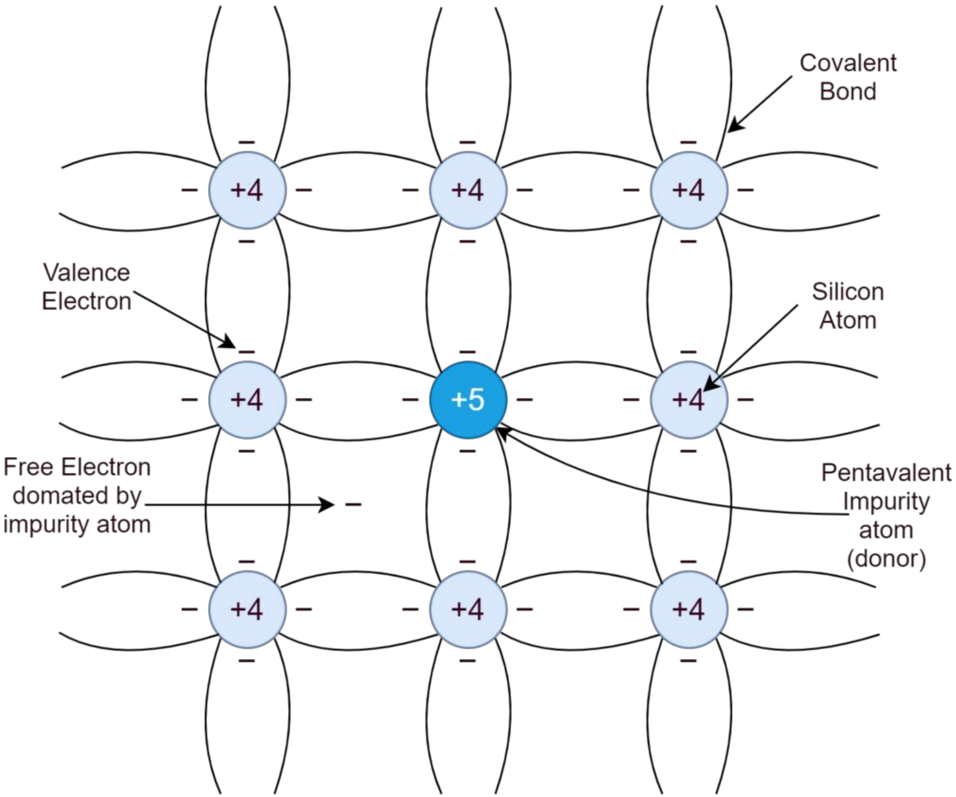


n-type doped → Si lattice is riddled with pentavalent atoms

p-type doped → Si lattice is riddled with trivalent atoms

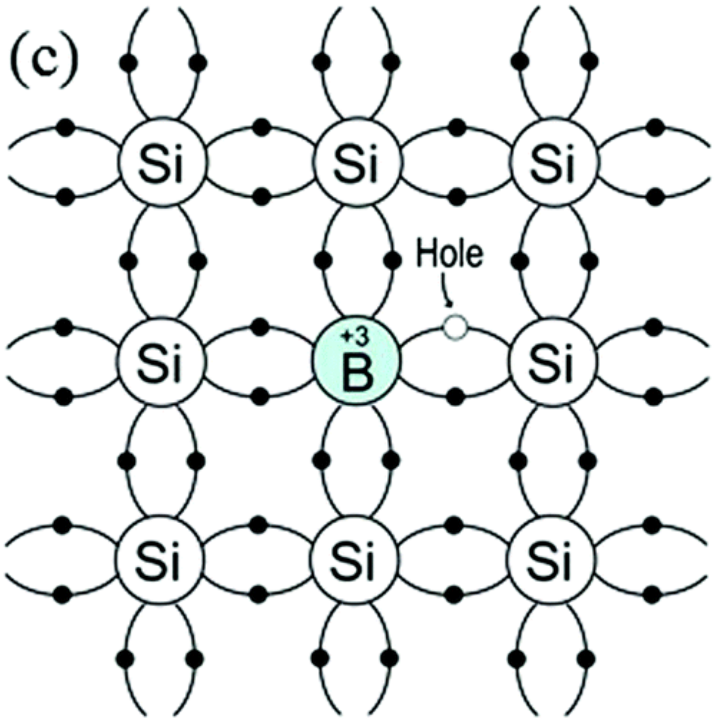
n-type doping

- 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

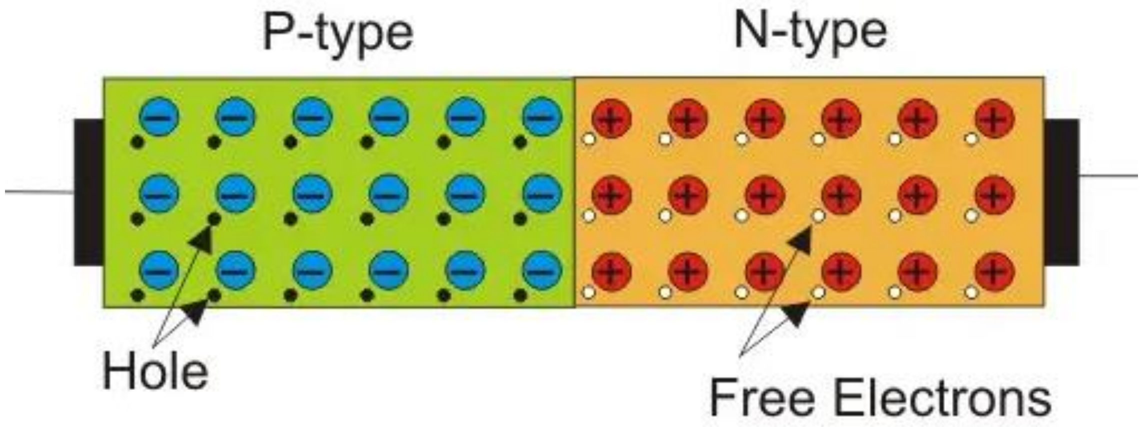
- p-type materials are doped with trivalent atoms.
- Trivalent atoms have one less electron than the surrounding tetravalent Si atoms.
- This absence of an electron (termed as a hole) acts as can flow easily from atom to atom across the material as it is not bonded to any atom. The flow of holes is opposite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



p-type

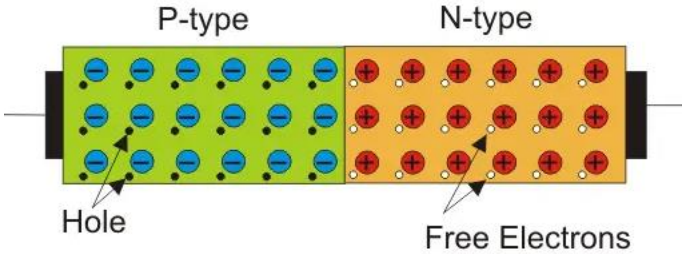
Semiconductor Devices

- Diode 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**.



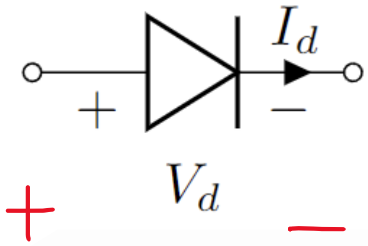
The **pn** junction diode: Physical characteristics

Internal Structure



Circuit Schematic

Anode



Cathode

Real device image

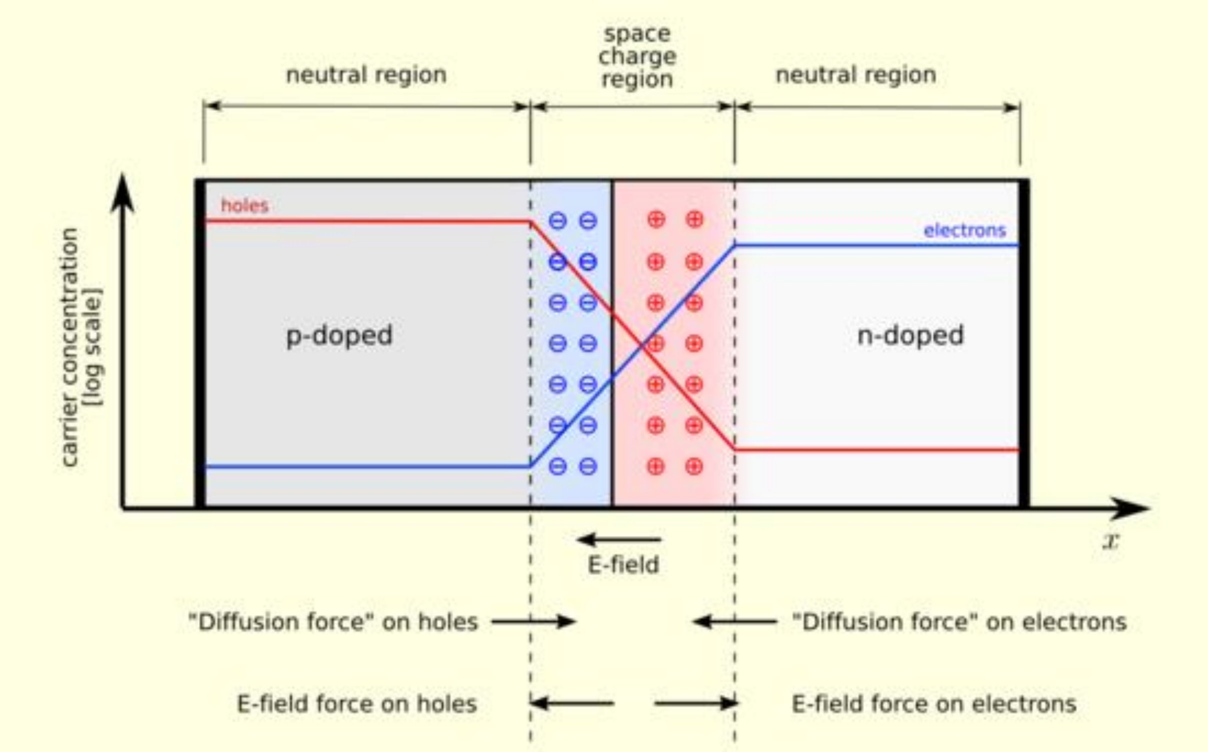
The **pn** junction diode: Physical characteristics

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.



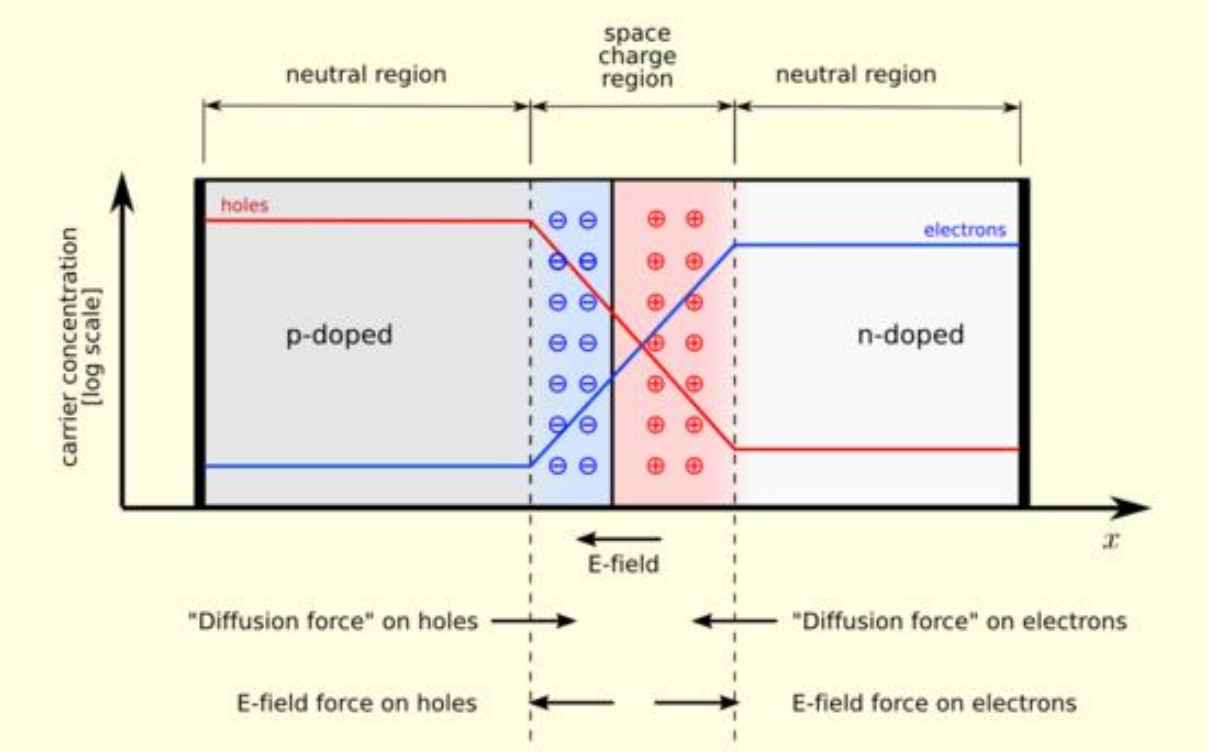
The **pn** junction diode: Physical characteristics

The depletion region:

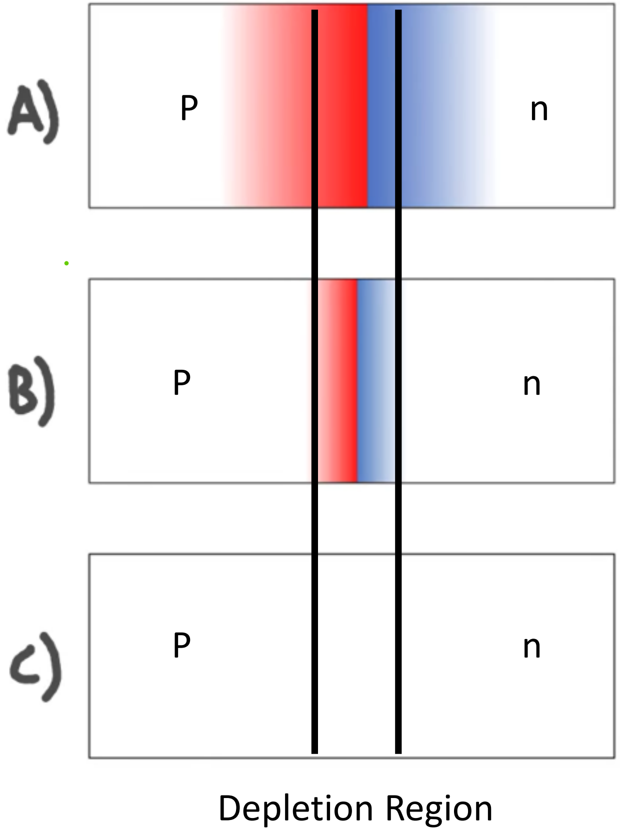
In a pn-junction depletion regions form naturally, as charge carriers (holes in p-type and electrons in n-type) near the pn junction boundary seep into each other.

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

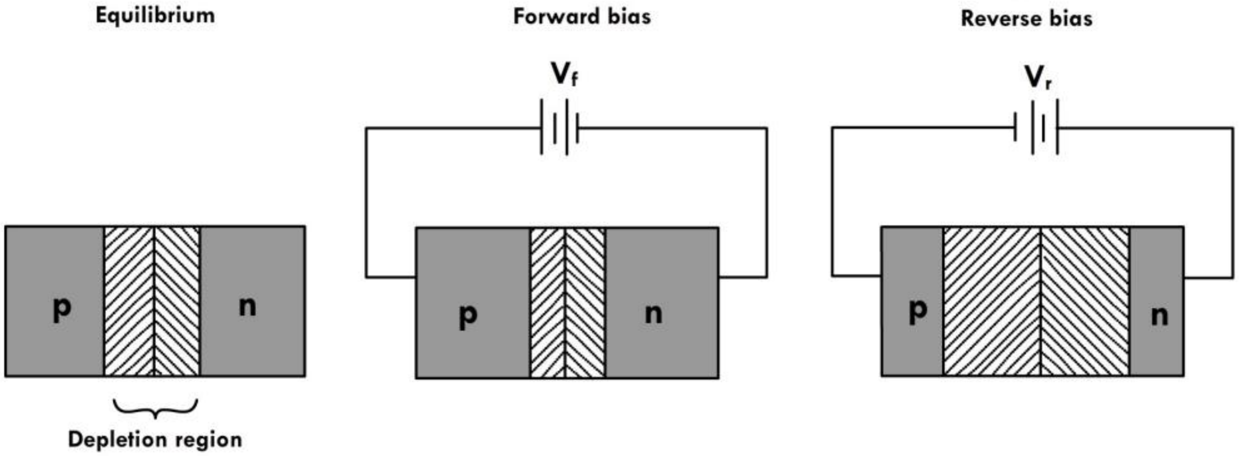
This mutual overflow into the opposite region, creates a space charge barrier, (like that in a capacitor).



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

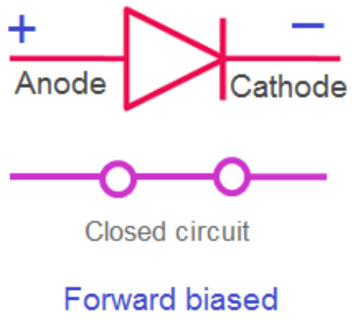


A) Reverse Bias
B) No Bias
C) Forward Bias

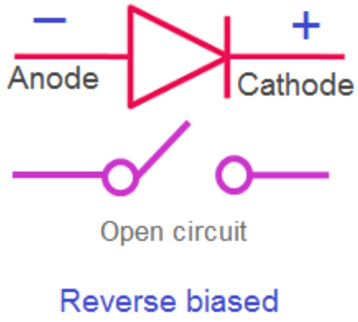


The **pn** junction diode: 2 Modes of operation

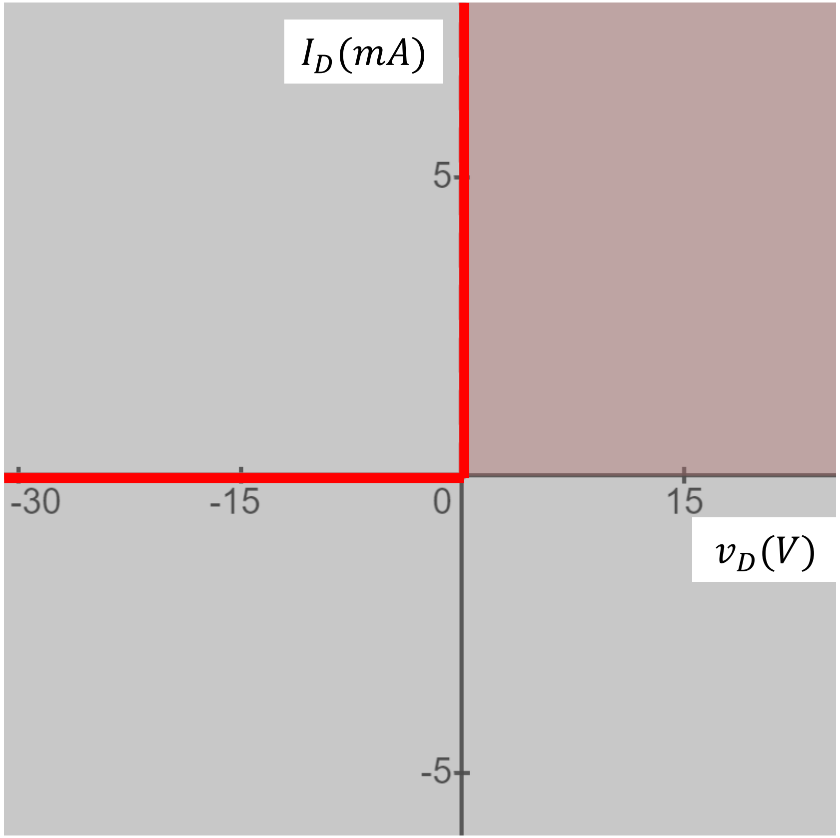
1. Forward Bias (FB):
   - Depletion Region is **constricted**.
   - ***Allow*** electrons to flow through the junction
   - Ideally acts as a **short circuit**

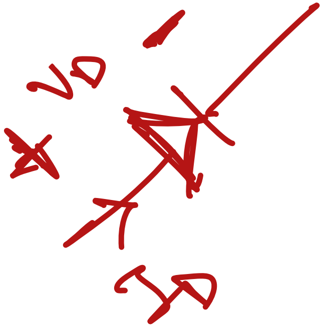


2. Reverse Bias (RB):
   - Depletion Region is **expanded**.
   - Bars / does not allow electron flow through the junction.
   - Ideally acts as an **open circuit**



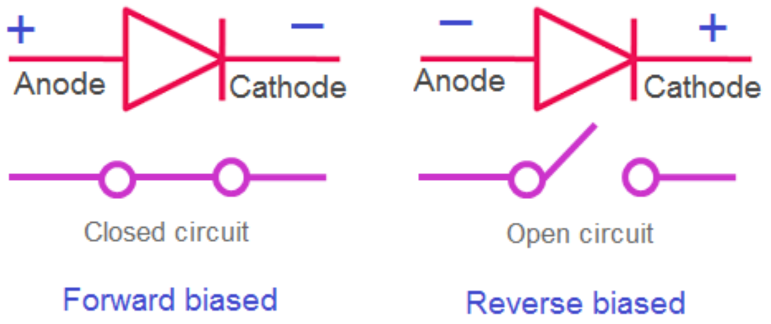
Piecewise Linear IV Models

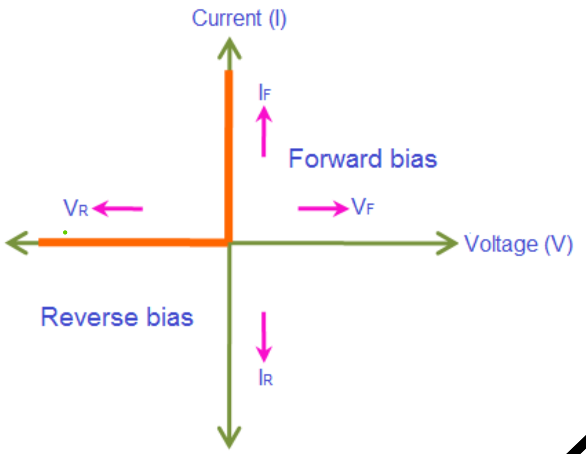




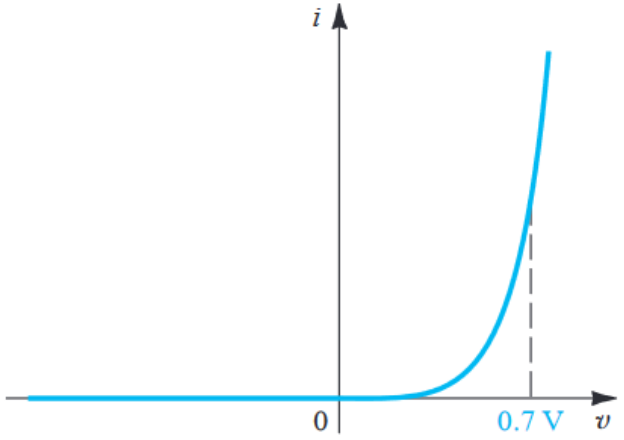
Diode Circuit Models

Ideal *Versus* Real Diode





Constant Voltage Drop
(CVD) Model



Ideal Model → **Real / Shockley** Model

Low Accuracy

Simple

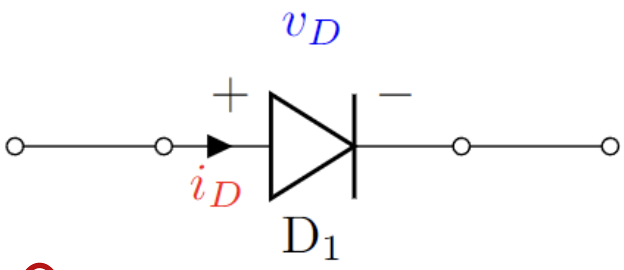
CVD with resistance
(CVD+R) Model

Increased Accuracy

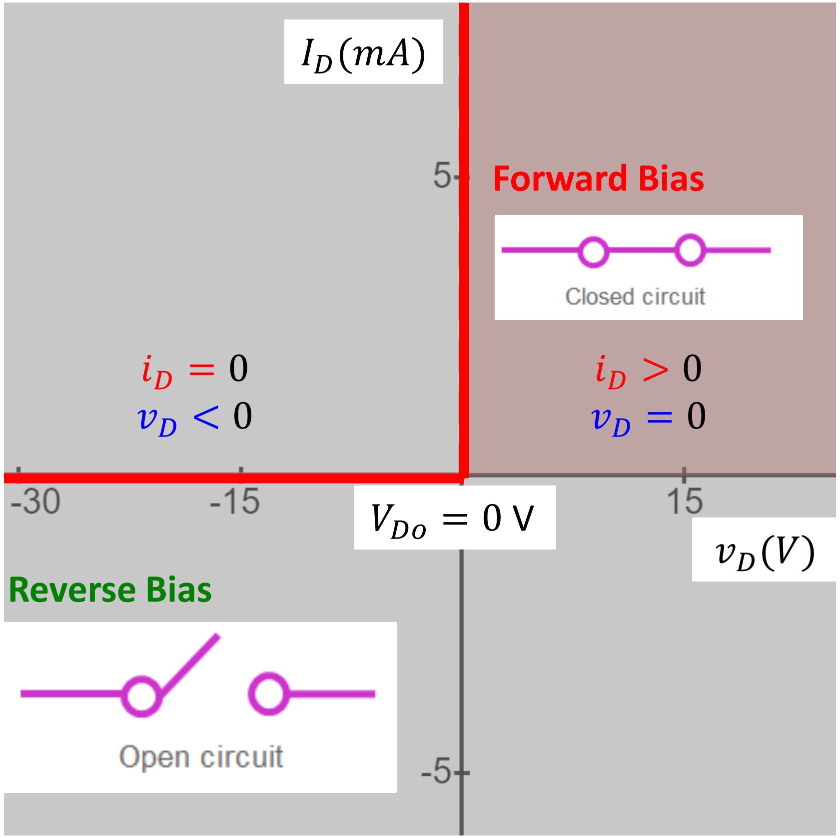
More Complex

Diode Models

1. Ideal Diode Model:

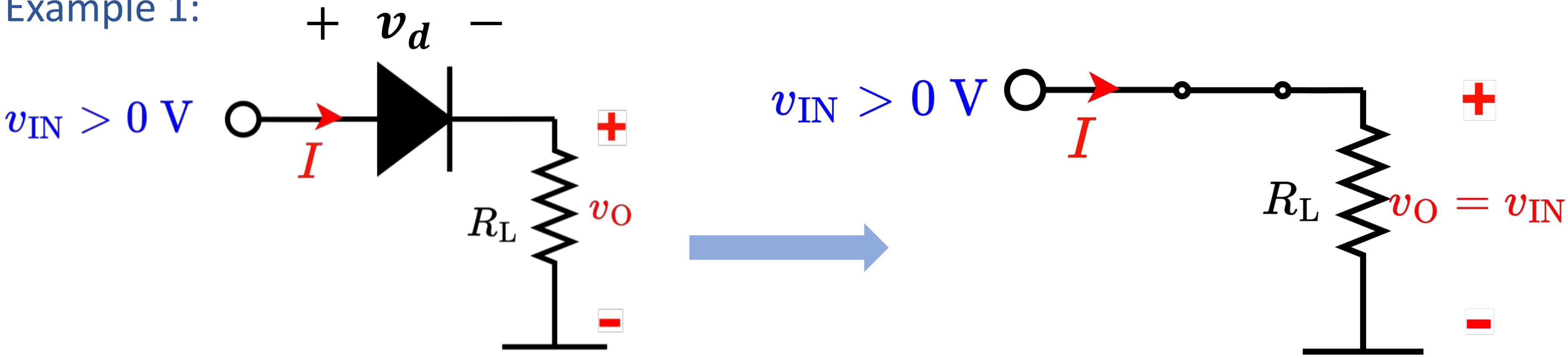


$V_{DO} = 0$



Example Problems (Ideal Diode)

Example 1:

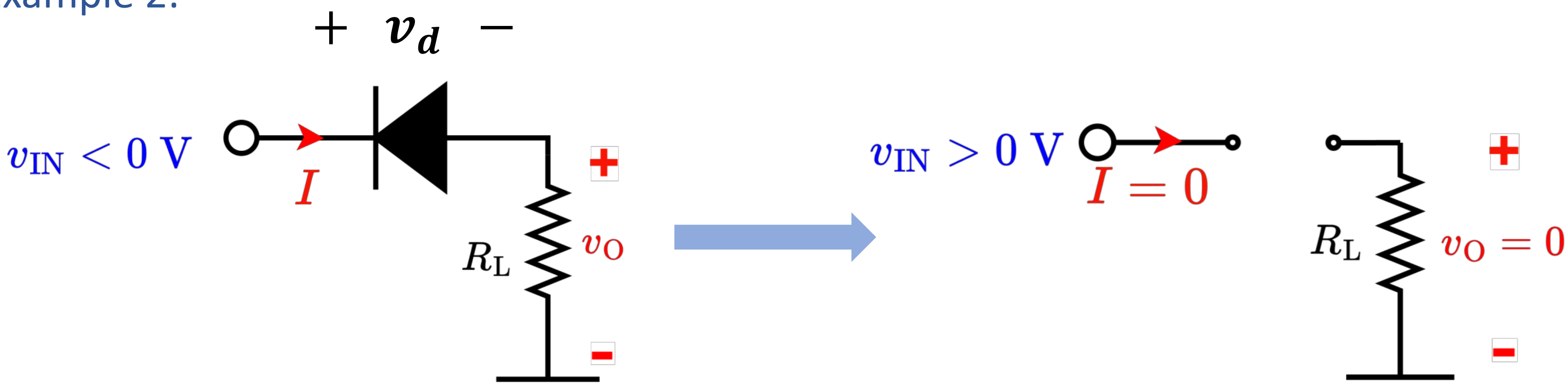


$$v_O = v_{IN} = 5\ \mathrm{V}$$

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

Example Problems (Ideal Diode)

Example 2:

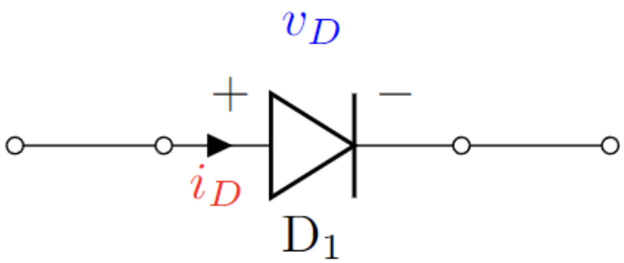


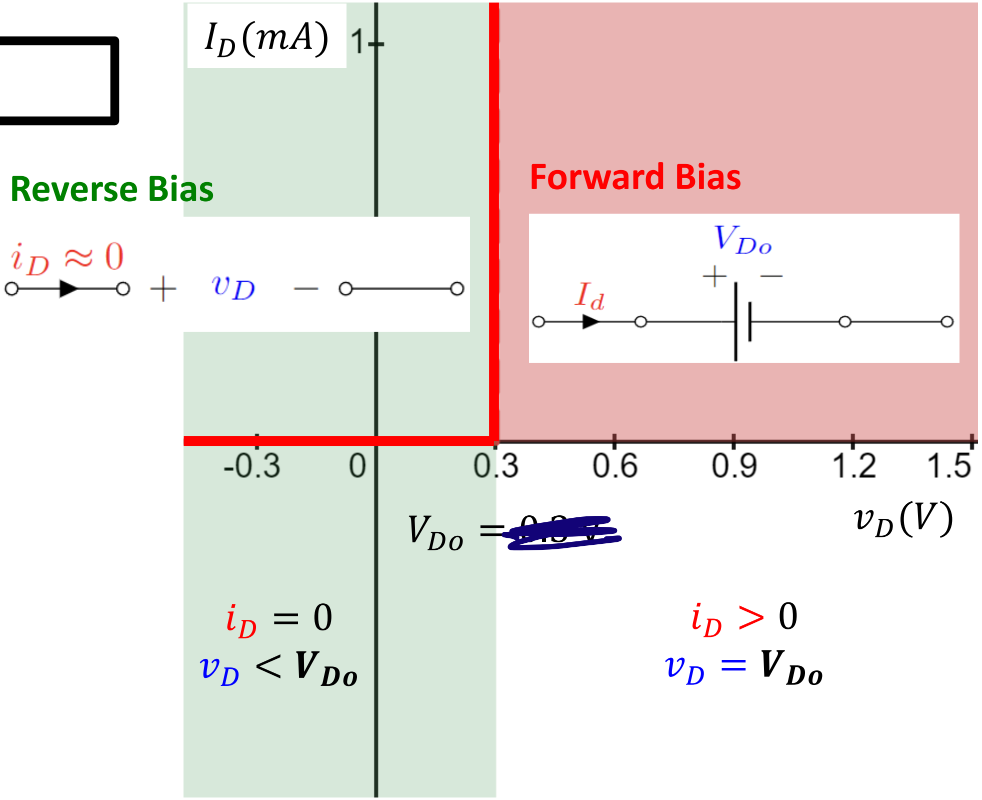
$$v_O = \cancel{v_{IN} = 5\ \mathrm{V}} = \mathbf{0\ V}$$

$$I \cancel{= \frac{v_O}{R_L}} = \mathbf{0\ mA}$$

Diode Models

2. Constant Voltage Drop (CVD) Model:



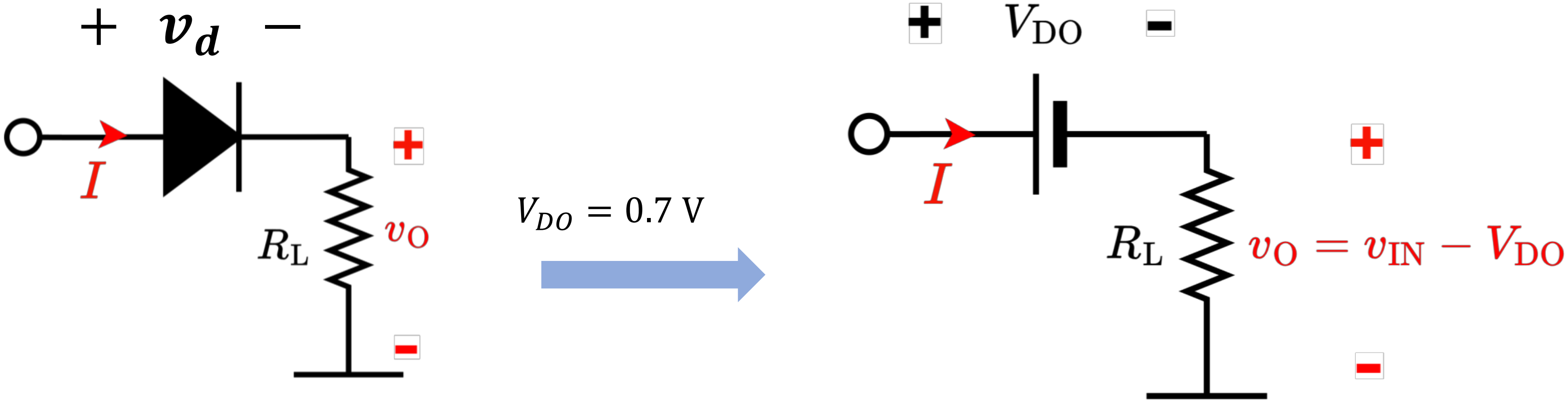


v_D: Total Voltage Across diode

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

Example Problems (CVD Model)

Example 3:



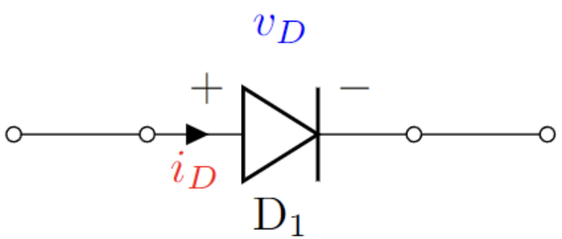
$$v_O = v_{IN} - V_{DO} = 5 - 0.7 \text{ V}$$

Let, $V_{DO} = 0.7$ V

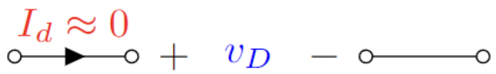
$$I = \frac{v_O}{R_L} = \frac{4.3 \text{ V}}{2.5 \text{ k}\Omega} = 1.72 \text{ mA}$$

Diode Models

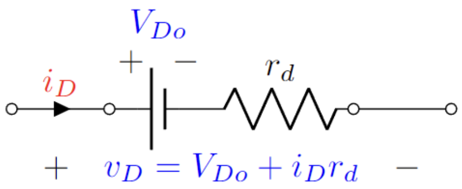
3. CVD+R Model:



Reverse Bias

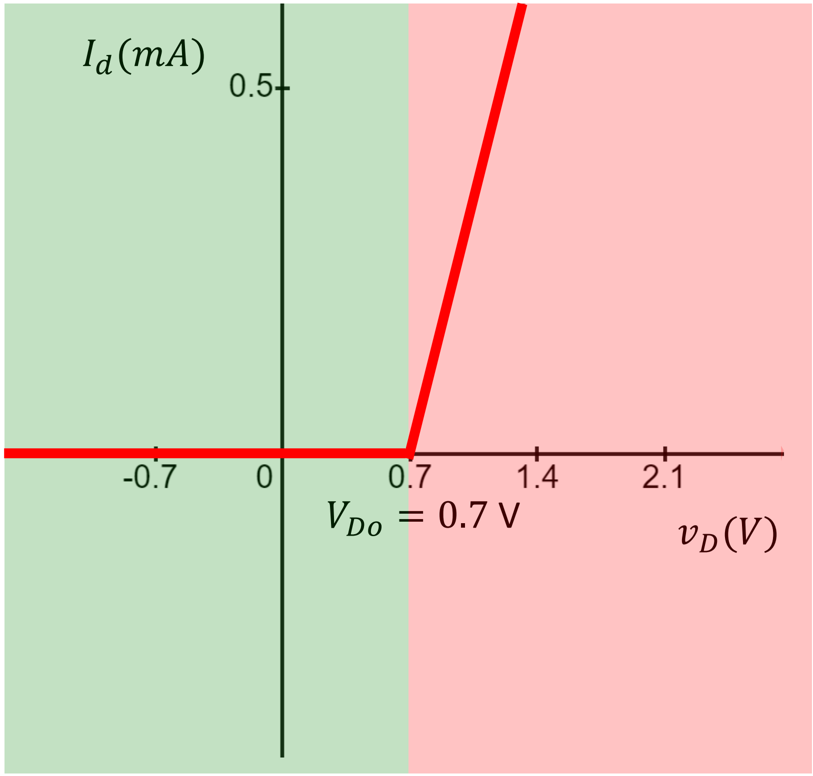


Forward Bias



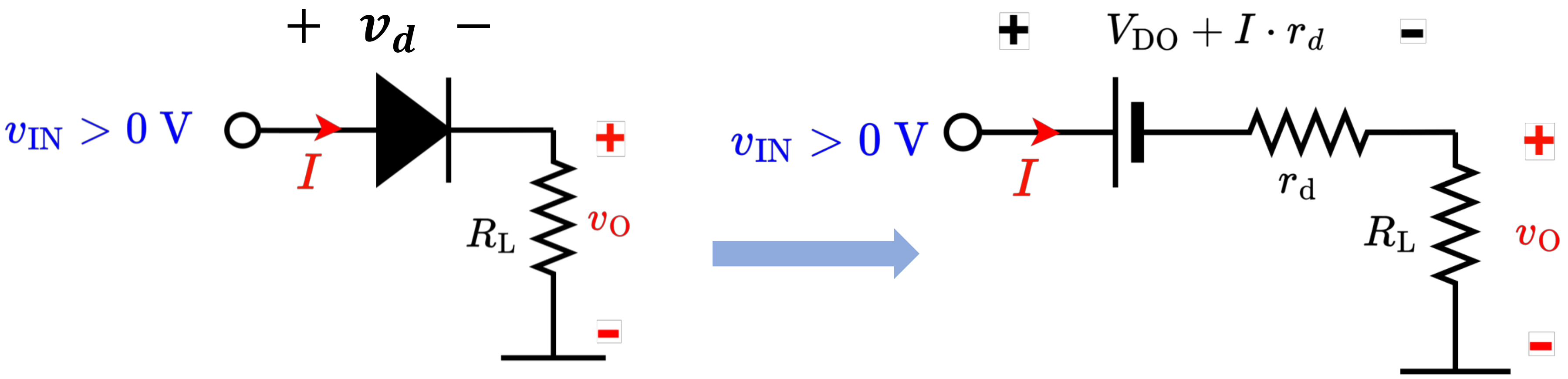
v_D: Total Voltage Across diode

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



Example Problems (CVD Model)

Example 3:



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

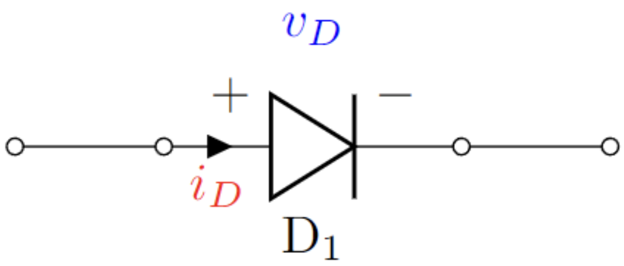
Let, $V_{DO} = 0.7$ V

$r_d = 50\ \Omega$

$$v_O = IR_L = 1.70 \times 2.5\ \text{V}$$

Diode Models

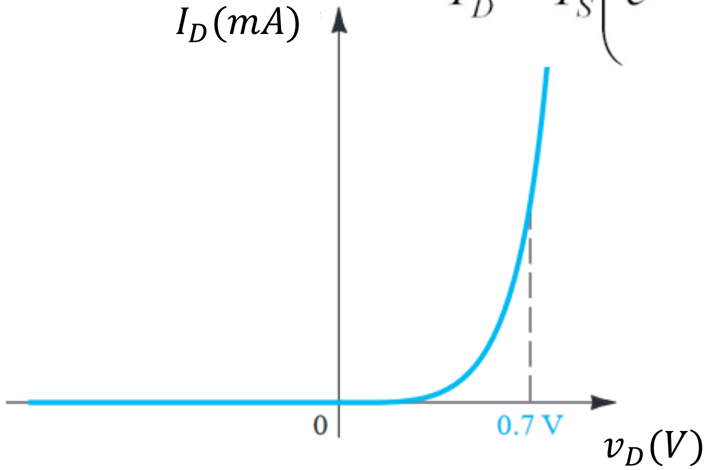
4. Shockley Diode Equation Model:



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

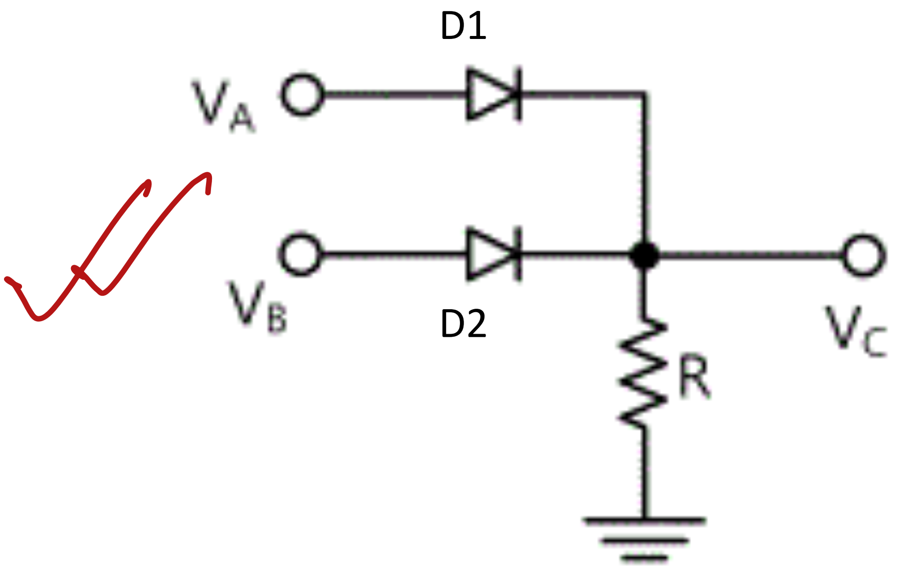
$k = 1.38 \times 10^{-23}$ J/K is Boltzmann's constant and $q = 1.60 \times 10^{-19}$ C is the magnitude of the electrical charge of an electron. At a temperature of 300 K, we have $V_T \simeq 26\,\text{mV}$

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



Where I_S is reverse saturation current

Logical Operations with Diode (OR)



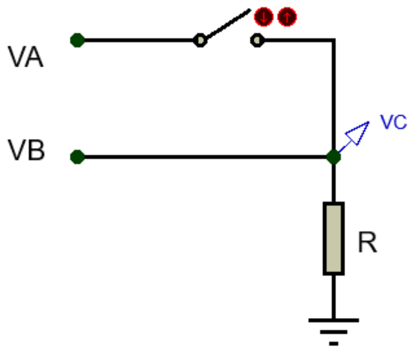
$V_C = \mathrm{Max}(V_A - V_{D1}, V_B - V_{D2})$

Case 1: V_A= 0V, V_B= 5V

D1 is off and D2 is on

Replace D1 with open circuit and D2 with short circuit.

So, V_C= V_B= 5V



Logical Operations with Diode (OR)

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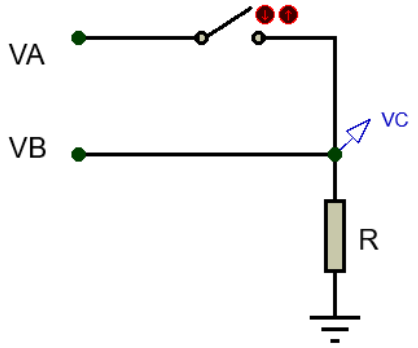
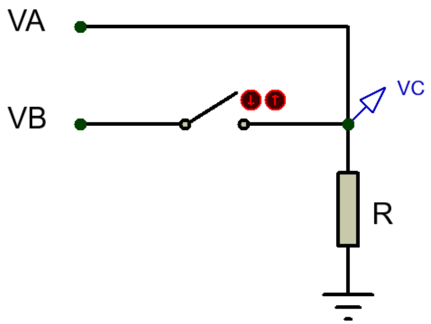


Case 2: V_A= 5V, V_B= 0V

D1 is on and D2 is off

Replace D1 with short circuit and D2 with open circuit.

So, V_C= V_A= 5V

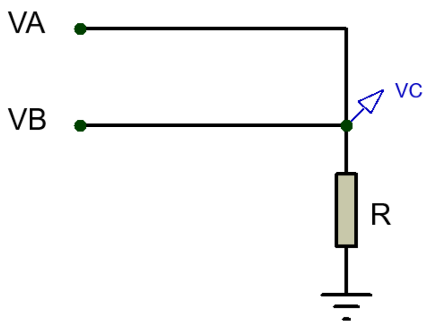


Case 3: V_A= 5V, V_B= 5V

Both D1 and D2 are on

Replace D1 and D2 with short circuits.

So, V_C= V_A= V_B= 5V



Logical Operations with Diode (AND)

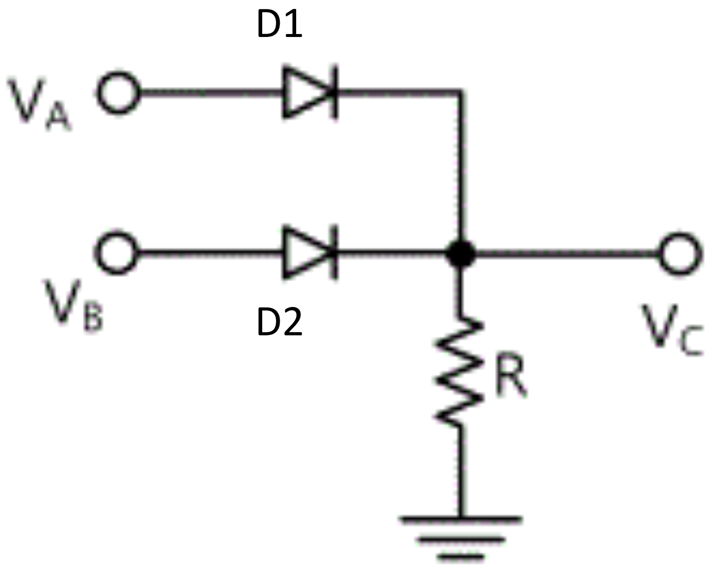
Logic Truth Table

INPUTS		OUTPUT
X	Y	Z
0	0	0
0	1	0
1	0	0
1	1	1

Voltage Truth Table

INPUTS		OUTPUT
X	Y	Z
0 V	0 V	0 V
0 V	5 V	0 V
5 V	0 V	0 V
5 V	5 V	5 V

Effect of input Voltage Variation in Logic Gates (OR)



If V_A= 4V and V_B= 5V, what is the value of output V_C?

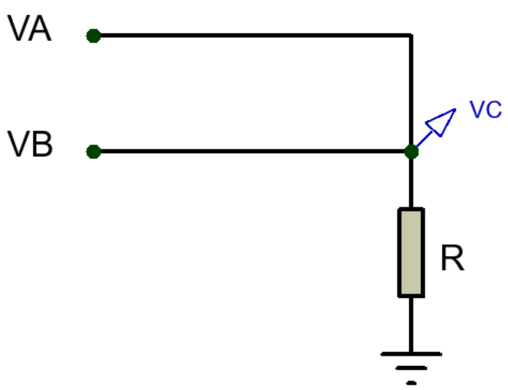
Case 1: Assuming both D1 and D2 are on

Replace D1 and D2 with short circuits.

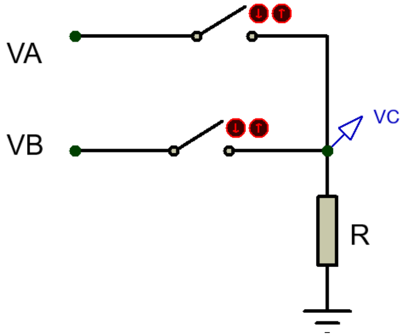
So, V_C is short with both V_A and V_B

Can V_C be 4V and 5V at the same time???

So this assumption is wrong!

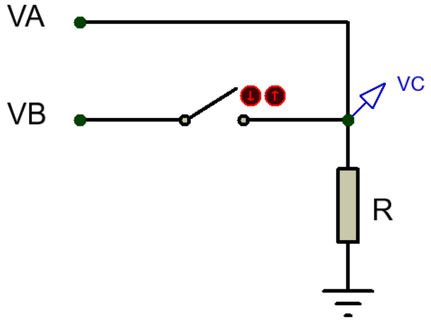


Effect of input Voltage Variation in Logic Gates (OR)



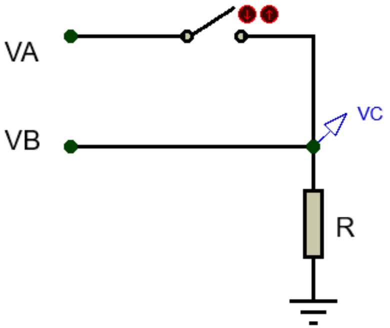
Case 2: Assuming both D1 and D2 are off

Replace D1 and D2 with open circuits. So, V_C= 0V
But now V_{anode}(4V for D1, 5V for D2)>$V_{cathode}$(0V) for both diode
So this assumption is also wrong!



Case 3: Assuming D1 is on and D2 is off

Replace D1 with short circuit and D2 with open circuit. So, V_C= V_A= 4V
But now for D2, V_{anode}(5V)>$V_{cathode}$(4V). So, D1 should have been ON!
So this assumption is also wrong!

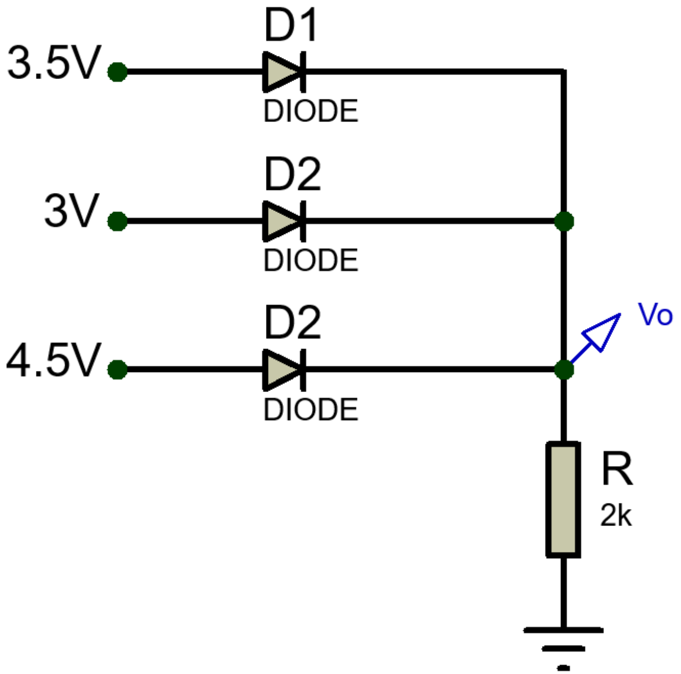


Case 4: Assuming D1 is off and D2 is on

Replace D1 with open circuit and D2 with short circuit. So, V_C= V_B= 5V
Now for D1, V_{anode}(4V)<$V_{cathode}$(5V). So, D1 should be **OFF!**
So this assumption is **correct!**

Effect of input Voltage Variation in Logic Gates (OR)

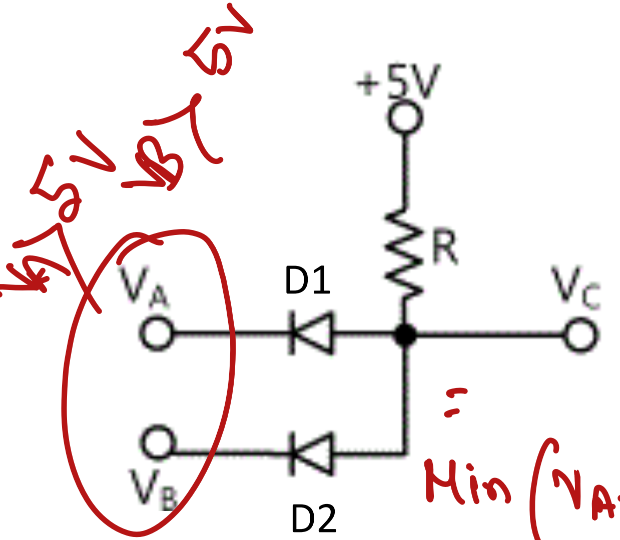
Example 4: Find the value of Vo



D1 and D2 are OFF → Open Circuit
Only D3 is ON → Short Circuit

Vo= 4.5V
Current, I= 4.5V/2kΩ= 2.25 mA

Logical Operations with Diode (AND)



V_A	V_B	V_C
0	0	0
0	5	0
5	0	0
5	5	5

$= Min(V_A + V_{D1}, V_B + V_{D2})$

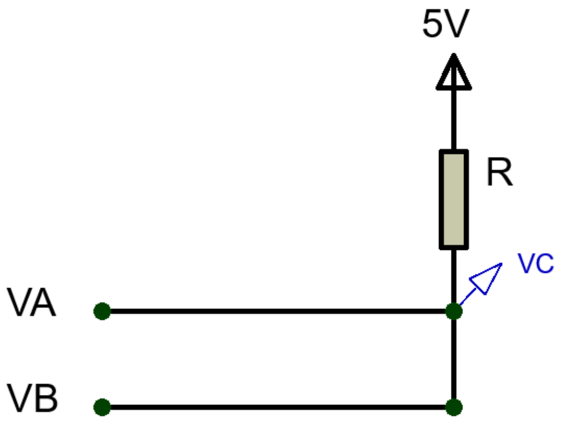
R is a **Pull Up Resistor** which pulls up the voltage of V_C from floating condition to 5V.

Case 1: V_A= 0V, V_B= 0V

Both D1 and D2 are on as V_{anode}>$V_{cathode}$

Replace D1 and D2 with short circuits.

So, , V_C= V_A= V_B= 0V



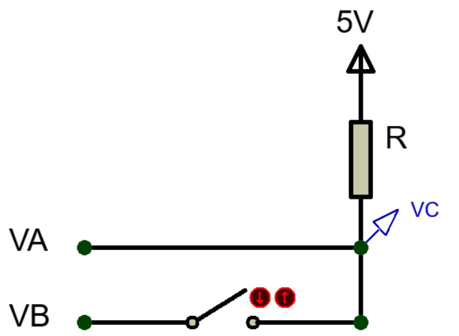
Logical Operations with Diode (AND)

Case 2: V_A= 0V, V_B= 5V

D1 is on and D2 is off

Replace D1 with short circuit and D2 with open circuit.

So, V_C= V_A= 0V

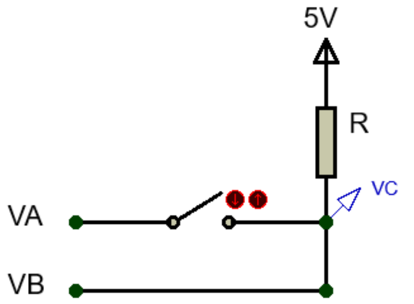


Case 3: V_A= 5V, V_B= 0V

D1 is off and D2 is on

Replace D1 with open circuit and D2 with short circuit.

So, V_C= V_B= 0V

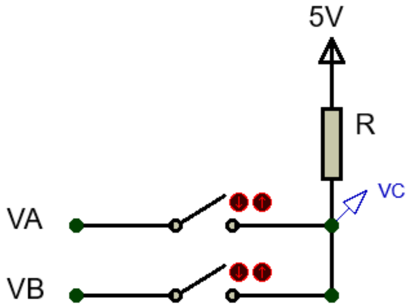


Case 1: V_A= 5V, V_B= 5V

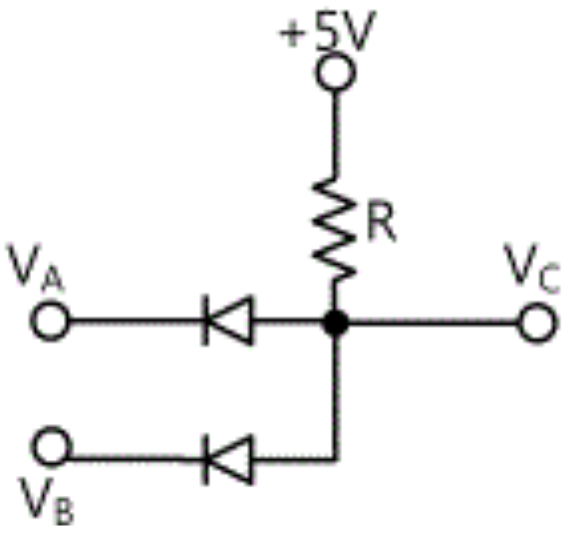
Both D1 and D2 are off

Replace D1 and D2 with open circuits.

So, V_C= 5V



Effect of input Voltage Variation in Logic Gates (AND)



If V_A= 1V and V_B= 2V, what is the value of output V_C?

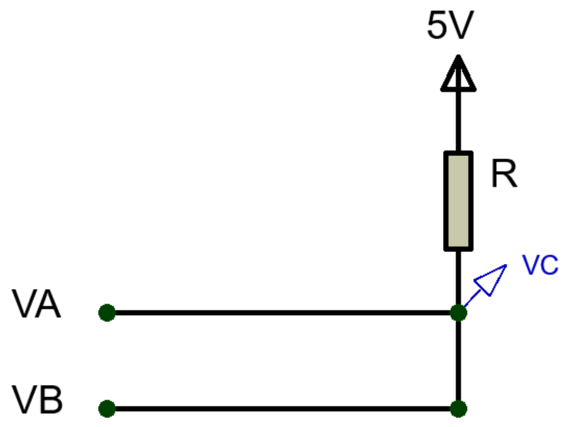
Case 1: Assuming both D1 and D2 are on

Replace D1 and D2 with short circuits.

So, V_C is short with both V_A and V_B

Can V_C be 1V and 2V at the same time???

So this assumption is wrong!



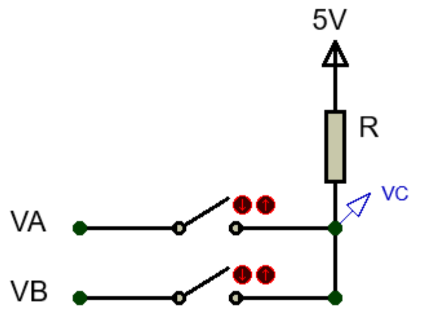
Effect of input Voltage Variation in Logic Gates (AND)

Case 2: Assuming both D1 and D2 are off

Replace D1 and D2 with open circuits. So, V_C= 5V

But now V_{anode}(5V)>$V_{cathode}$(1V for D1 & 2V for D2) for both diode

So this assumption is also wrong!

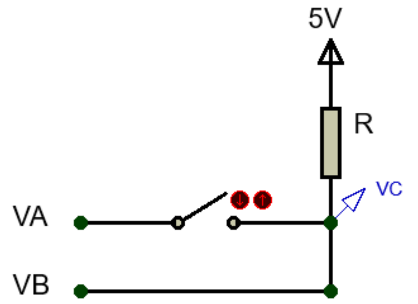


Case 3: Assuming D1 is off and D2 is on

Replace D1 with open circuit and D2 with short circuit. So, V_C= V_B= 2V

But now for D1, V_{anode}(2V)>$V_{cathode}$(1V). So, D1 should have been ON!

So this assumption is also wrong!

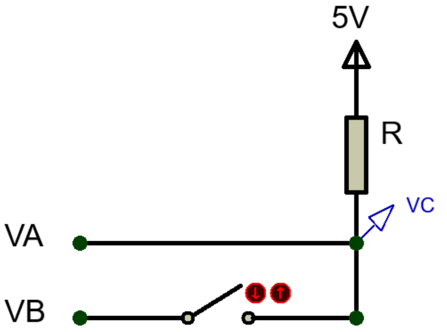


Case 4: Assuming D1 is on and D2 is off

Replace D1 with short circuit and D2 with open circuit. So, V_C= V_A= 1V

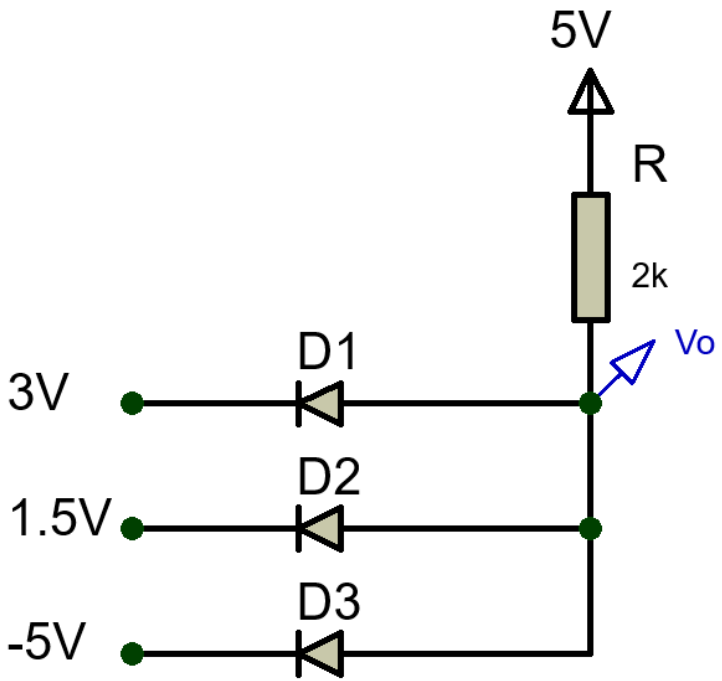
Now for D2, V_{anode}(1V)<$V_{cathode}$(2V). So, D2 should be **OFF!**

So this assumption is **correct!**



Effect of input Voltage Variation in Logic Gates (AND)

Example 5: Find the value of Vo



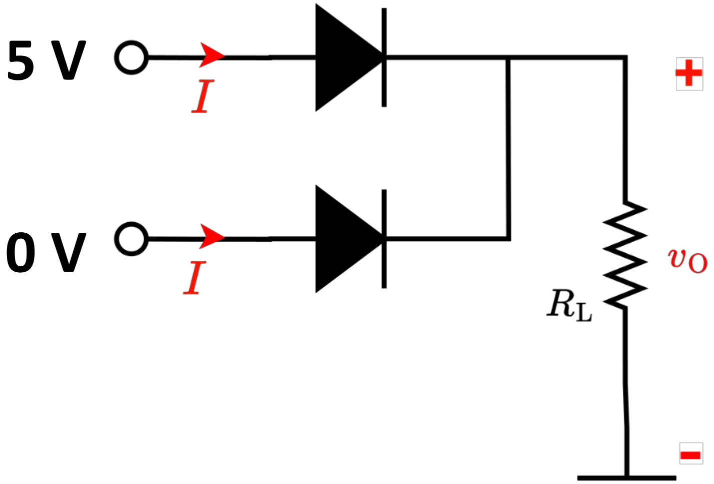
D1 and D2 are OFF → Open Circuit
Only D3 is ON → Short Circuit

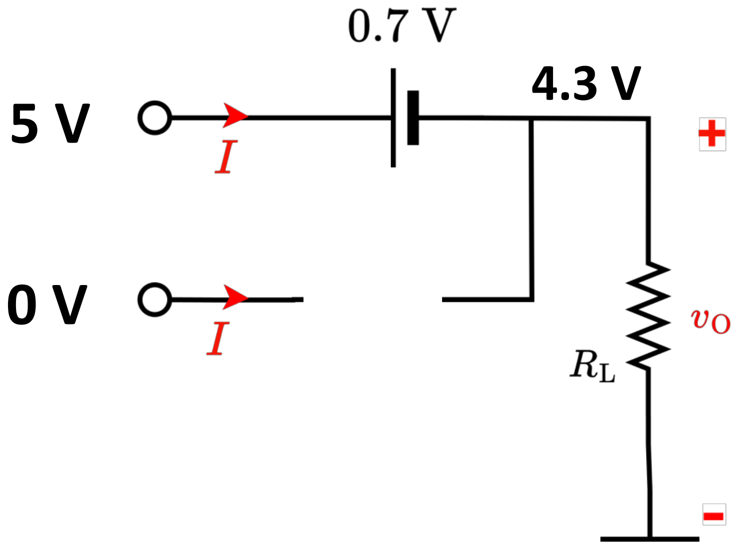
Vo= -5V

Current, $I = \frac{5V-(-5V)}{2k\Omega}$ = 5 mA

Logical Operations with Diode (OR)

CVD diode



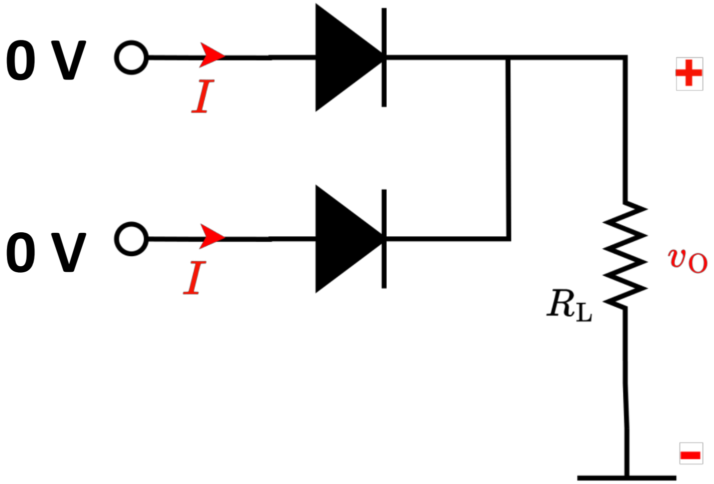


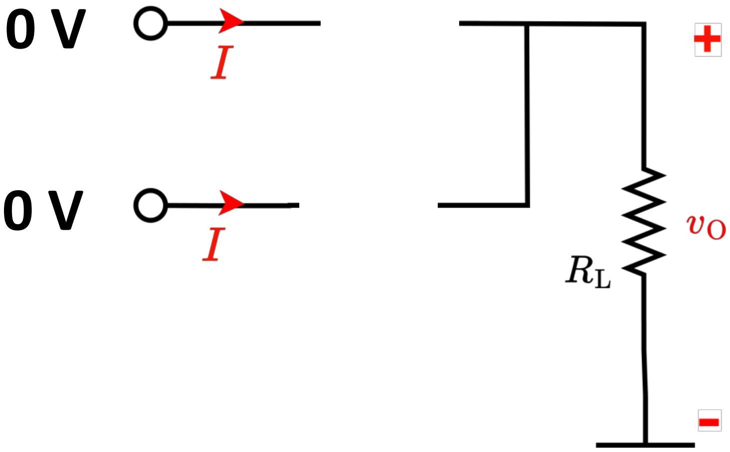
Z = 4.3 V

Degraded 5 V

Logical Operations with Diode (OR)

CVD diode

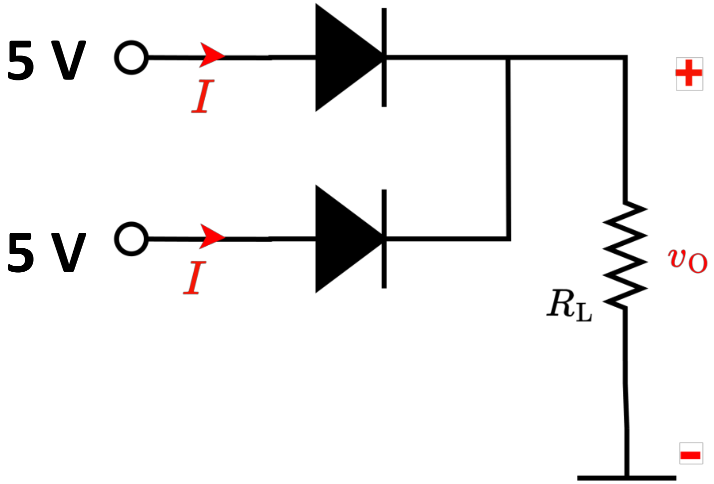


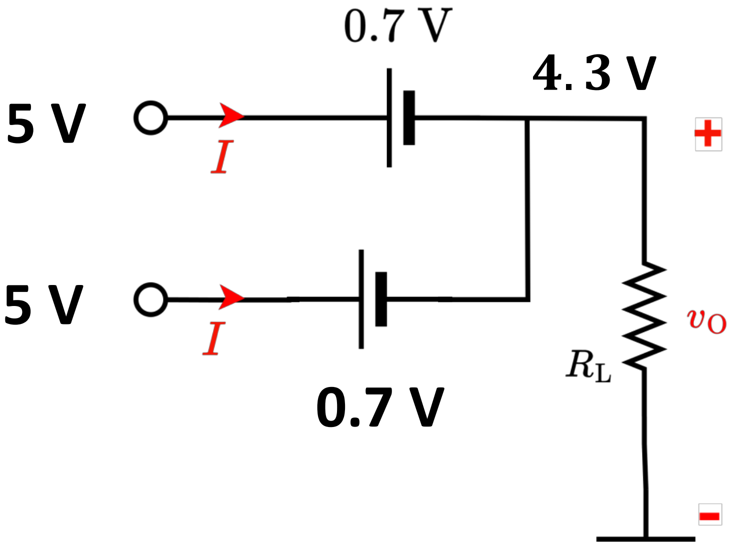


Z = 0 V

Logical Operations with Diode (OR)

CVD diode





Z = 4.3 V

Degraded 5 V

Both diodes have same V_{DO}

Logical Operations with Diode (OR)

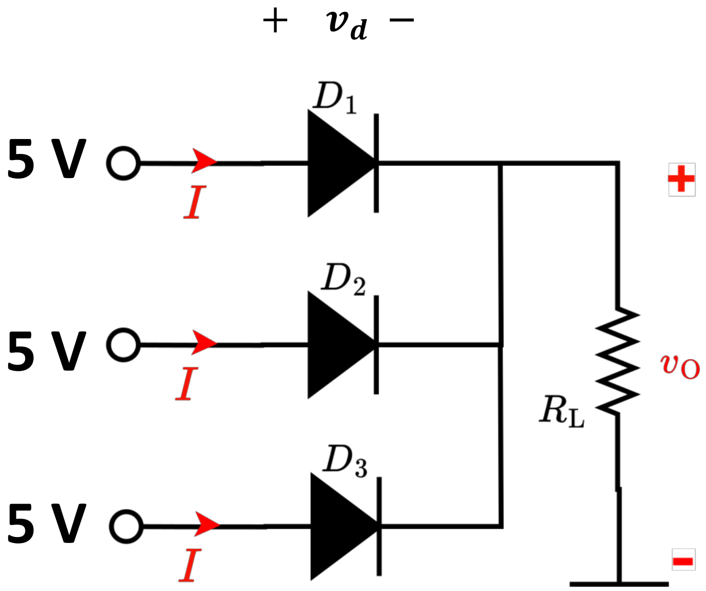
CVD diode

What if the diodes have different V_{DO}?

$$V_{D1} = 1\ \text{V}$$

$$V_{D2} = 0.7\ \text{V}$$

$$V_{D3} = 0.5\ \text{V}$$



Logical Operations with Diode (OR)

CVD diode

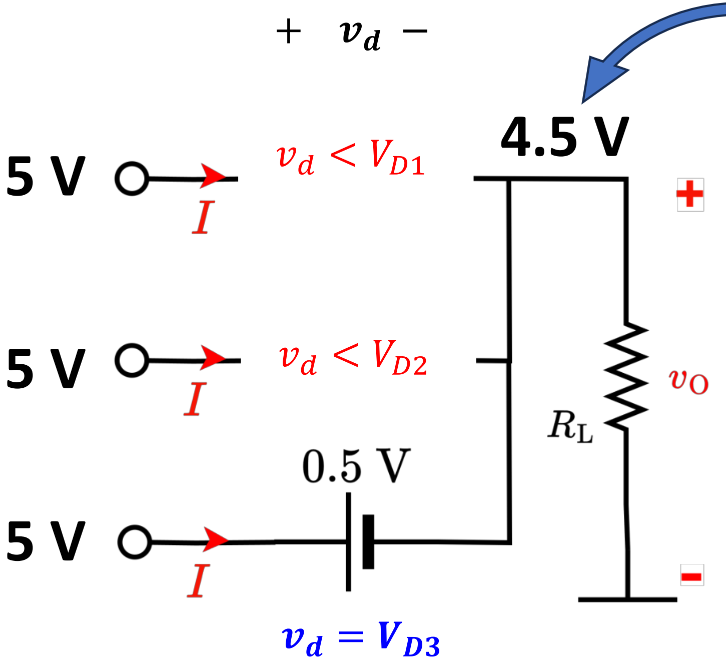
What if two diodes have different V_{DO}?

Highest (possible – and consistent) voltage here!

$$V_{D1} = 1\ \text{V}$$

$$V_{D2} = 0.7\ \text{V}$$

$$V_{D3} = 0.5\ \text{V}$$



Z = 4.5 V

Logical Operations with Diode (OR)

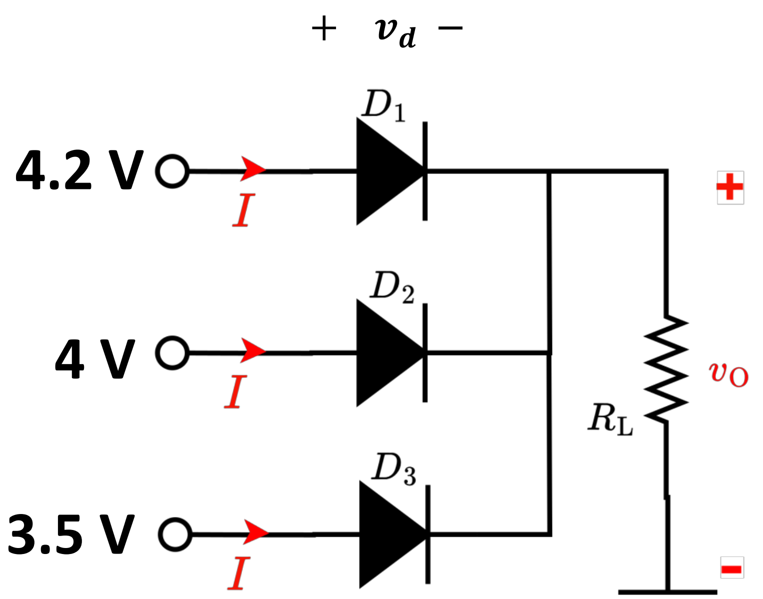
CVD diode

What if the input voltages are different?

$V_{D1} = 1\text{ V}$

$V_{D2} = 0.7\text{ V}$

$V_{D3} = 0.5\text{ V}$



Logical Operations with Diode (OR)

CVD diode

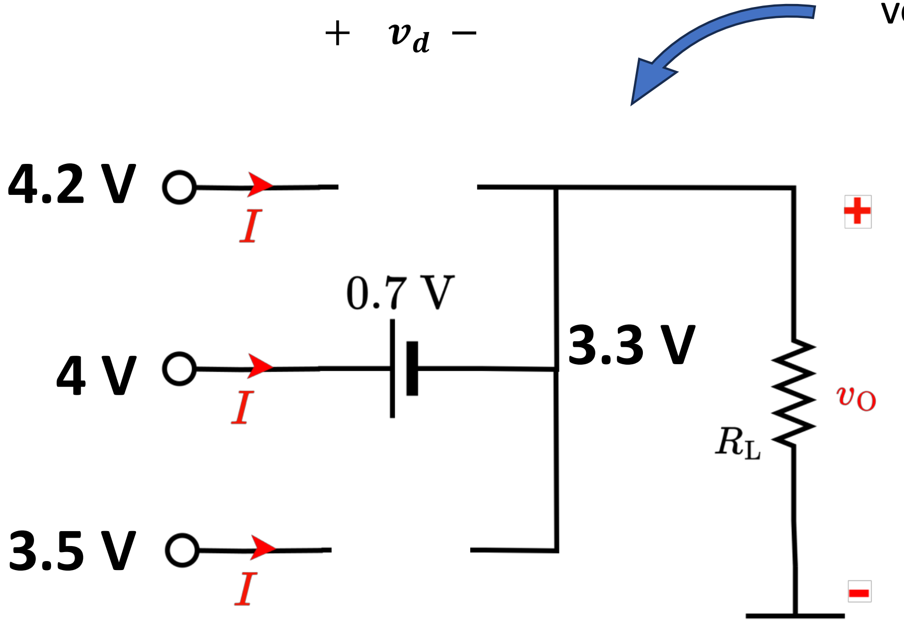
What if the input voltages are different?

Highest (possible – and consistent) voltage here!

$$V_{D1} = 1\text{ V}$$

$$V_{D2} = 0.7\text{ V}$$

$$V_{D3} = 0.5\text{ V}$$



Z = 4.5 V

Logical Operations with Diode (AND)

Logic Truth Table

INPUTS		OUTPUT
X	Y	Z
0	0	0
0	1	0
1	0	0
1	1	1

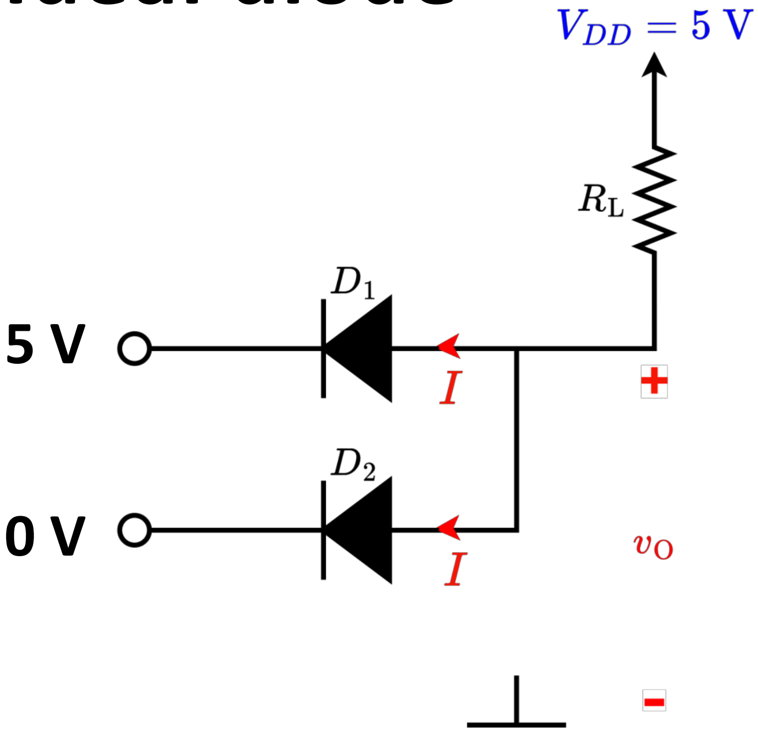
Voltage Truth Table

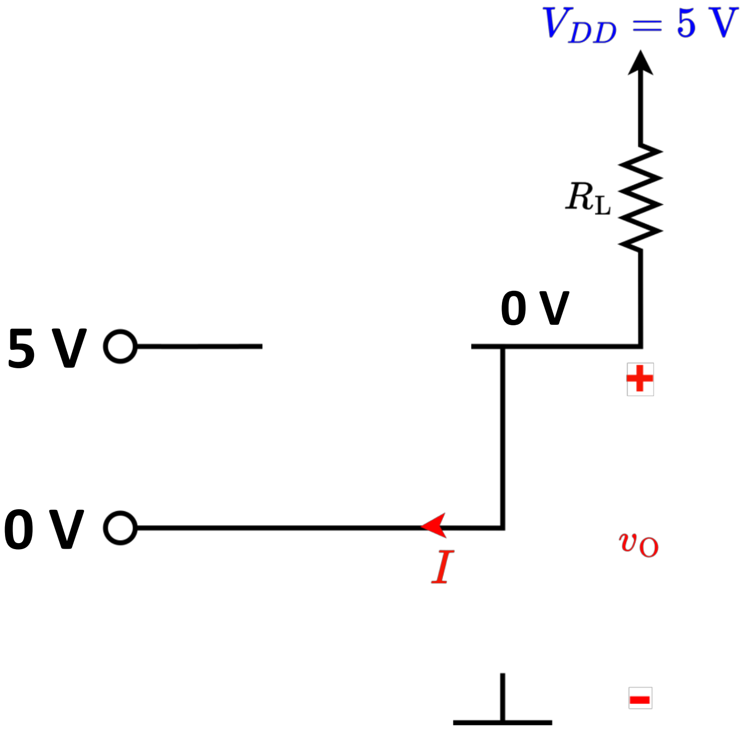
INPUTS		OUTPUT
X	Y	Z
0 V	0 V	0 V
0 V	5 V	0 V
5 V	0 V	0 V
5 V	5 V	5 V

	Low/False	High/True
Logic Levels:	0	1
Corresponding voltage levels:	0V	5V

Logical Operations with Diode (AND)

Ideal diode

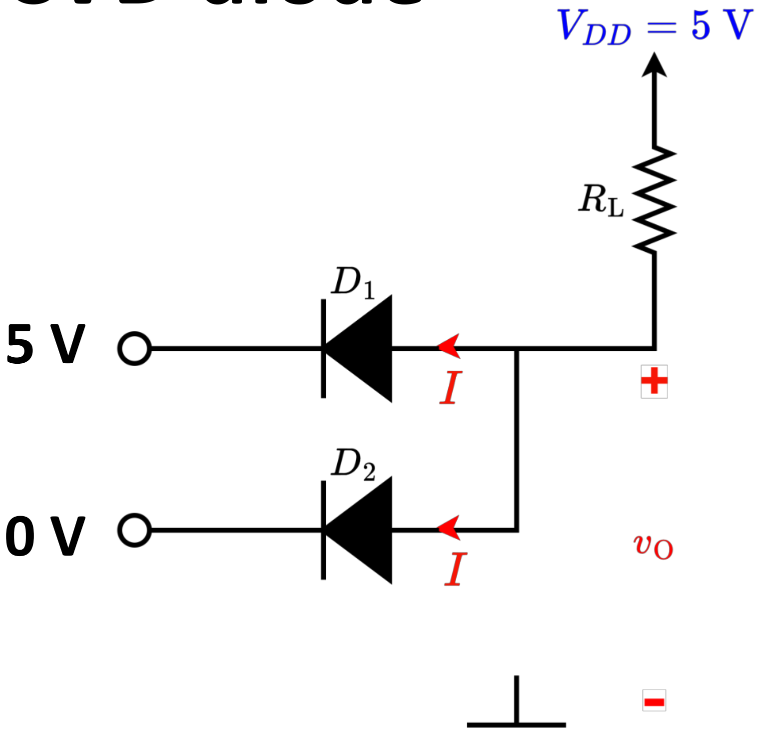


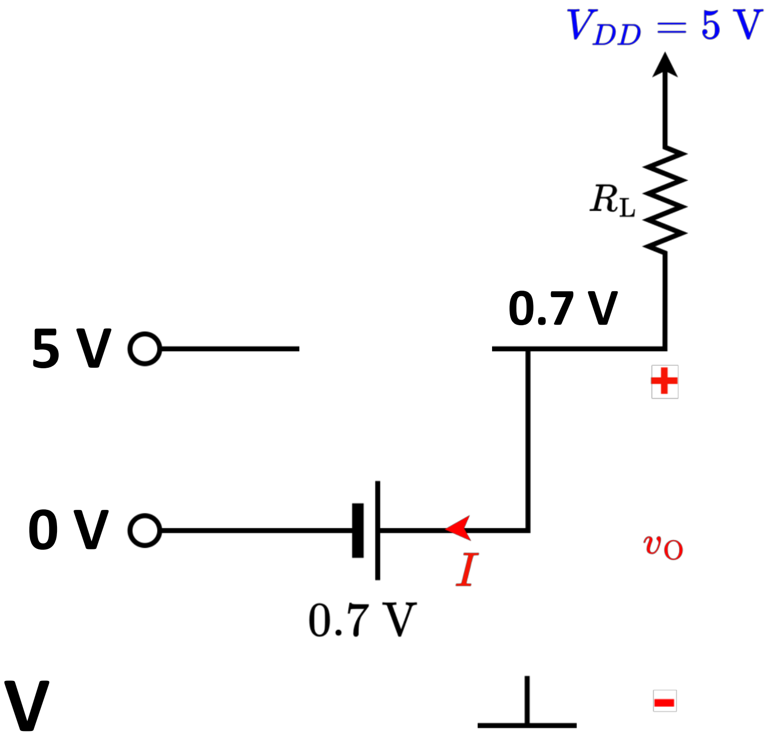


Z = 0 V

Logical Operations with Diode (AND)

CVD diode



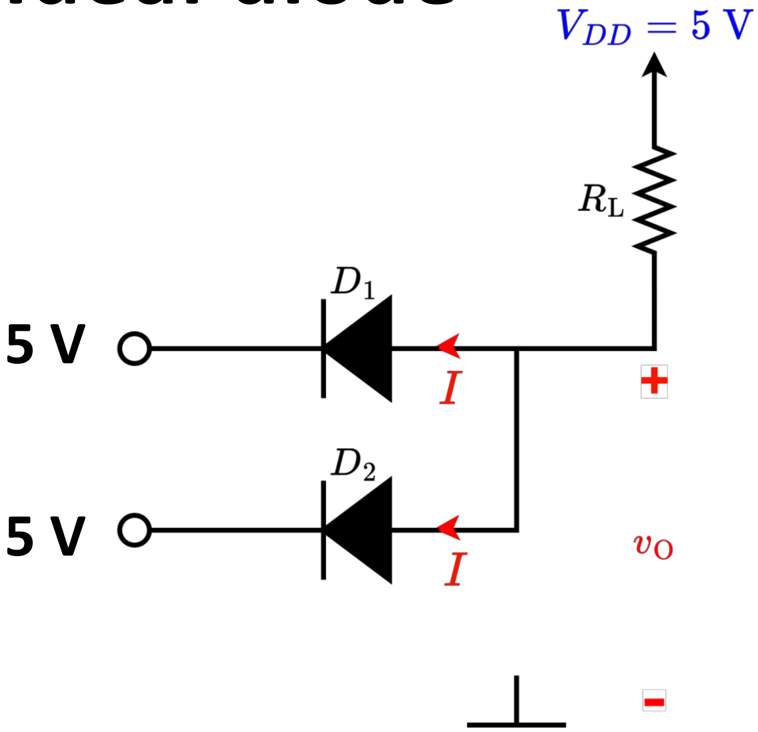


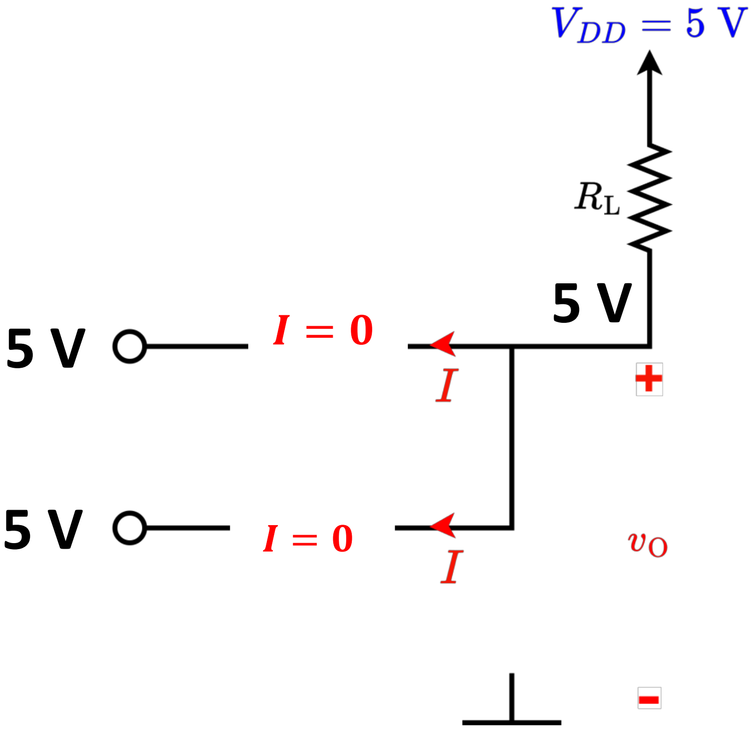
Z = 0.7 V

Degraded 0 V

Logical Operations with Diode (AND)

Ideal diode

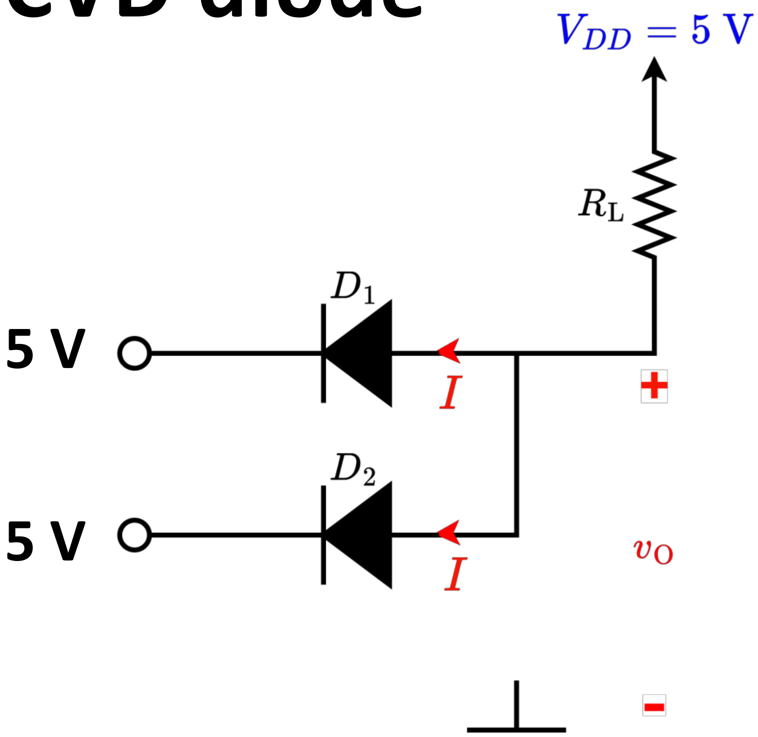


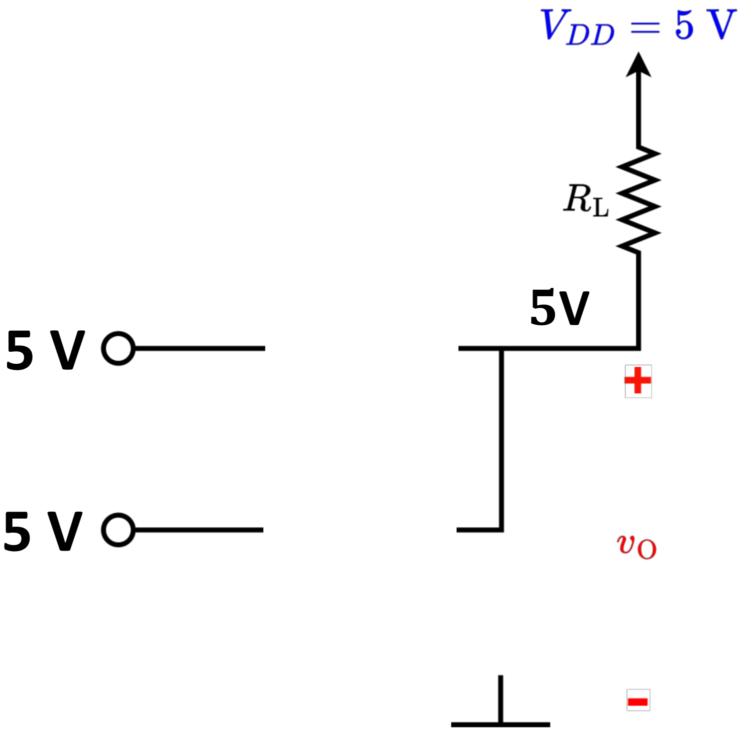


Z = 5 V

Logical Operations with Diode (AND)

CVD diode

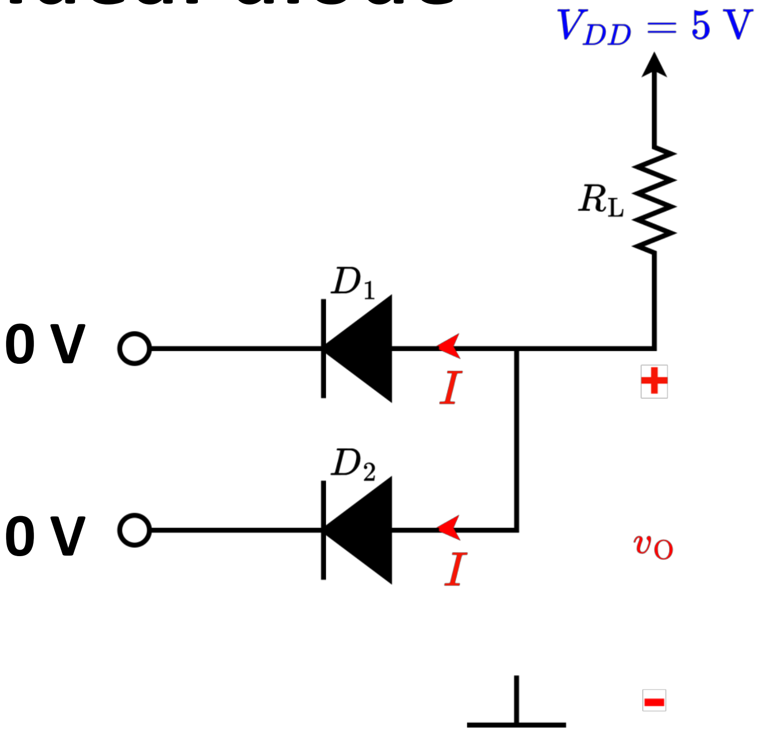


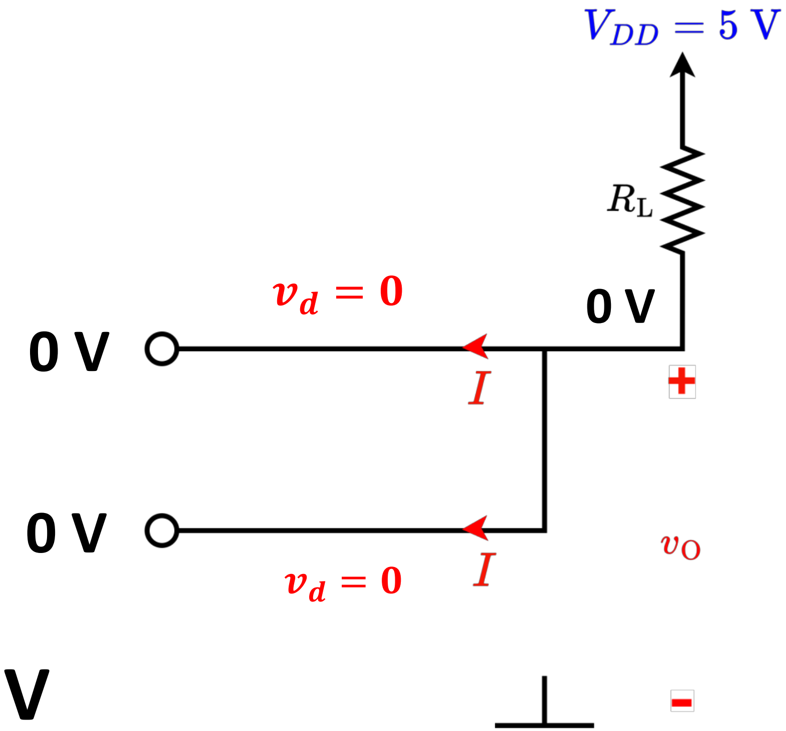


Z = 5 V

Logical Operations with Diode (AND)

Ideal diode

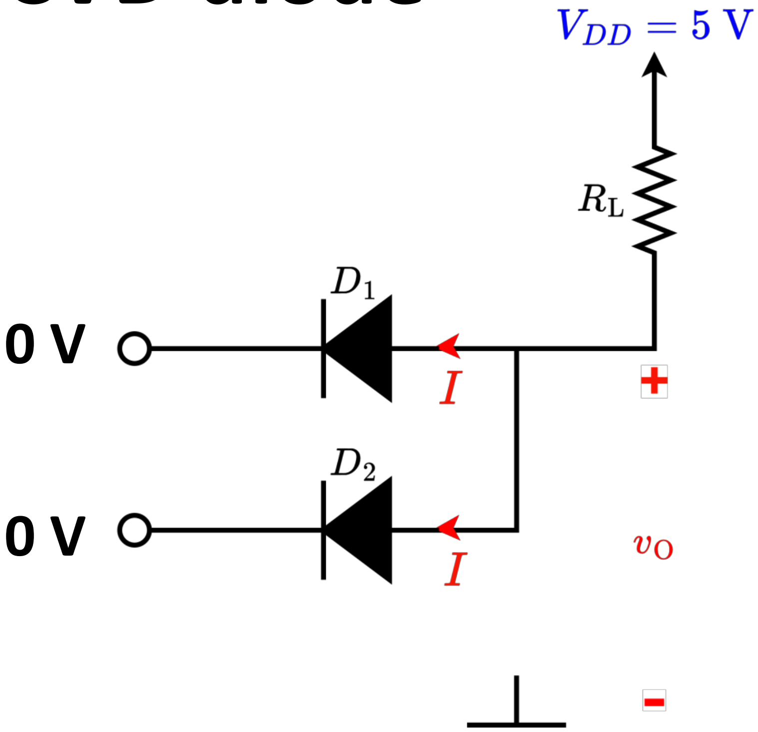


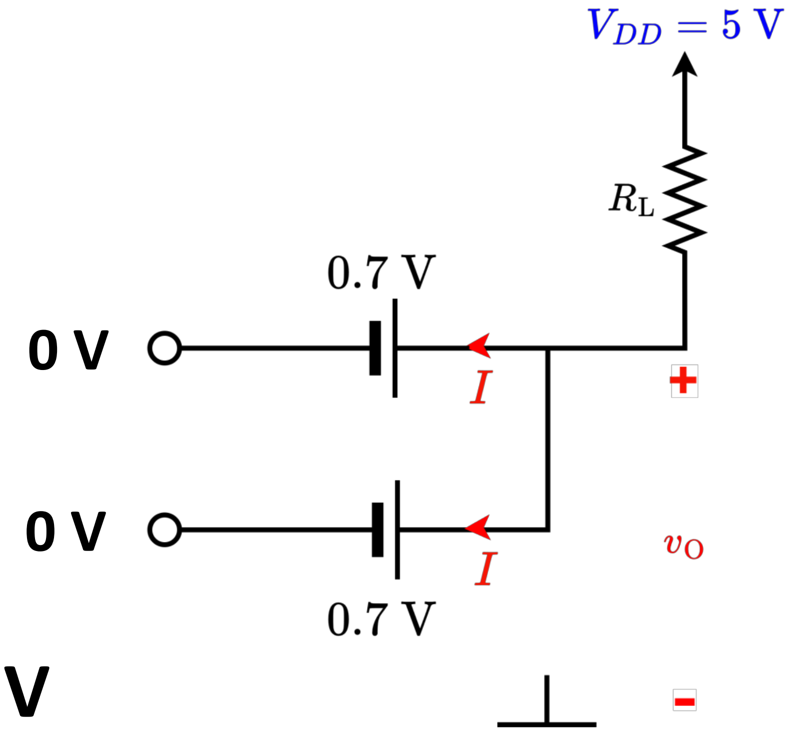


Z = 0 V

Logical Operations with Diode (AND)

CVD diode





Z = 0.7 V

Degraded 0 V

Both diodes have same V_{DO}

Logical Operations with Diode (AND)

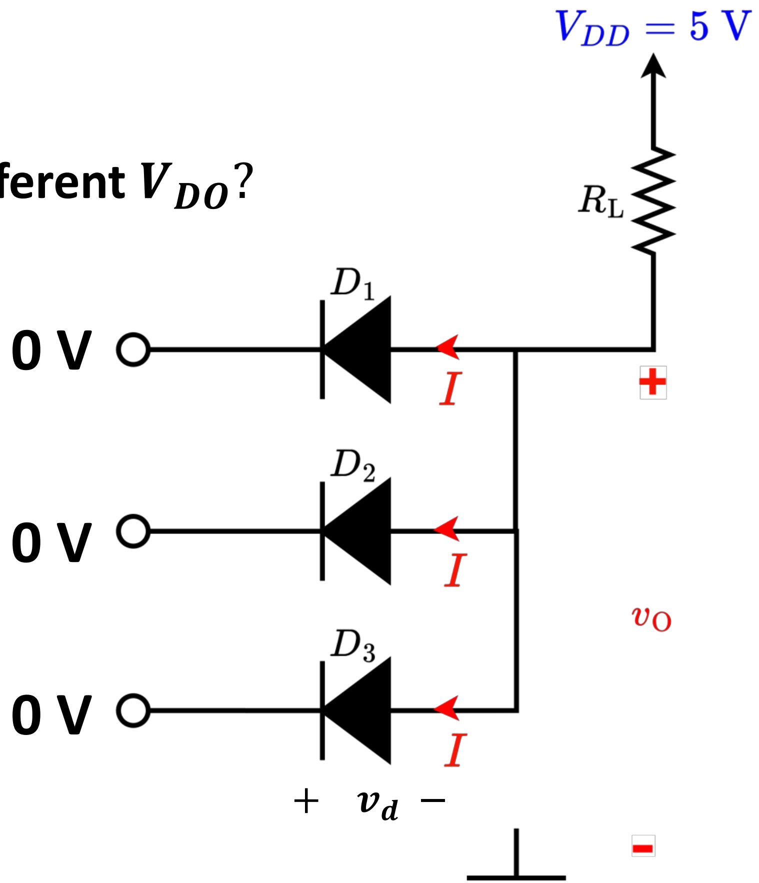
CVD diode

What if the diodes have different V_{DO}?

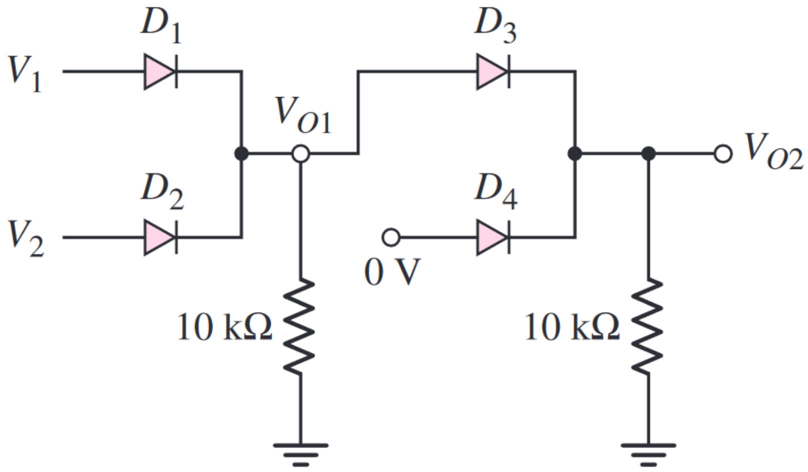
$V_{D1} = 1\text{ V}$

$V_{D2} = 0.7\text{ V}$

$V_{D3} = 0.5\text{ V}$



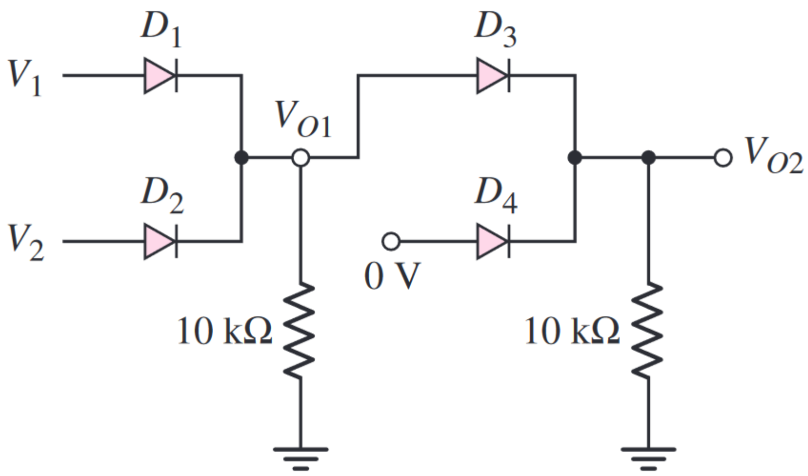
Combined Logic Circuits



$$\boldsymbol{V_{O1} = V_1 \text{ OR } V_2 = V_1 | \, V_2}$$

$$\boldsymbol{V_{O2} = (V_{O1} \text{ OR } 0) = V_{O1} = V_1 \mid V_2}$$

Combined Logic Circuits



** In CVD diode models, we are assuming that all diodes have equal drop.

***Suppose:* $\boldsymbol{V_1 = 3}$ V, $\boldsymbol{V_2 = 2}$ V.**

For Ideal diodes assumption:

$V_{O1} = V_1 \text{ OR } V_2$ → *Largest Value of the inputs*

$$\therefore\ V_{O1} = 3\text{ V}$$

$\boldsymbol{V_{O2}} = (V_{O1} \text{ OR } 0) = V_{O1} = \mathbf{3\ V}$

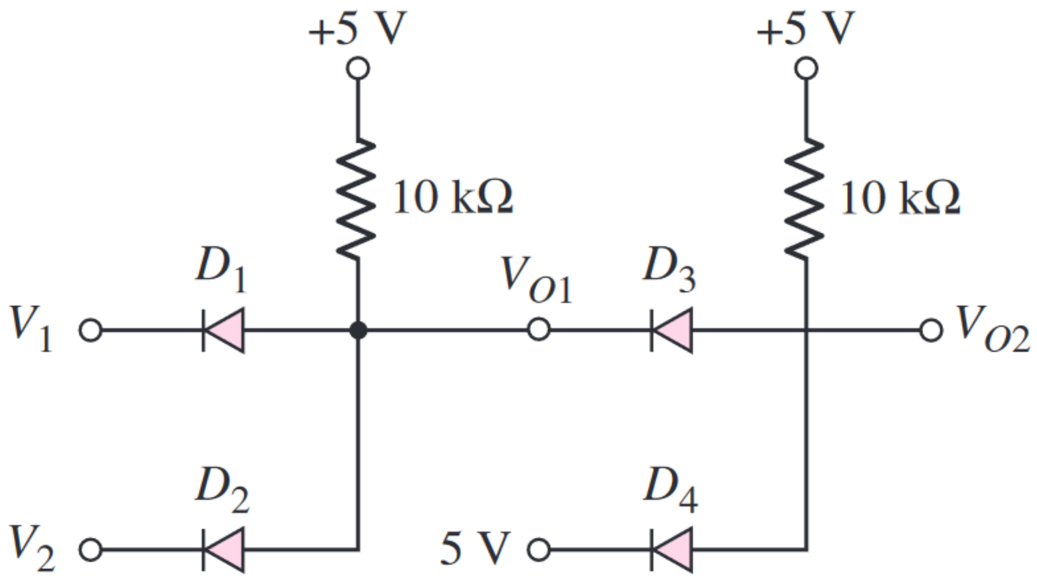
For CVD diodes assumption:

$V_{O1} = V_1 \text{ OR } V_2$ → *Largest Value of the inputs -* $\boldsymbol{V_{DO}}$

$$\therefore\ V_{O1} = (3\ - V_{DO})\text{ V}$$

$\boldsymbol{V_{O2}} = (V_{O1} \text{ OR } 0) = V_{O1} - V_{DO} = (\mathbf{3 - 2}\ \boldsymbol{V_{DO}})\ \mathbf{V}$

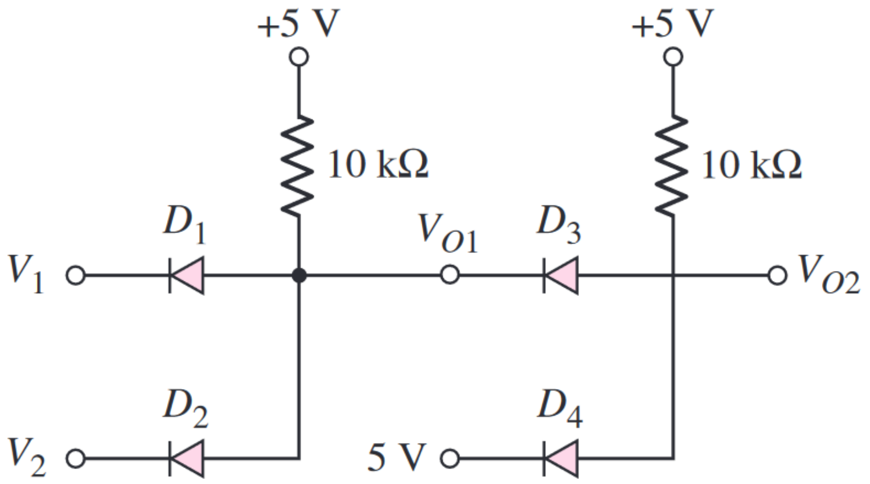
Combined Logic Circuits



$$V_{O1} = V_1 \text{ AND } V_2 = V_1 \cdot V_2$$

$$V_{O2} = (V_{O1} \text{ AND } 5) = V_{O1} = V_1 \cdot V_2$$

Combined Logic Circuits



** In CVD diode models, we are assuming that all diodes have equal drop.

Suppose: $\boldsymbol{V_1 = 3\ \mathrm{V}, V_2 = 1.5\ \mathrm{V}.}$

For Ideal diodes assumption:

$V_{O1} = V_1 \text{ AND } V_2$ → *Smallest Value of the inputs*

$$\therefore\ V_{O1} = 1.5\ \mathrm{V}$$

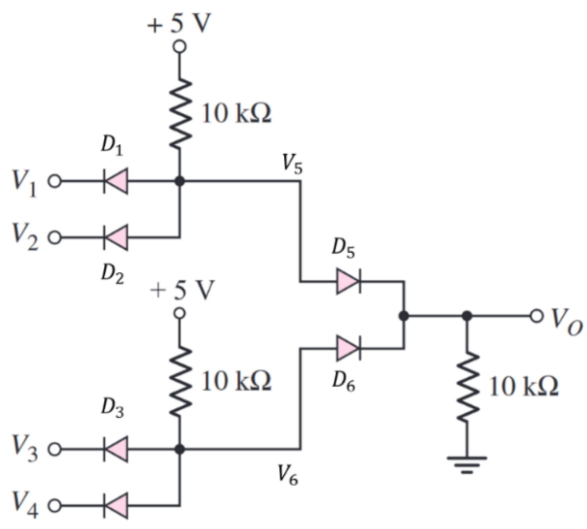
$\boldsymbol{V_{O2}} = (V_{O1} \text{ AND } 5) = V_{O1} = \mathbf{1.5\ V}$

For CVD diodes assumption:

$V_{O1} = V_1 \text{ AND } V_2$ → *Smallest Value of the inputs* **+** $\boldsymbol{V_{DO}}$

$$\therefore\ V_{O1} = (1.5 + V_{DO})\ \mathrm{V}$$

$\boldsymbol{V_{O2}} = (V_{O1} \text{ AND } 5) = V_{O1} + V_{DO} = (\mathbf{1.5 + 2}\ \boldsymbol{V_{DO}})\ \mathbf{V}$



$$V_{D1} = 0.3\text{ V}, \qquad V_1 = 2\textbf{ V}$$
$$V_{D2} = 0.5\text{ V}, \qquad V_2 = 1.7\textbf{ V}$$
$$V_{D3} = 0.7\text{ V}, \qquad V_3 = 1.5\textbf{ V}$$
$$V_{D4} = 0.9\text{ V}, \qquad V_4 = 1.1\textbf{ V}$$
$$V_{D5} = V_{D6} = 1.1\text{ V}$$

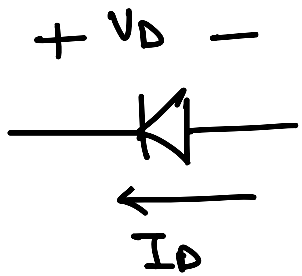
i. Find V_5 and V_6. [5]

ii. Find V_O. [5]

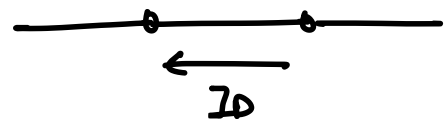
iii. **[BONUS – 5 Marks]:** Solve the circuit to get V_O when $V_1 = 7\,V$, $V_2 = 8\,V$ and all other parameters remain the same.

Diode Models:

Ideal:

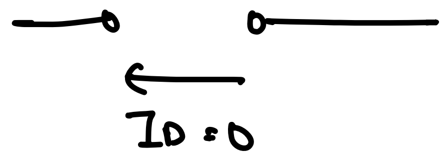


$V_D > 0$



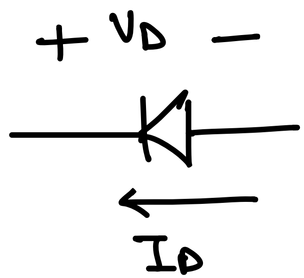
FB

$V_D < 0$

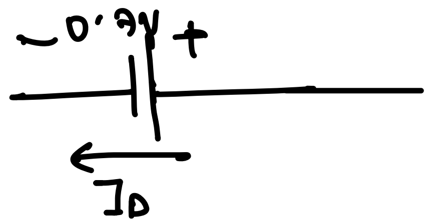


RB

Constant Voltage Drop (CVD) model:

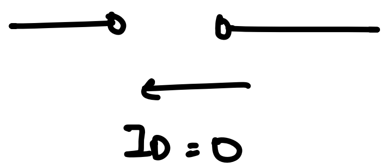


$V_D > V_{D0}$



FB

$V_D < V_{D0}$

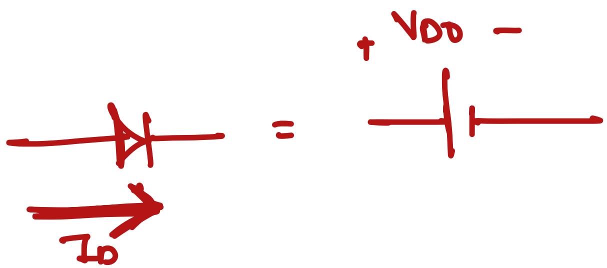


RB

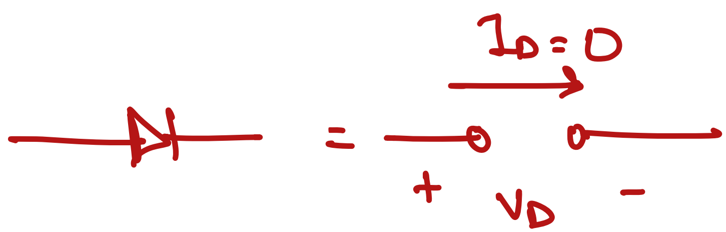
Method of assumed state:

Assumed:

ON



OFF



Validate:

$I_D > 0$ Assumption correct

$I_D < 0$ " wrong

$V_D < V_{DO}$ correct

$V_D > V_{DO}$ wrong

Solving Circuits with diodes

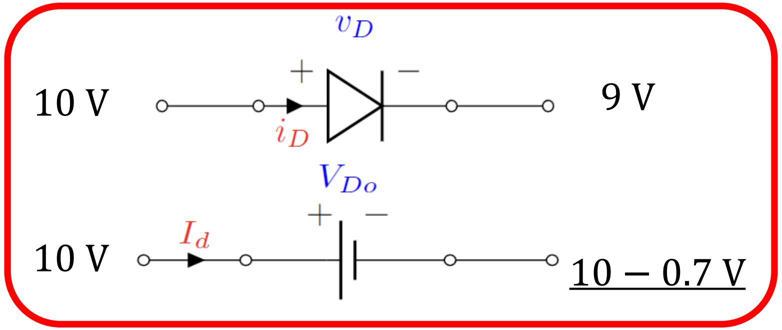
- Method of assumed states

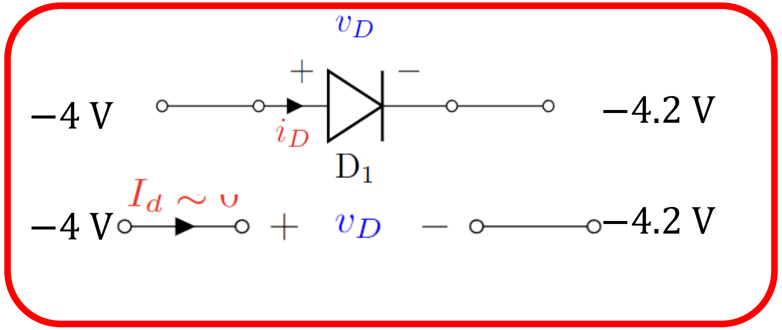
1. Assume a diode state – FB or RB
2. Replace FB/RB diode with circuit model
3. Solve circuit. Find current through diode and voltage across diodes

4. **Verify if current direction and voltage polarity matches with assumption (TRUE or FALSE).**
5. If assumption is false assume other state and repeat. Else, the result is finalized.

Verify Assumptions

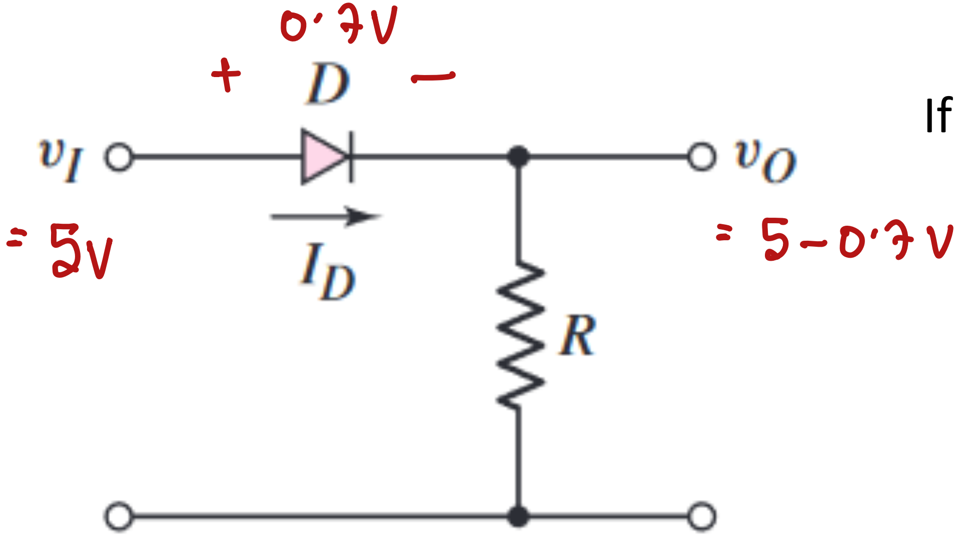
CVD Diode





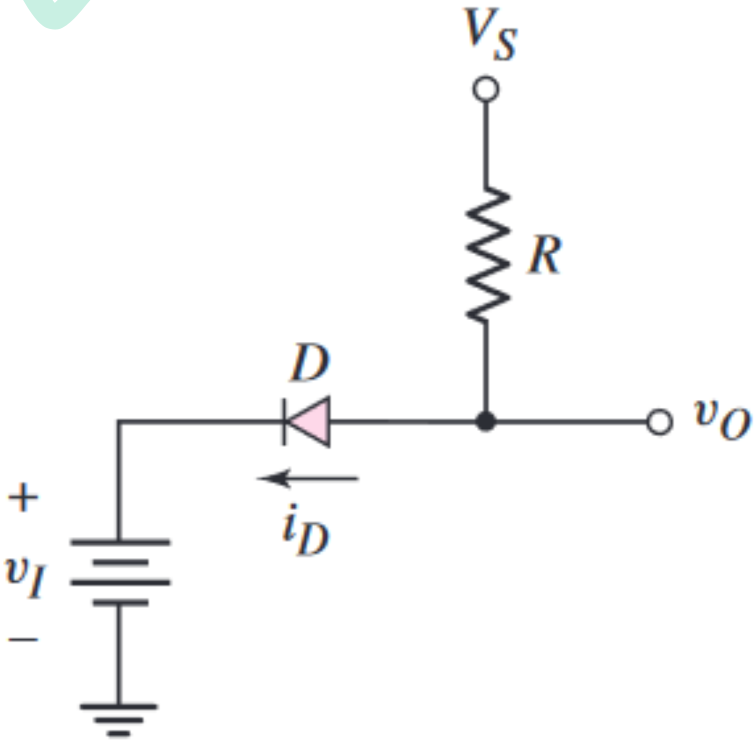
$V_{Do} = 0.7$ V

Solving Circuits with diodes



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

Solving Circuits with diodes

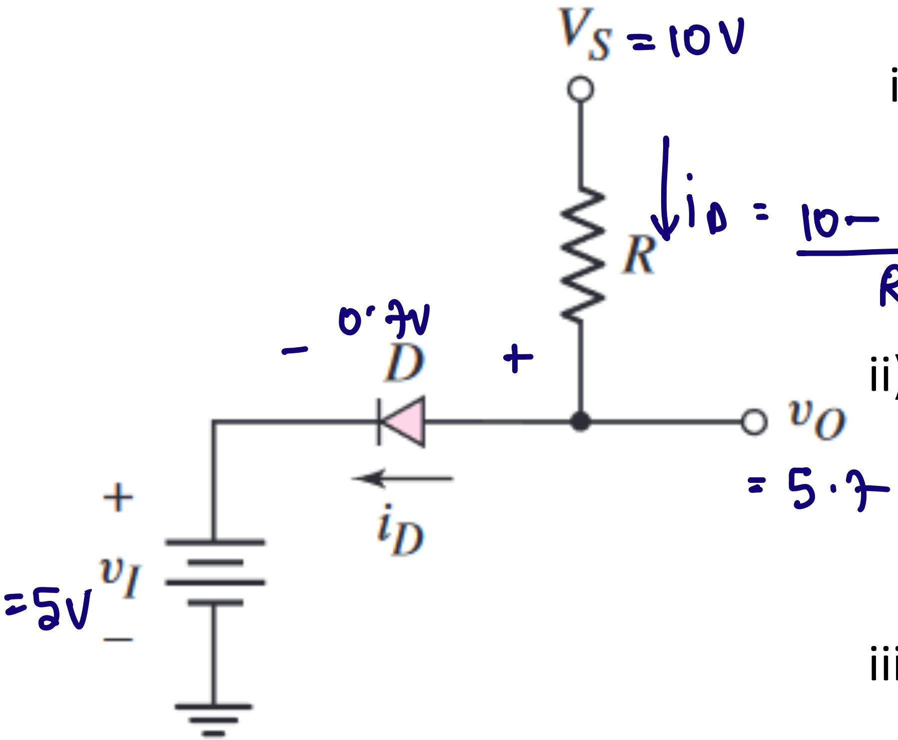


i) If $v_I = 5$ V , $V_S = 10$ V and $V_{DO} = 0.7$ V, find $\boldsymbol{v_O}$

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

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

Solving Circuits with diodes



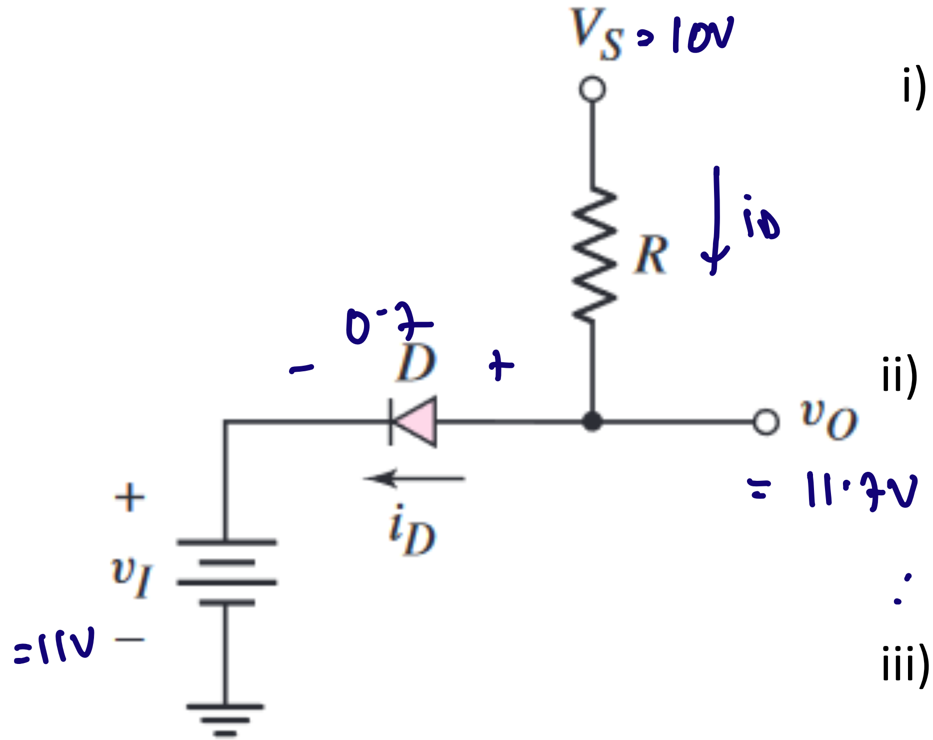
i) If $v_I = 5\text{ V}$, $V_S = 10\text{ V}$ and $V_{DO} = 0.7\text{ V}$, find $\boldsymbol{v_O}$

$i_D = \dfrac{10 - 5.7}{R} > 0$ $\therefore$ Diode on and assumption correct.

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

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

Solving Circuits with diodes



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

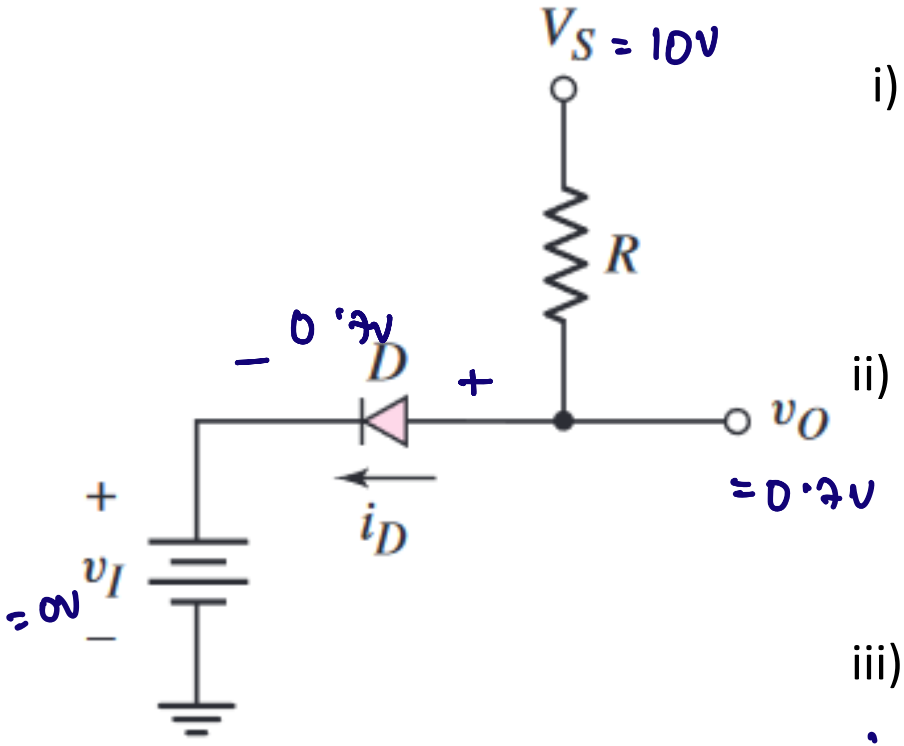
ii) If $v_I = 11\text{ V}$, $V_S = 10\text{ V}$ and $V_{DO} = 0.7\text{ V}$, find $\boldsymbol{v_O}$

$i_D = \dfrac{10-11.7}{R} < 0$ ∴ Diode cutoff.

∴ $i_D = 0$, $V_O = 10V$

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

Solving Circuits with diodes



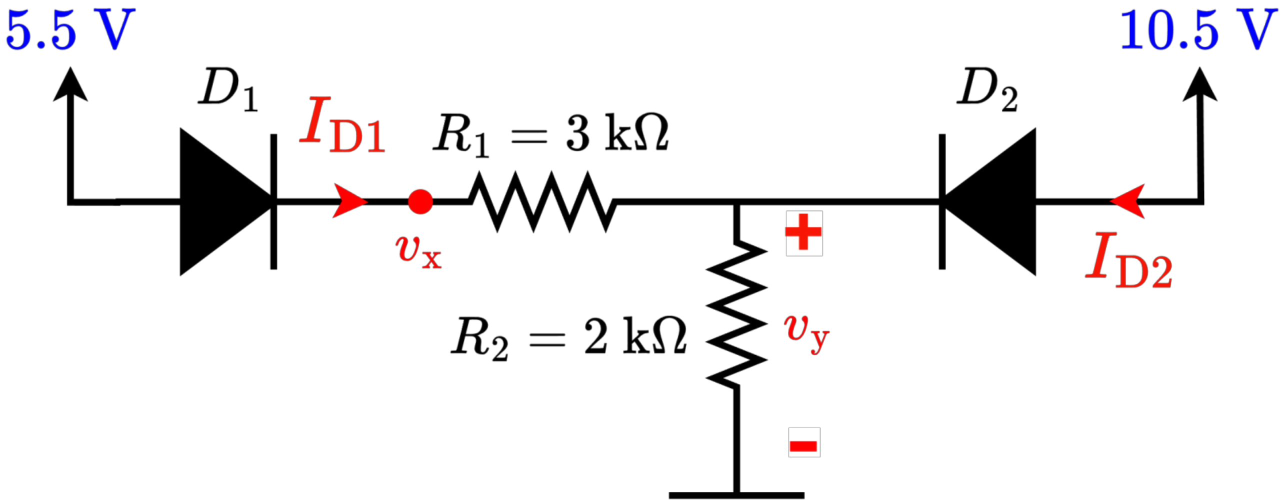
i) If $v_I = 5\text{ V}$, $V_S = 10\text{ V}$ and $V_{DO} = 0.7\text{ V}$, find $\boldsymbol{v_O}$

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

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

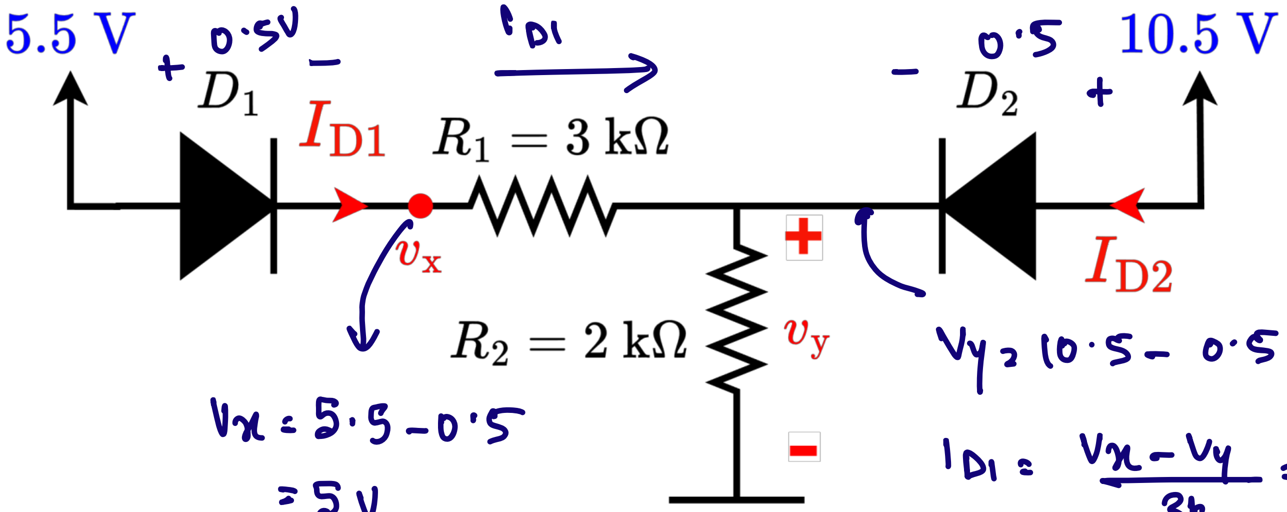
$i_D = \dfrac{10 - 0.7}{R} > 0$ $\therefore$ Diode on and assumption correct

Solving Circuits with diodes



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



$V_x = 5.5 - 0.5$
$= 5V$

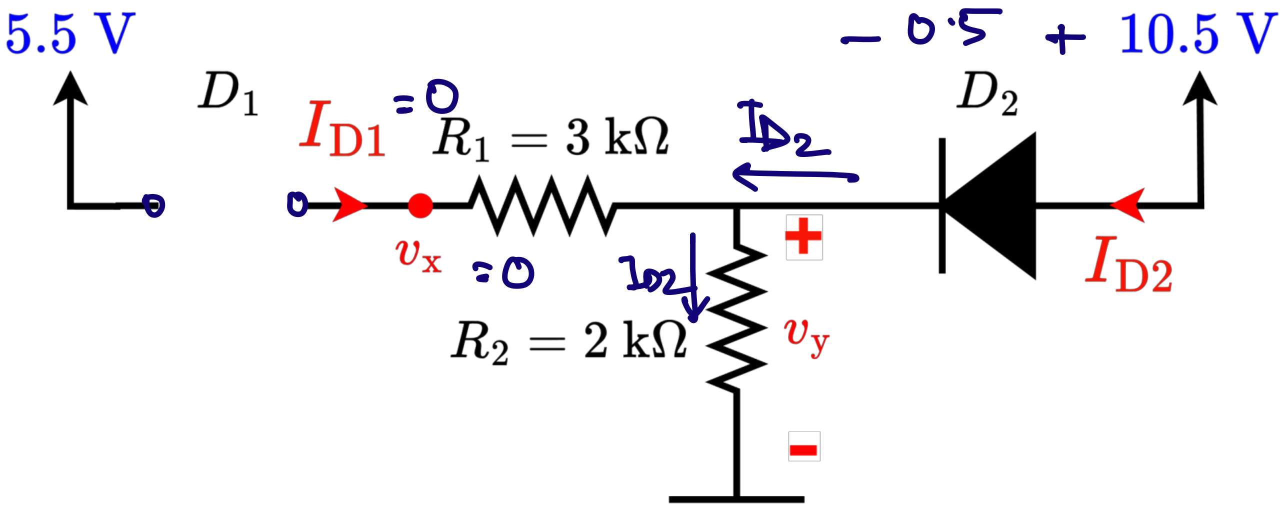
$V_y = 10.5 - 0.5 = 10V$

$I_{D1} = \dfrac{V_x - V_y}{3k} = \dfrac{5 - 10}{3k} < 0$

$\therefore$ D_1 off.

$\therefore$ $V_x = 0$

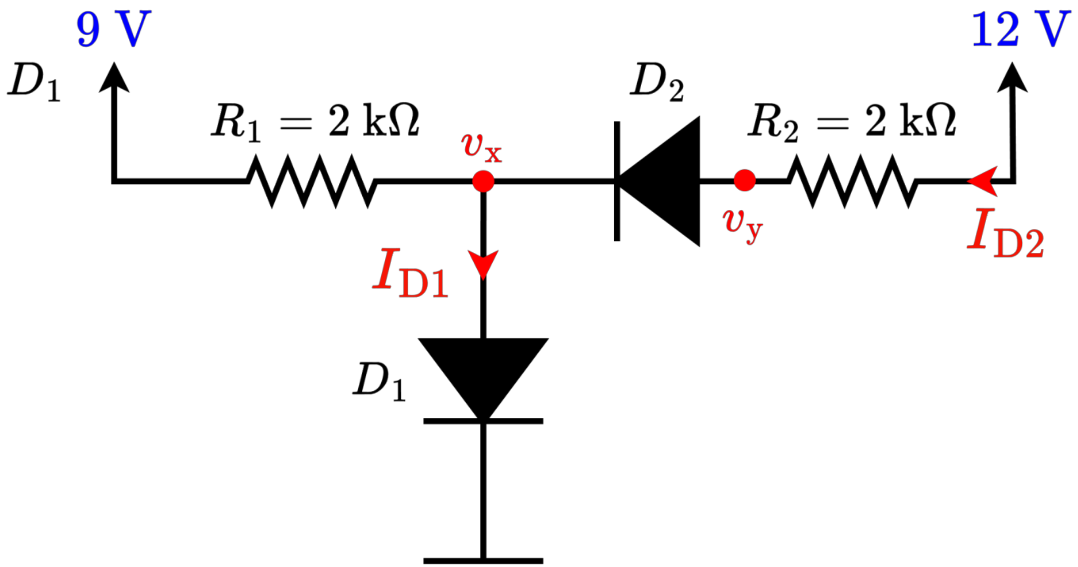
Solving Circuits with diodes



$$V_y = 10.5 - 0.5 = 10\ \text{V}$$

$$I_{D2} = \frac{V_y - 0}{2k} = \frac{10}{2k} = 5\ \text{mA}$$

Solving Circuits with diodes



Analyze the circuit to find I_{D1}, I_{D2}, v_x and v_y. Consider $\boldsymbol{V_{DO} = 1\ \mathrm{V}}$.
[Validate Assumptions]

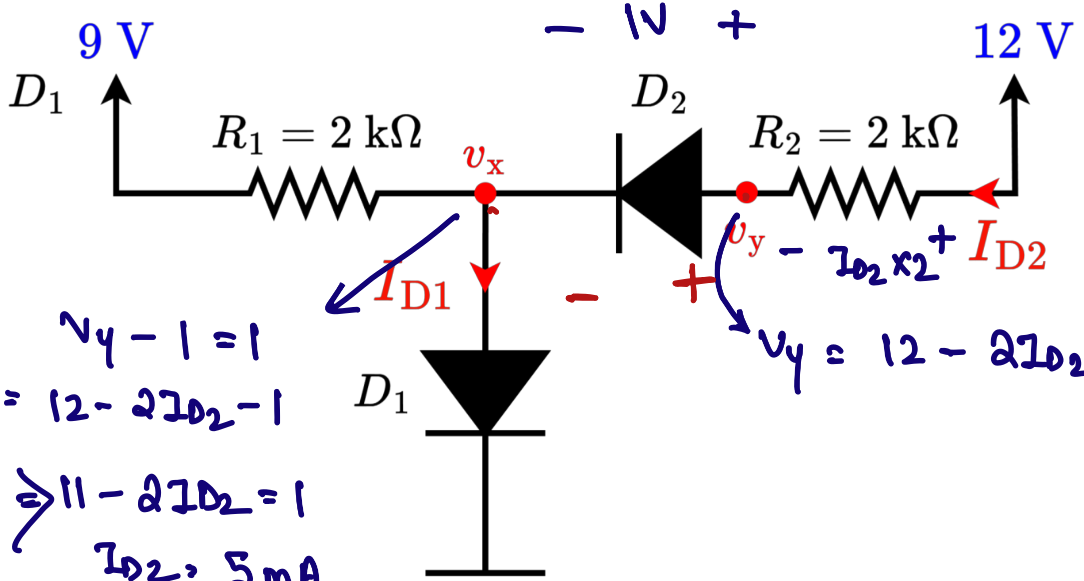
Are the diodes consuming power or delivering power?

Solving Circuits with diodes

OR. $v_y - v_x = 1$

$v_y = 1 + v_x$

$-$ 1V $+$



$v_y \; - \; I_{D2} \times 2 \; +$

$v_y = 12 - 2I_{D2}$

$\Rightarrow v_y - 1 = 1$

$= 12 - 2I_{D2} - 1$

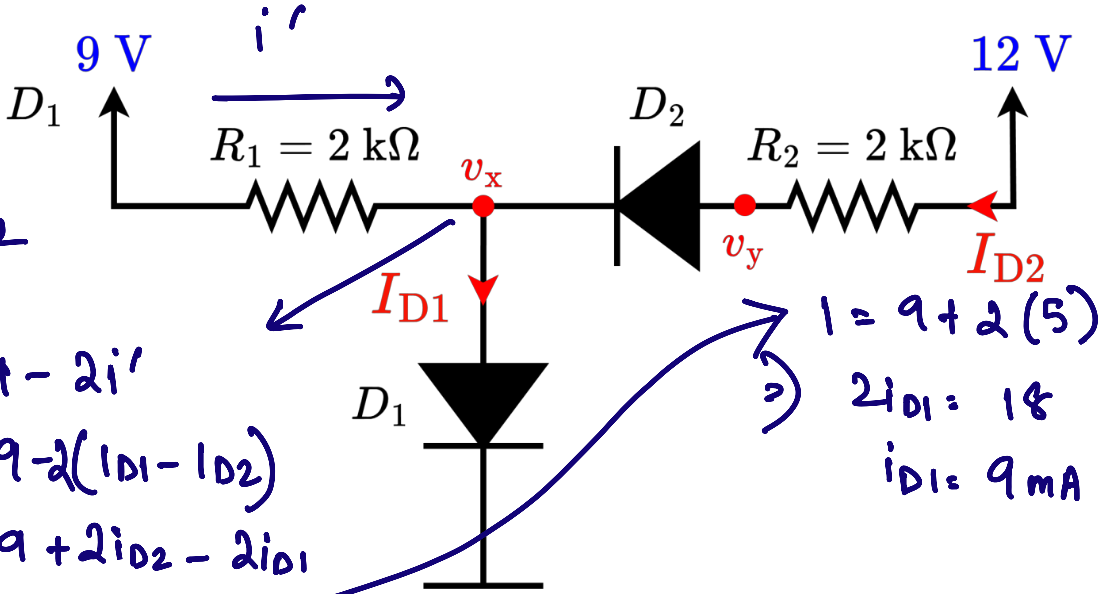
$\Rightarrow 11 - 2I_{D2} = 1$

$I_{D2} = 5\text{mA}$

Analyze the circuit to find I_{D1}, I_{D2}, v_x and v_y. Consider $\boldsymbol{V_{DO} = 1}$ **V.**
[Validate Assumptions]

Are the diodes consuming power or delivering power?

Solving Circuits with diodes



$i' = I_{D1} - I_{D2}$

Also, $V_x = 9 - 2i'$

$\Rightarrow \quad 1 = 9 - 2(I_{D1} - I_{D2})$

$\Rightarrow \quad 1 = 9 + 2i_{D2} - 2i_{D1}$

$1 = 9 + 2(5) - 2i_{D1}$

$\Rightarrow \quad 2i_{D1} = 18$

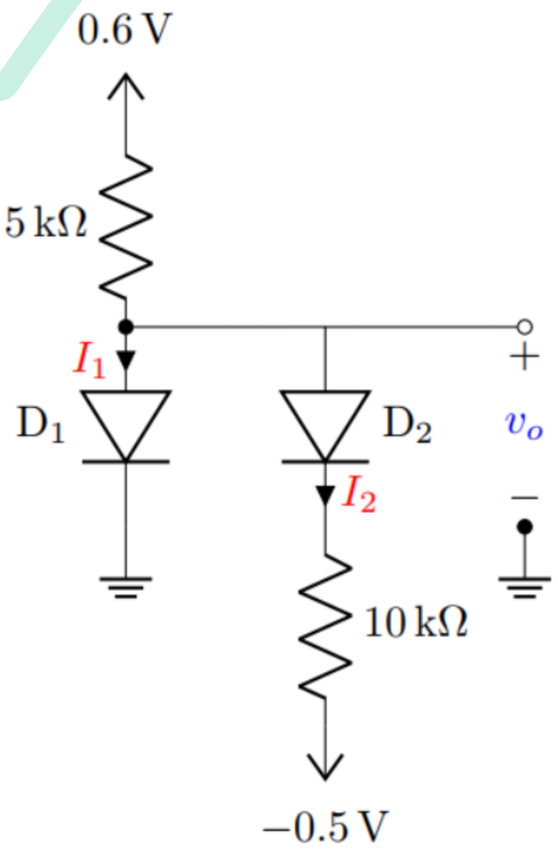
$i_{D1} = 9\ \mathrm{mA}$

Analyze the circuit to find I_{D1}, I_{D2}, v_x and v_y. Consider $\boldsymbol{V_{DO} = 1\ \mathrm{V}}$. $+\ 1\mathrm{V}\ -$ i_D

[Validate Assumptions]

Are the diodes consuming power or delivering power? D_1, D_2 absorbing

Solving Circuits with diodes



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

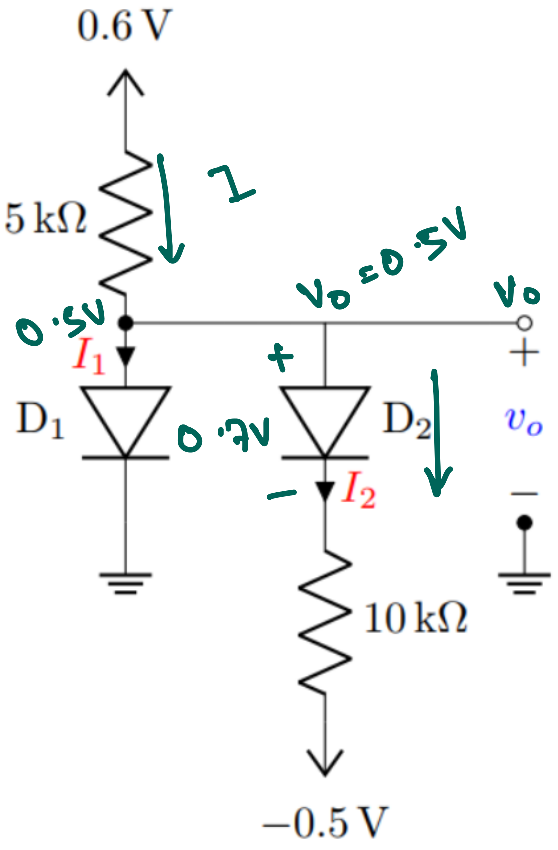
i. Assuming all diodes as ideal

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



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

[Validate Assumptions]

$$I_2 = \frac{V_o - 0.7 - (-0.5)}{10k}$$

$$= \frac{0.5 - 0.7 - (-0.5)}{10k}$$

$$I = I_1 + I_2$$

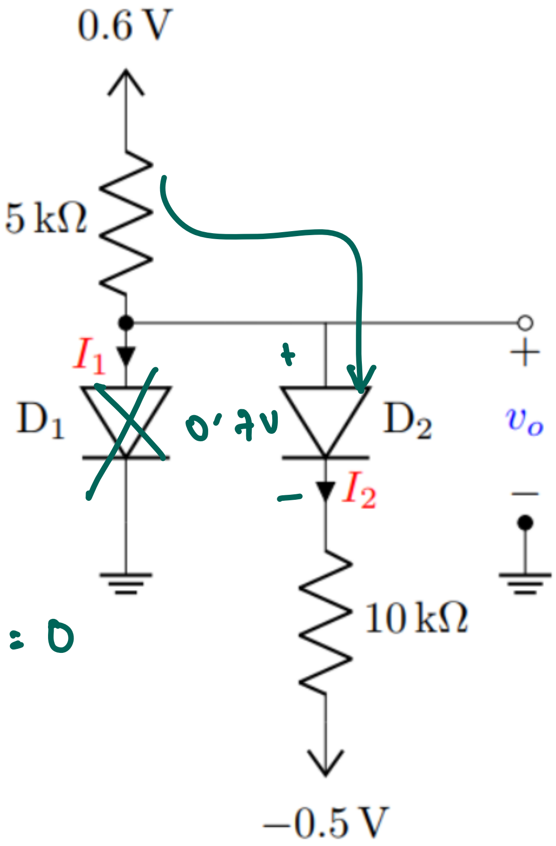
$$\frac{0.6 - 0.5}{5} = I_1 + I_2$$

$I_2 = 0.03\text{ mA}$

$I = 0.02\text{ mA}$

$I_1 = -0.01\text{ mA}$ X

Solving Circuits with diodes



$I_1 = 0$

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

i. Assuming all diodes as ideal

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

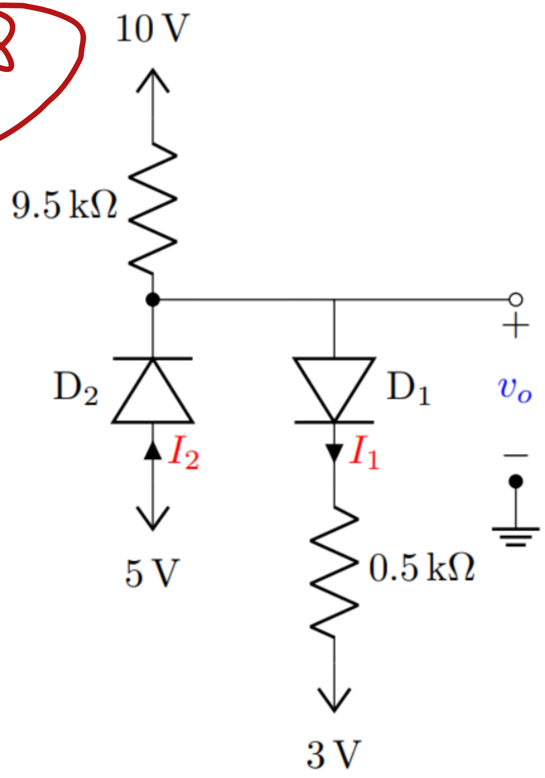
iii. Consider $\boldsymbol{V_{DO} = 0.6}$ **V** and $\boldsymbol{r_d = 50\ \Omega}$**. (CVD+R model)**

[Validate Assumptions]

$$I_2 = \frac{0.6 - (-0.5) - 0.7}{5 + 10} = 0.0267\ mA$$

$$v_o = -0.5 + 0.7 + 10I_2$$

Solving Circuits with diodes



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

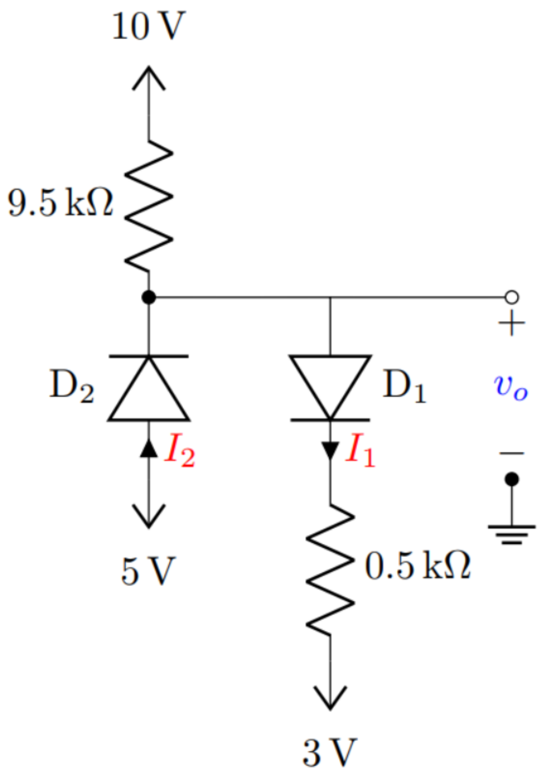
i. Assuming all diodes as ideal

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



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

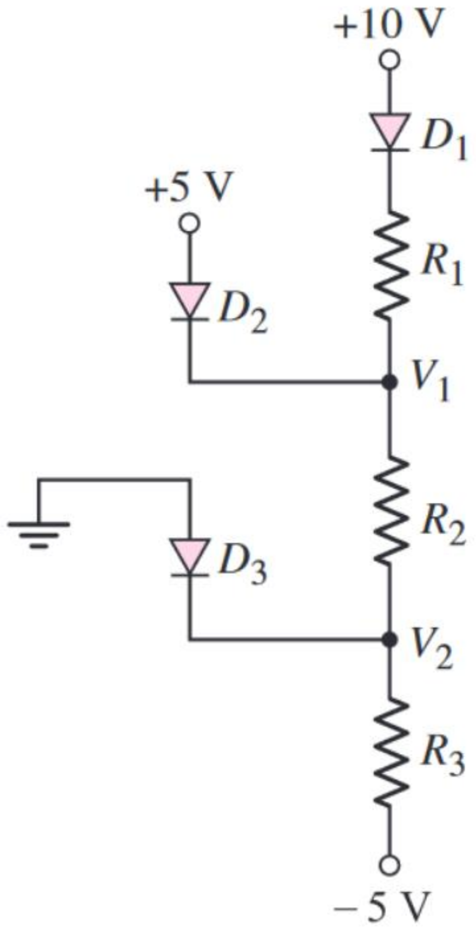
i. Assuming all diodes as ideal

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



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

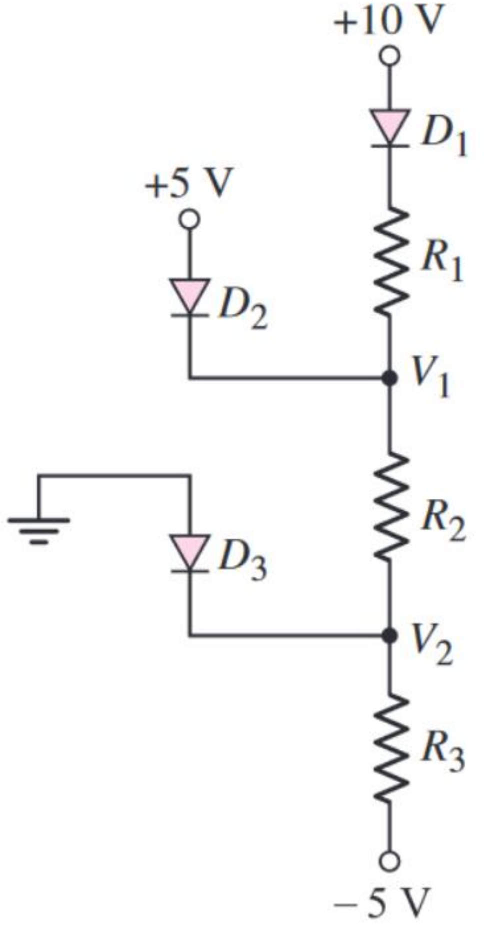
$$I_{D1} = 0.2 \text{ mA},$$
$$I_{D2} = 0.3 \text{ mA}$$
$$I_{D3} = 0.5 \text{ mA}$$

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



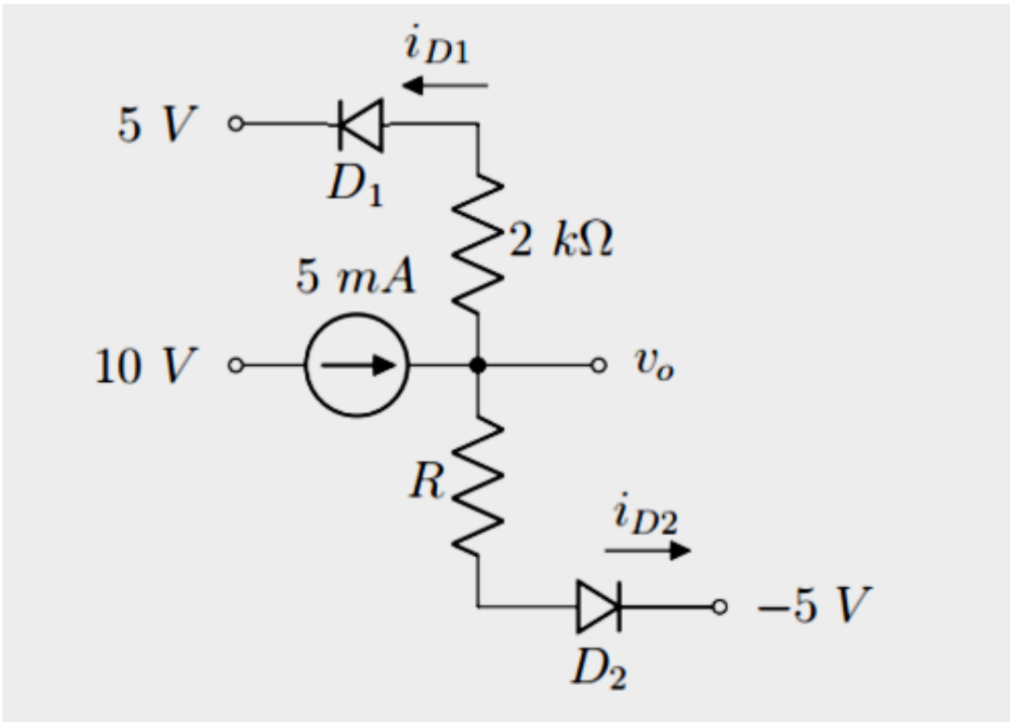
a. Find $\boldsymbol{V_1, V_2}$ and each diode current for

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

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

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

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



Find **Vo, $\mathbf{i_{D1}}$ and $\mathbf{i_{D2}}$** for R = 1 kΩ. Assume diode constant voltage drop model with Vdo = 0.7v . In each case, write down the states of the diodes (ON/OFF). You must verify your assumptions.

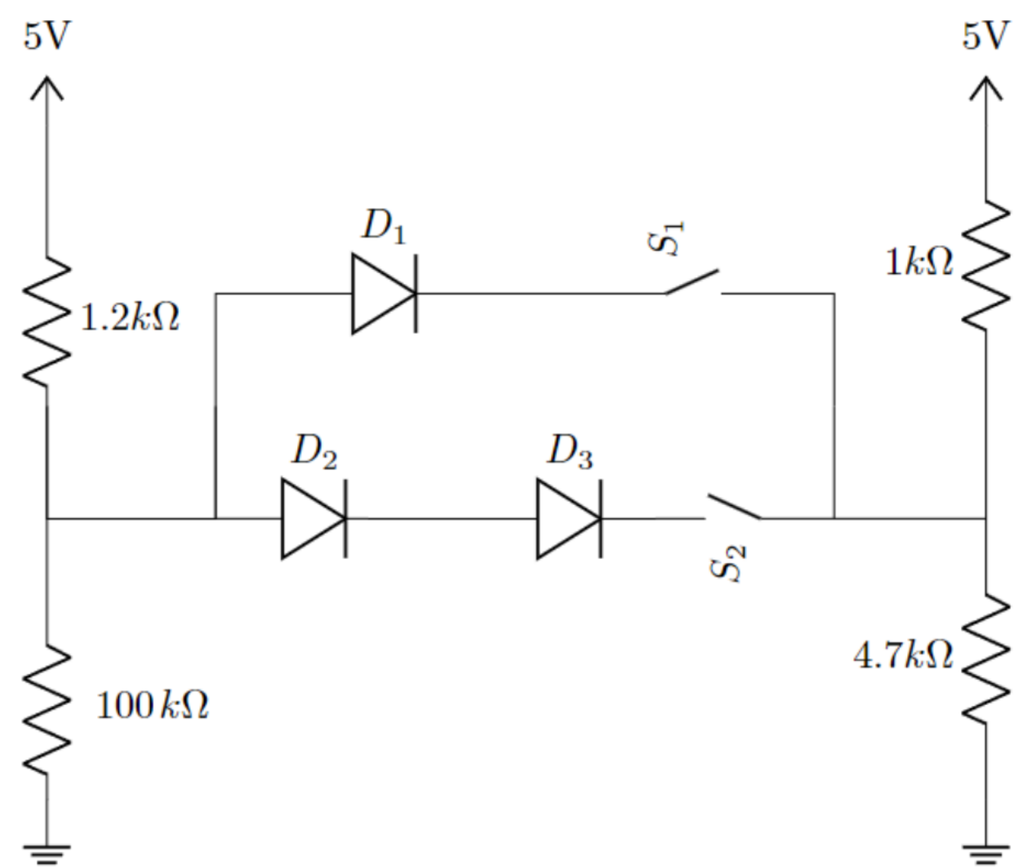
7.

The switches S1 and S2 are shown in open configuration below.

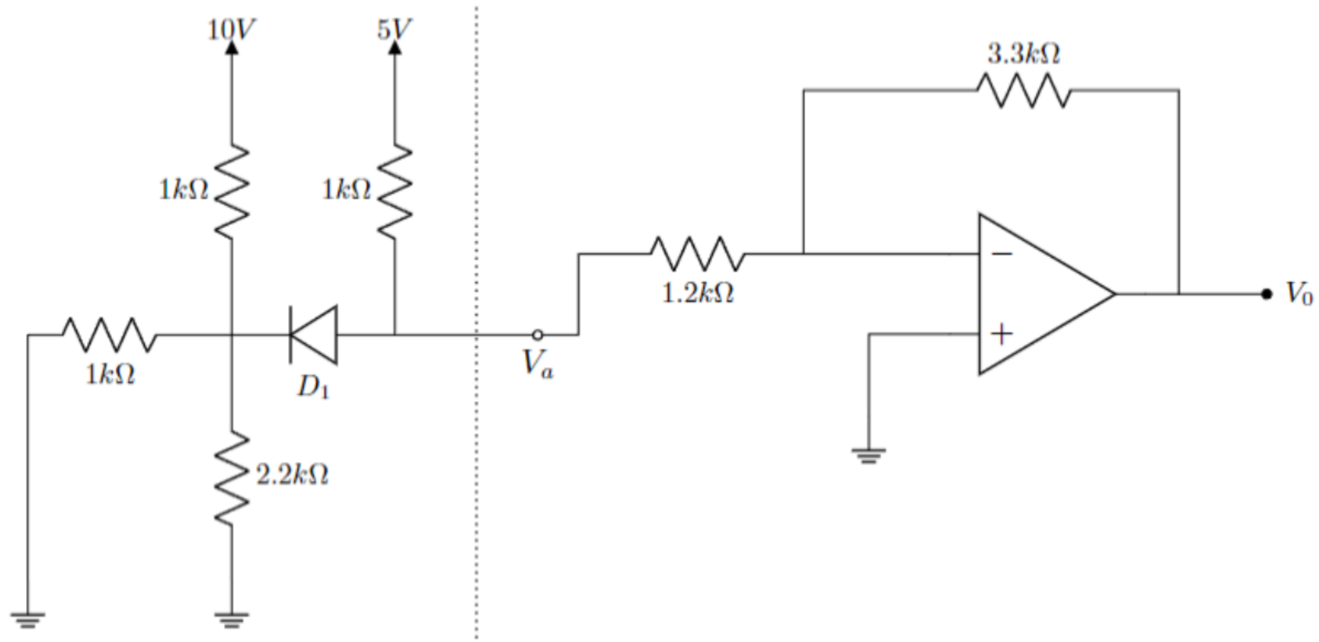
Assume, $V_{D0} = 0.7V$ (CVD model)

(i) Find the current passing through the $100k\Omega$ resistor when only S1 is closed.

(ii) Find the current passing through the $100k\Omega$ resistor when only S2 is closed.



Q)



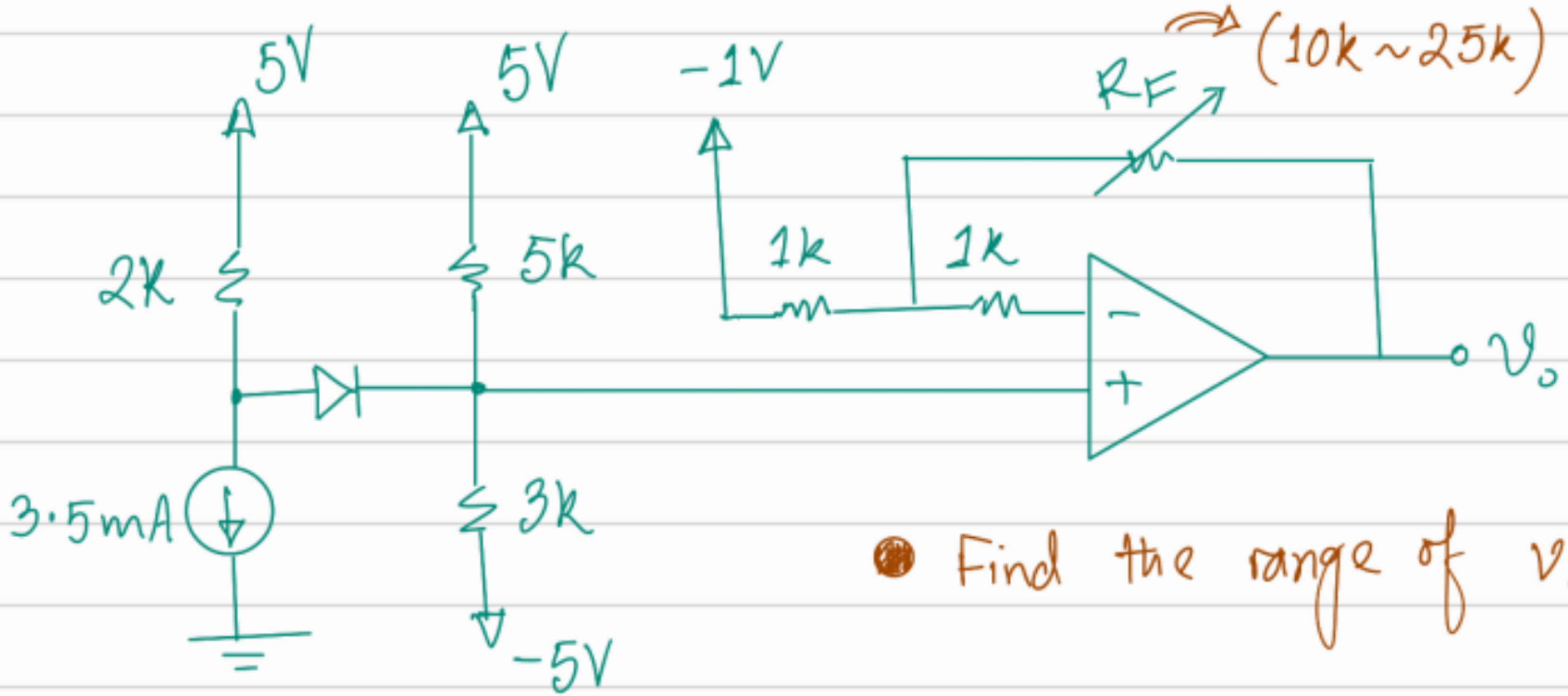
The saturation voltages of the Op-Amp are given as- $V^{+}_{sat} = +10V$ and $V^{-}_{sat} = -10V$. The forward voltage drop of the diode, V_D is $0.7V$.

(a) **Determine** the operating mode diode, D_1. Verify your assumption with necessary calculations.

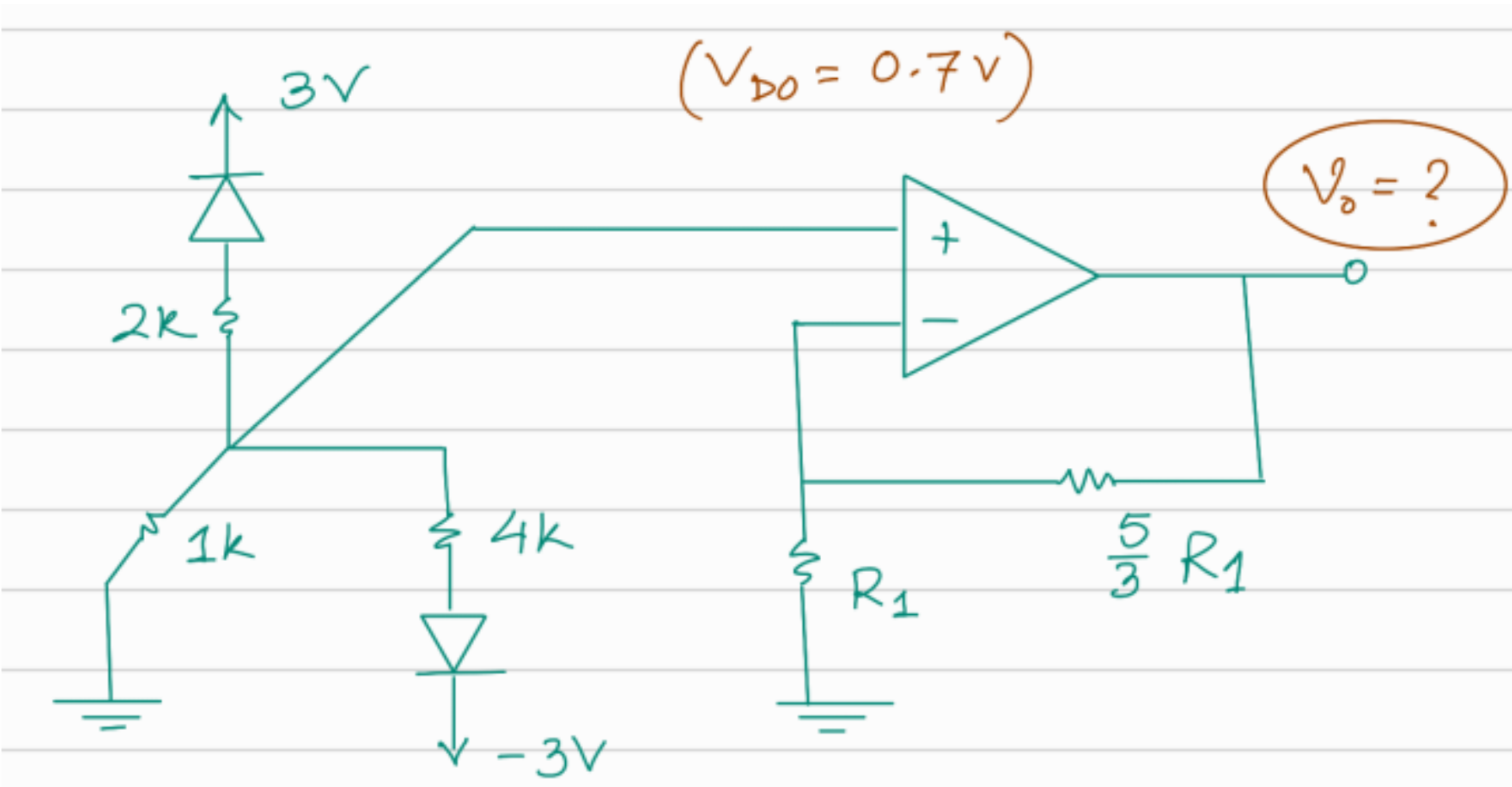
(b) **Calculate** the voltage at - (i) node 'Va', (ii) non-inverting terminal of the Op-Amp, (iii) inverting terminal of the Op-Amp.

(c) Find out the output voltage, Vo of the Op-Amp.

$(V_{D0} = 0.7V)$



- Find the range of v_o



(VDO = 0.7V)
Vo = ?
3V
2k
1k
4k
-3V
+
−
R1
5/3 R1