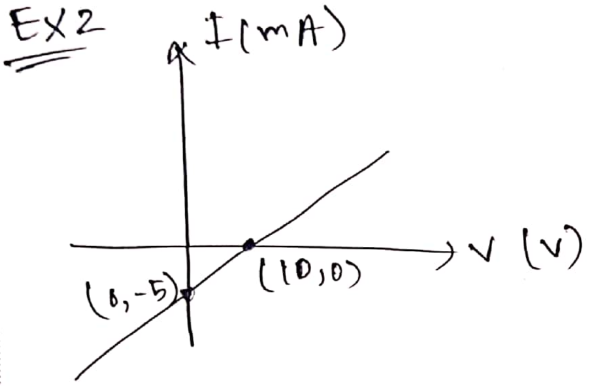
Example: (from lecture 6)

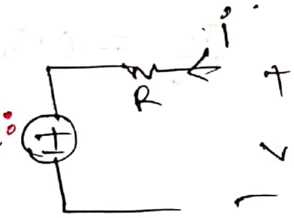
Ex2



① model = ?

② parameter = ?

Sol^n: ① model:



or

model

② parameter V_0, R or I_0, R

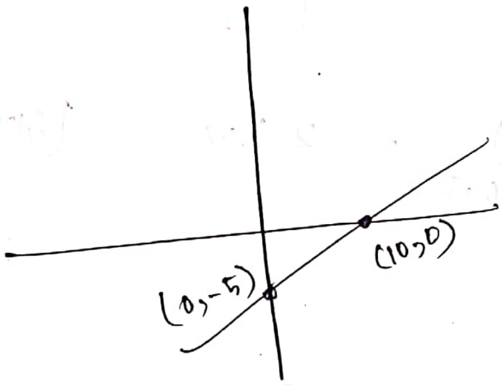
For solving we need equation like $\boxed{y = mx + c}$

$$\text{slope} = \frac{y_2 - y_1}{x_2 - x_1}$$

if voltage source with resistor | where $R = \frac{1}{m}$, V_0 = x intercept $(y=0)$

if current source with resistor,
$R = \frac{1}{m}$
I_0 = y intercept

Solve



$\because (x_1, y_1) \equiv (0, -5)$ $\qquad \therefore$ slope $= \dfrac{y_2 - y_1}{x_2 - x_1} = \dfrac{0-(-5)}{10-0}$

$(x_2, y_2) \equiv (10, 0)$ $\qquad = \dfrac{5}{10} = 0.5$

$\because y = mx + c$

$= 0.5x + c$

Now ~~path~~ from the point $(x_2, y_2) = (10, 0)$

$y = mx + c$

$0 = m \times 10 + c$

$\Rightarrow 0 = 0.5 \times 10 + c$

$\therefore c = -5$

$\therefore$ equation will be

$$\boxed{y = 0.5x - 5}$$

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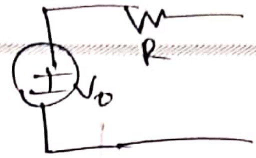
Now let's the model is 

$\therefore R = \frac{1}{m} = \frac{1}{0.5} = 2\,k\Omega$ [since I is in mA]

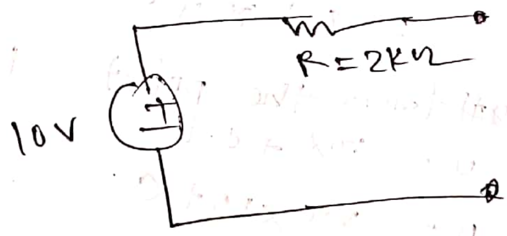
For V_0, $y = 0$

$\Rightarrow \therefore 0 = 0.5x - 5$

$\Rightarrow 0.5x = 5$

$\therefore x = 10$

$\therefore V_0 = x = 10$



(Ans)

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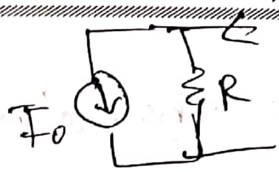
or lets the model is like



$\therefore$ $R = \frac{1}{m} = 2\,k\Omega$

For I_0, $x = 0$

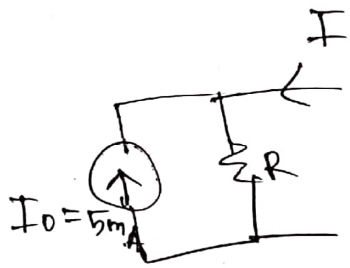
$\therefore$ $y = 0.5 \times 0 - 5$

$\Rightarrow y = -5$

$\therefore$ $I_0 = y = -5$

$\therefore$ model:

or



(Ans)

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IV characteristic of non linear device:

Non-linear device: Those device, whose IV curve can't be possible to represent with straight line.

Generic Non-linear device symbol

+ -

A  C

↓ ↓

Anode cathod

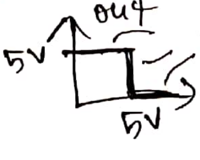
Now why do we need non-linear device.

① Because linear devices have limited application. (can only perform linear operation like $ax+by=0$

but not possible x^2+bx+c

e^x, $\sin x$, etc

② we need non-linear device for logic gate. For example



multiple segment IN not linear

$\frac{0}{0V}$  1(5V)

Sub.: (**) Technically, pure non-linear device is not possible SAT SUN MON TUE WED THU FRI

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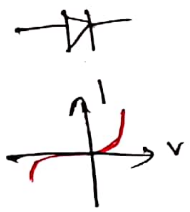
(3) Linear device have no control.

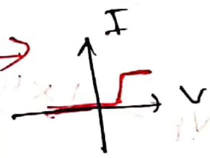
For example: R — No current direction if not specify manually

But previously we talked about valve that is not a linear device (Have 3 terminal and we can control the flow of current.

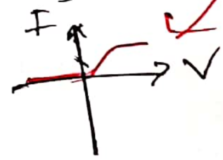
Non linear device we see in this course:

diode , BJT , MOSFET





Hopefully



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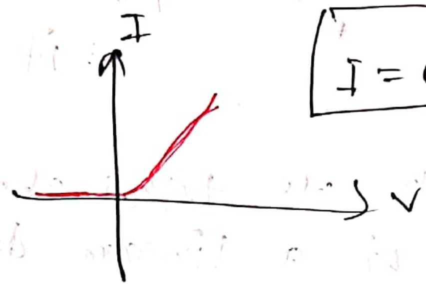
~~But there are~~

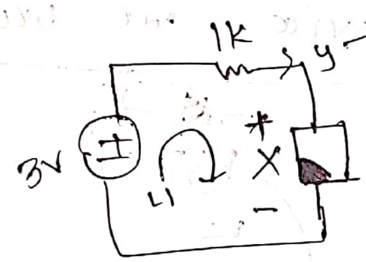
Down sides of Non-linear device



$\boxed{I = e^{V}}$ that is $\boxed{y = e^{x}}$

suppose the device associated to this graph is

so,

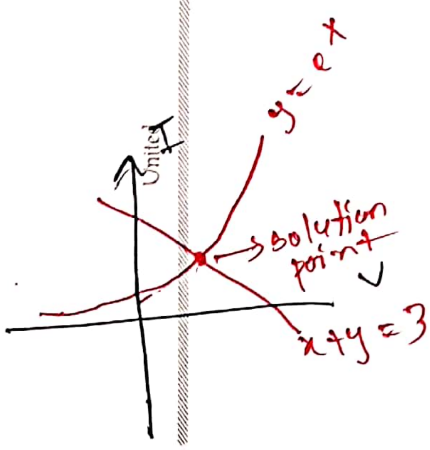


$\therefore V_R = 1 \times y = y$

~~3 = y + x~~

L1 KVL

$3 = 1 * y + x$



$\boxed{\begin{array}{c} \therefore x + y = 3 \\ \text{again } y = e^{x} \end{array}}$ → But its very hard to solve (have to use numerical technique or graphical solution but doesnt get actual result)

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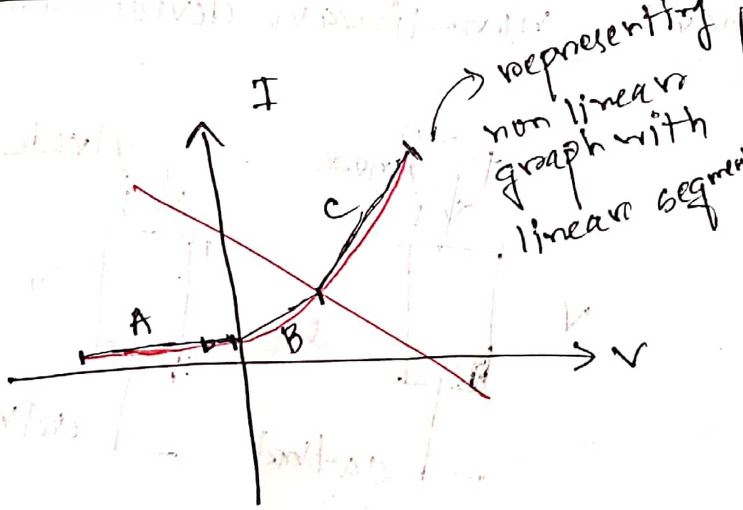
Therefore biggest disadvantage is that there's no actual solution (or close form solution). OR can say, can't solve easily.

But solution is ~~can~~ we can solve ~~it~~ this type of non-linear IV using piecewise linear approximation.

piece wise linear approximation:



non_linear = Σ linear segment

Main idea is, if we have any non-linear graph, we divide it small pieces so that each ~~piece~~ pice works like straight line.

So advantage is now equation become linear. ~~that~~ can easily solve it But there will be some error.

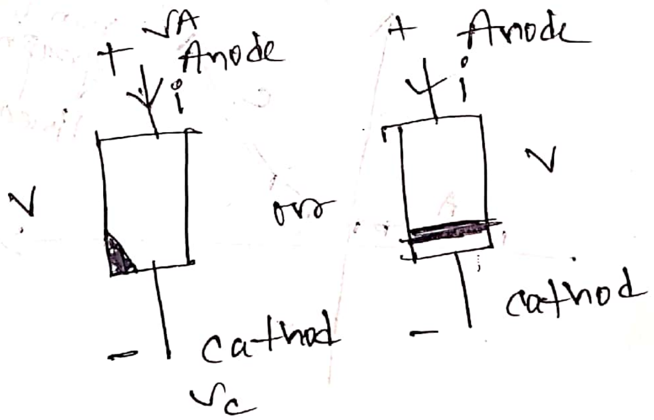
United

But another problem in this piecewise linear approximation that in which segment our device (non-linear) works.

↳ solution: method of assumed state.

⊛ So if theres in question non-linear then we assumed it piece-wise linear approximation

Generic non-linear device and its model



$$\therefore \boxed{v = v_A - v_C}$$

$\boxed{i = \text{from } \text{~~anod~~ Anode to cathod}}$

Ex:

$V_A = ?$

$V_C = ?$

$V = ?$

$I = ?$

Ans:

$V_A = 3V$

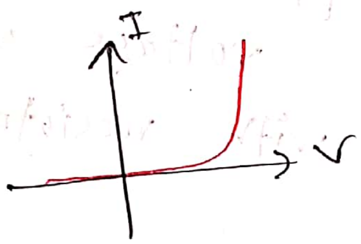
$V_C = 2V$

$V = V_A - V_C$

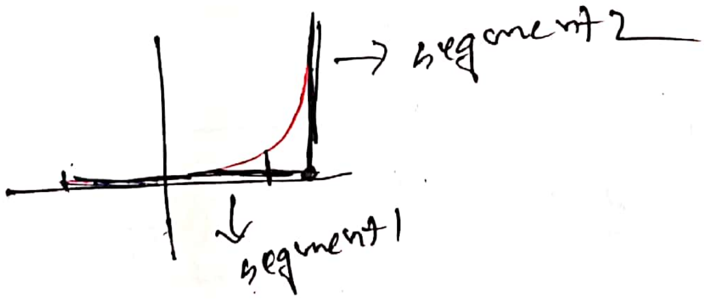
$= 3 - 2 = 1V$

$I = -5A$

suppose the IV curve of this device,

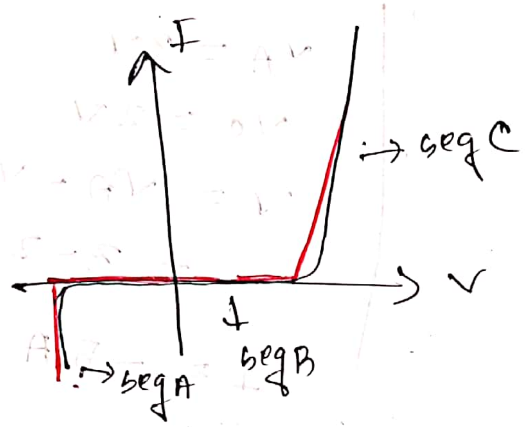


so according to piecewise approx.



Now question How can we model it using linear device.

modeling non-linear device using linear device :

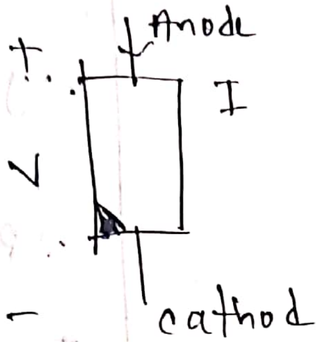


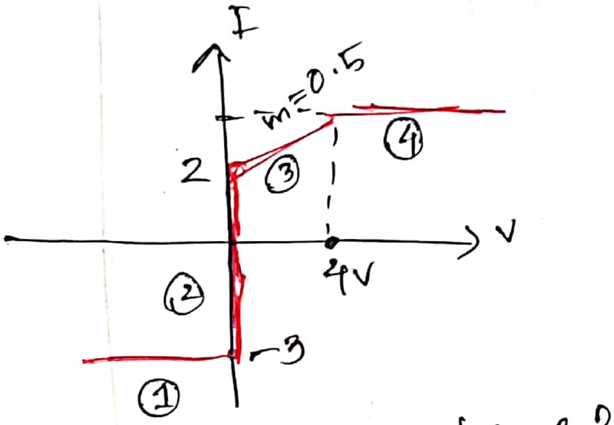
Here segment A like, voltage source 1V

segment B like, open circuit or $R = \infty$

segment C like voltage source 1V
series with resistor.

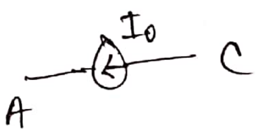
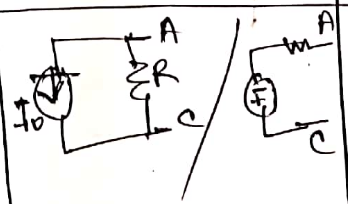
Ex:





Q1) Find PWL modeling of the device above?

Soln: Have to find condition, model & parameter

	condition	model	parameter
segment ①	$V \le 0$	current source 	$I_0 = 3\,mA$
segment ②	$-3\,mA < I \le 2\,mA$		X
segment ③	$0V < V \le 4V$		$y = mx + c$ $m = 0.5$ $\therefore y = 0.5x + c$ (0,2) point on y axis $\Rightarrow 2 = 0.5 \times 0 + c$ $\Rightarrow c = 2$

include less than $[a < v \le b]$ in condition (Better)

Sub.:

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$\therefore y = 0.5x + 2$

$\therefore R = \frac{1}{m} = \frac{1}{0.5} = 2k\Omega$

$I_o = y$-intercept

$\therefore I_o = c = 2mA$

segment (4)

$v > 4V$

From segment (3)

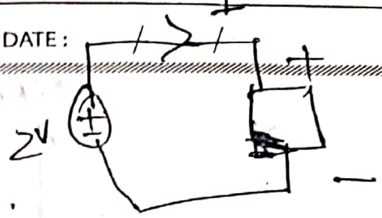
$y = 0.5x + 2$

now $x = 4$

$\therefore y = 0.5 \times 4 + 2$

$= 4$

$\therefore I_o = y = 4\ mA$



Now Question:

Q2# Find I when $V = 2V$?

so Have to go to match with the condition.

so it matches with segment ③ condition.

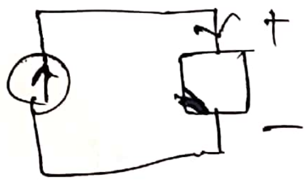
so from segment ③ so device operate at segment ③

$$y = 0.5x + 2$$

$$\therefore I = 0.5V + 2$$

$$\Rightarrow I = 0.5 \times 2 + 2$$

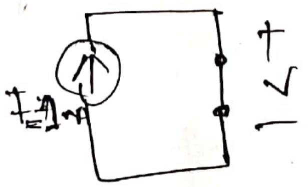
$$= 3mA \text{ (Answer)}$$



Q3 Find V when $I = 1mA$?

Soln: will operate in segment ②.

$\therefore$



$\therefore V = 0V$

Sub.: Goal : AC → DC converters circuit

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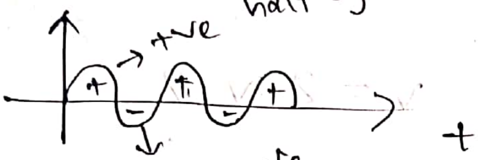
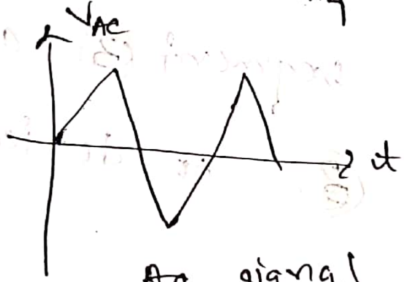
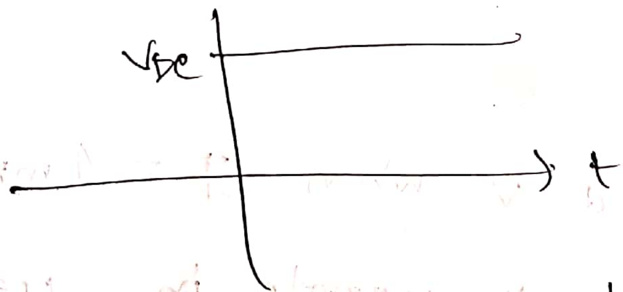


AC signal

AC signal



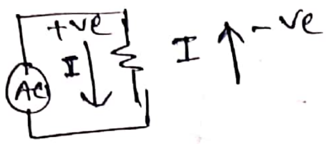
AC signal



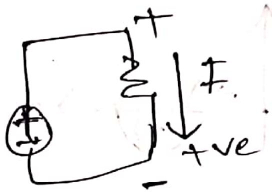
DC signal

United

For AC



But for DC



~~Ac~~ we have AC supply in our electricity line because we can reduce transmission loss or power loss using AC [(P = VI) via increasing or decreasing voltage using transformer (step up or step down)].

Historical perspective

$$\boxed{I = \frac{\overset{\text{constant}}{P}}{V}}$$

~~But with DC we ca~~

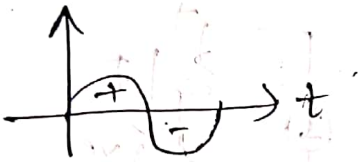
And Transformer only works with AC.

But AC supply has more power loss than DC and noise.

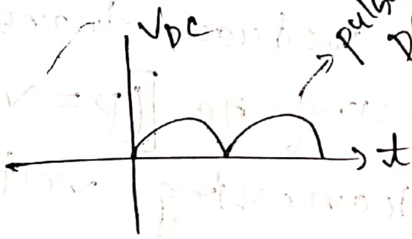
So now a days in china they use DC transmission. for long ~~tr~~ transmission line.

Step of convention technique of from Ac to DC

V_{AC}



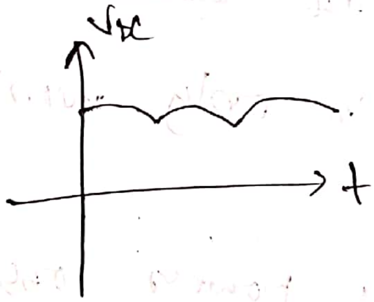
rectification



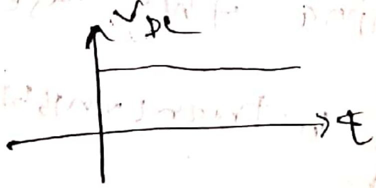
pulsating DC

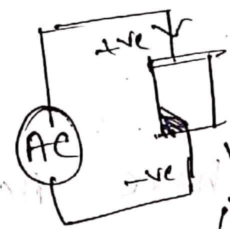
pulsating means its not a constant value, it changes over time

Filtering



regulation





+ve only pass the positive half cycle current

(e-valve)

How we Develop it.

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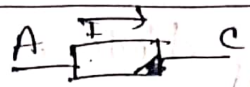
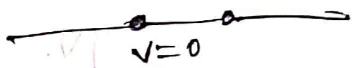
What should be the IV of an ideal e-valve.

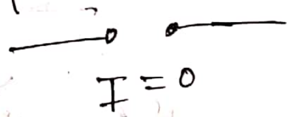


If $I > 0$, allow current (no resistance), should behave like short circuit.

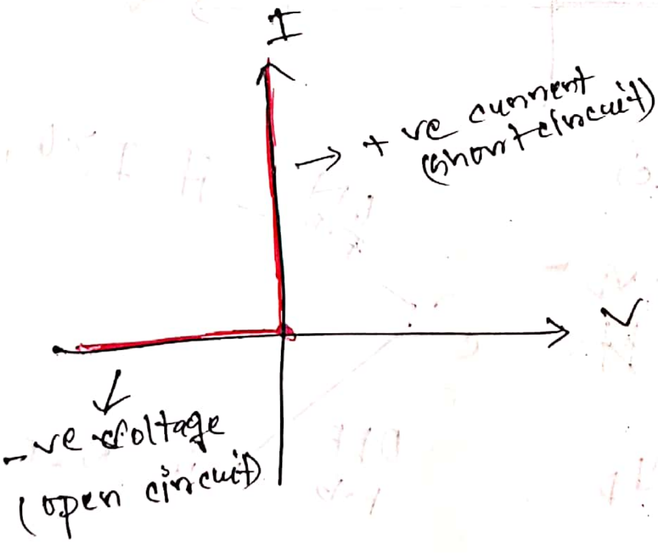


→ ON mode

If $V < 0$, doesnt allow current (Infinite resistance), should behave like open circuit



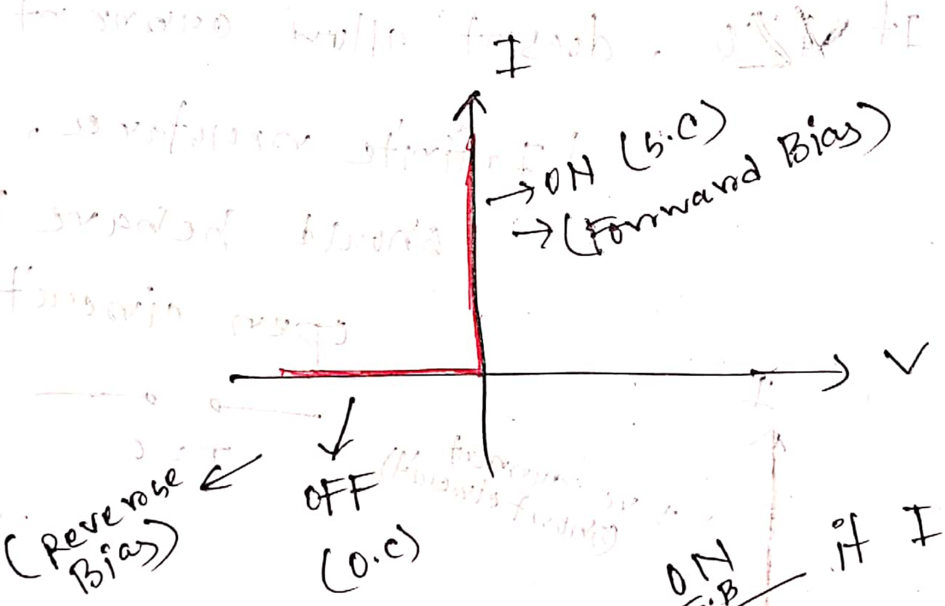
→ OFF mode.



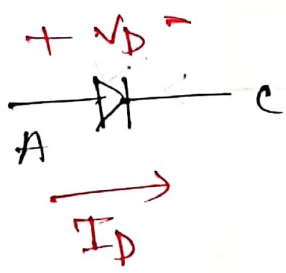
And this valve (after many refinement) they ~~made~~ called diode.

Diode (Ideal)

IV chars.



circuit symbol



ON F.B — if $I > 0$, $V_D = 0$

OFF R.B — if $V < 0$, $I_D = 0$

$V_D = V_A - V_C$

I_D = from Anode A to cathod C.

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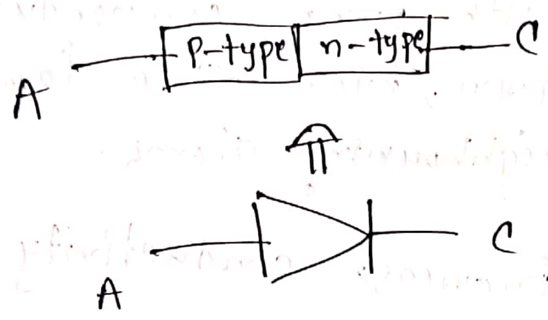
Real diode: (making) briefly:



p-type semiconductor:

⇒ carrier: Holes (absense of electron)

⇒ Difference with pure semiconductor: It has empty electron spaces (called holes) in certain bonds with neighbouring atoms.

⇒ Electrons from neighbouring bonds try to fill up the empty spaces by creating a flow of electrons hence increasing the conductivity.

~~not~~

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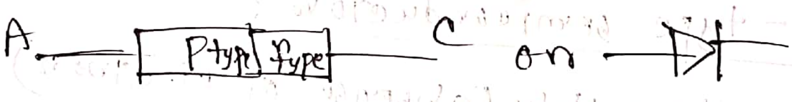
n type semiconductor:

Carrier: electron

~~Net~~ Difference with pure semiconductor: It has more free electron, even after forming bonds with the neighbouring atoms.

Free electron increase conductivity.



Ⓐ

* A junction between p-type and n-type semiconductor forms a diode.
* current flows only in one direction.

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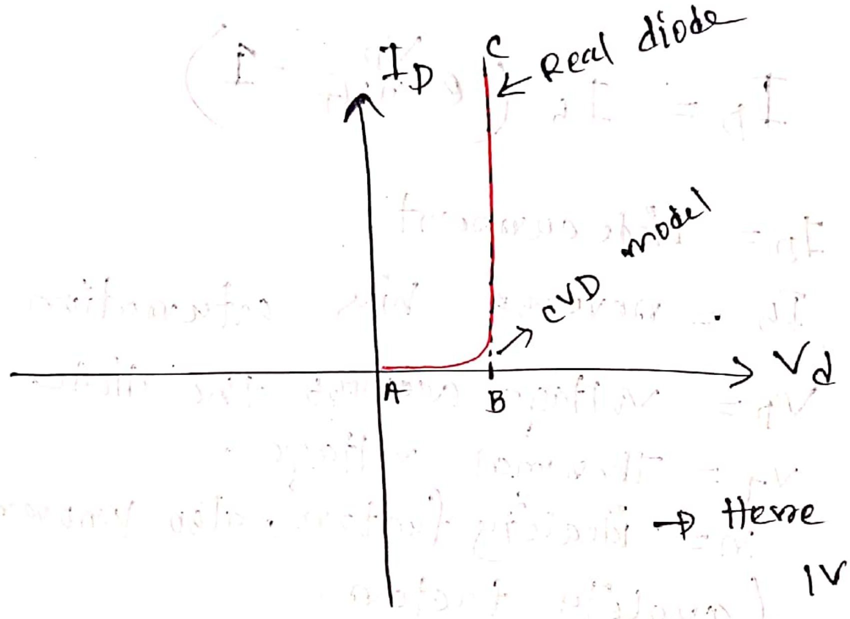
Real Diode IV



→ Here AB resembles IV of a open circuit

→ BC resembles IV of a voltage source.

condition

i. $V_d > V_{threshold}$.

→ The diode will be ON

→ It act as constant voltage source.

ii. $V_d < V_{threshold}$

– The diode will be OFF

– It will act as a open circuit.

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shockely Diode equation or diode equation :

$$I_D = I_S \left(e^{\frac{V_D}{n V_T}} - 1 \right)$$

I_D = Diode current

I_S = reverse bias saturation current

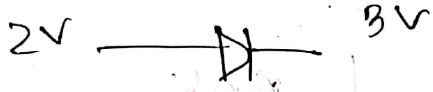
V_D = voltage across the diode.

V_T = Thermal voltage.

n = ideality factor, also known as the quality factor.

$\boxed{n = 1}$

Ex.



$V_A = ?$

$V_C = ?$

$V_D = ?$

$I_D = ?$

Ans:

$V_A = 2V$

$V_C = 3V$

$\therefore V_D = V_A - V_D$

$= 2 - 3 = -1V$

$I_D = 0$ [since here V_D is less than 0 so it behaves like open circuit.]

[so diode is OFF]

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Ex:

$I_D = ?$

$V_A = ?$

$V_D = ?$

$V_C = ?$

Ans:

$I_D = 2mA$

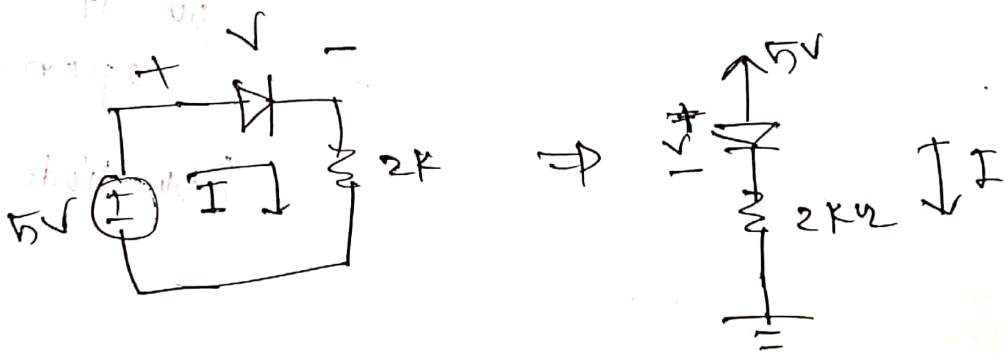
$V_A = 3V$

$V_D = 0$ [Diode ON]

$V_C = 3V$

can replace the diode with short circuit

Ex



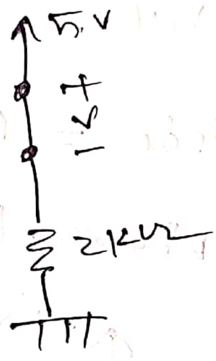
~~E~~ Firsts: If we have circuit like this having non-linear device, First we have to find in which mode it ~~ope~~ is operating. For example: for diode ON or OFF mode.] For this we have to find the direction of current.

∴ For this circuit.

current will flow : ↓ (From 5V to GND)

∴ Diode will be ON. (so behave like short circuit)

so circuit will be,

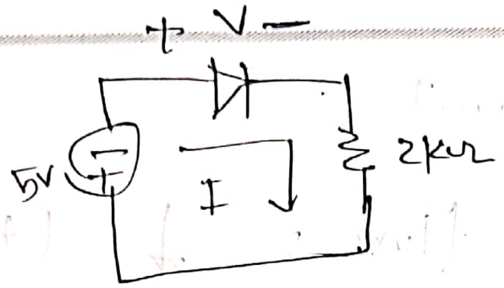


$\therefore V = 0$

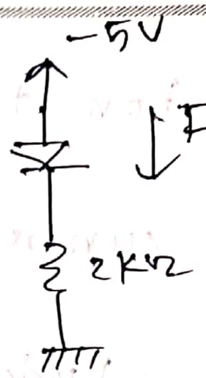
$$I = \frac{5-0}{2k} = 2.5\ mA$$

* current always want to flow from Higher potential to lower potential.

EX:



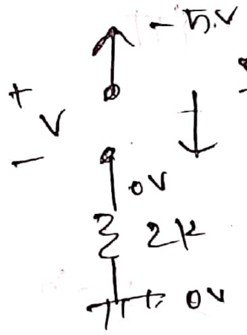
=▷



Now current want to flow from 0v to −5V.

So diode = OFF.

Behave like open circuit.



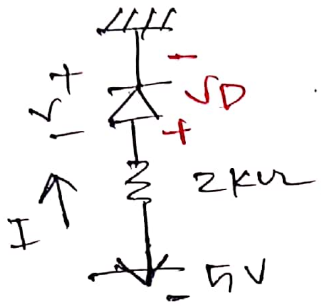
$\therefore I = 0$

$V = -5 - 0$

$= -5\,V$

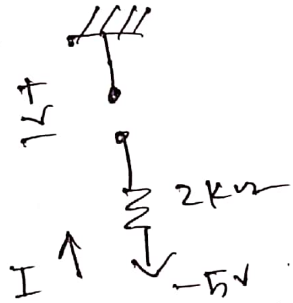
(10)

Ex



∴ current wants to flow from 0V to −5V so Diode will not allow it so Diode = OFF

∴



∴ $I = 0\ mA$

$v = 0 - (-5)$

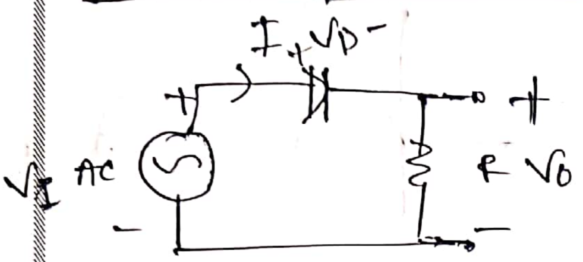
$= 5V$

But if I ask to know the voltage of Diode then it will be

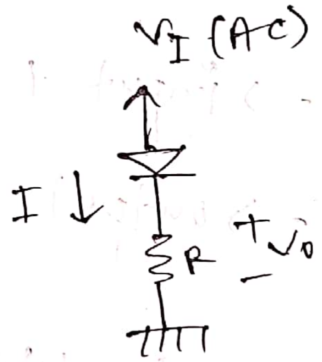
$$\boxed{\begin{aligned} V_D &= -5 - 0 \\ &= -5V \end{aligned}}$$

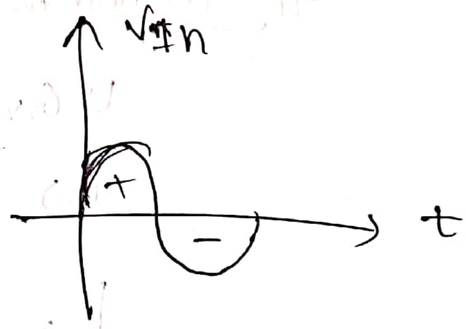
Rectifier: (Half wave)

$$V_D = V_I - V_o$$



when positive cycle, current will flow through the diode.

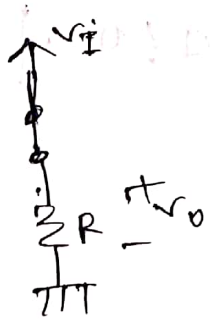




+ve half cycle

ON [conducting]

⇒ short circuit



$\Rightarrow V_o = V_I - 0$

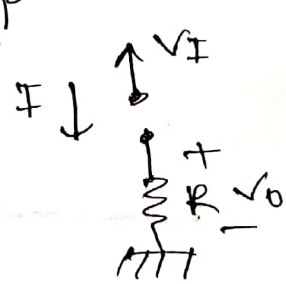
$\boxed{V_o = V_I}$

$\boxed{I = \frac{V_o}{R} = \frac{V_I}{R}}$

-ve half cycle

OFF (not conducting)

⇒ open circuit



$\boxed{V_o = 0}$

$\boxed{I = 0}$

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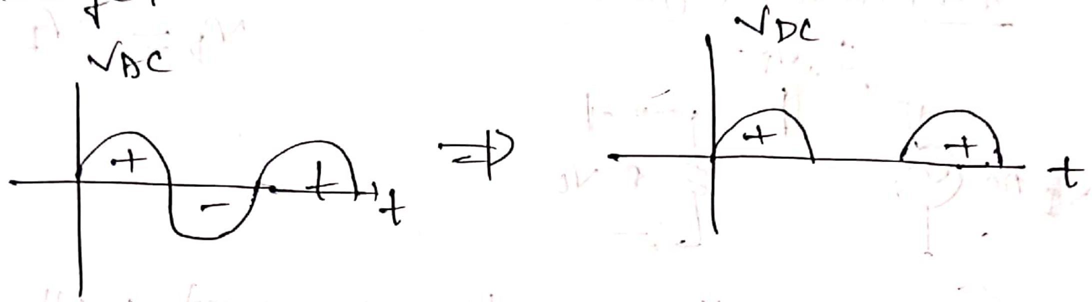
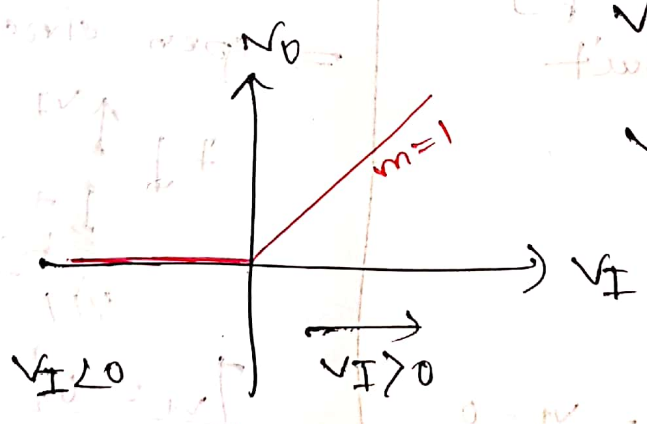
So we get



Transfer characteristic

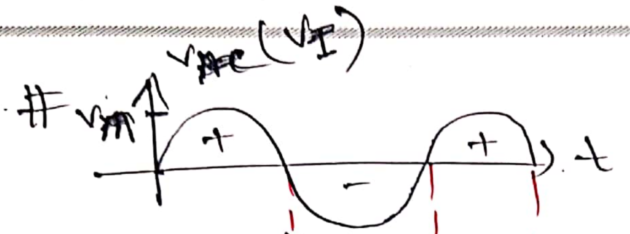
↳ Graph
↳ x axis → input (V or I)
↳ y axis → output (V or I)

Voltage transfer characteristic of a half wave rectifier.

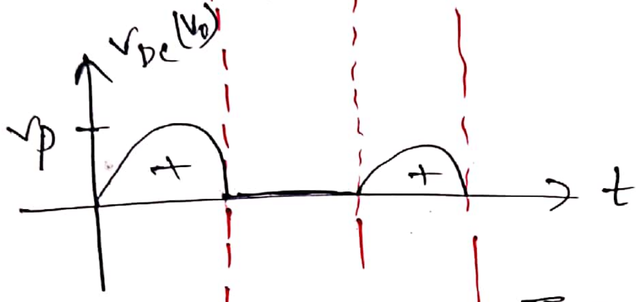


$V_I > 0 \Rightarrow \boxed{V_0 = V_I}$ ∴ y=x

$V_I \le 0$, $\boxed{V_0 = 0}$ ∴ y=0

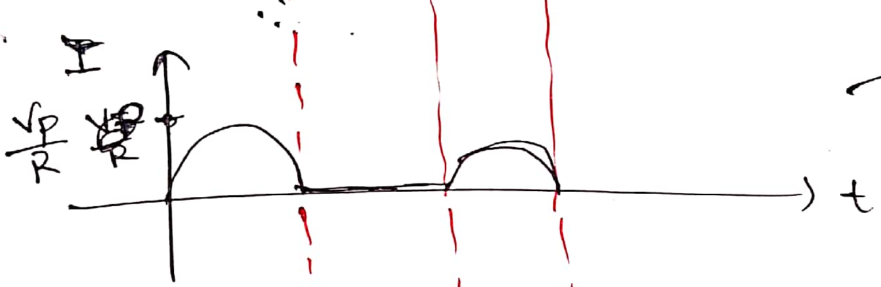


→ input voltage (V_I)

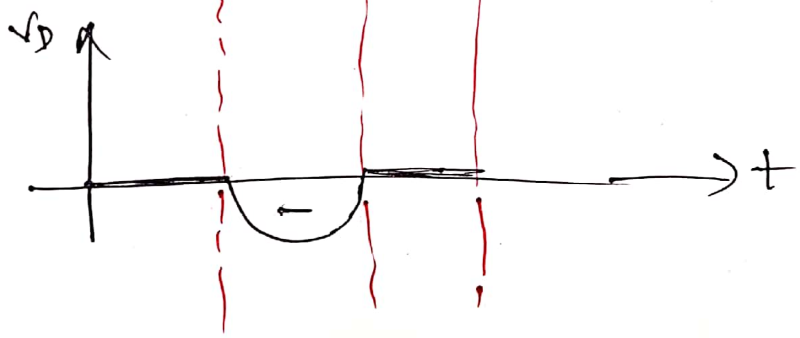


→ output voltage (V_O)

Both peak are equal $[V_M = V_P]$



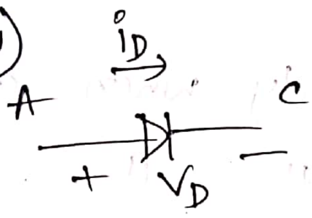
→ current I

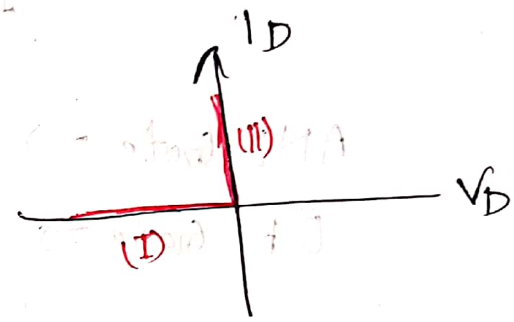


→ Diode voltage V_D

Diode logic gates

IDEAL Diode (Review)





$V_D = V_A - V_C$

I_D = from A to C

if $V_D \Rightarrow +ve$, → Forward Bias

$V_D \Rightarrow -ve$, → Reverse Bias.

Region I : $V_D < 0$ → OFF mode / Reverse Bias → OC → $i_D = 0$

Region II : ~~$V_D > 0$~~ ~~$I_D > 0$~~ $\underbrace{I_D > 0}_{\text{condition}}$ → ON mode / Forward Bias → SC → $\underbrace{V_D = 0}_{\text{state equation}}$

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Logic levels: 0 → False

1 → True

AND Gate → 1 only when all inputs = 1

OR Gate → 0 " " " " = 0

(A) But for this course we will use voltage value to define logic level (0 or 1)

0 → −5V or 0 → 0V or 0 → +12V
1 → +5V 1 → 5V 1 → −12V

we will use this type of convention.

OR operation

$y = x_1 \text{ or } x_2$

x_1	x_2	y
0	0	0
0	1	1
1	0	1
1	1	1

→ Logical Truth table of OR operation.

If converting it into voltage value

V_{x_1}	V_{x_2}	V_y
0V	0V	0V
5V	5V	5V
5V	0V	5V
5V	5V	5V

⟹ voltage truth table

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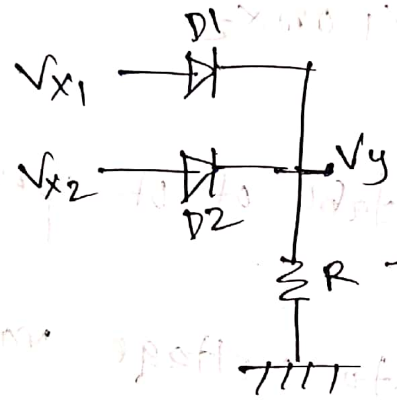
circuit of logical or using Diode :



→ pull down resistor.
(It basically pull down the voltage of V_y Node when both diod are OFF)

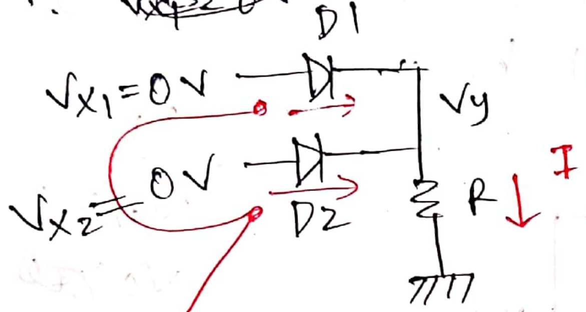
Here V_{x1}, V_{x2} and V_y all are node voltages, terminal voltages (voltage respect to ground)

proof of voltage truth table

cases:

Case 1 : $\boxed{V_{x_1}, V_{x_2} = 0}$

∵ ~~$V_{x_2} = 0V$~~



so if diod are ON current will flow to this direction.

And we also know current flow from higher potential to Lower potential.

∵ For this flow of I Here's need $V_y \geq 0V$

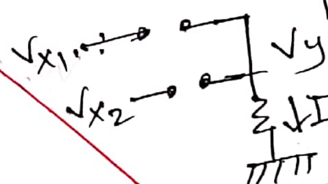
so we can say the cathod of both of the diod connected to 0V or higher than zero volt. (As connected to V_y node)

And Here Both diod Anode V_{x_1} and $V_{x_2} = 0V$

But for conducting current or to ON diode we need ~~V_A~~ $V_d > 0$ or $V_A > V_C$. For this case we need $V_{x_1} > V_y$ and $V_{x_2} > V_y$. So Here Both D1 and D2 is OFF (Reverse bias)

Now OFF means D1 and D2 creates open circuit. so No current flow.

from ohms law $V_y - 0 = IR$ $\Rightarrow V_y = 0$



∴ $\boxed{V_y = 0V}$

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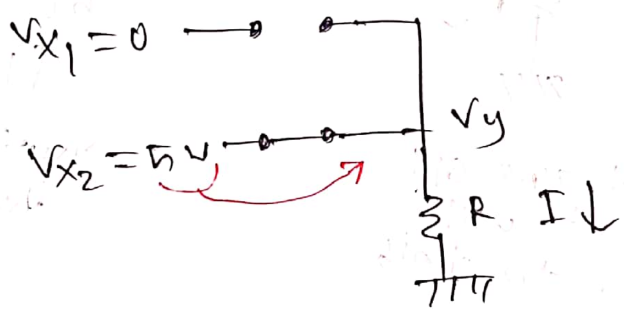
Case II : $\boxed{V_{x_1} = 0V, V_{x_2} = 5V}$

so For this (see previous case) circuit will be.



$\therefore V_y = V_{x2}$

$\therefore \boxed{V_y = 5V}$

D1

$V_A = 0$

$V_C = V_y \geq 0$

D1 = OFF (O.C)

D2

$V_A = 5V$

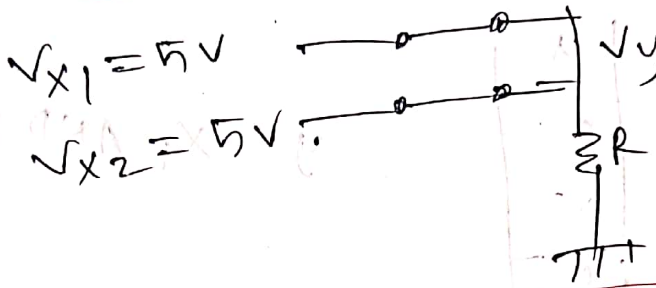
$V_y \geq 0V$

D2 = ON. S.C

Case III : $\boxed{V_{x_1} = 5V, V_{x_2} = 5V}$

similar to case II

case IV: $\boxed{V_{x_1} = 5V,\ V_{x_2} = 5V}$



$\boxed{\therefore V_y = V_{x_1} = V_{x_2} = 5V}$

D1

$V_A = 5V$

$V_C = V_y \geq 0$

ON

(S.C)

D2

$V_A = 5V$

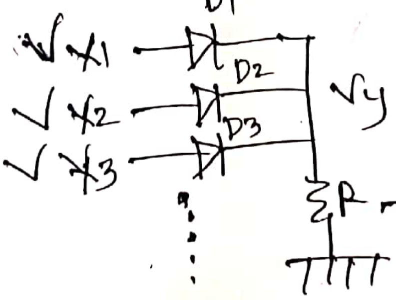
$V_C = V_y \geq 0$

ON

(S.C)

So all case for voltage truth table fullfil.

★★ Now if we want more input just add them like this:



★★

R → pull down resistor.

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AND operation

x_1	x_2	y
0	0	0
0	1	0
1	0	0
1	1	1

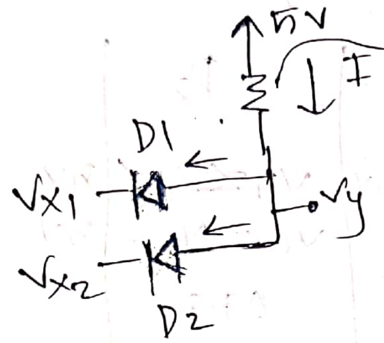
$y = x_1 \text{ AND } x_2$

⇕

V_{x1}	V_{x2}	V_y
0V	0V	0V
0V	5V	0V
5V	0V	0V
5V	5V	5V

Voltage truth table.

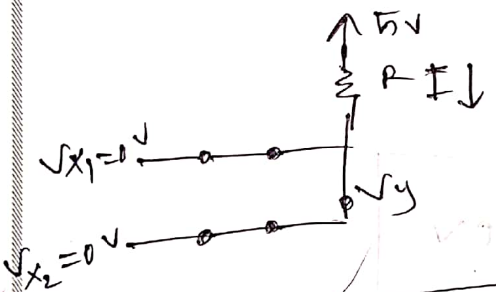
diod circuit of ~~A~~ for AND operation:



→ pull up resistor.
pulling up the voltage of V_y Node when both diod are off and Node V_y is floating.

case 1: $\boxed{V_{x_1} = 0V,\ V_{x_2} = 0V}$

$V_y \le 5$ [for flowing current]



D1	D2
→ $V_A \le 5V$	→ $V_A \le 5V$
→ $V_C = 0V$	→ $V_C = 0V$
ON	ON
S.C.	S.C.

∴ $\boxed{V_y = V_{x_1} = V_{x_2} = 0V}$

Sub.:

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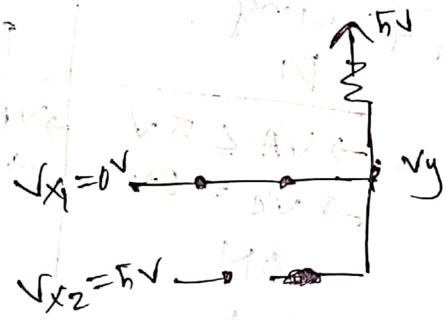
Case 2: $\boxed{V_{x_1} = 0V, \; V_{x_2} = 5V}$ $V_y \nleq 5V$, to flow current

P1	P2
$V_A \Rightarrow V_y < 5V$	$V_A \nleq V_y \leq 5V$
$V_C = 0V$	$V_C = V_{x_2} = 5V$
ON	OFF
S.C	O.C



$$\boxed{\therefore V_y = V_{x_1} = 0V}$$

Case 3: $\boxed{V_{x_1} = 5V, \; V_{x_2} = 0V}$

same as case 2

$$\boxed{V_y = V_{x_2} = 0V}$$

Case 4: $\boxed{V_{x1} = 5V, \quad V_{x2} = 5V}$

D1

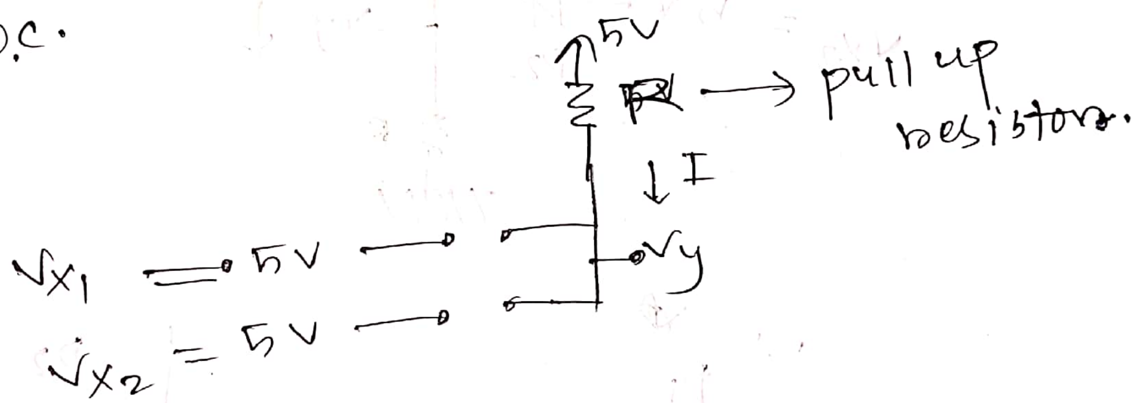
$V_A \Rightarrow V_y \leq 5V$
$V_C \Rightarrow V_{x1} = 5V$
OFF

O.C.

D2

$V_A \Rightarrow V_y \leq 5V$
$V_C \Rightarrow V_{x2} = 5V$
OFF

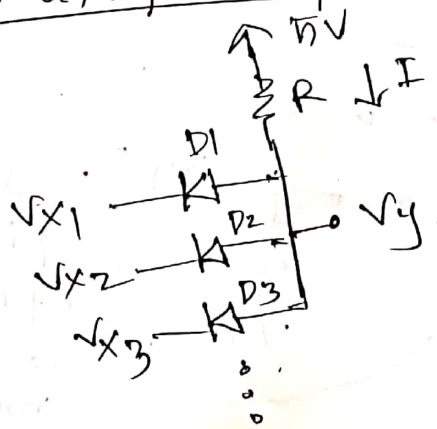
O.C.



$\therefore$

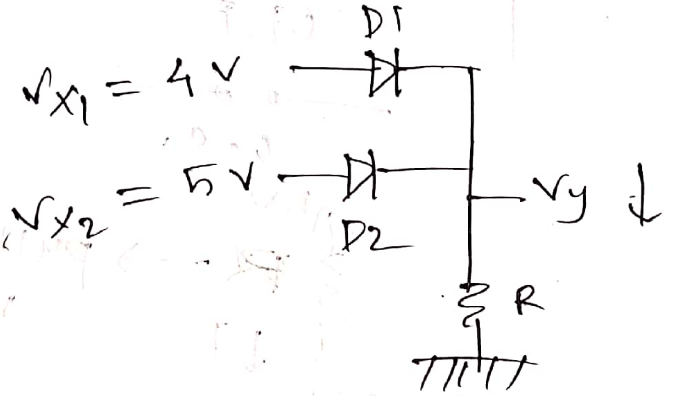
$\boxed{V_y = 5V}$

** For multiple input



what if we input different type of voltage? [~~OR~~ For OR operation]

lets we have this OR gate configuration:

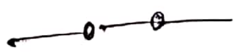


∴ D1

$V_A = V_{x_1} = 4V$

$V_C = V_y \geq 0$

∴ ON



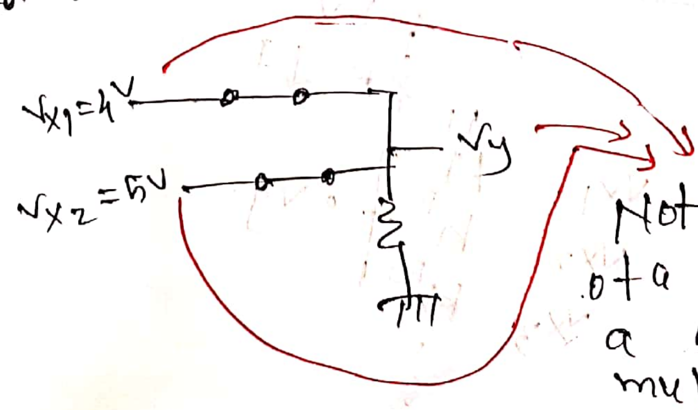
D2

$V_A = V_{x_2} = 5V$

$V_C = V_y \geq 0$

ON

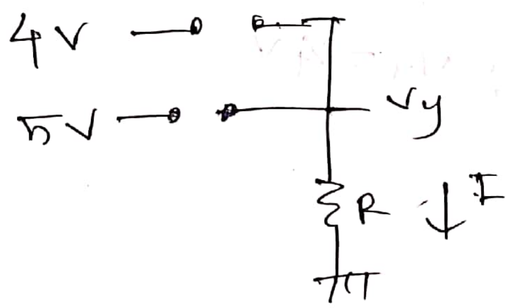
∴



Not possible. of a Node at a same time multiple voltage.

So what will be the right case?

Assume D_1 and D_2 are off.

∴ 

So here I will be zero

$$\therefore V_y - 0 = IR$$
$$\Rightarrow V_y = 0 \times R$$
$$= 0\,V$$

But here ~~Both~~ D_1's Anode's has 4V and D_2 anodes has 5V

So this case not possible. (Because According to Anode and cathod voltage Both should be ON.

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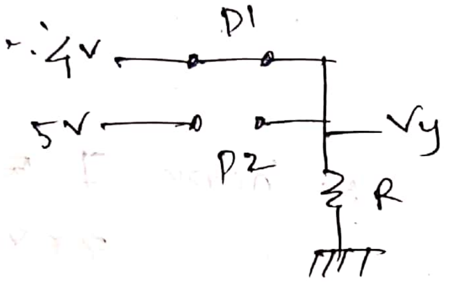
Assuming $D_1 \Rightarrow ON$
$D_2 \Rightarrow OFF$



$\therefore V_y = 4V$

Now if $V_y = 4V$

~~Va~~ for D_2,

$V_A = 5V$
$V_C = 4V$

$\therefore D_2$ should be ON Also

But here we assume OFF.

so this is not possible.

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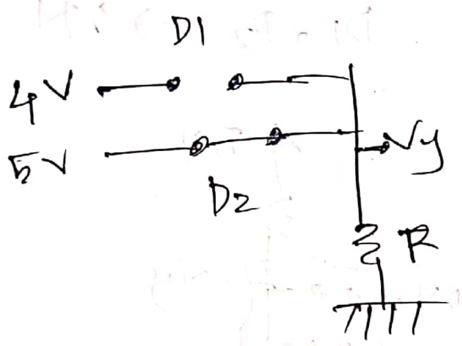
Now Assuming

$D_1 \Rightarrow$ OFF
$D_2 \Rightarrow$ ON



$\therefore \boxed{V_y = 5V}$

Now if $V_y = 5V$
then for D1

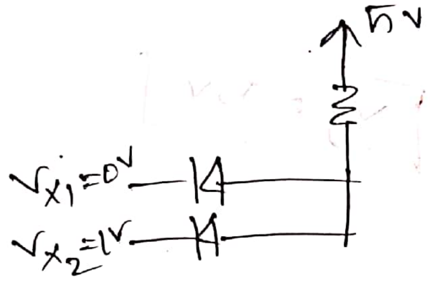
$V_A = 4V$
$V_C = V_y = 5V$ $\therefore V_A < V_C$

$\therefore$ OFF

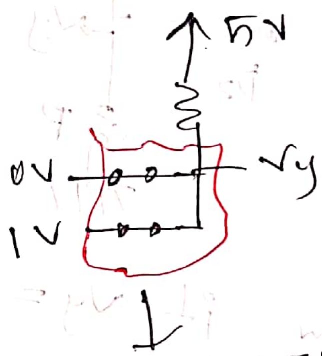
so this assumtion is correct.

From this we ~~say~~ can say if we have multiple voltage source with different voltage source then the output voltage ~~wo~~ will be ~~the~~ equal to the voltage of higher voltages source voltage.
[For OR operation]

Now For AND operation [Different voltage input]

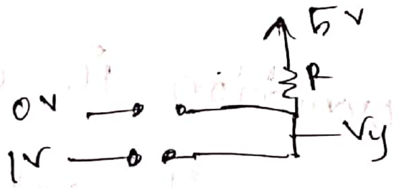


$D_1, D_2 \rightarrow ON$



Not possible because one same Node cant have different value.

Now Assume D_1 and $D_2 \Rightarrow OFF$



$\downarrow I = 0\ mA$ (so current will be zero

$\therefore 5 - V_y = IR$

$\therefore V_y = 5V$

Now D_1, $V_c = 0$ and $V_A = V_y = 5V$

D_2 $V_c = 1V$, $V_A = V_y = 5V$

$\therefore$ Both should be ON

so this case also Not possible

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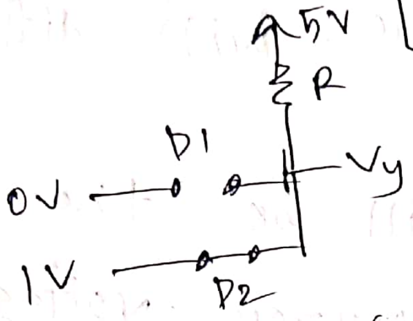
Now assume $D_1 = OFF$, $D_2 = ON$



$\therefore V_y = 1V$

Now for D1

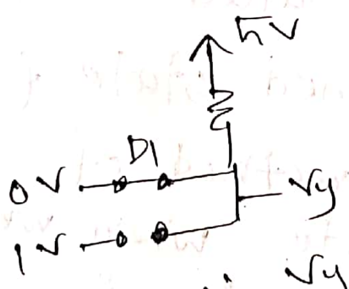
$V_A = 1V = V_y$

$V_C = 0V$

$\therefore$ ON

But we assume here OFF so Not possible (wrong assumption)

Now Assume $D_1 = ON$, $D_2 = OFF$



$\therefore V_y = 0V$

$\therefore$ D2

$V_A = 0V$

$V_C = 1V$

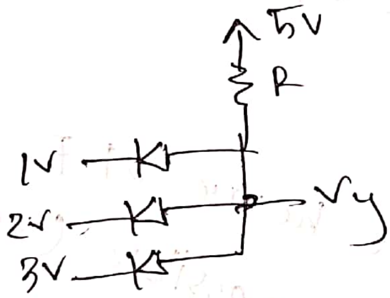
$\therefore V_A < V_C$

$\therefore$ OFF

so this assumption correct.

A+

so From this we can say ~~we~~ if we have more diods with different voltage input.
then output will be the lowest voltage sources voltage for AND operation.



$\boxed{\therefore V_y = 1V}$

~~AM~~

This is called method of (Assumed state (we have to use method of Assumed state when we have multiple diode in circuit)