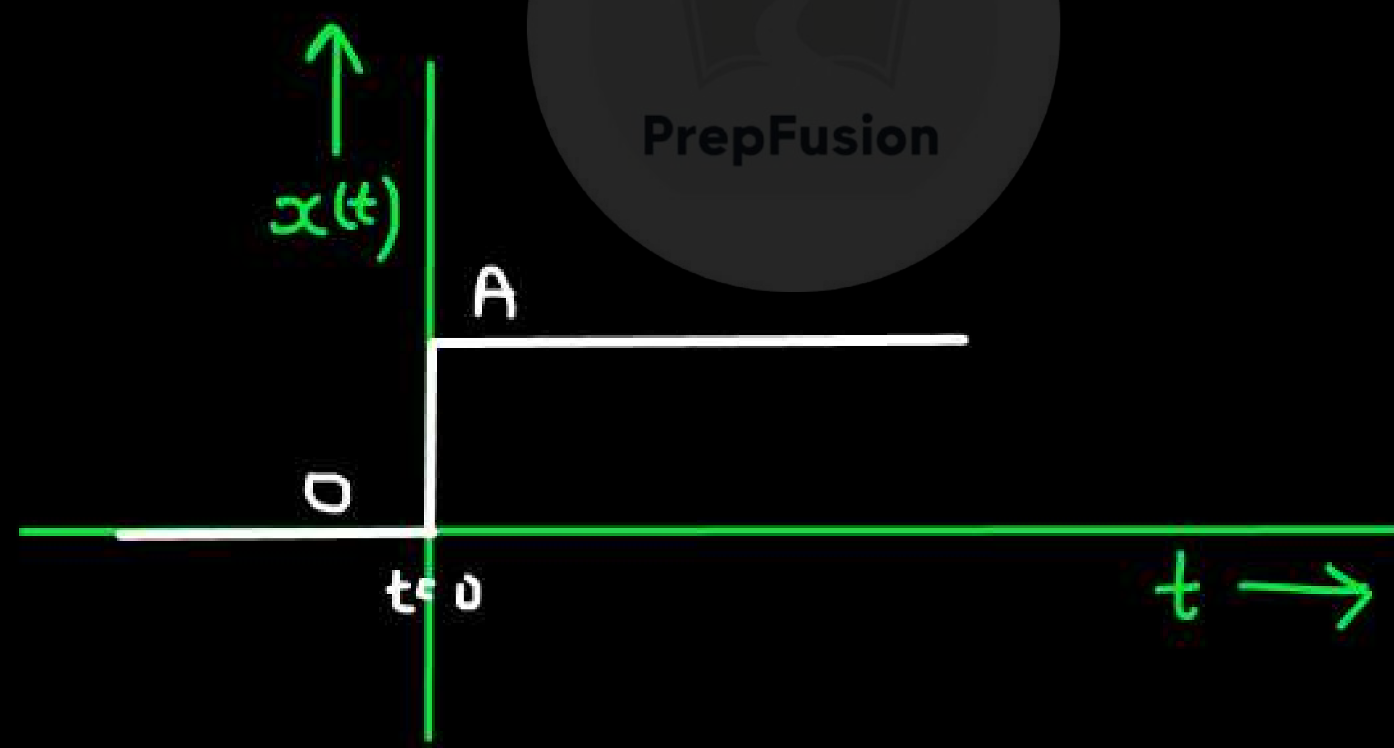
Basics of Signals :-

(a) Step Signal :-

$$x(t) = A\,u(t) = \begin{cases} A, & t > 0 \\ 0, & t < 0 \end{cases}$$

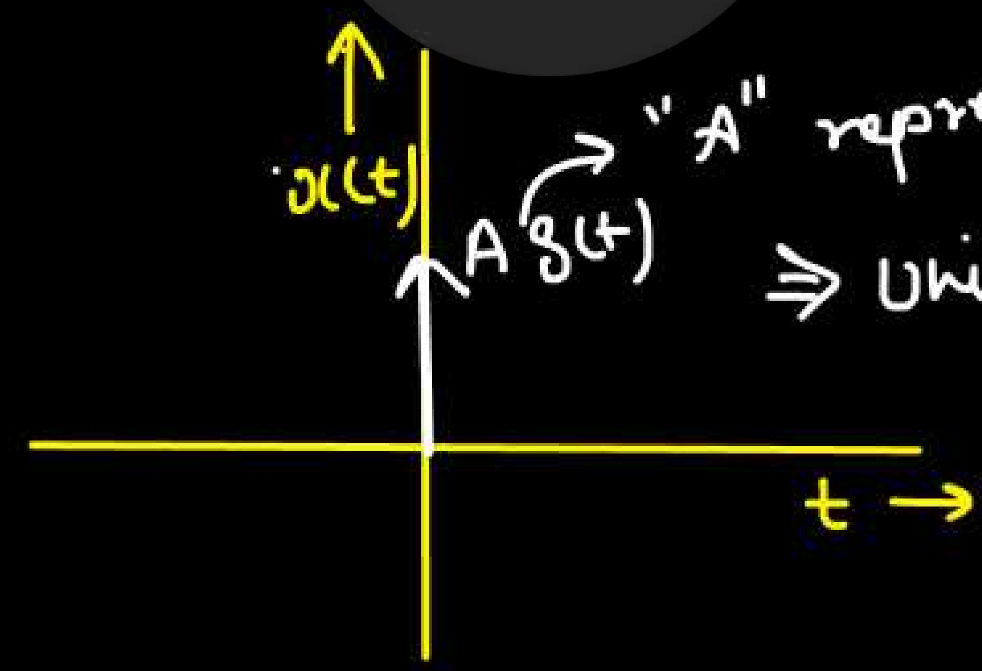


② Impulse Signal:-

$$x(t) = A\delta(t) = \begin{cases} \infty, & t=0 \\ 0, & t\neq 0 \end{cases}$$

↳ Area = A

↳ Magnitude = ∞



→ "A" represent the area.

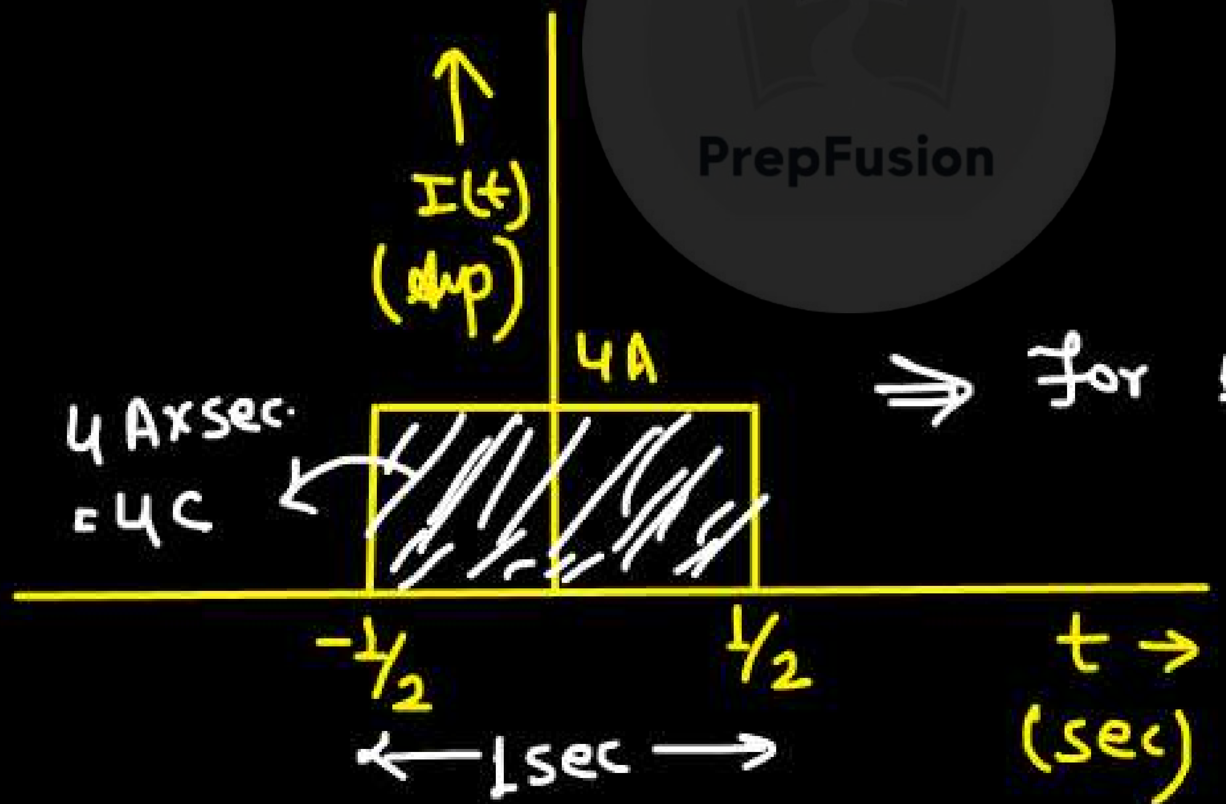
⇒ Unit of "A" = [Unit of x(t)] × [Unit of t]

Actual meaning of impulse signal :-

Suppose in a circuit, you have to deliver 4C charge.

$$Q = \int_{-\infty}^{\infty} I(t)\cdot dt \quad ; \quad I(t) = \frac{dQ(t)}{dt}$$

Way-1

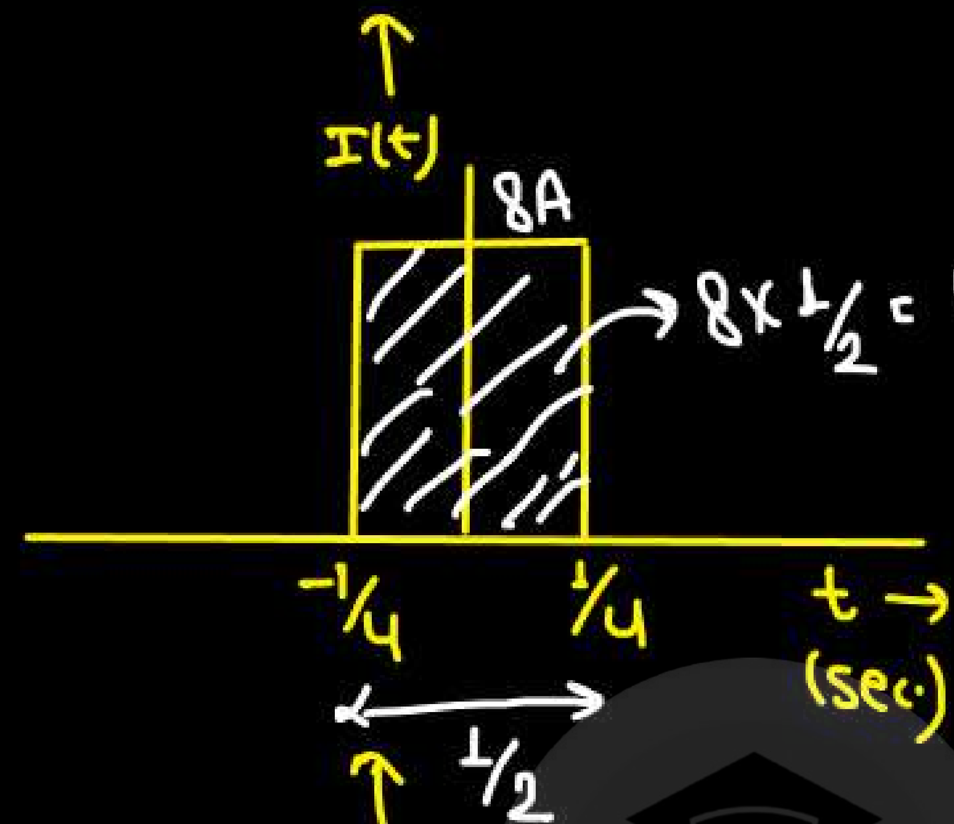


⇒ for 1 sec., I'm giving 4A current

$Q = 4 \times 1 = 4C$

⇒ you are giving 4C charge in 1 sec.

Way.2



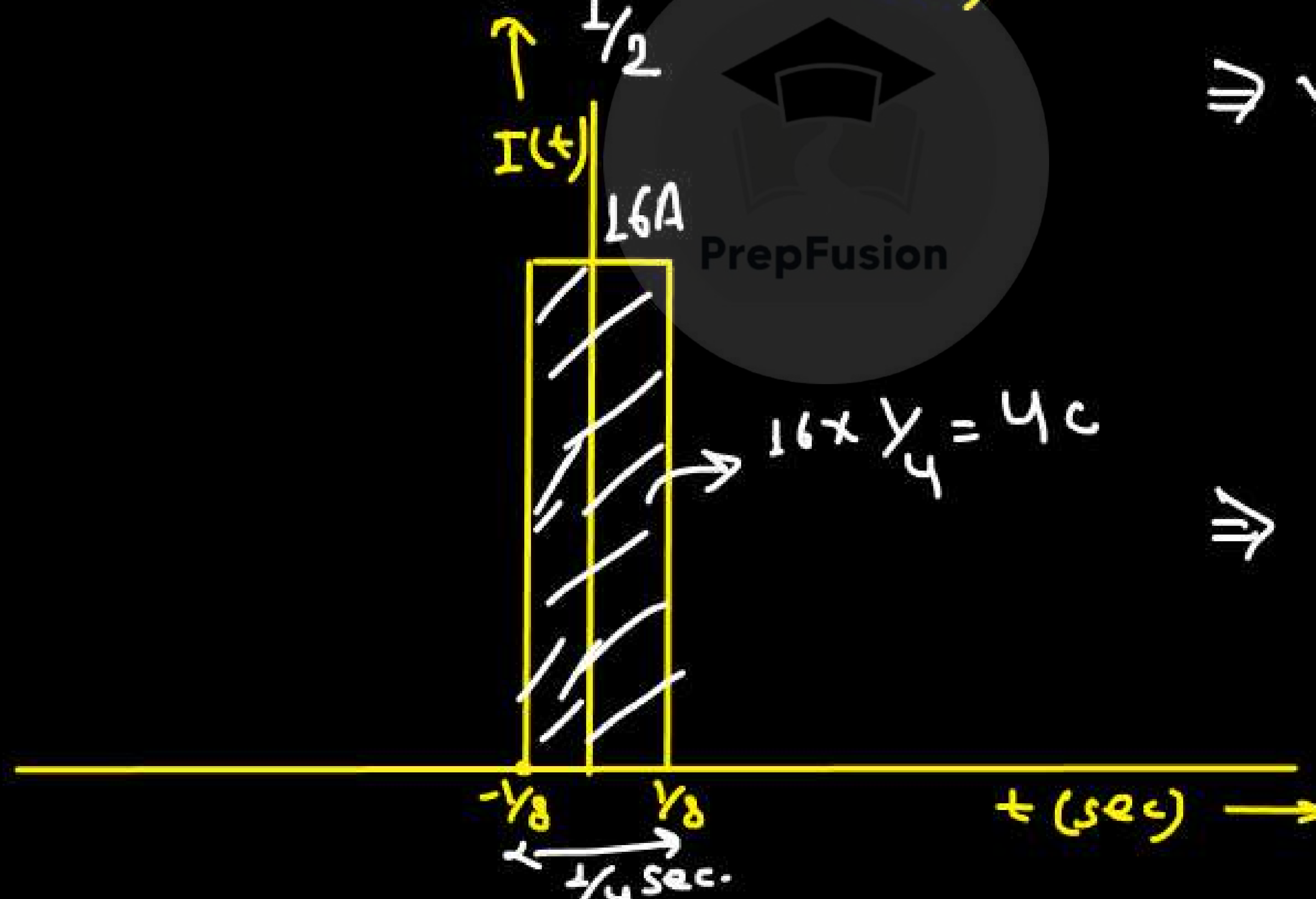
$8 \times \frac{1}{2} = 4C$ $\Rightarrow$ decreased the time span

$\Downarrow$

Increased the value of I(t)

$\Rightarrow$ You are giving 4C charge in 1/2 sec.

Way-3



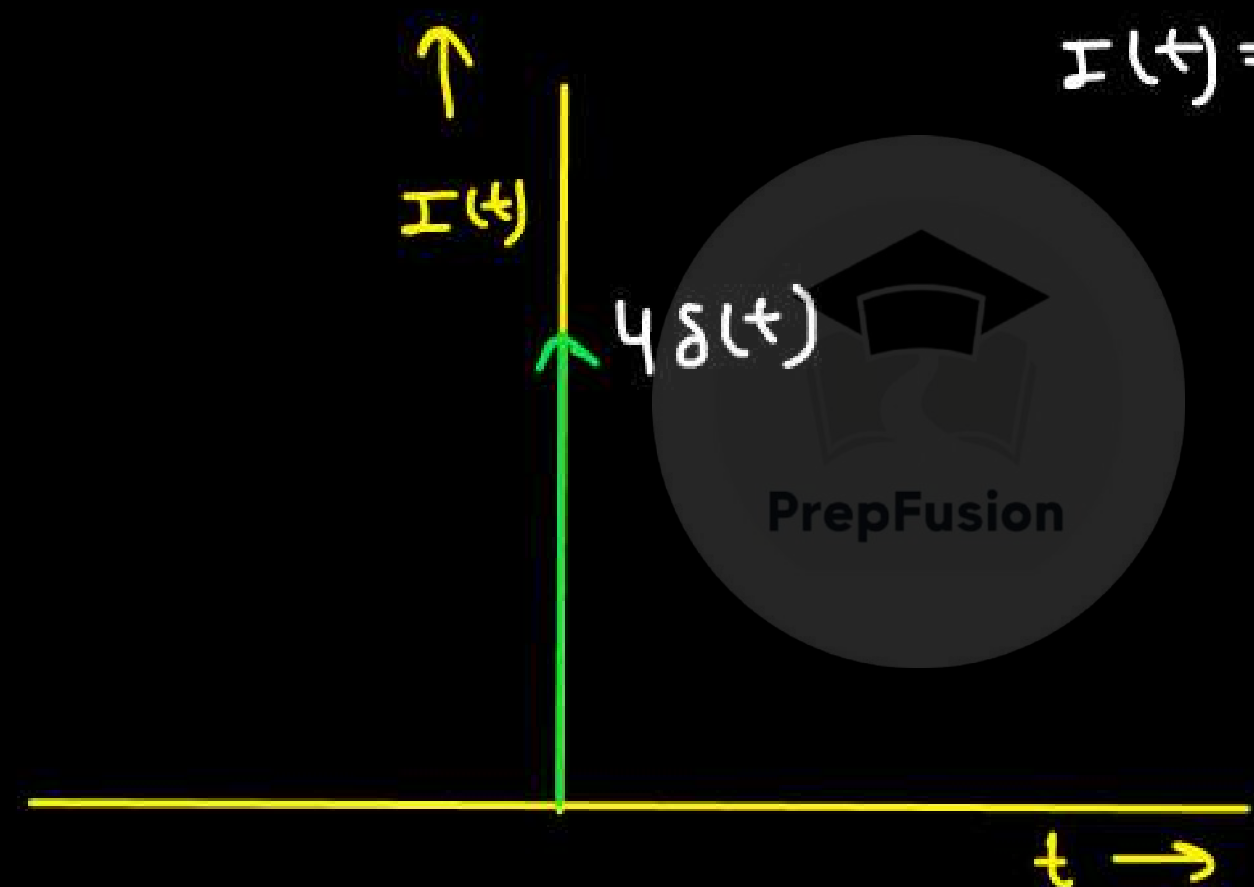
$16 \times \frac{1}{4} = 4C$

$\Rightarrow$ you are giving 4C charge in 1/4 sec.

now, what if $t \to 0$

$\Rightarrow I(t) \to \infty$

But Area $= Q(t) = 4C$



$I(t) = \underbrace{4}\,\delta(t)$

$\Downarrow$

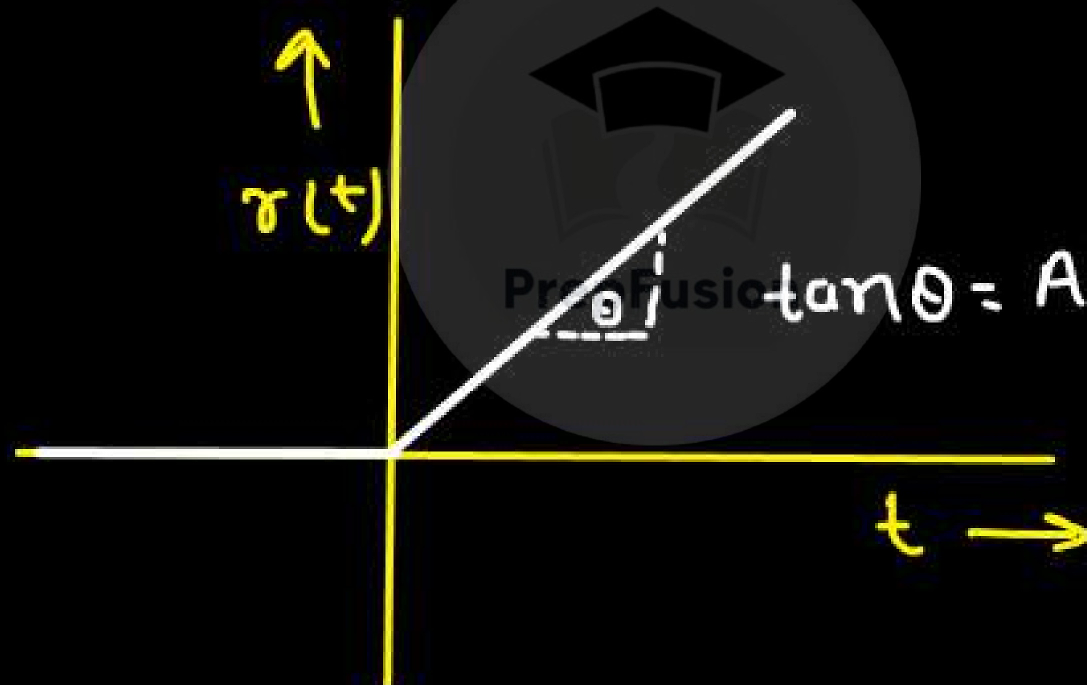
Amp × Sec. = columb

$\Downarrow$

You are giving 4C charge in no time

③ Ramp Signal :-

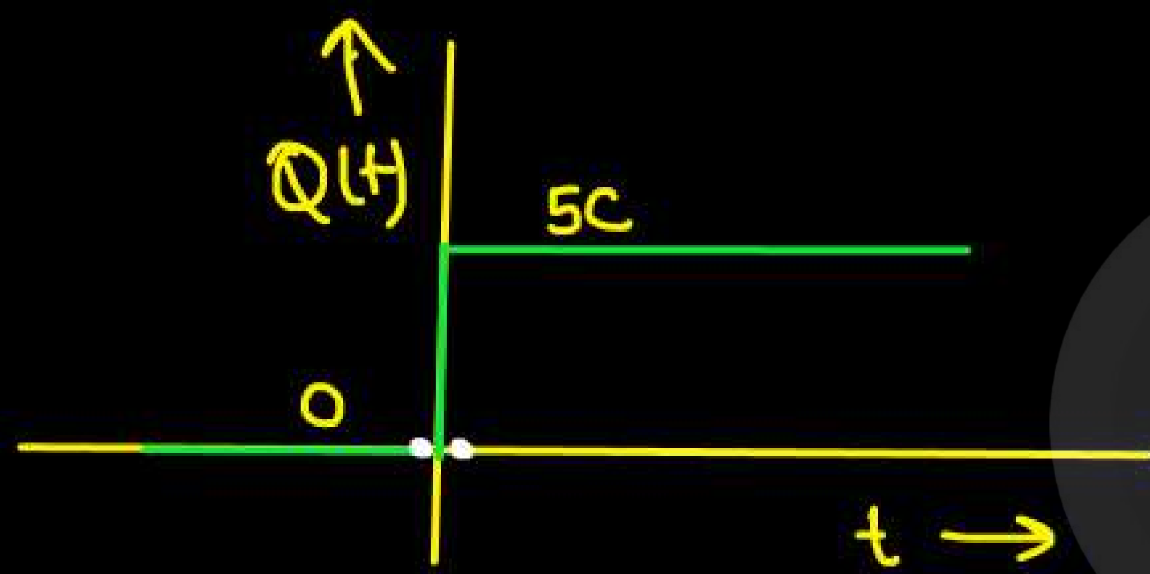
$$x(t) = A\,r(t) = At \cdot u(t) = \begin{cases} At & , \; t \geq 0 \\ 0 & , \; t < 0 \end{cases}$$



$\tan\theta = A = \text{slope}$

Differentiation of a step signal:-

$$\frac{d}{dt}(\text{step}) = \text{Impulse}$$

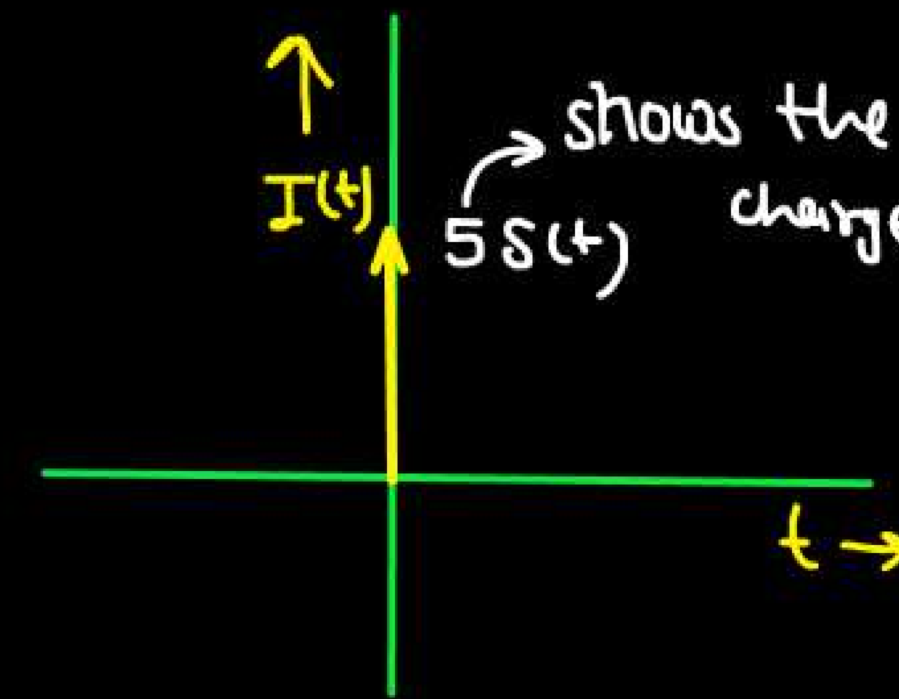


differentiation →

$$I(t) = \frac{dQ(t)}{dt}$$

$@\ t = 0^- \rightarrow 0^+$

$$= \frac{5}{0} = \infty$$



Differentiation of ramp signal:-

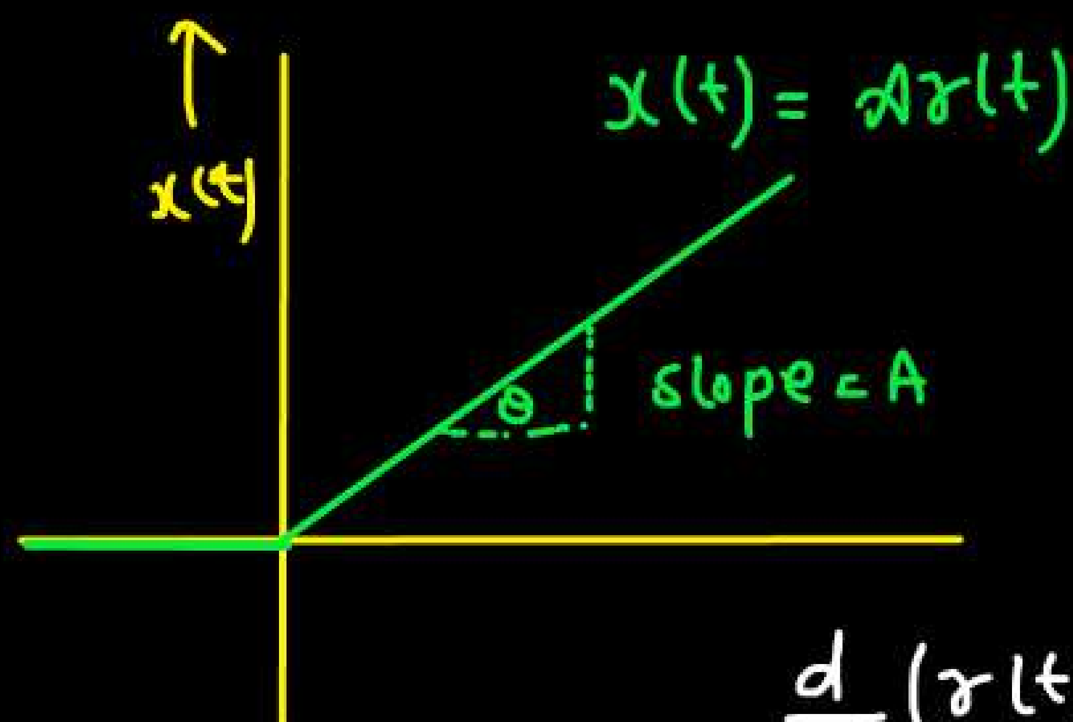
$$\frac{d}{dt}(\text{Ramp}) = \text{Step}$$

derivation :

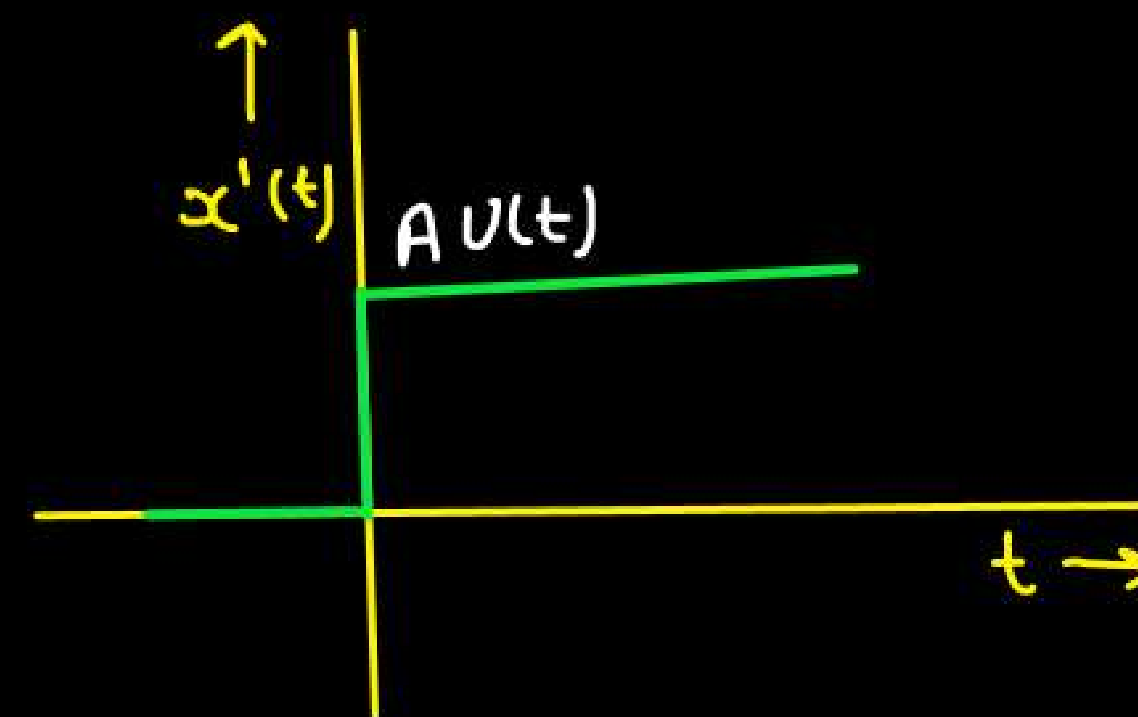
$$x(t) = A\,r(t) = A\,t \cdot u(t)$$

$$\frac{dx(t)}{dt} = A\left[t \cdot \delta(t) + u(t)\right]$$

$$\frac{dx(t)}{dt} = A\,u(t)$$



Differentiation



$$\frac{d}{dt}\left(r(t)\right) = u(t)$$

Summary :-

Impulse $\xrightarrow{\quad\text{Integration}\quad}$ Step $\rightarrow$ Ramp

Ramp $\rightarrow$ Step $\xrightarrow{\quad\text{Differentiation}\quad}$ Impulse

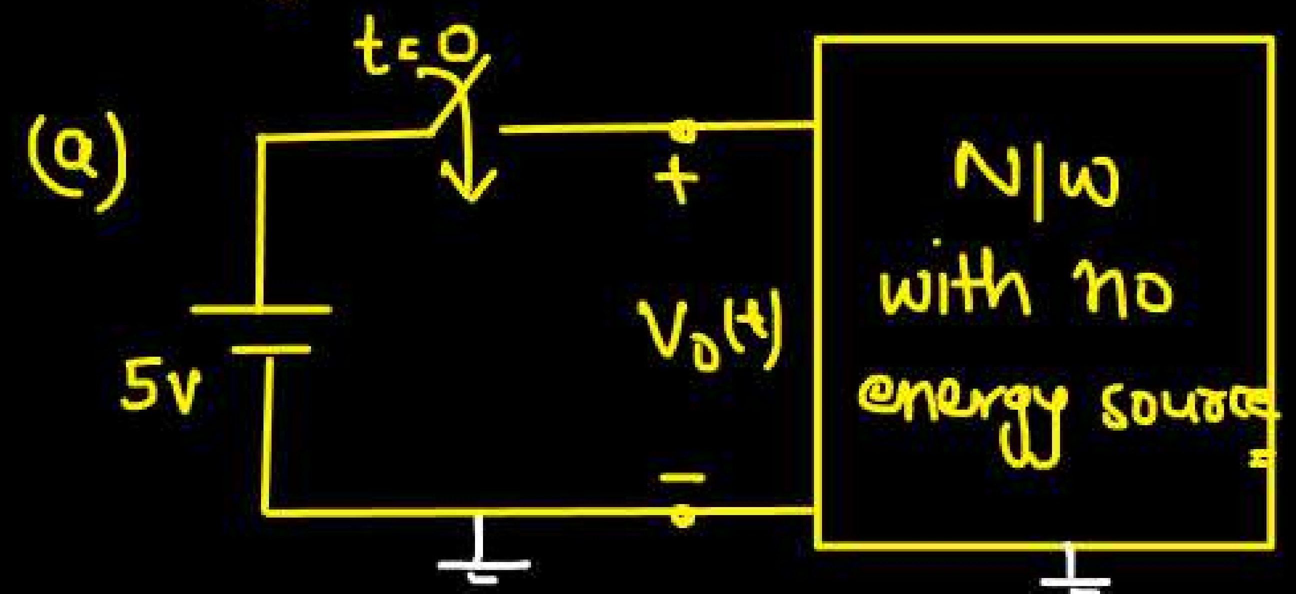
$$\int_{-\infty}^{t} \delta(t)\cdot dt = u(t)$$

$$\int_{-\infty}^{t} u(t)\cdot dt = r(t)$$

Generating a step signal :-

Q. Find $V_0(t)$.

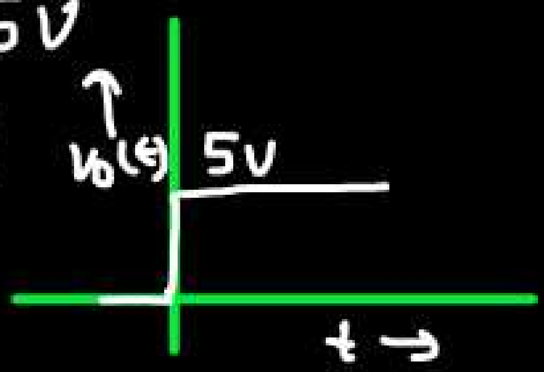
(a)



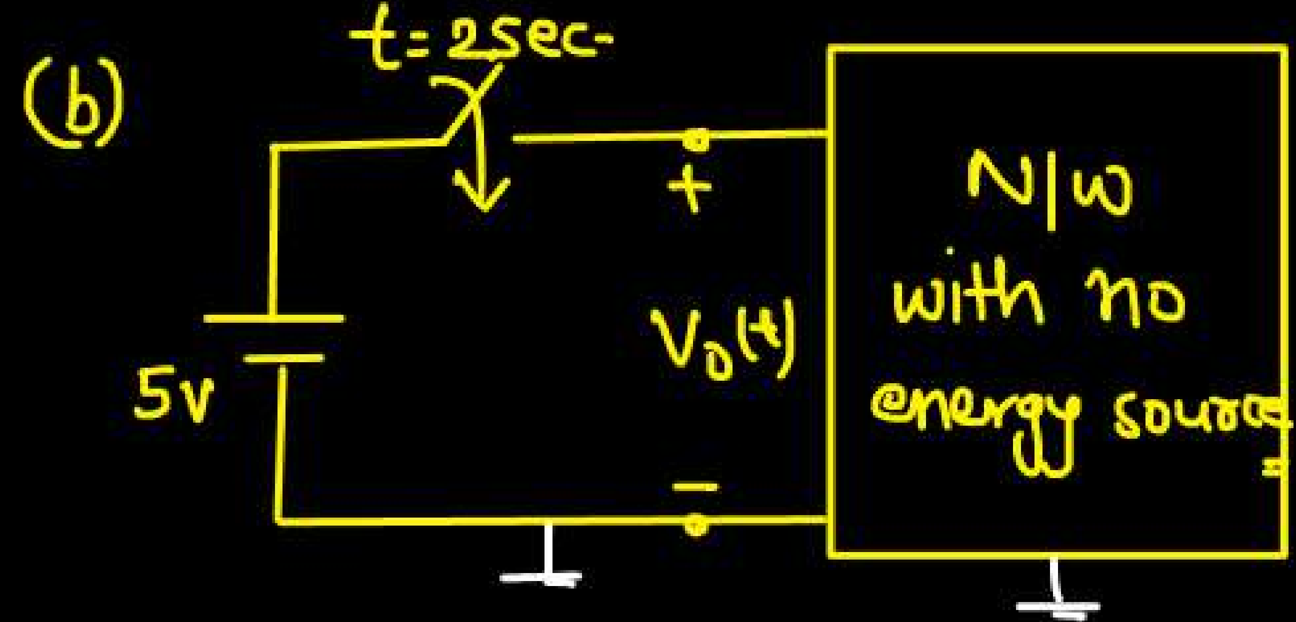
For $t<0 \Rightarrow V_0(t) = 0\text{ V}$

For $t>0 \Rightarrow V_0(t) = 5\text{V}$

$\Rightarrow V_0(t) = 5u(t)$

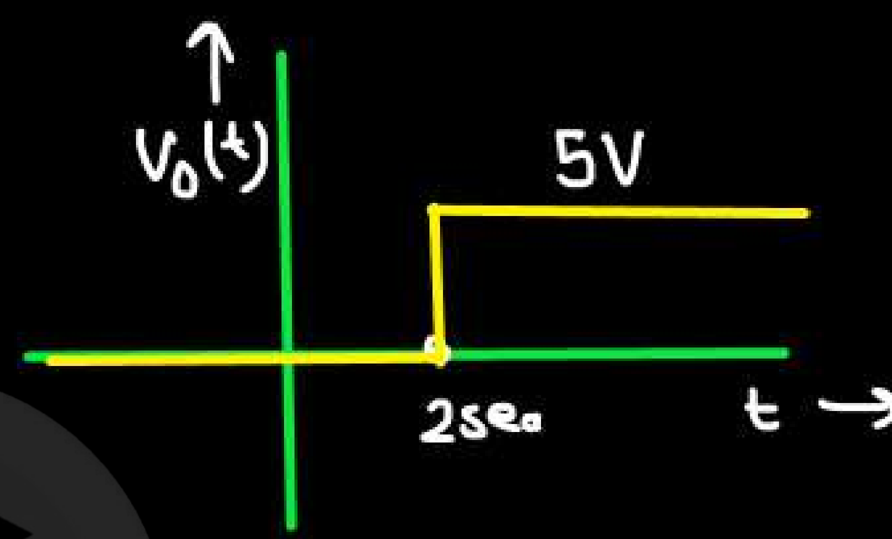


(b)



For $t < 2\,sec. \rightarrow V_0(t) = 0$

$t > 2\,sec. \rightarrow V_0(t) = 5V$

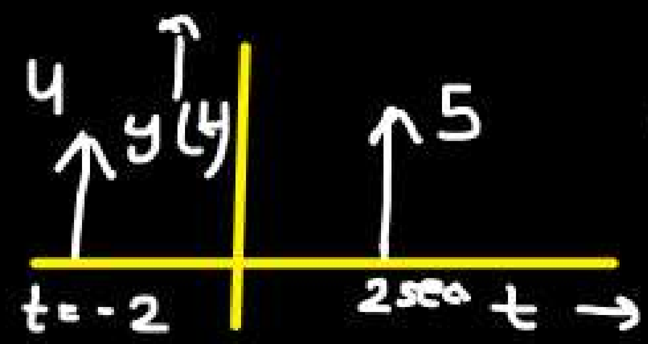


$V_0(t) = 5u(t-2)$

Right shift $\Rightarrow u(t-t_0)$

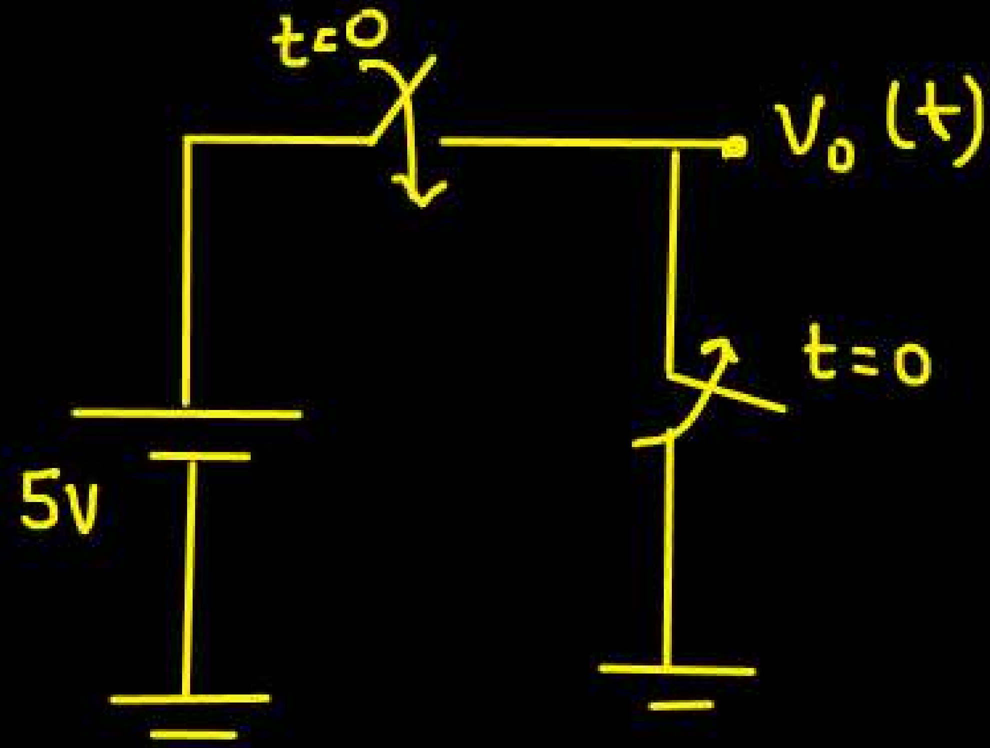
Left shift $\Rightarrow u(t+t_0)$

Q. Write y(t) in terms of impulse signal

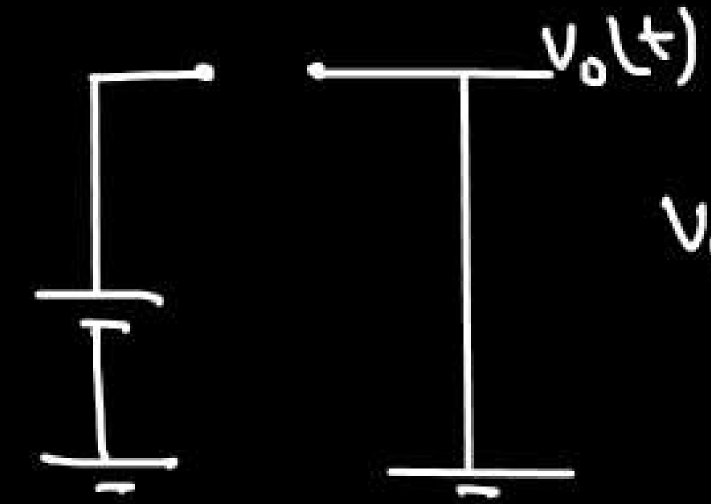


$y(t) = 5\delta(t-2) + 4\delta(t+2)$

(C)

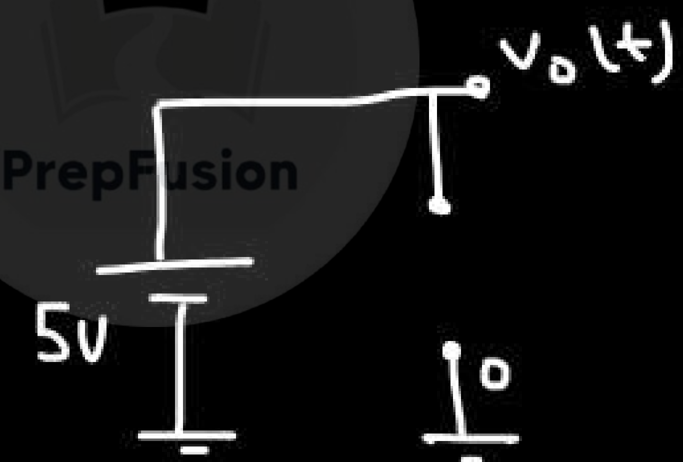


For $t<0$



$V_o(t) = 0V$

For $t>0$

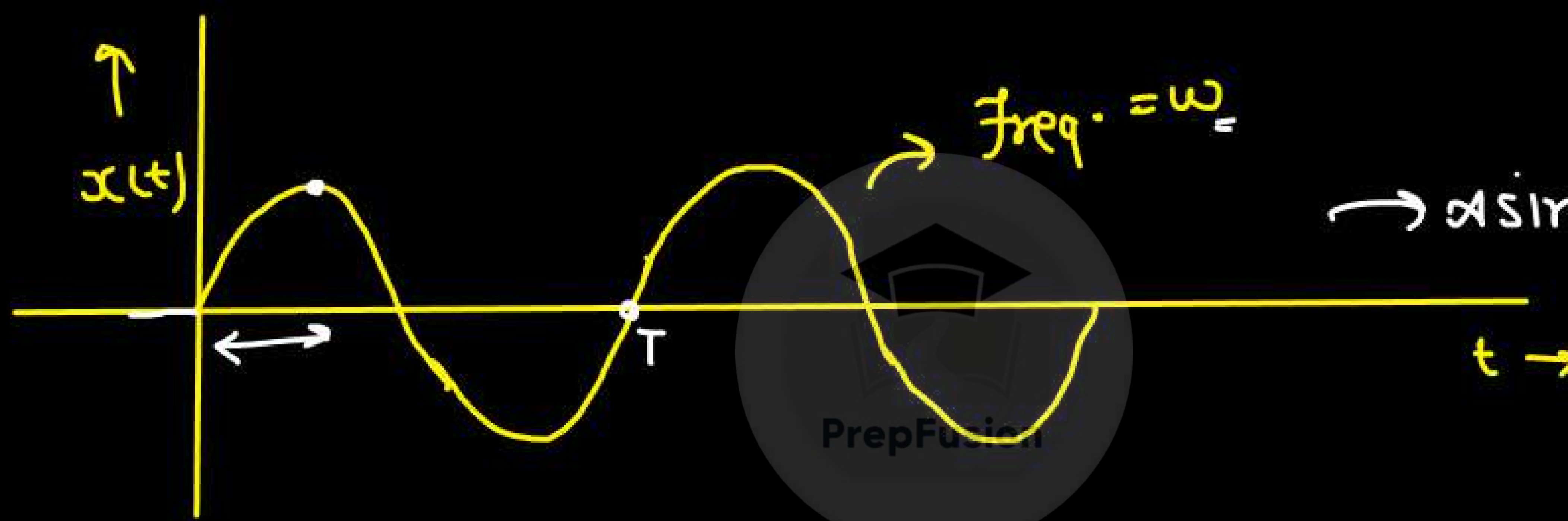


$V_o(t) = 5V$

$\Rightarrow V_o(t) = 5U(t)$

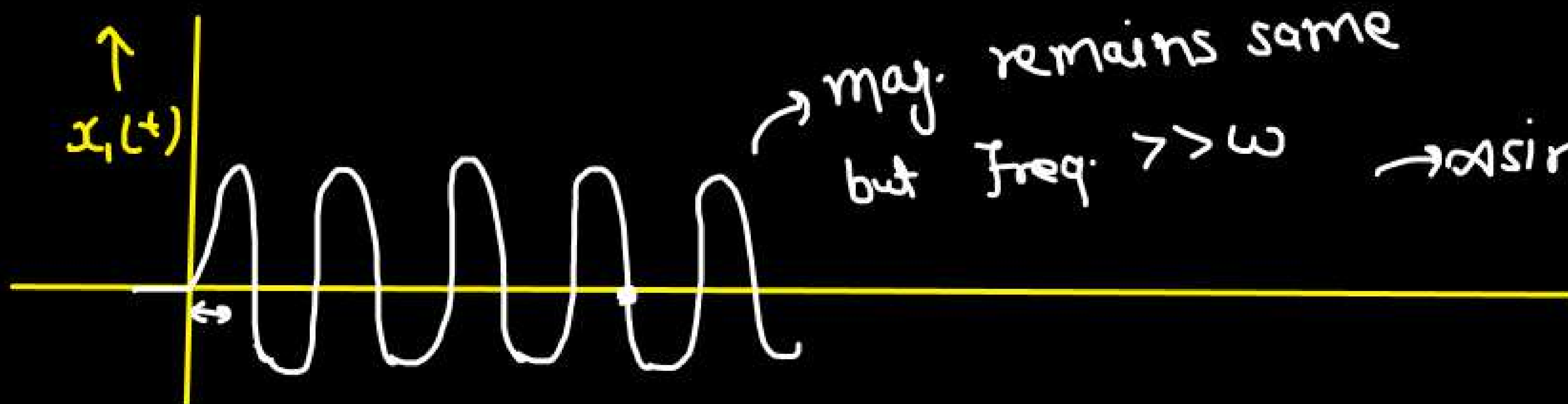
Frequency content in a step signal :-

↳ Let's take an example of a sinusoid signal.



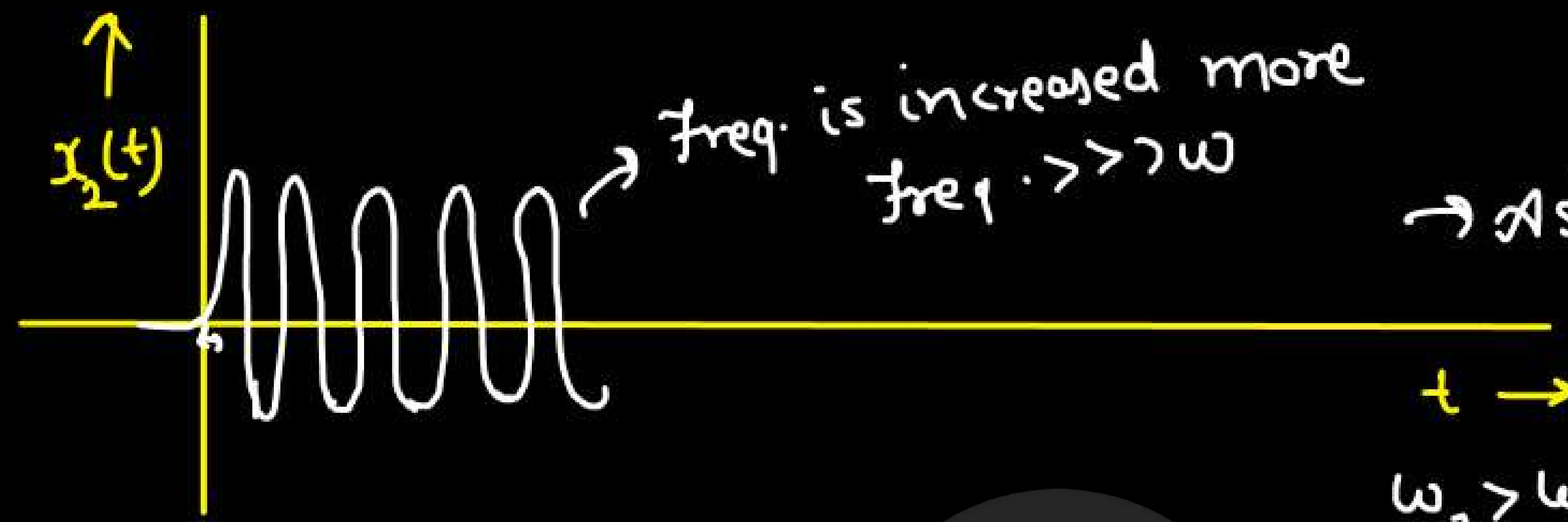
Freq. = ω_0

→ $A \sin \omega t$



mag. remains same but freq. >> ω

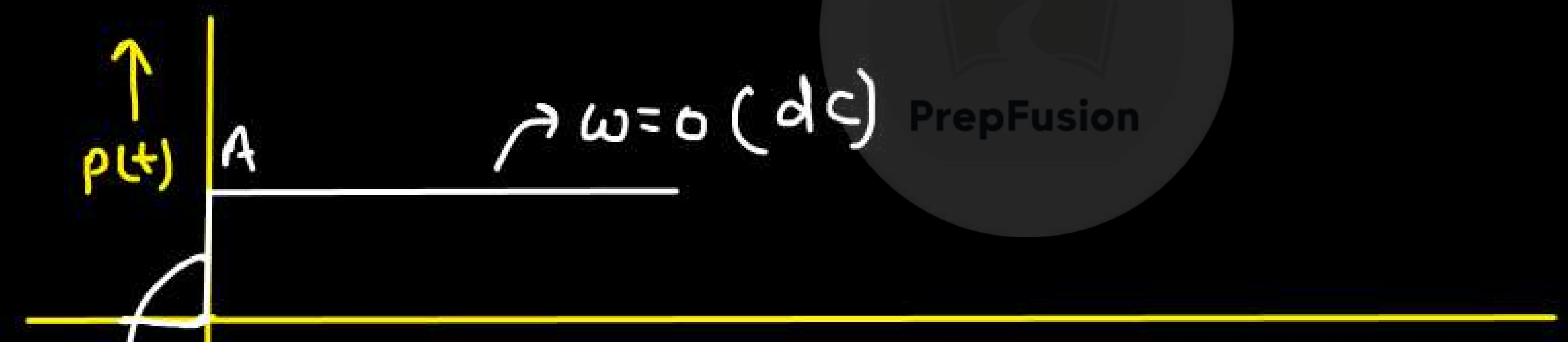
→ $A \sin \omega_1 t$



→ Freq. is increased more
freq. >>> ω

$\rightarrow A \sin \omega_2 t$

$\omega_2 > \omega_1 > \omega$



$\rightarrow \omega = 0$ (dc)

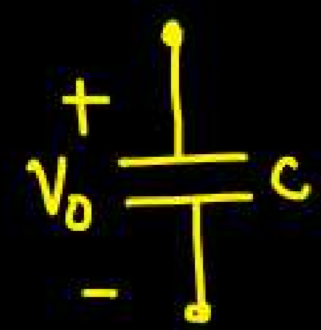
$\omega = \infty$ → Because there is a sudden jump in the value.

$\Rightarrow$ For a step signal $\Rightarrow \omega = \infty$ (at $t = 0$)

In-depth analysis of capacitors

Capacitors :-

Let's assume a capacitor is initially charged to V_0 voltage.



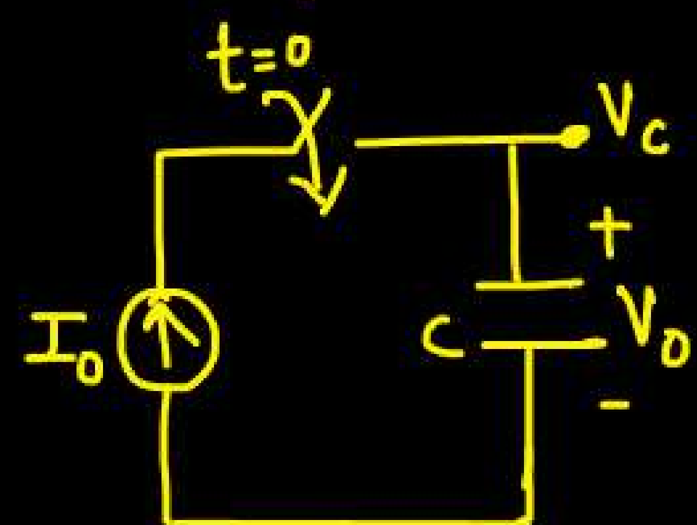
Initial charge $Q_0 = CV_0$

Initial voltage $= V_0$

Now let's assume, we are forcing some current to the capacitor.

$\Downarrow$

It will charge and gain voltage



$$\boxed{V_c(t) = V_0 + \frac{1}{C}\int_0^{\infty} I_0 \, dt}$$

If you are giving some current to the capacitor, The capacitor will charge and gain voltage.

Properties of Capacitors:-

1. Capacitor is a charge storing element.
2. When there is finite current (not impulse) flowing through the capacitor,

then
$$\boxed{\begin{array}{l} V_c(t^-) = V_c(t) = V_c(t^+) \\ \text{But } I_c(t^-) \neq I_c(t^+) \end{array}}$$

→ capacitor doesn't change its voltage instantenously but it can change its current instantenously.

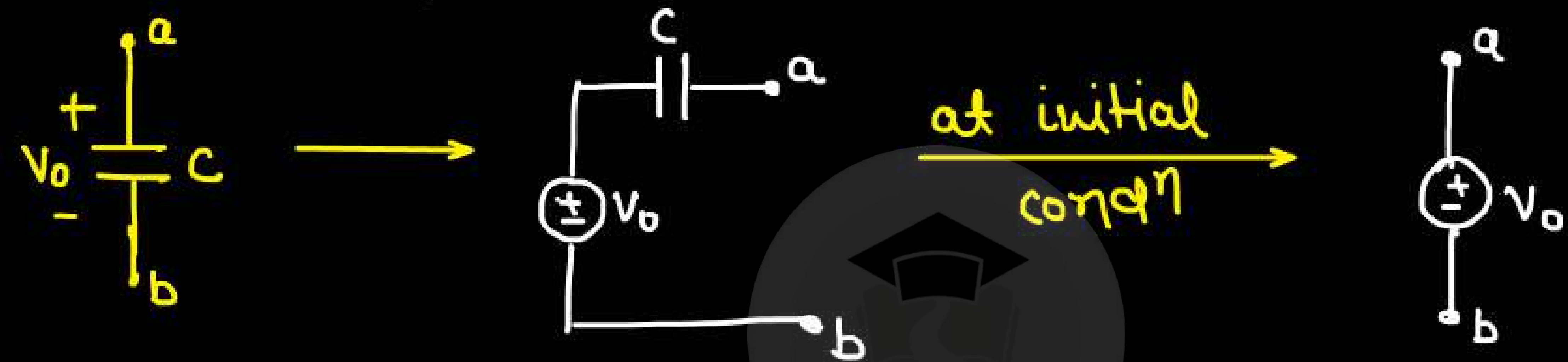
Eg. → $V_c(0^-) = 5V \Rightarrow V_c(0^+) = 5V$

$I_c(0^-) = 1A \Rightarrow I_c(0^+) \neq 1A$

Initial and Final condition:-

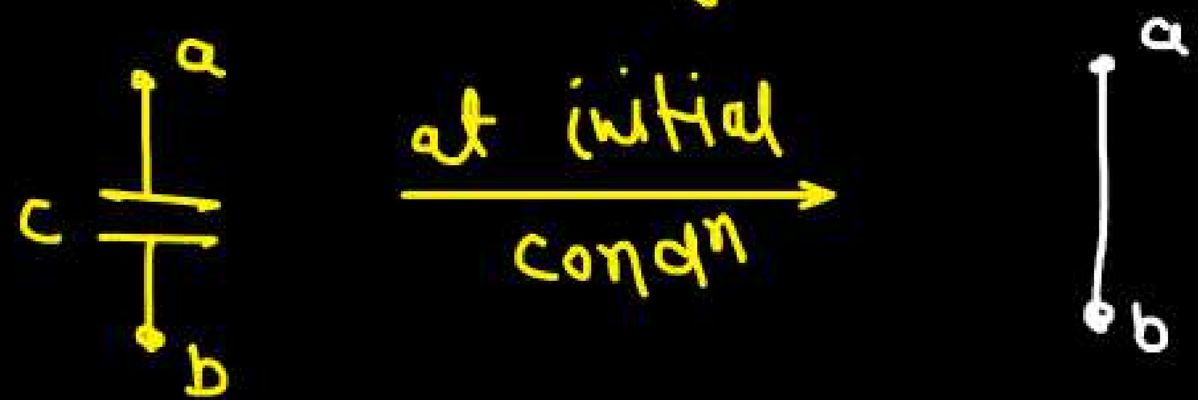
☆ Initial Cond^n of capacitor:- $(t=0)$

Let's assume a capacitor is initially charged to V_0 voltage.



↳ Replace the cap. with it's initial voltage.

↳ if there is no charge on cap.



$\boxed{\begin{array}{l}\text{current zero} = \text{O.C.} \\ \text{voltage zero} = \text{S.C.}\end{array}}$

Steady state of Capacitor :- $(t=\infty)$

↳ When the current flow stops in the capacitor

⇓

The capacitor will not charge further

⇓

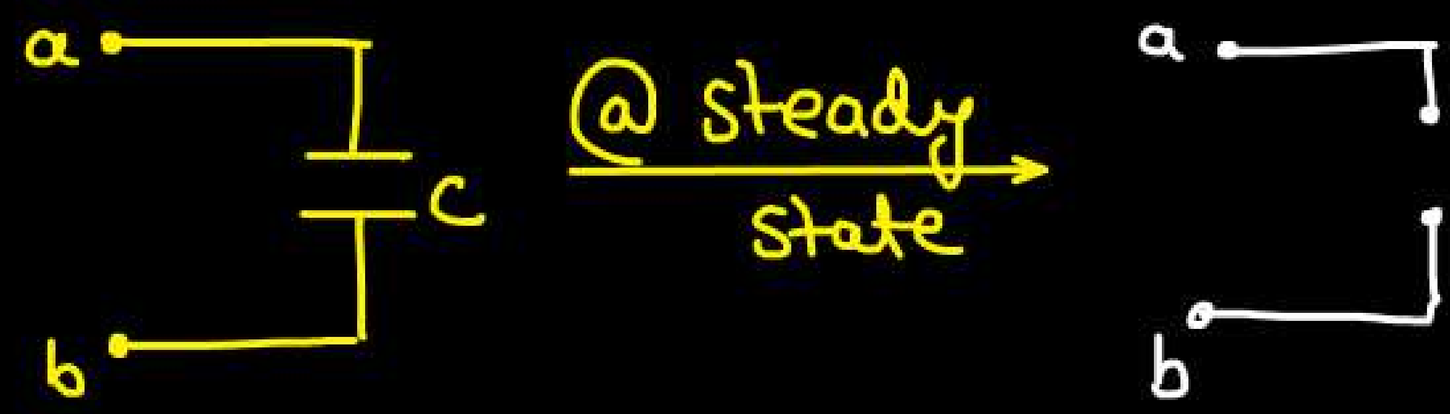
The capacitor has reached it's max voltage

⇓

Steady state

So, at steady state, The cap. will have zero current $\Rightarrow I_c = 0$
↳ o.c.

$\Rightarrow$ at steady state, cap is replaced with o.c.



2^{nd} analogy:-

@ steady state, V_c = max value it can attain

$$i_c = C\frac{dV_c}{dt}$$

$$\text{if } V_c = \text{max} \Rightarrow \frac{dV_c}{dt} = 0$$

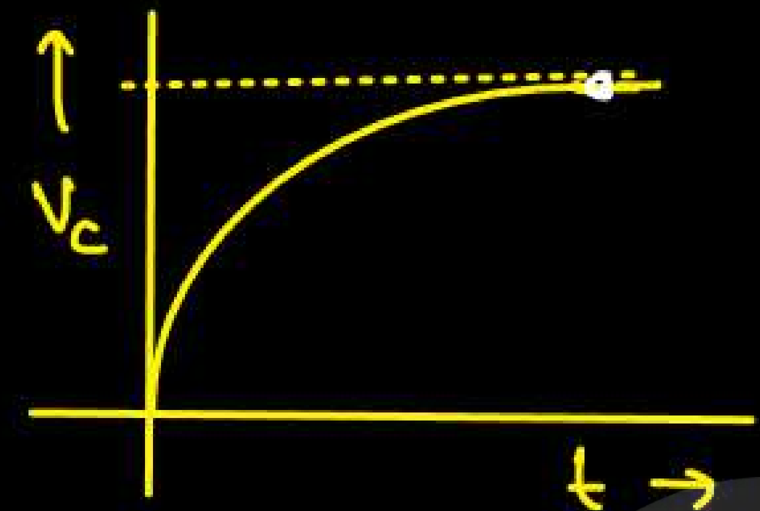
$$\Rightarrow \boxed{i_c = 0 \Rightarrow \text{O.C.}}$$

Summary:-

(t=0) Initial condⁿ → S.C. (if there is no initial voltage)

(t=∞) Steady state → O.C.

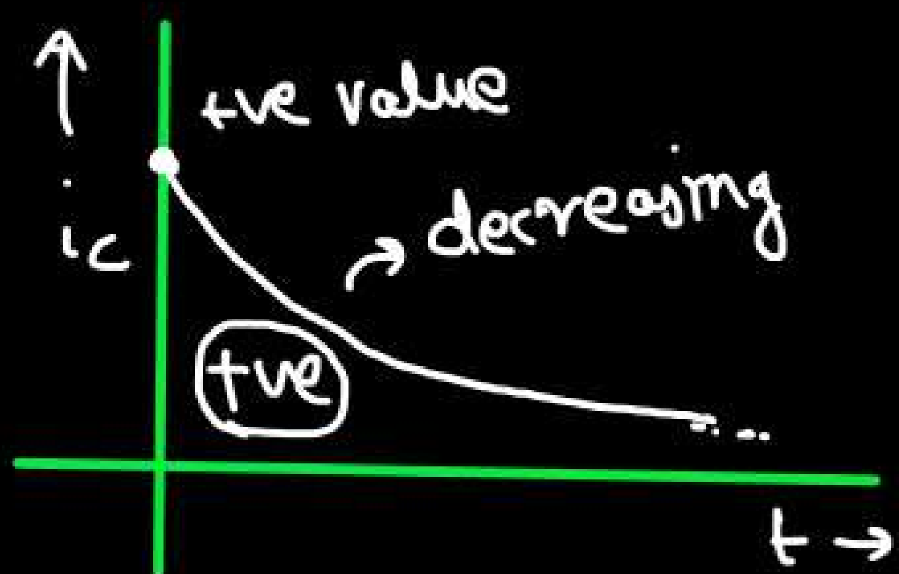
Q. The curve for "Voltage across cap. V_c" is given.



Comment on the current curve I_c across the capacitor.

→

$$i_c = C\frac{dv_c}{dt}$$



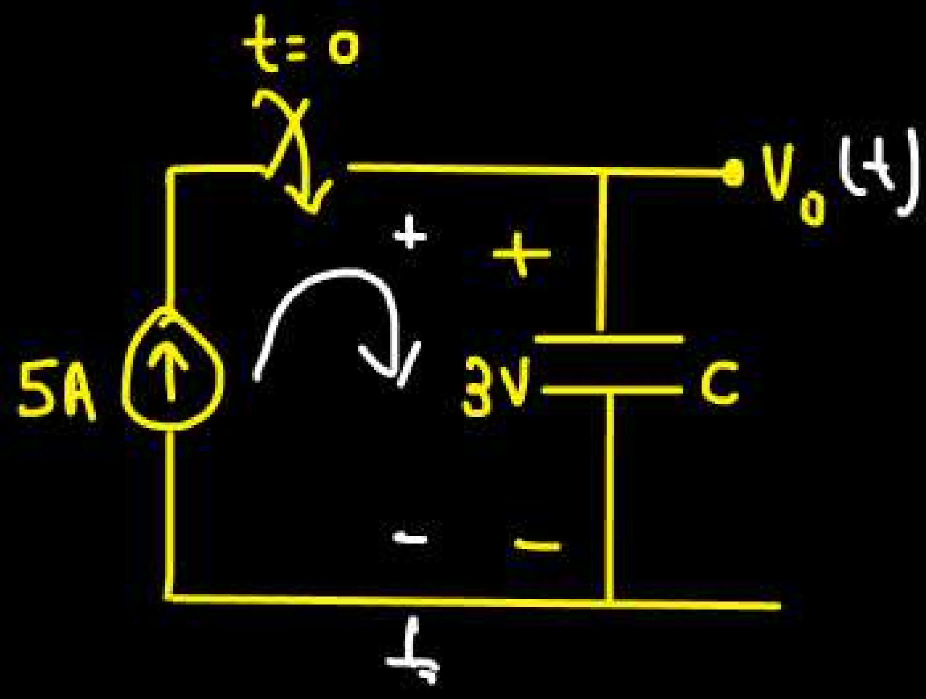
↳ For the given curve; $\frac{dv_c}{dt} = +ve \Rightarrow i_c = +ve$

↳ $\frac{dv_c}{dt}$ is always decreasing and goes down to 0.

$\Rightarrow i_c$ always decreases and goes to 0.

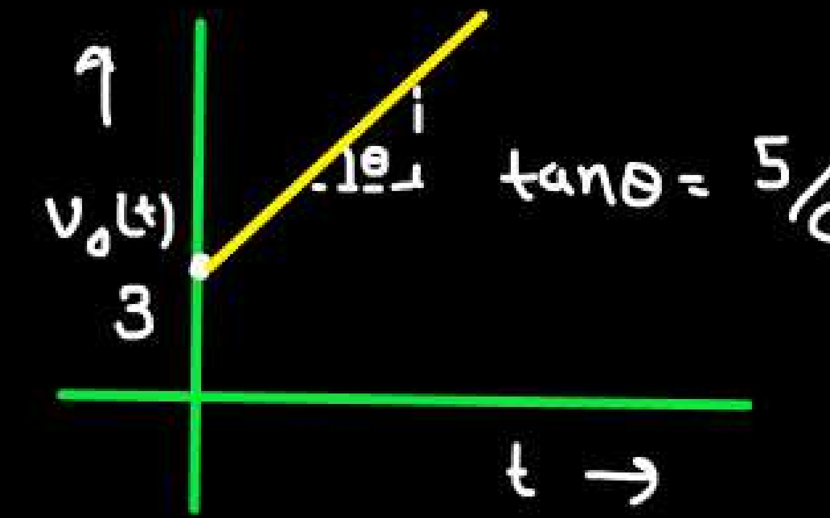
Q. Write the eqn for $v_0(t)$.

(a)



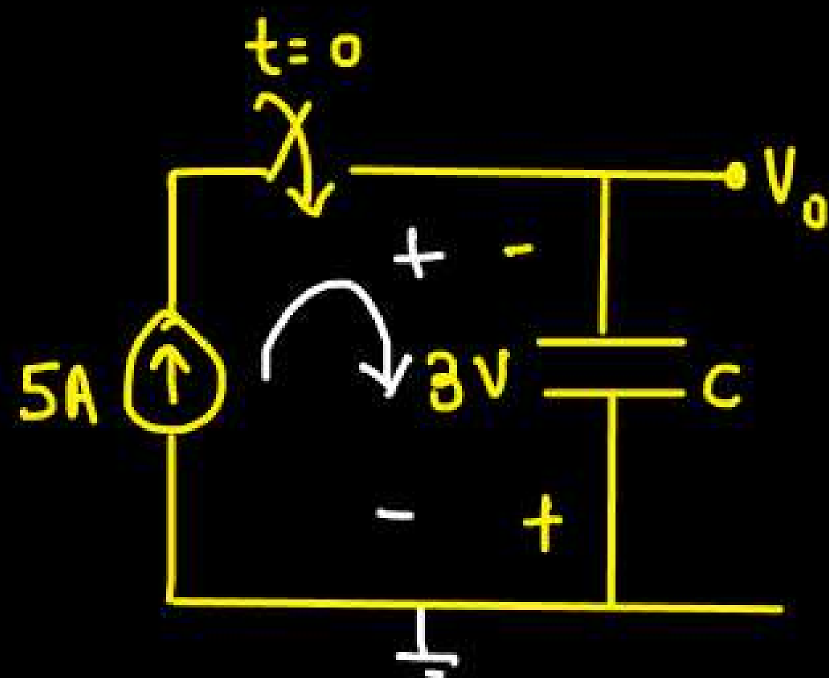
$$V_0(t) = 3 + \frac{1}{C}\int 5 \cdot dt$$

$$= 3 + 5t/C$$



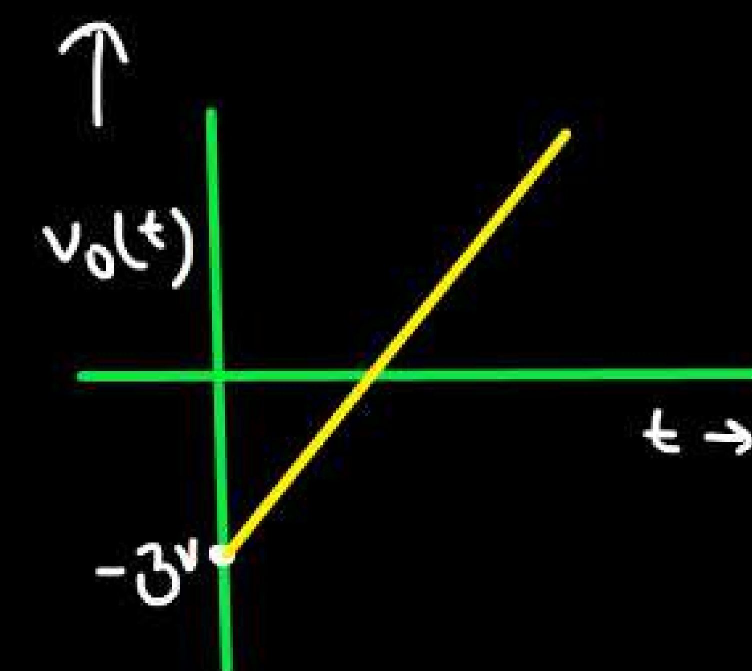
$\tan\theta = 5/C$

(b)

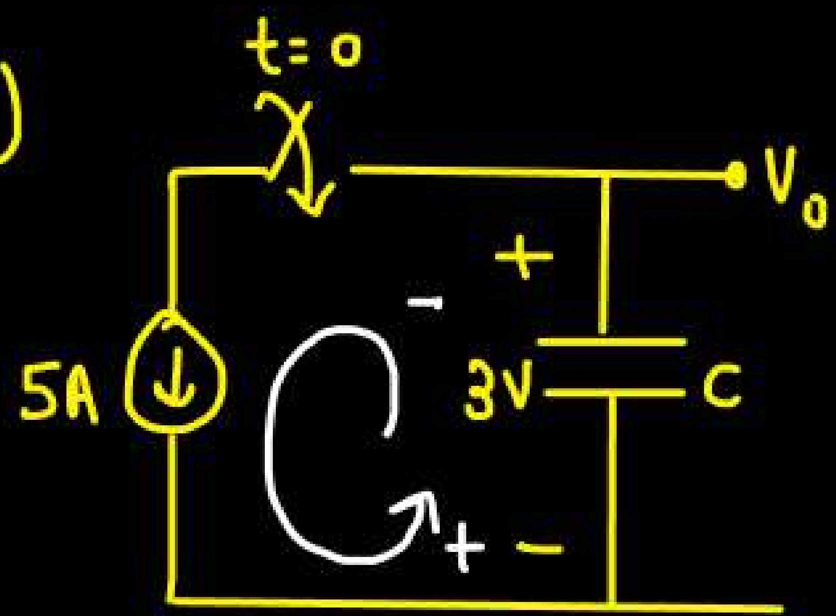


$$V_0(t) = -3 + \frac{1}{C}\int i\, dt$$

$$= -3 + 5t/C$$

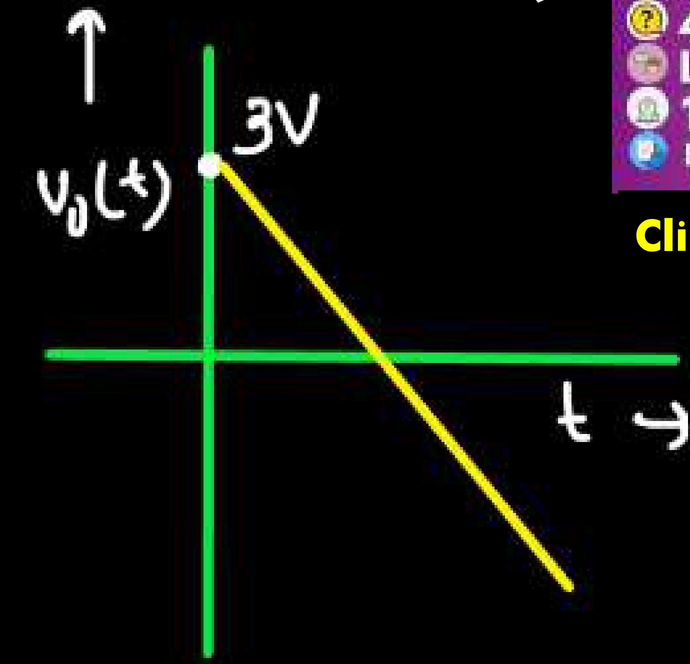


(c)

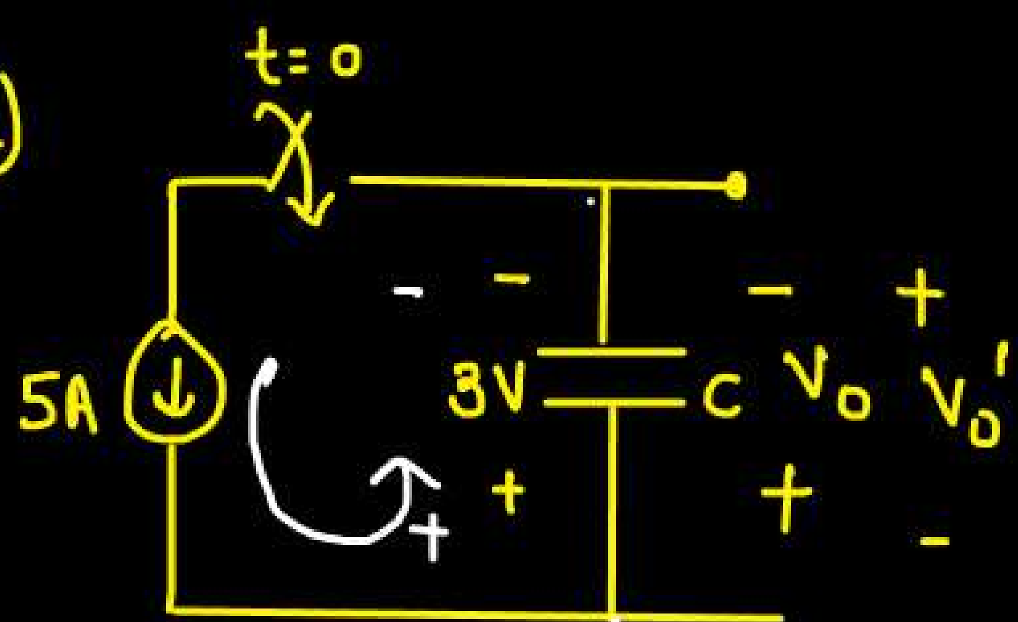


$$V_0(t) = 3 - \frac{1}{C}\int i\,dt$$

$$V_0(t) = 3 - 5t/C$$

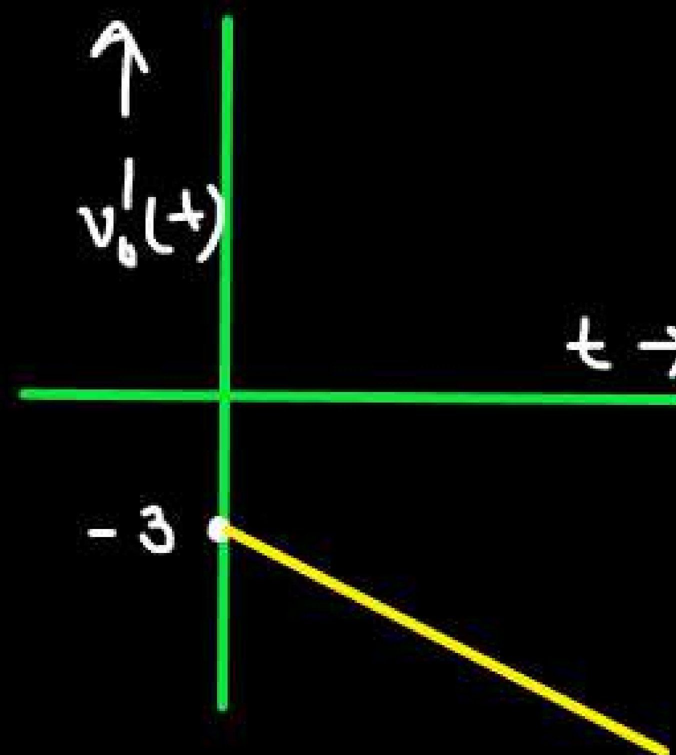


(d)



$$V_0(t) = 3 + 5t/C$$

$$V_0'(t) = -\left[3 + 5t/C\right]$$

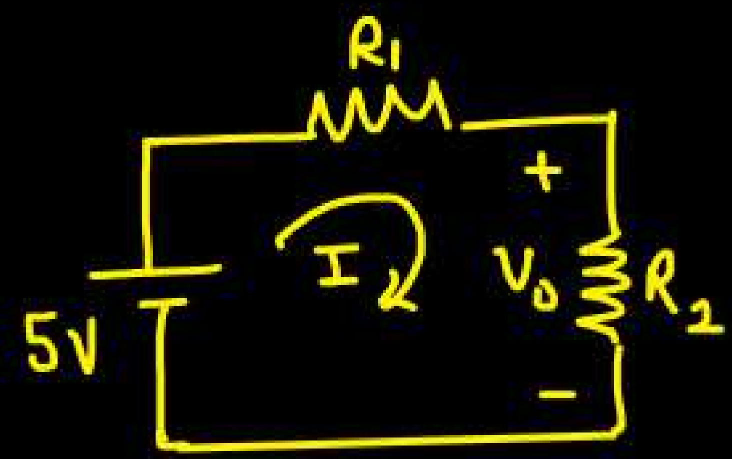


Zero order ckt:-

↳ ckts having no storing elements. (Cap. & Indu

↳ Order of differential eqⁿ is zero.

Eg. :



$$I = \frac{5}{R_1+R_2} \rightarrow \text{zero order differential eq}^n$$

$$V_o = \frac{5R_2}{R_1+R_2} \rightarrow \quad ''$$

$\Downarrow$

Zero order ckt

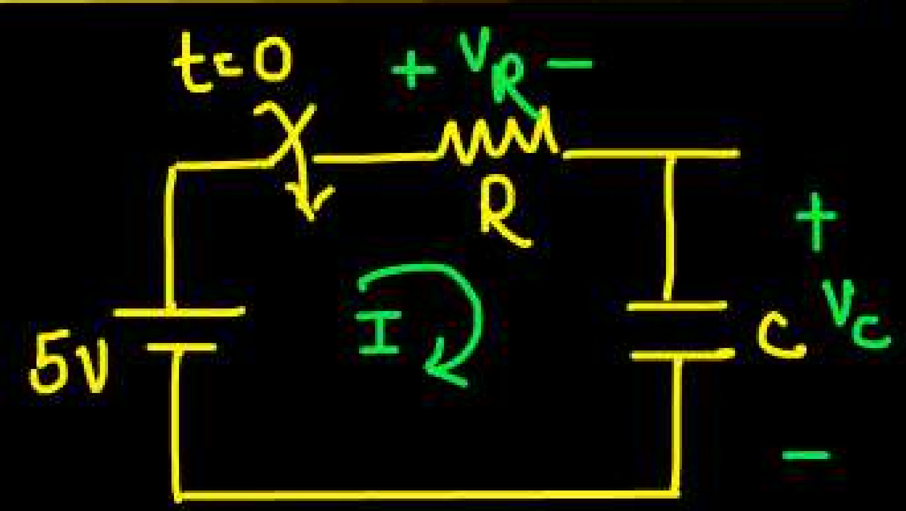
First order ckt :-

↳ ckts having one effective storing element.

↳ Order of differential eqⁿ will be one.

Eg. →

First order RC ckts :-



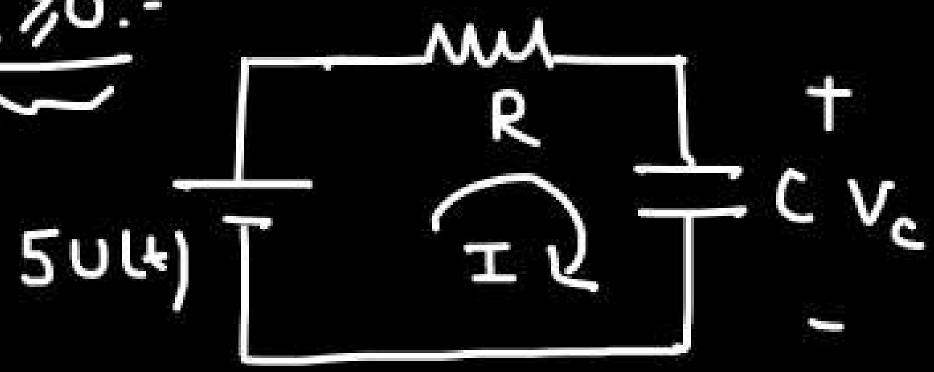
Find V_R, V_c, I = ?

→ Method 1 :-

By writing differential eqⁿ :-

① For Current I :-

$t \geq 0$:-



KVL :-

$$5 = IR + \frac{1}{C}\int I\,dt$$

differentiation on both side

$$0 = R\frac{dI}{dt} + \frac{I}{C}$$

$$\Rightarrow R\frac{dI}{dt} + \frac{I}{C} = 0 \rightarrow 1^{st} \text{ order differential eq}^n$$

$\Longrightarrow$ It's a first order ckt

Solve

$$R\frac{dI}{dt} + \frac{I}{C} = 0$$

$$f(D) = RD + \frac{1}{C} = 0$$

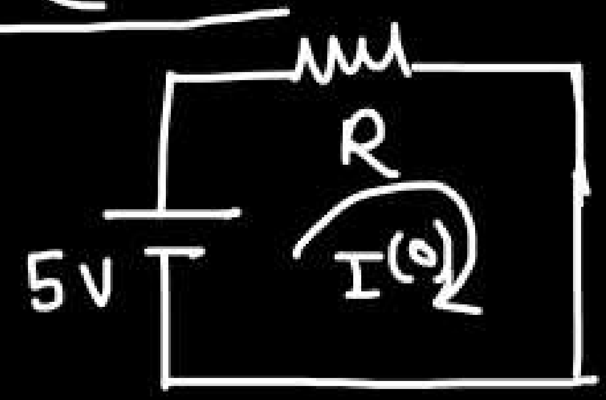
$$D = -\frac{1}{RC}$$

$$\boxed{I(t) = c_1 e^{-\frac{1}{RC}t}}$$

$$I(t) = C_1 e^{-t/RC}$$

at $t=0$ $I(0) = C_1$

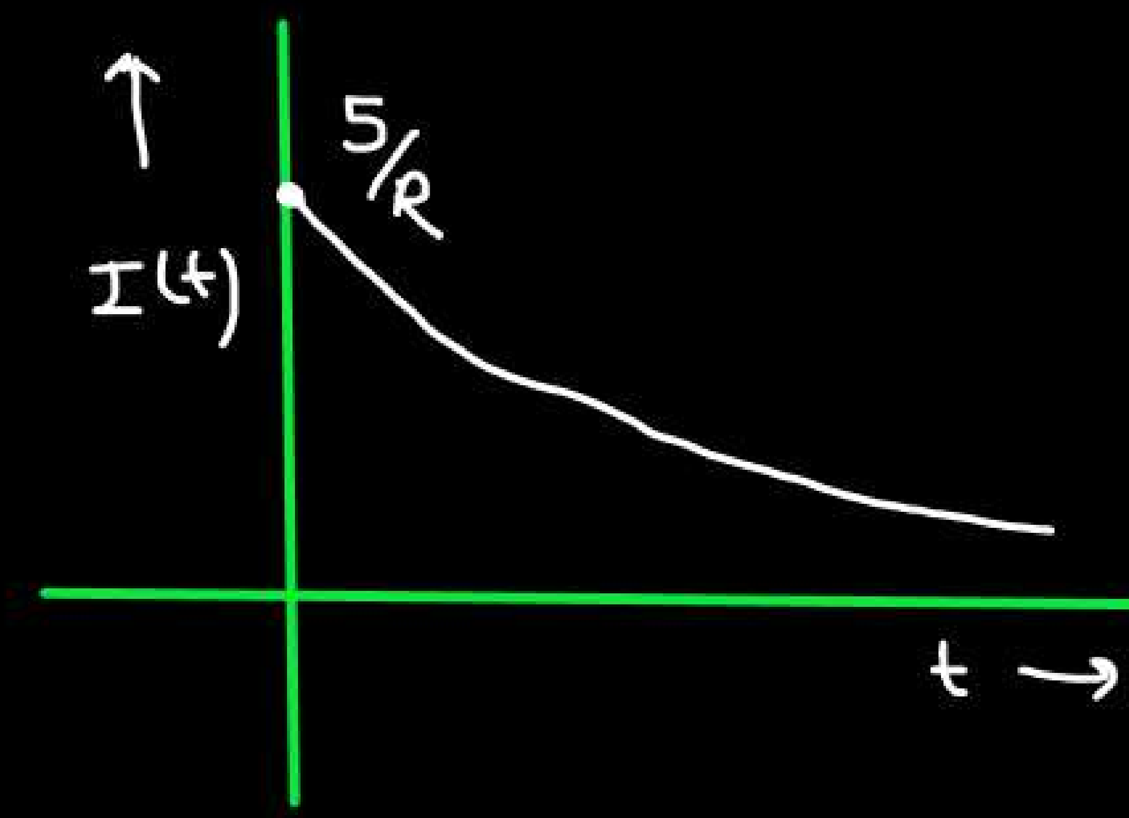
ckt @ t=0:-



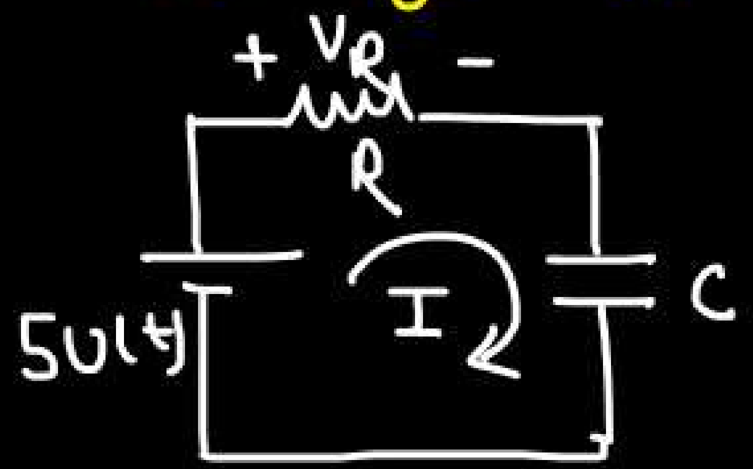
→ cap is shorted @ t=0

$$I(0) = 5/R = C_1$$

$$\Rightarrow \boxed{I(t) = \frac{5}{R} e^{-t/RC}}$$



② for voltage V_R



$$5 = V_R(t) + \frac{1}{C}\int I(t)\cdot dt$$

$$V_R(t) = I(t) \times R$$

$$I(t) = \frac{V_R(t)}{R}$$

$$\Rightarrow \quad 5 = V_R(t) + \frac{1}{C}\int \frac{V_R(t)}{R}\cdot dt$$

differentiating →

$$0 = \frac{d}{dt}V_R(t) + \frac{V_R(t)}{RC} \rightarrow 1^{st} \text{ order ckt}$$

$$\left(D + \frac{1}{RC}\right)V_R(t) = 0$$

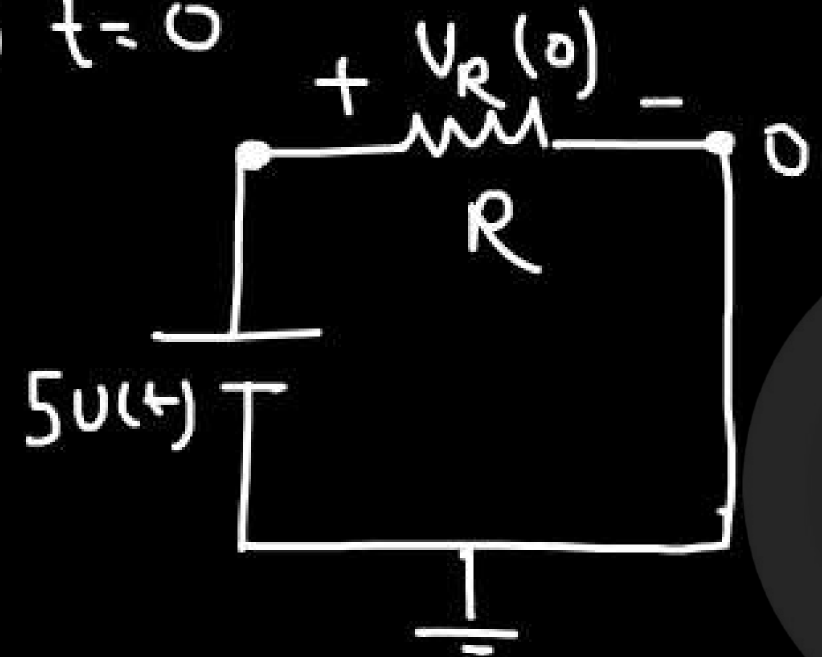
$$\Rightarrow D = -\frac{1}{RC}$$

$$\boxed{V_R(t) = c_1 e^{-\frac{1}{RC}t}}$$

$$V_R(t) = c_1 e^{-\frac{1}{RC}t}$$

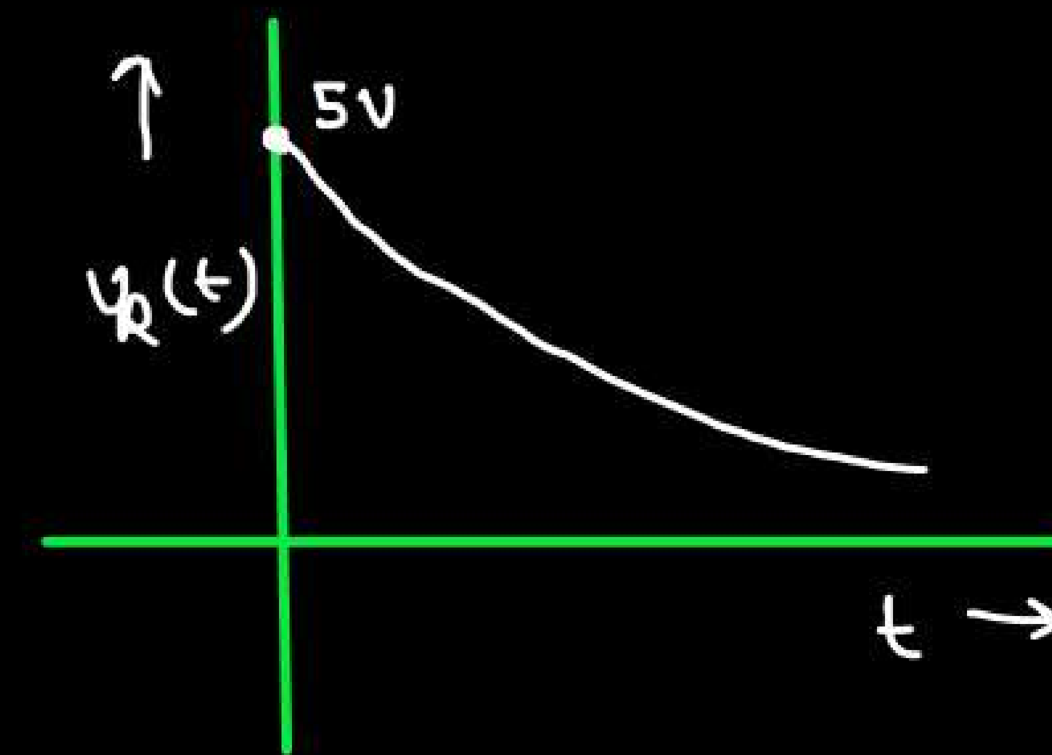
$$@\ t = 0\ ;\quad V_R(0) = c_1$$

ckt @ $t = 0$

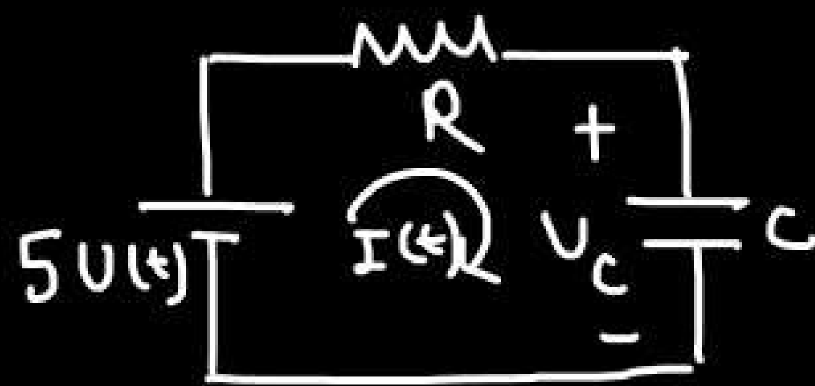


$$V_R(0) = 5V = c_1$$

$$\Rightarrow \boxed{V_R(t) = 5e^{-t/RC}} \Rightarrow$$



③ for voltage V_c :-



$$V_c(t) = \frac{1}{C}\int I(t)\cdot dt$$

$$I(t) = C\frac{dV_c(t)}{dt} \quad \text{— ①}$$

$$5 = I(t)R + V_c(t)$$

By eq^n ①

$$\boxed{5 = RC\frac{dV_c(t)}{dt} + V_c(t)} \rightarrow 1^{st} \text{ order ckt}$$

$$V_c(t) = CF + PI$$

CF:-

$$DRC + 1 = 0$$

$$D = -\frac{1}{RC}$$

$$CF = c_1 e^{-\frac{1}{RC}t}$$

PI:-

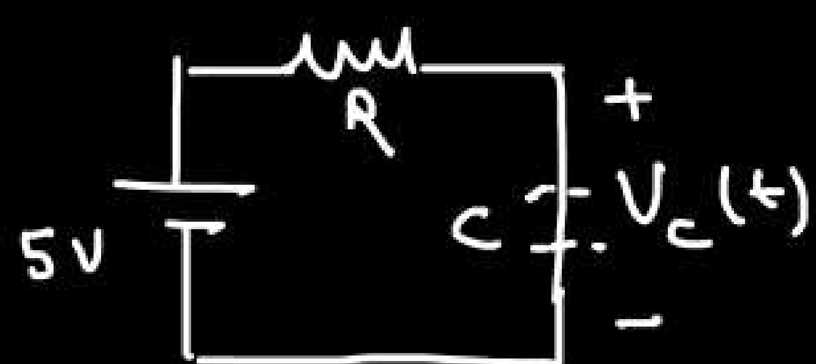
$$V_c(t) = \frac{5}{DRC+1}$$

Put $D = 0$

$$PI = 5$$

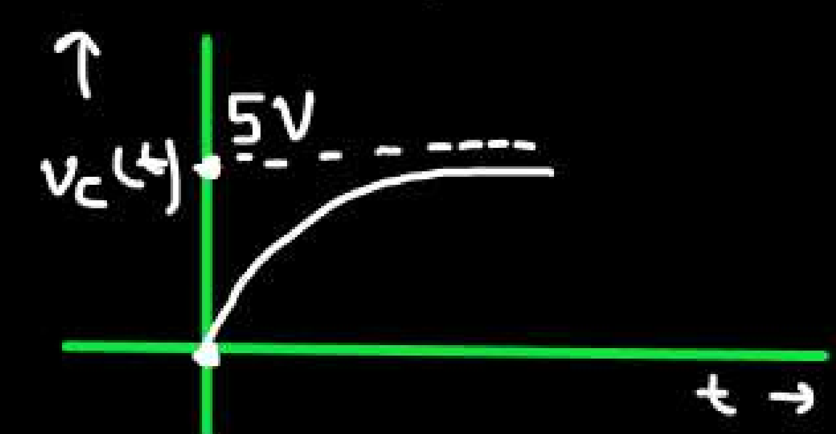
$$\boxed{V_c(t) = 5 + c_1 e^{-t/RC}} \Rightarrow @\ t=0 \Rightarrow V_c(0) = 5 + c_1$$

ckt @ $t=0$



$$\Rightarrow V_c(0) = 0V \Rightarrow 5 + c_1 = 0 \Rightarrow c_1 = -5$$

$$\Rightarrow \boxed{V_c(t) = 5 - 5e^{-t/RC}}$$



N.B. -

If there is only one effective storing element

$\Downarrow$

The ckt is first order ckt

$\Downarrow$

The differential eq^n for all the parameters (current / voltage) will be of 1^{st} order only.

sol^n for first order eq^n: -

$$\boxed{y(t) = \underbrace{y(\infty)}_{\text{Steady state part}} + \underbrace{\left(y(0) - y(\infty)\right) e^{-t/\tau}}_{\text{Transient part}}} \rightarrow \tau = \text{Time constant}$$

M - II

General solⁿ of a 1st order differential eqⁿ

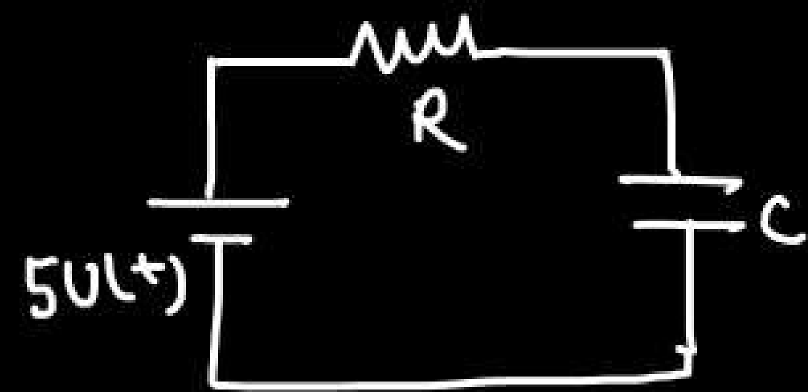
$$Y(t) = Y(\infty) + [Y(0) - Y(\infty)]\, e^{-t/\tau}$$

τ = ? = Time const.

↳ How to find time const. of first order ckt.

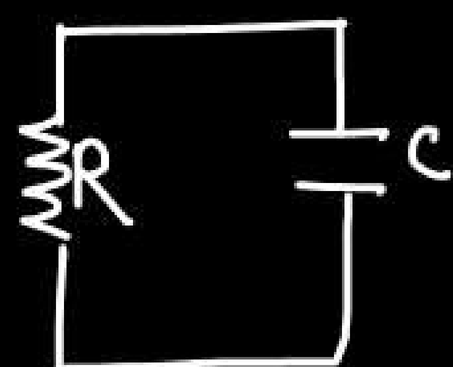
* Nullify the independent Sources. [Voltage source → S.C., Current source → O.C.]
* Find the effective Storing component.
  (Effective cap. | Effective inductance)
* Find the equivalent resistance across the effective storing element.
* For 1st order RC ckts, Time constant $\tau = R_{eq} C_{eff}$
  1st order RL ckts, Time constant $\tau = \frac{L_{eff}}{R_{eq}}$

Given ckt :-



$\tau = ?$

$\Rightarrow$ ① S.C. the voltage source



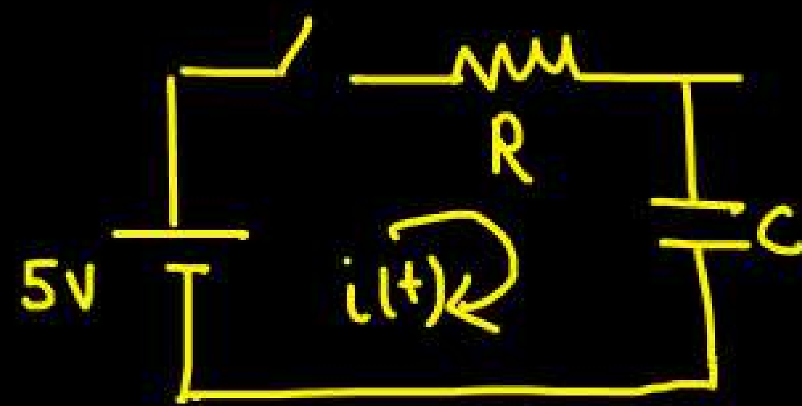
$\Rightarrow C_{eff} = C$

$R_{eq} = R$

$$\boxed{\tau = RC}$$

Method II :-

① Solving for current $i(t)$



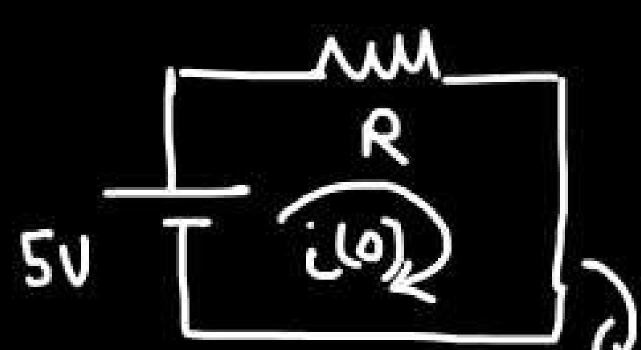
→ 1^{st} order ckt

$\Rightarrow \tau = RC$

$$i(t) = i(\infty) + \left(i(0) - i(\infty)\right) e^{-t/\tau}$$

$i(0) = ?$, $i(\infty) = ?$

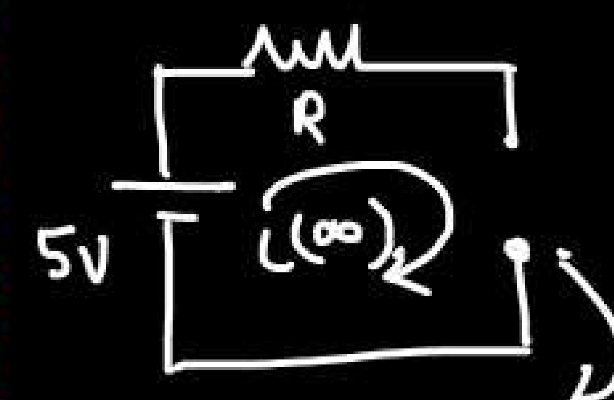
$\Rightarrow$ ckt @ $t = 0$



$i(0) = 5/R$

Cap. shorted

ckt @ $t = \infty$



$i(\infty) = 0$ Amp.

Cap. O.C.

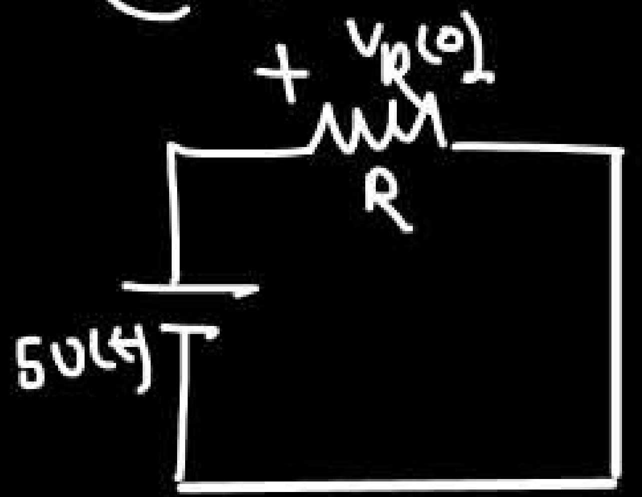
$$i(t) = 0 + \left(5/R - 0\right) e^{-t/RC}$$

$$\Rightarrow \boxed{i(t) = \frac{5}{R} e^{-t/RC}}$$

Solving for $V_R(t)$:-

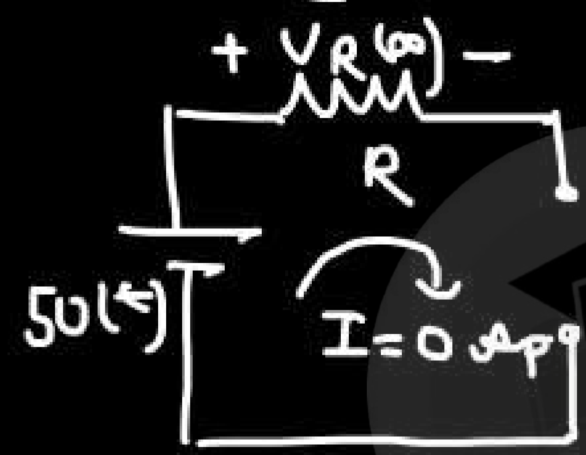
$$V_R(t) = V_R(\infty) + \left[V_R(0) - V_R(\infty)\right]e^{-t/\tau} \quad ; \text{ Here } \tau = R$$

Ckt @ $t=0$



$$V_R(0) = 5V$$

Ckt @ $t=\infty$



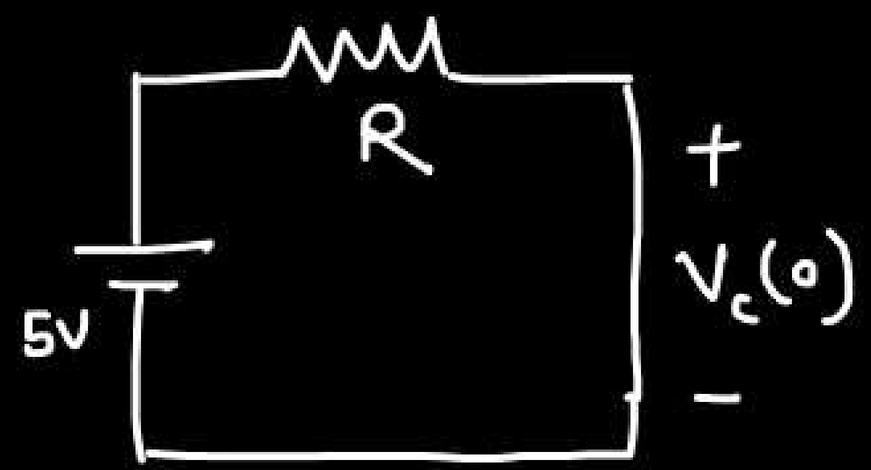
$$V_R(\infty) = 0V$$

$$\boxed{V_R(t) = 5e^{-t/RC}}$$

Solving for $v_c(t)$:-

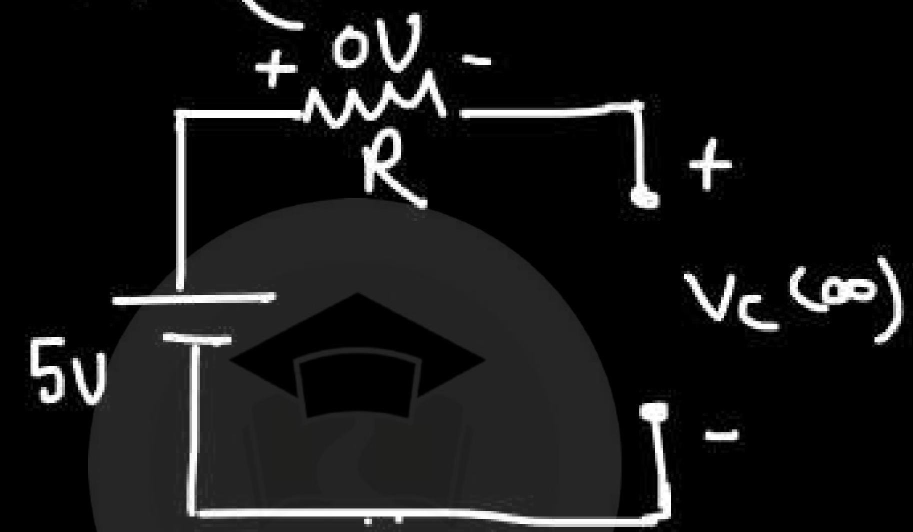
$$v_c(t) = v_c(\infty) + [v_c(0) - v_c(\infty)]\, e^{-t/\tau} \quad ; \quad \tau = RC$$

ckt @ $t=0$



$v_c(0) = 0\,V$

ckt @ $t=\infty$

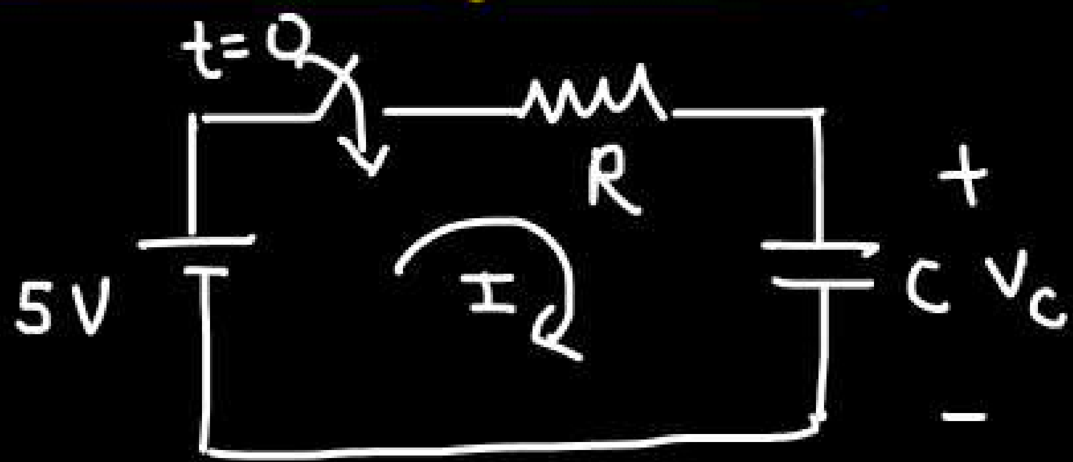


$v_c(\infty) = 5\,V$

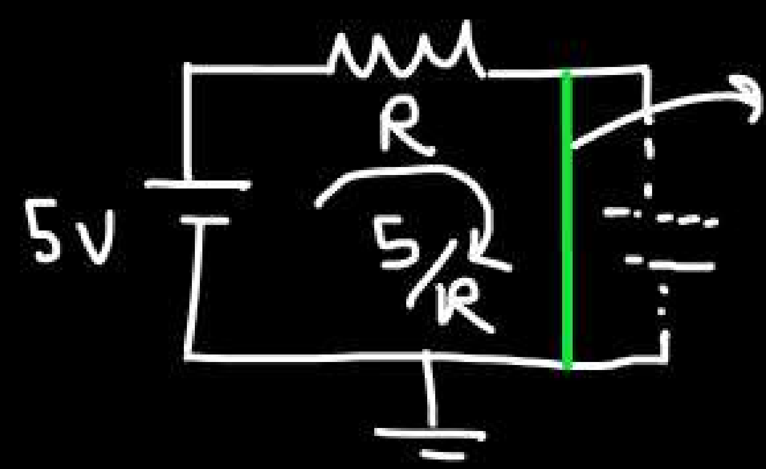
$$v_c(t) = 5 + [0 - 5]\, e^{-t/RC}$$

$$\boxed{v_c(t) = 5\left(1 - e^{-t/RC}\right)}$$

✱ Understanding the ckt:-



@ $t=0$ ⇒ cap. acts as S.C.



shorted ⇒ This $5/R$ current flows through the cap ⇒ This charges the cap.

⇓

cap. start developing the voltage.

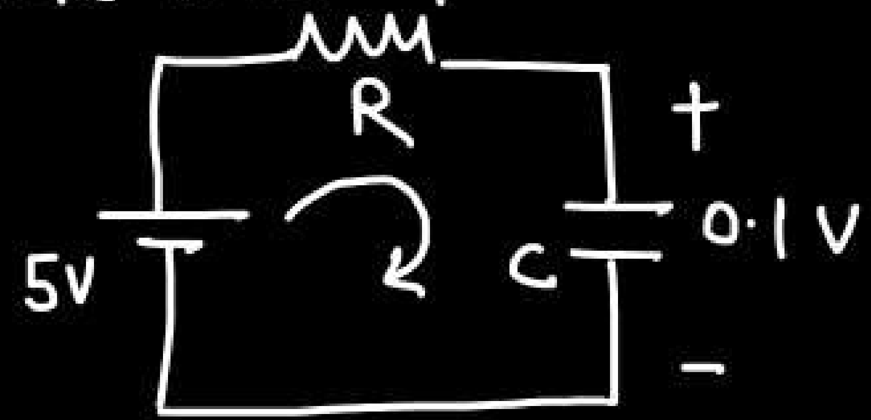
$I(0) = 5/R$ ⇒ charging the cap.

Let's assume, after sometime the cap. is charged to

(Because of the

current)

@ some time t_1

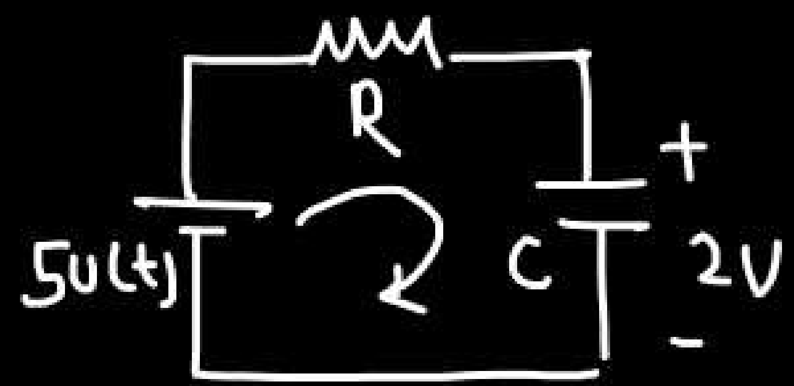


$I(t_1) = 4.9/R$ ⇒ charges the cap. in the same dir^n

⇒ Although the current has reduced but still it's flowing in the same dir^n that charges the cap. with more voltage.

now, let's assume, after some more time, the cap. is charged to 2V.

@ some time t_2



$I(t_2) = 3/R$ Amps

$\Rightarrow$ But still it charges the cap.

$\Rightarrow \quad I(0) = 5/R \quad , \quad I(t_1) = 4.9/R \quad , \quad I(t_2) = 3/R$

$v_c(0) = 0 \quad , \quad v_c(t_1) = 0.1 \quad , \quad v_c(t_2) = 2V$

$\Rightarrow$ Slowly the current is reducing and the voltage across the cap is increasing

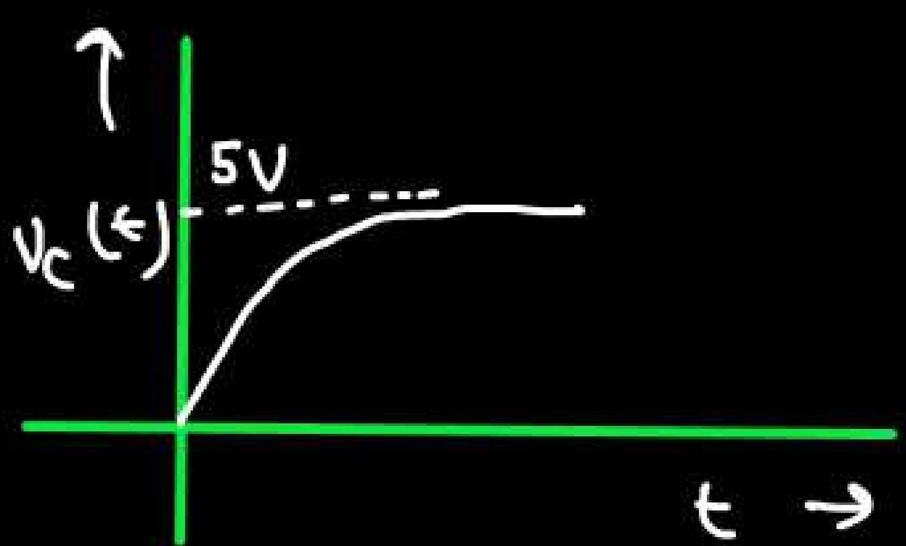
@ sometime t_3, $v_c(t_3) \approx 5V \Rightarrow I_c(t_3) = 0$ Amps $\Rightarrow$ steady state

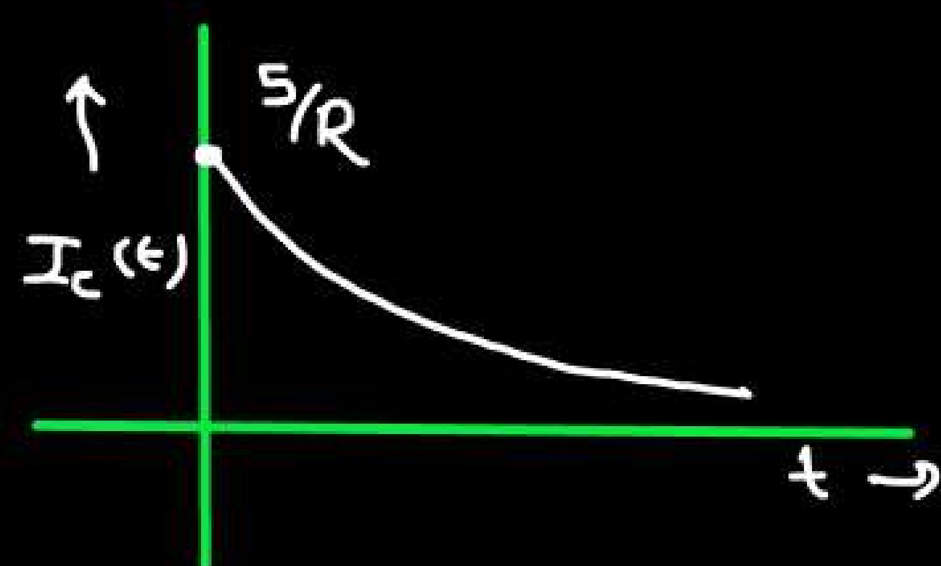
Also, Here we see that the current is continuously decreasing.

more current ⇒ more voltage

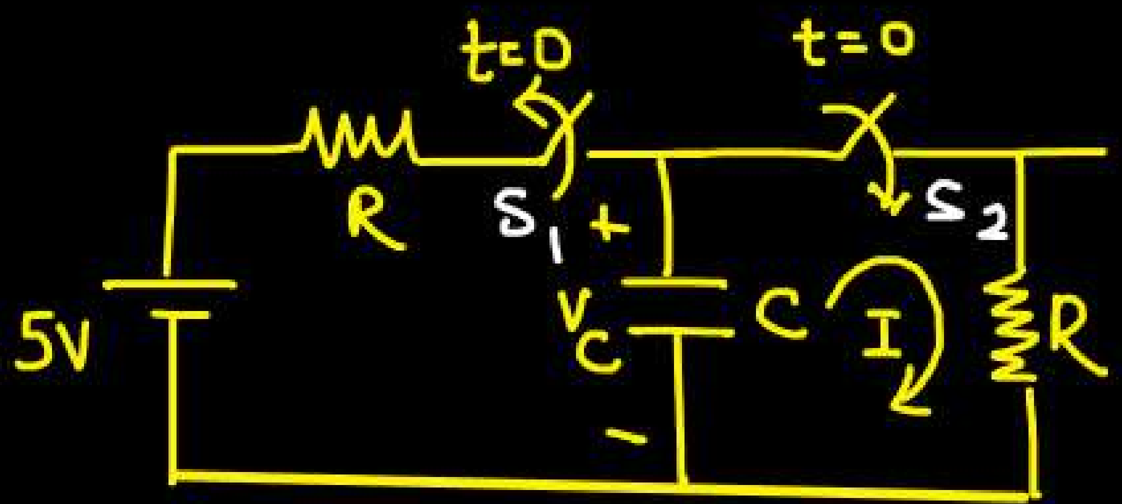
Speed of charging $\propto$ Amount of current

⇒ since current continously decreases, speed of charging (I), cap. will develop voltage slowly. ⇒ with time $\frac{dV_c(t)}{dt}$ is reducing.





Q.

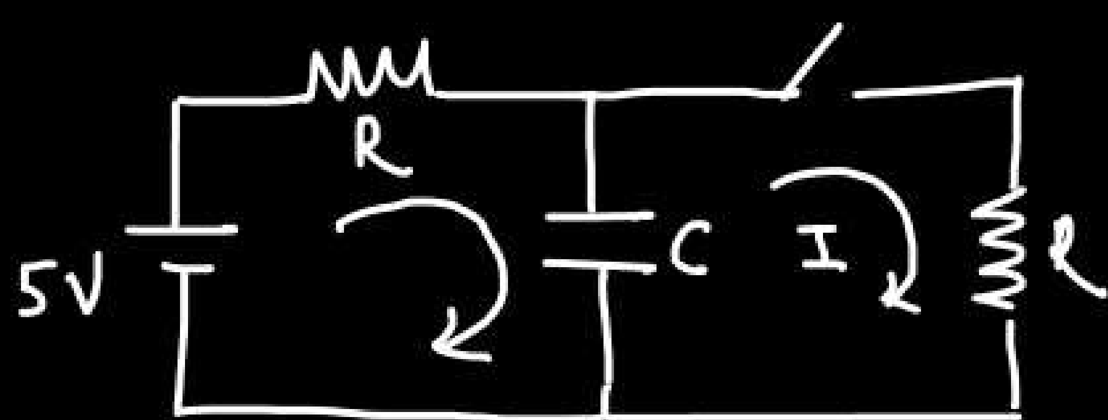


Comment on V_c & I.

→ S_1 is closed for $t<0$; S_2 is closed for $t>0$

S_1 is opened for $t>0$; S_2 is opened for $t<0$

ckt for $t<0$ $\{-\infty < t < 0\}$



For $t<0$

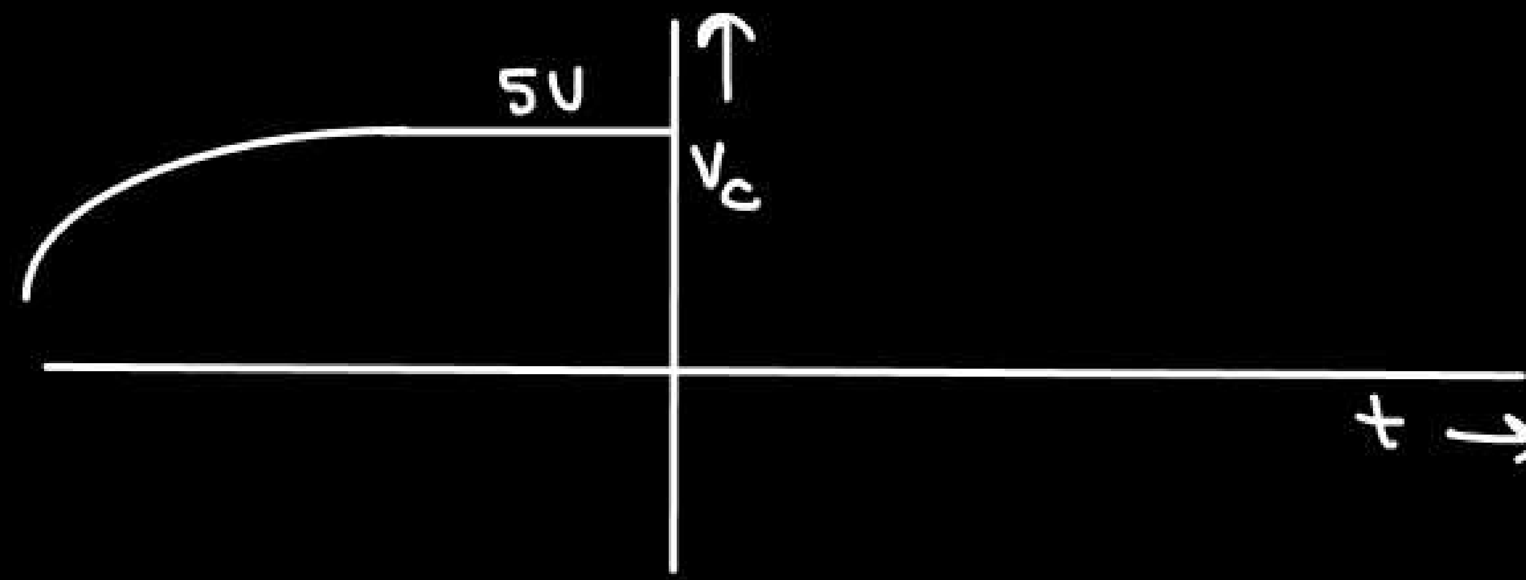
$I(t<0) = 0$ Amp

$V_c(0^-) = 5V$

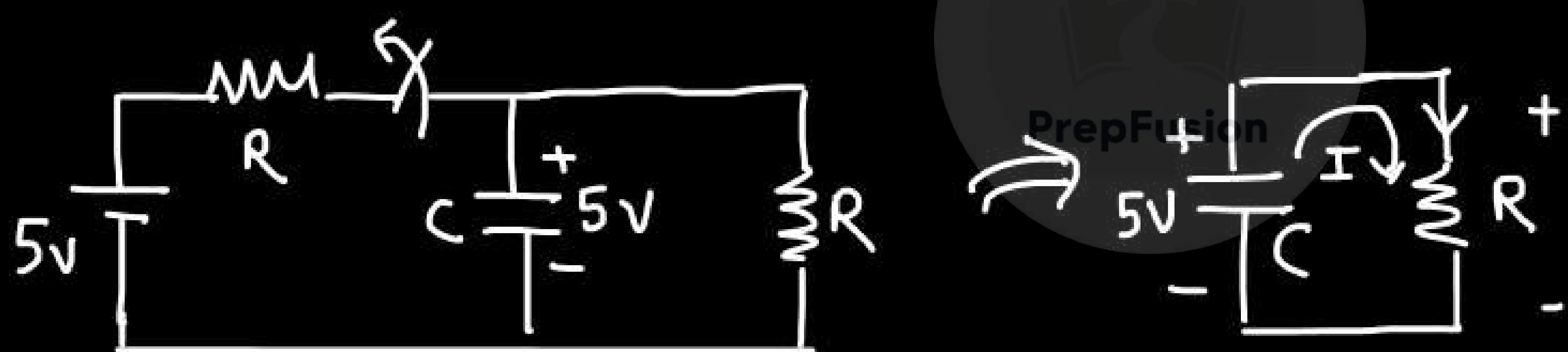
⇒ Switch S_1 is closed for long time

⇓

5V will charge the cap. ⇒ cap. will fully get charged to 5V



now, ckt for $t > 0$



$\because$ $v_c(0^-) = 5V$
$v_c(0^+) = 5V$

$\Downarrow$ property of cap.

$I(0^+) = \frac{5}{R} \rightarrow$ finite

$\Downarrow$

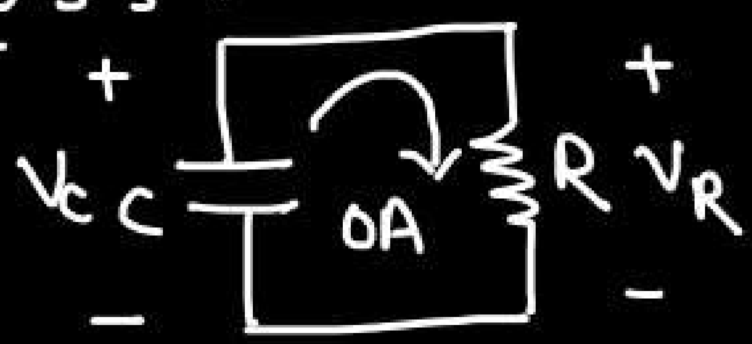
current flowing out of the cap.

@ steady state:-

$\Downarrow$

no current flow through the cap.

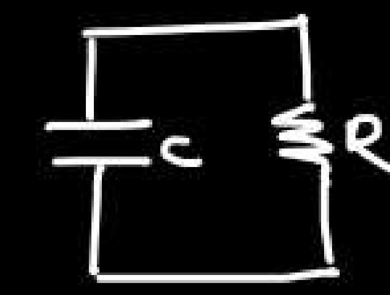
@ S.S. →



$I(\infty) = 0$ Amp.

$V_c(\infty) = 0 \times R = 0V = V_R$

Time constant (for $t>0$):-



$C_{eff} = C$

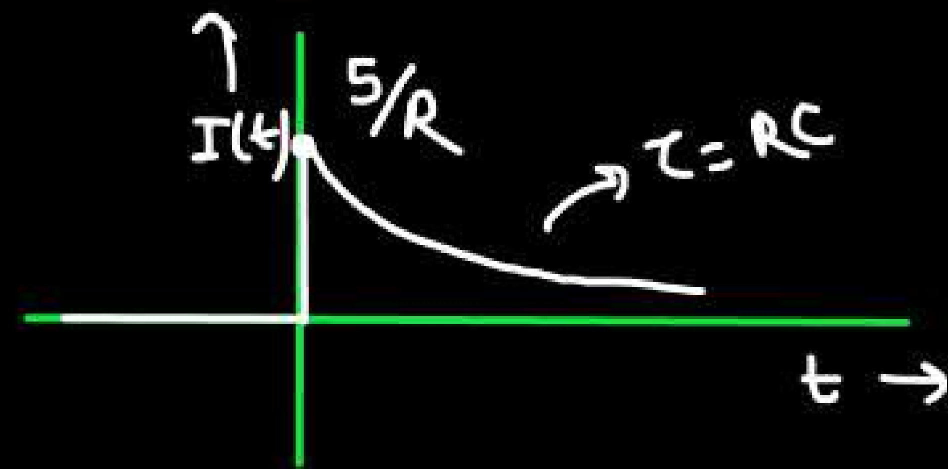
$R_{eq} = R$

$\tau = RC$

Conclusion:-

$I(0^+) = 5/R$ $\quad$ $I(\infty) = 0$ Amp.

$I(t) = \frac{5}{R} e^{-t/\tau} u(t)$ {Because we are writing the eq^n for $t>0$}

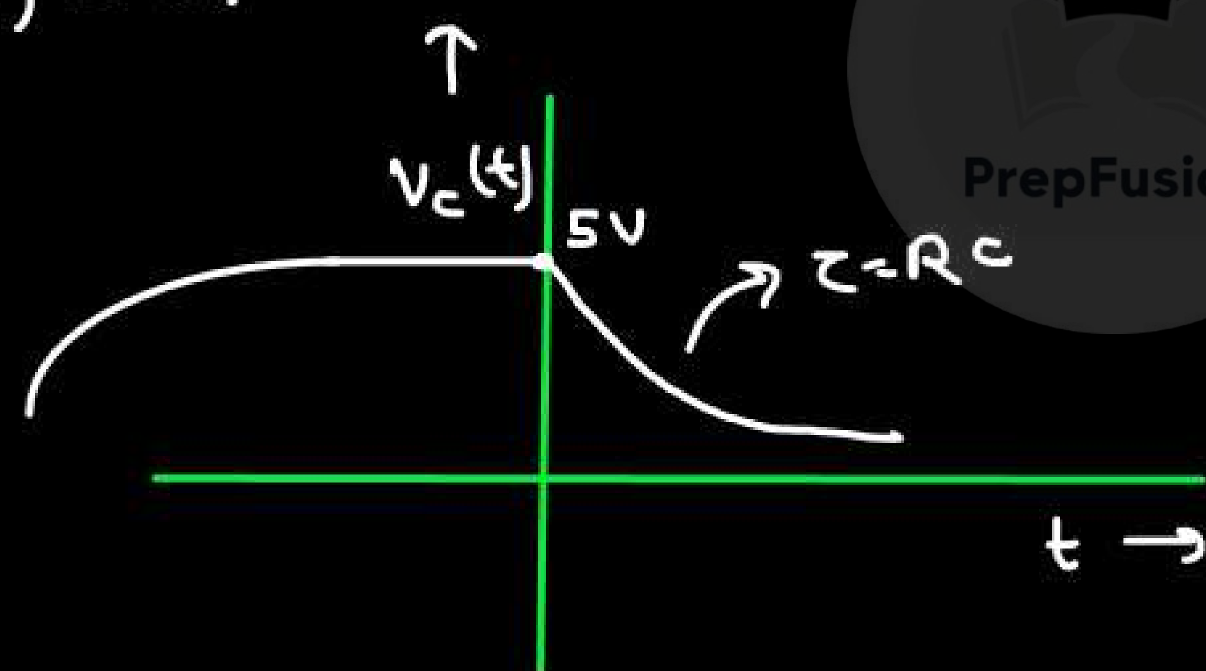


$V_c(t)$:-

$V_c(0^+) = 5V$

$V_c(\infty) = 0V$

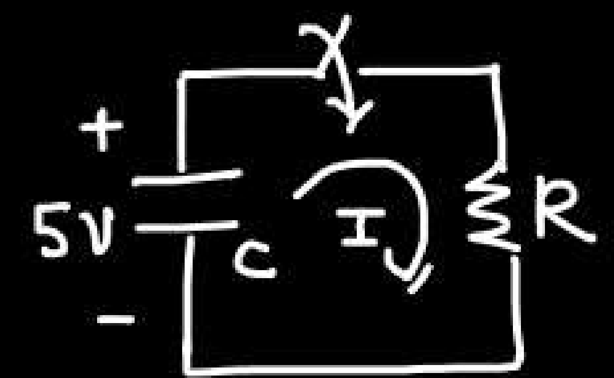
$$V_c(t) = 5e^{-t/RC}\,u(t)$$



Understanding the ckt :-

From $-\infty < t < 0 \Rightarrow$ cap. is being charged to 5V.

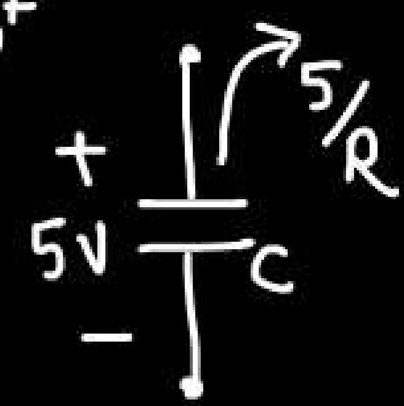
now for $t > 0$



This same 5V comes across the resistor

$$\Rightarrow I = 5/R$$

@ $t = 0^+$



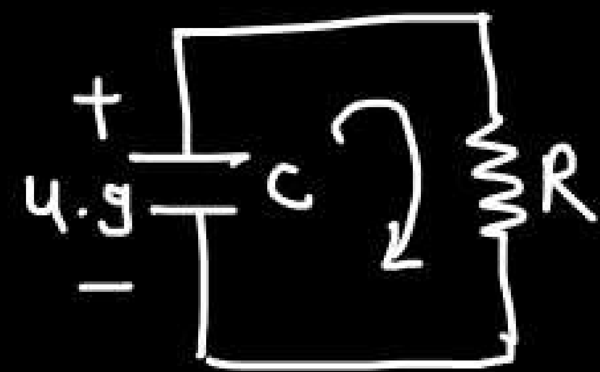
$\Rightarrow$ $5/R$ current is flowing out of the cap.

$\Downarrow$

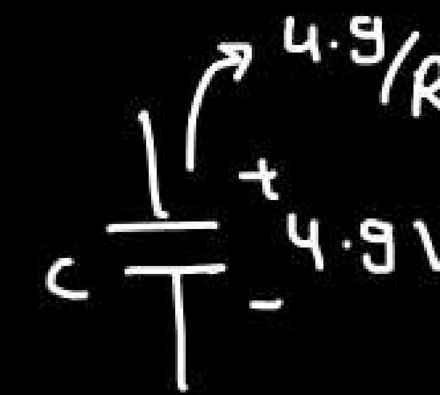
cap. discharges

let's assume @ $t = t_1$, cap is discharged to 4.9V

@ $t = t_1$



$I(t_1) = 4.9/R \Rightarrow$



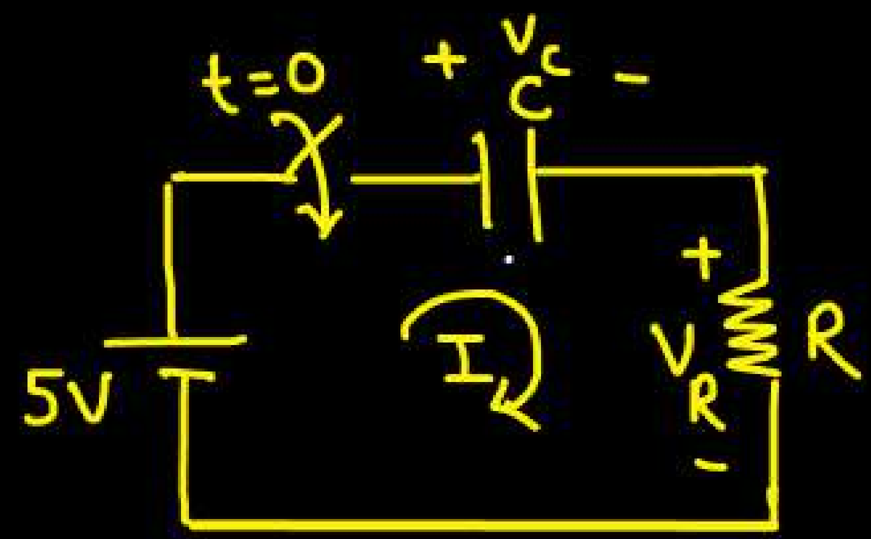
now $\frac{4.9}{R}$ current flows out of the cap. and discharges.

$\Rightarrow$ This shows that the cap. will keep on discharging until the current flowing out of it becomes zero

$\Downarrow$

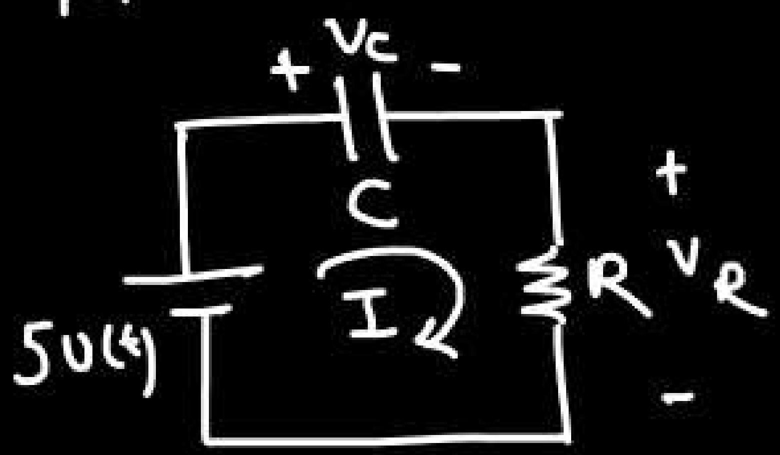
The cap. will have zero voltage.

Q.



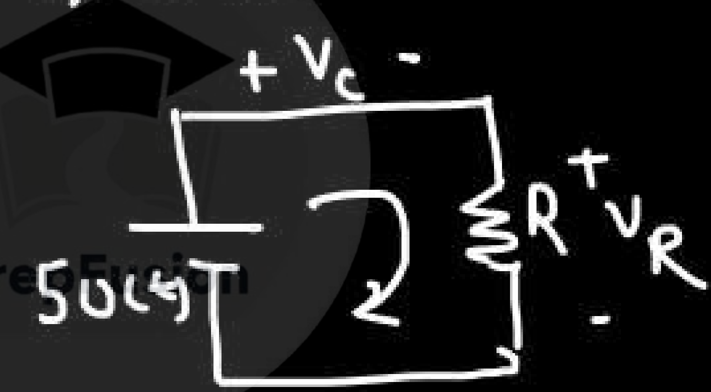
Comment on V_c, V_R & I.

→ ckt for $t>0$



@ $t=0$

$\Rightarrow C \to S.C.$

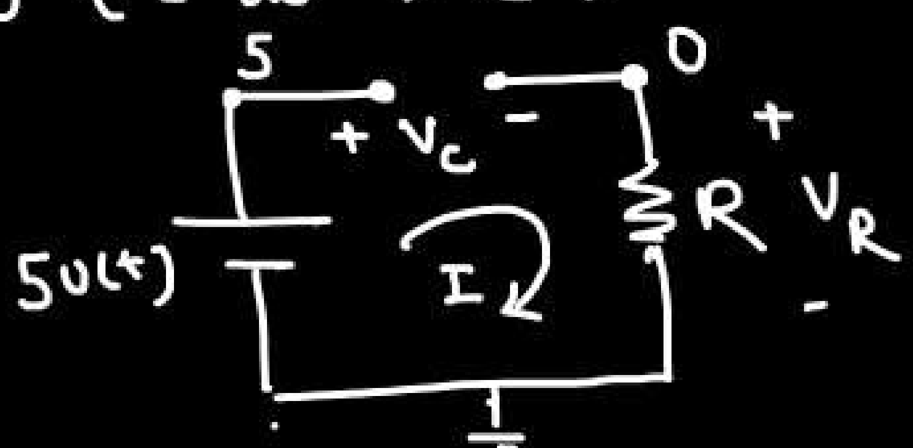


$$\left.\begin{aligned} V_c(0) &= 0V \\ V_c(0^+) &= 0V \end{aligned}\right\}$$

$I(0^+) = 5/R \to$ Finite

$V_R(0^+) = 5V$

@ $t=\infty \to C \Rightarrow O.C.$

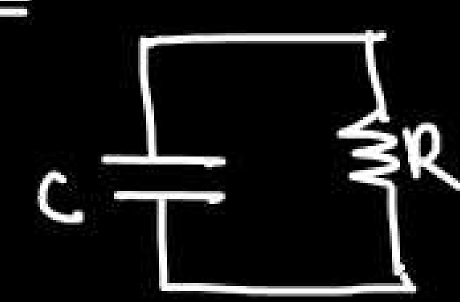


$I(\infty) = 0$ Amp.

$V_R(\infty) = 0V$

$V_c(\infty) = 5V$

$\tau \to$



$C_{eff} = C$

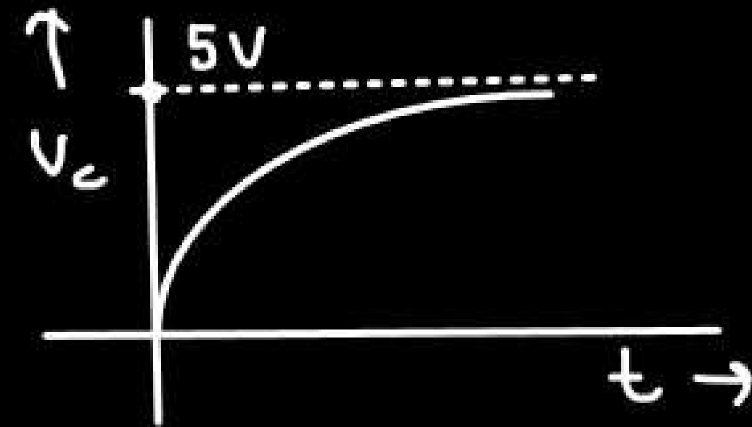
$R_{eq} = R$

$\tau = RC$

V_c :- $V_c(0^+) = 0V$, $V_c(\infty) = 5V$

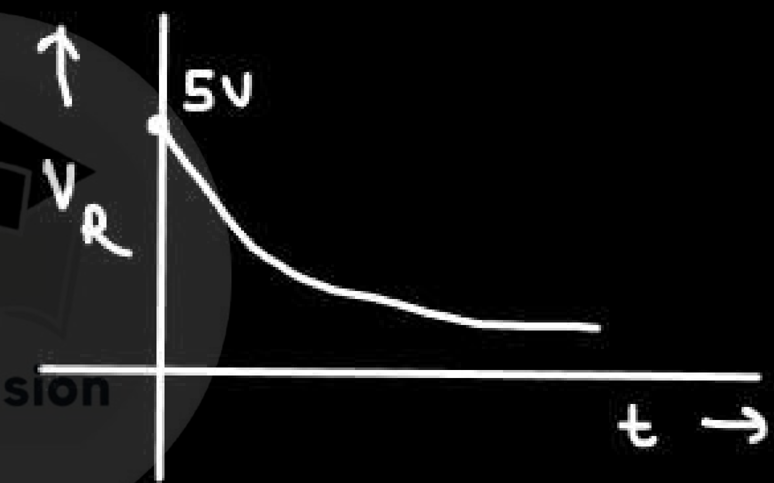
$$v_c(t) = 5 + (0-5)e^{-t/\tau}\, u(t) \; ; \quad \tau = RC$$

$$= 5\left(1 - e^{-t/\tau}\right) u(t)$$



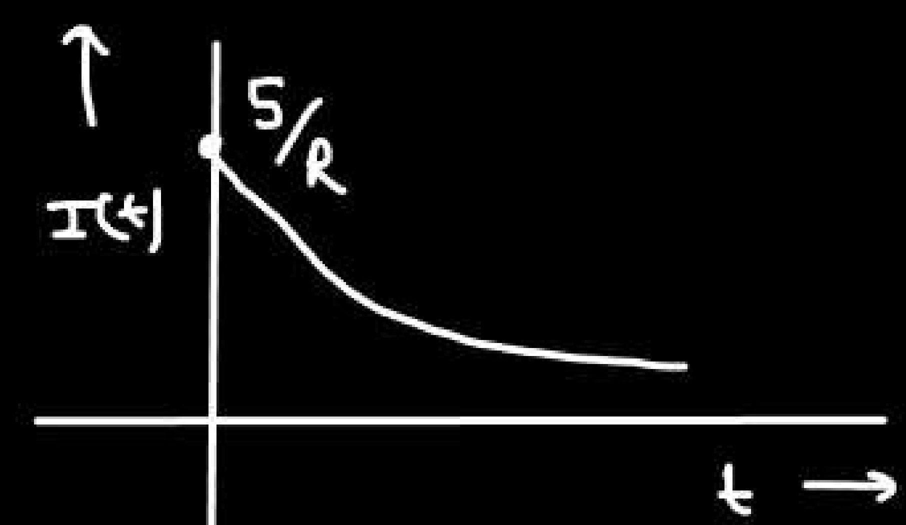
V_R :- $V_R(0^+) = 5V$, $V_R(\infty) = 0V$

$$V_R(t) = 5e^{-t/RC}\, u(t)$$

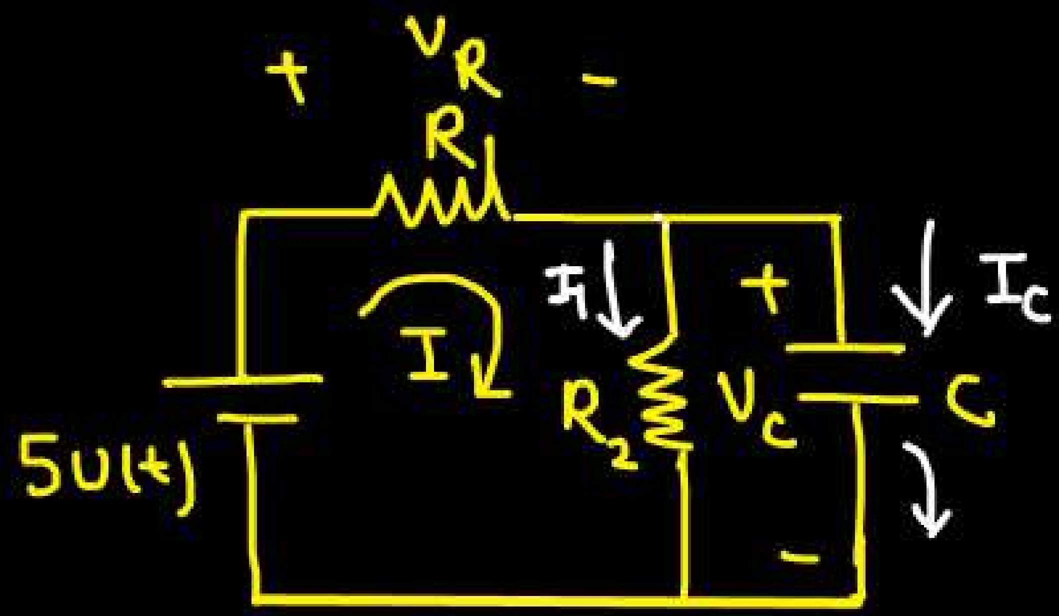


I :- $I(0^+) = 5/R$, $I(\infty) = 0$ Amp.

$$I(t) = \frac{5}{R} e^{-t/RC}\, u(t)$$



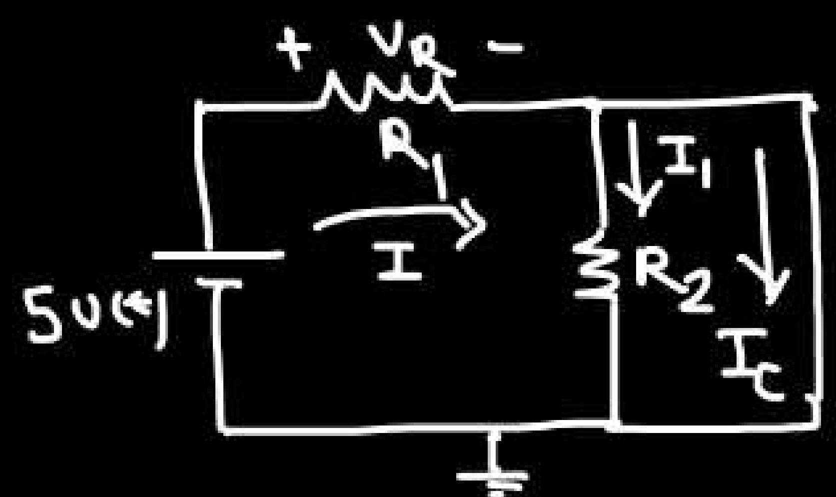
Q.



$R_1 = R$, $R_2 = 2R$

Comment on V_c, V_R & I.

→ $t=0 \rightarrow C \Rightarrow S.C.$



$I_1(0^+) = 0$ Amp.

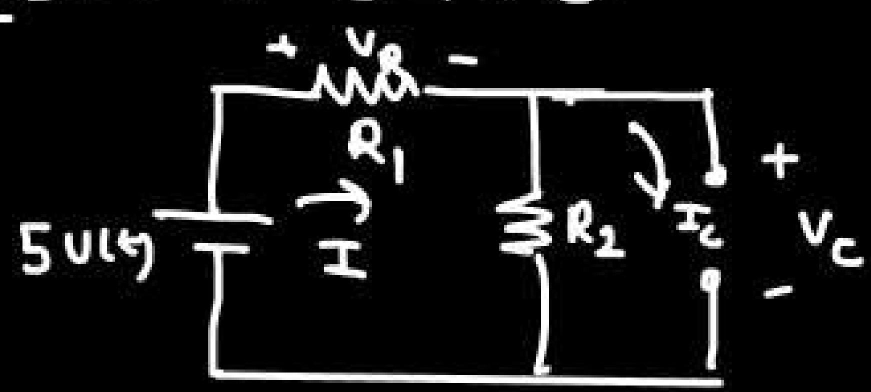
$I(0^+) = 5/R_1$

$I_c(0^+) = I(0^+) = 5/R_1 \rightarrow$ finite

$V_c(0) = 0\,V = V_c(0^+)$

$V_R(0^+) = 5\,V$

$t=\infty \rightarrow C \Rightarrow O.C.$



$I(\infty) = \dfrac{5}{R_1+R_2}$

$I_1(\infty) = \dfrac{5}{R_1+R_2}$

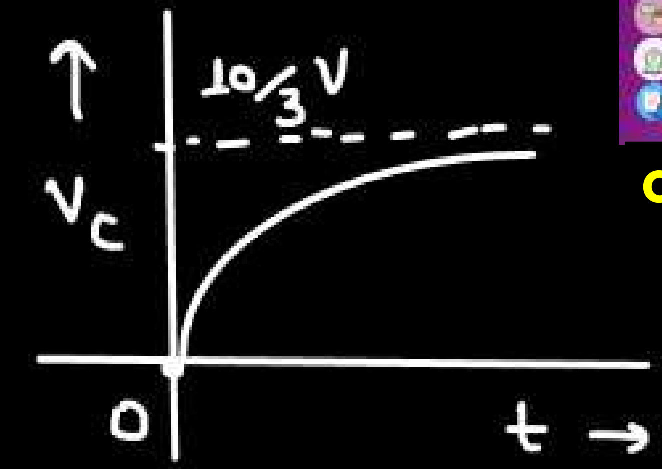
$I_c(\infty) = 0$ Amp. → Steady state

$V_c(\infty) = V_{R_2}(\infty) = \dfrac{5R_2}{R_1+R_2}$

$V_R(\infty) = \dfrac{5R_1}{R_1+R_2}$

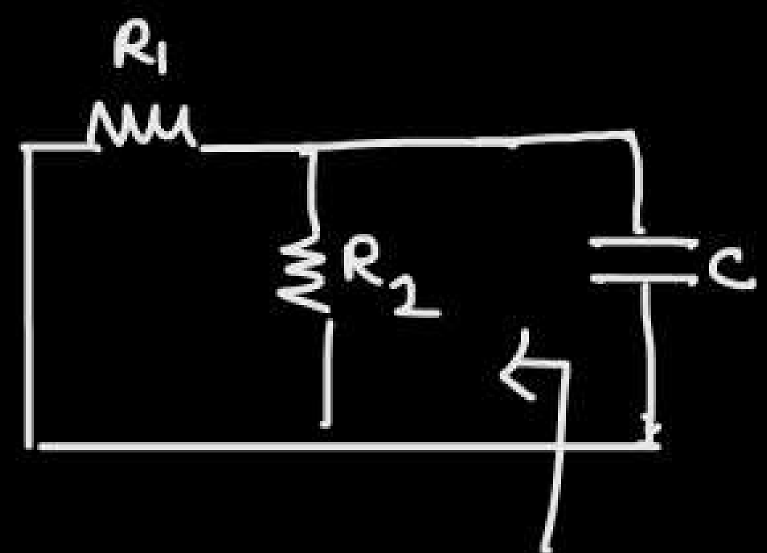
$\underline{\underline{V_c :-}}$

$$V_c(0^+) = 0\,V \quad , \quad V_c(\infty) = \frac{5R_2}{R_1+R_2} = \frac{5(2R)}{3R} = 10/3\,V$$



$$V_c(t) = 10/3\left(1 - e^{-t/\tau}\right)$$

$\underline{\underline{\tau = ?}}$



$$C_{eff} = C$$

$$R_{eq} = R_1 \| R_2 = R \| 2R = 2R/3$$

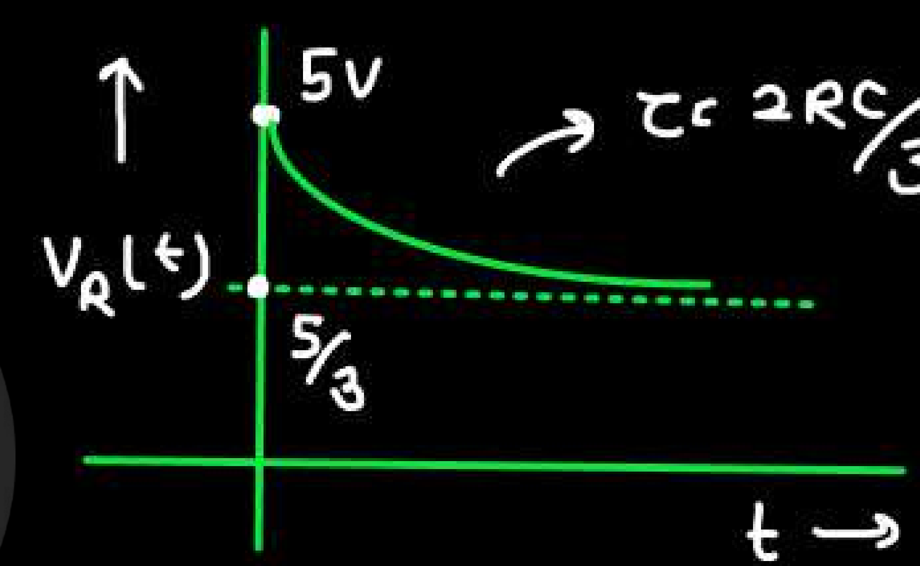
$$\tau = 2RC/3$$

$\underline{\underline{V_R}}$:-

$$V_R(0) = 5V \quad , \quad V_R(\infty) = \frac{5R_1}{R_1+R_2} = \frac{5R}{3R} = \frac{5}{3}V$$

$$V_R(t) = \frac{5}{3} + \left(5 - \frac{5}{3}\right)e^{-t/\tau}$$

$$= \frac{5}{3} + \frac{10}{3}e^{-t/\tau}$$

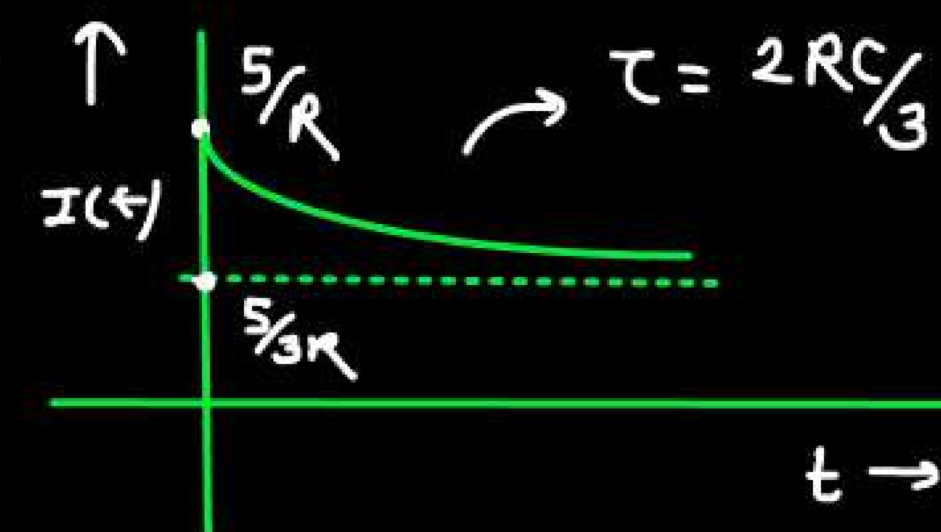


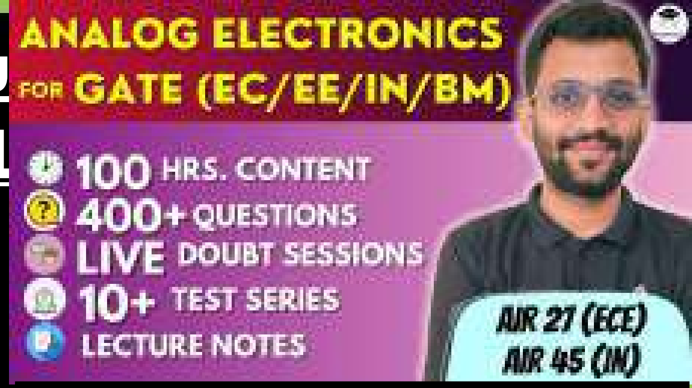
$\underline{\underline{I}}$:-

$$I_{R_1}(0) = \frac{5}{R_1} = \frac{5}{R} \; ; \quad I_{R_1}(\infty) = \frac{5}{R_1+R_2} = \frac{5}{3R}$$

$$I_{R_1}(t) = \frac{5}{3R} + \left(\frac{5}{R} - \frac{5}{3R}\right)e^{-t/\tau}$$

$$= \frac{5}{3R} + \frac{10}{3R}e^{-t/\tau}$$



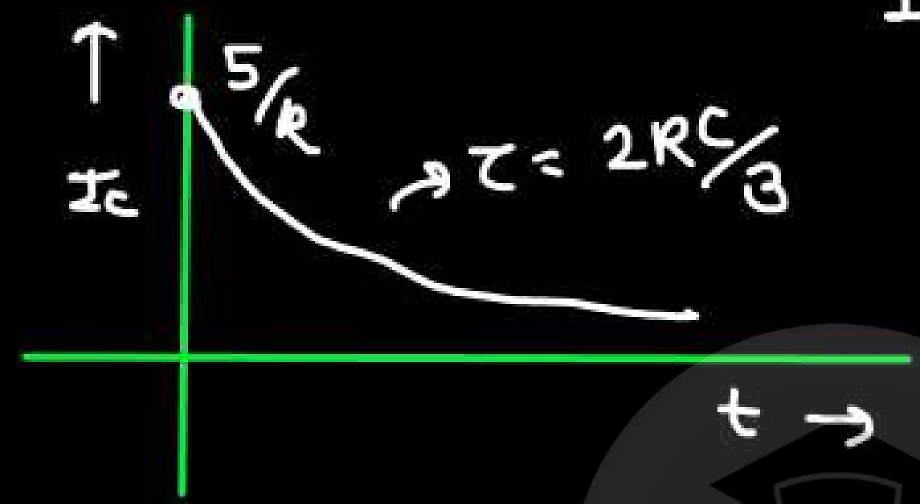


$\underline{\underline{I_c:-}}$

$I_c(0) = \frac{5}{R_1} = \frac{5}{R}$

$I_c(\infty) = 0$ Amp

$I_c(t) = \frac{5}{R} e^{-t/\tau}$

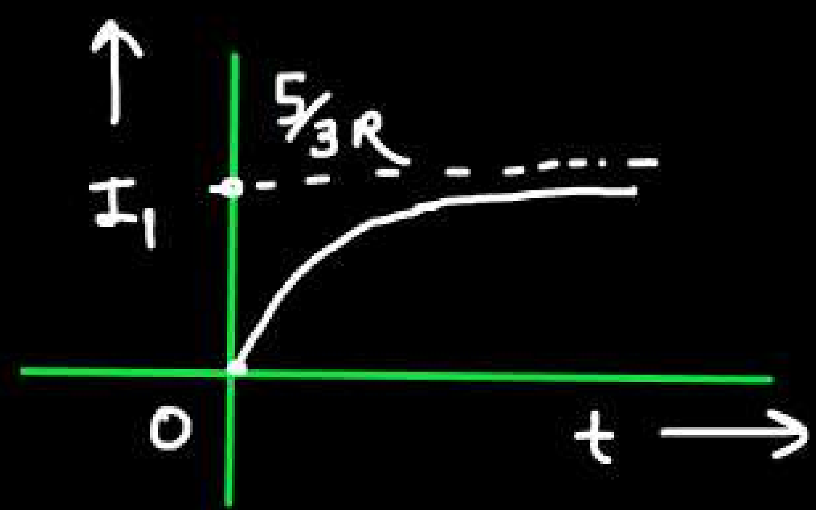


$\underline{\underline{I_1:-}}$

$I_1(0) = 0$ Amp.

$I_1(\infty) = \frac{5}{R_1 + R_2} = \frac{5}{3R}$

$I_1(t) = \frac{5}{3R}\left(1 - e^{-t/\tau}\right)$



Concept of ∞ current through capacitor:-

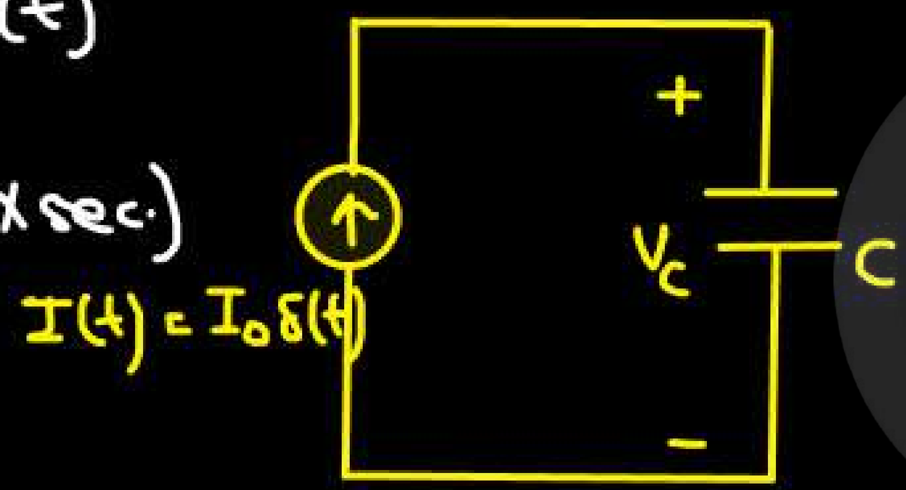
∞ current = Impulsive

$$\delta(t) = \begin{cases} \infty, & t= \\ 0, & t= \end{cases}$$

Capacitor with impulse/Infinite current Input:-

$I(t) = I_0\,\delta(t)$

I_0 → charge (A × sec.)

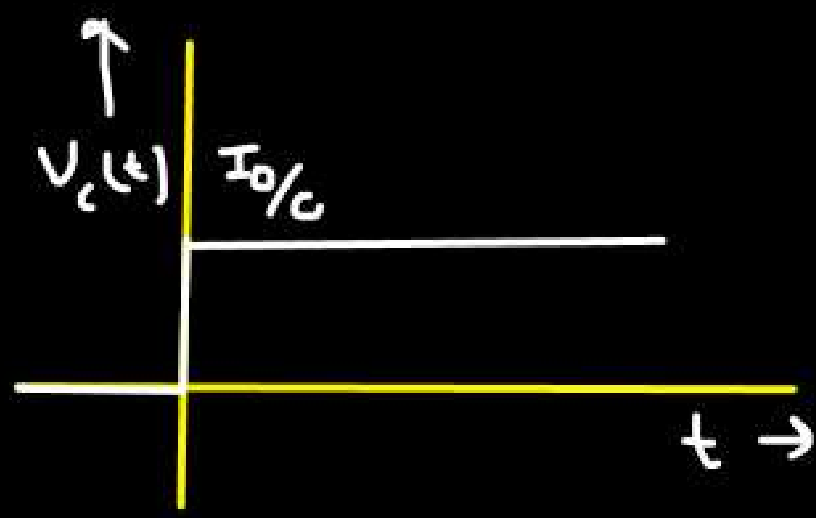


$$V_c(t) = \frac{1}{C}\int_{-\infty}^{t} I(t)\cdot dt$$

$$V_c(t) = \frac{1}{C}\int_{-\infty}^{t} I_0\,\delta(t)\cdot dt$$

$$= \frac{I_0}{C}\int_{-\infty}^{t} \delta(t)\cdot u(t)$$

$$\boxed{V_c(t) = \frac{I_0}{C}u(t)}$$



$I(t) = I_0 \delta(t)$

↳ You are giving I_0 amount of char[ge] in no time.

M-II

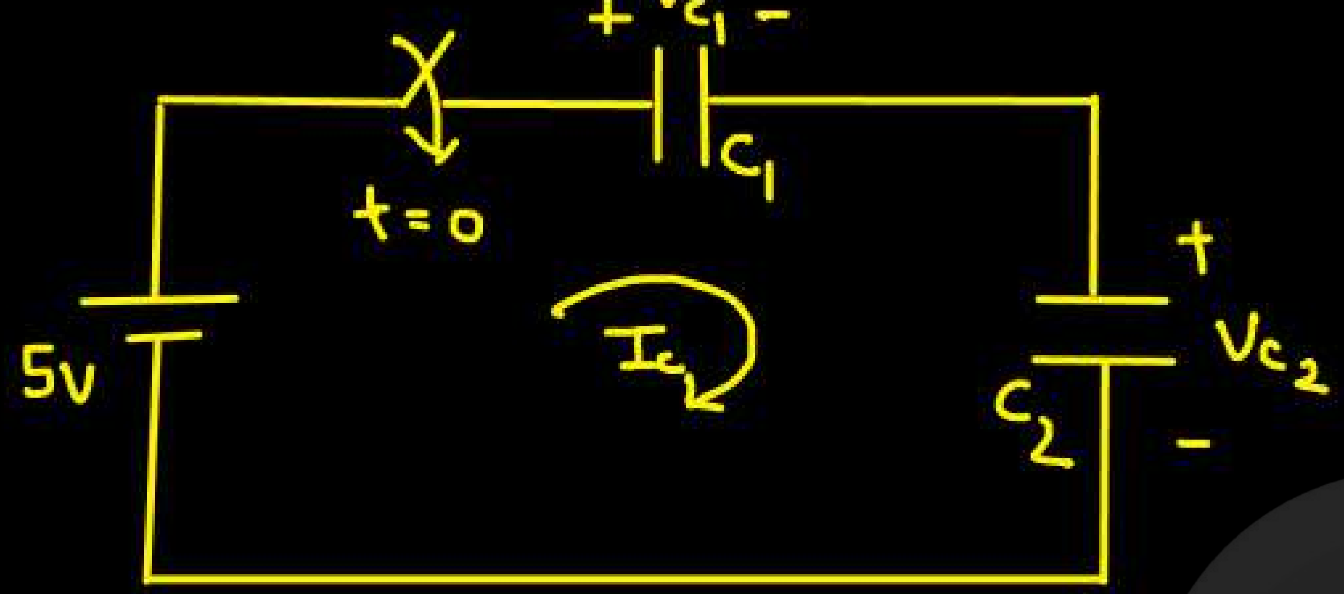
$$\left\{\begin{array}{l} \text{charge } (Q) = I_0 \\ \text{capacitor } (C) = C \\ \text{voltage } (V) = Q/C = I_0/C \end{array}\right.$$

$$\left.\begin{array}{l} V_c(0^-) = 0V \\ V_c(0^+) = I_0/C \end{array}\right\} \Rightarrow$$ The cap. doesn't follow its property of not changing the voltage immediately in case of impulse/infite current.

Imp:

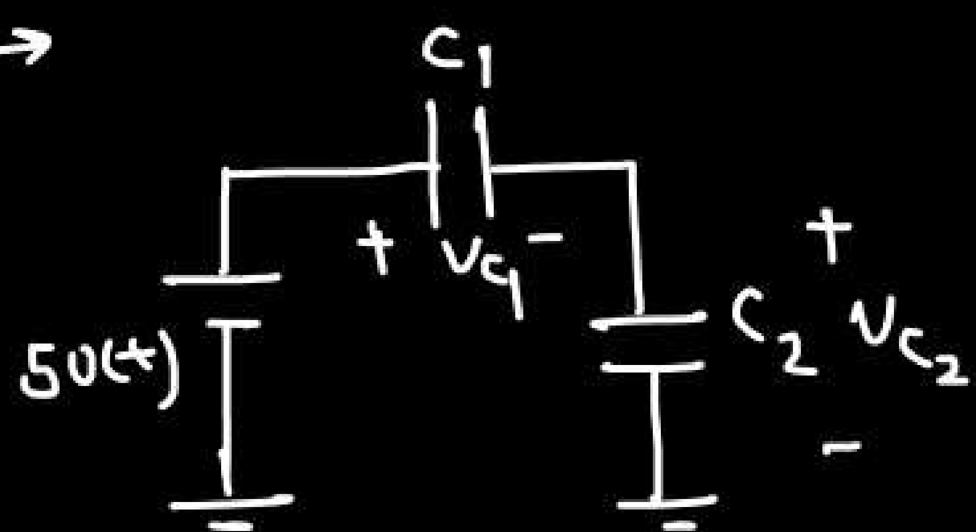
⇒ Whenever there is an infinite current flowing through the cap., it will change its voltage immediately.

Q. Draw the graph of V_{C_1} & V_{C_2}

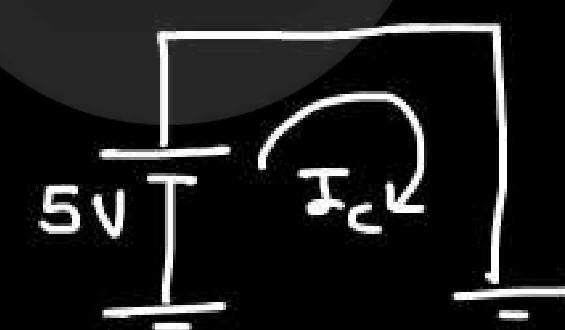


$V_{C_1}, V_{C_2}, I_C = ?$

→



ckt initially :- (@ t=0)

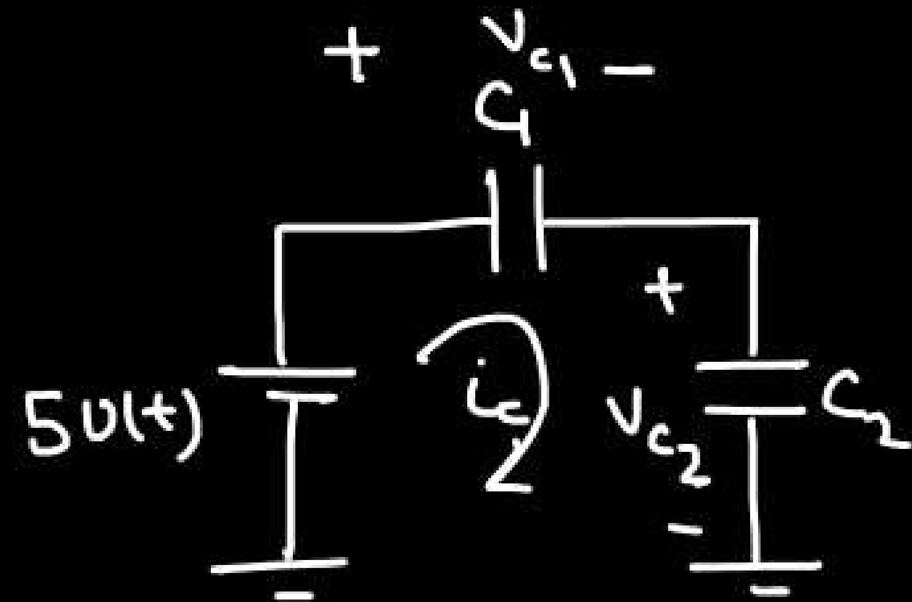


$I_C = \frac{5}{0} = \infty$ current

⇓

cap. will change it's voltage immediately.

M-I



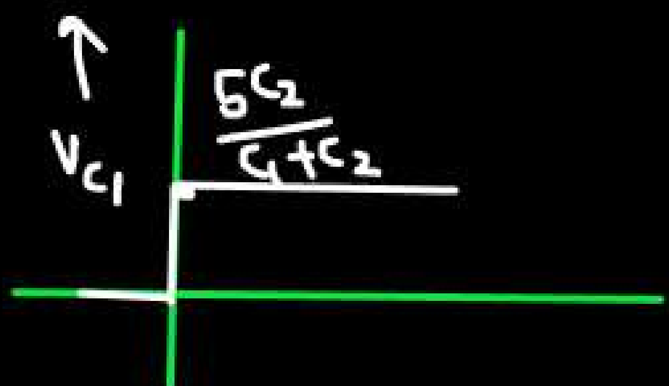
$$V_{C_2}(t) = \frac{5C_1}{C_1+C_2}u(t)$$

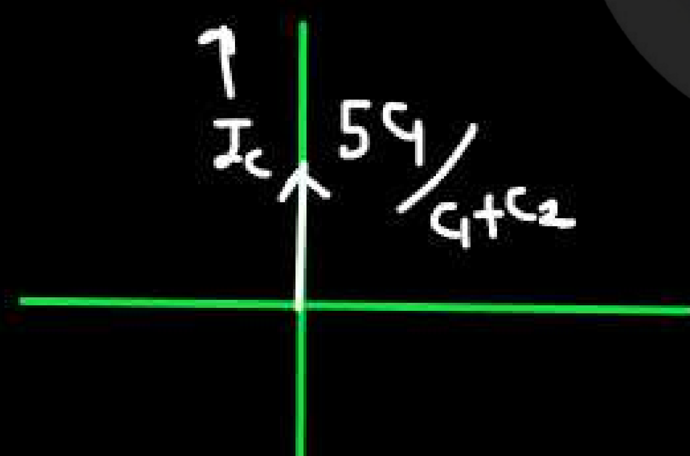
$$V_{C_1}(t) = \frac{5C_2}{C_1+C_2}u(t)$$

$$i_c(t) = C_1\frac{dV_{C_1}}{dt} = C_2\frac{dV_{C_2}}{dt}$$

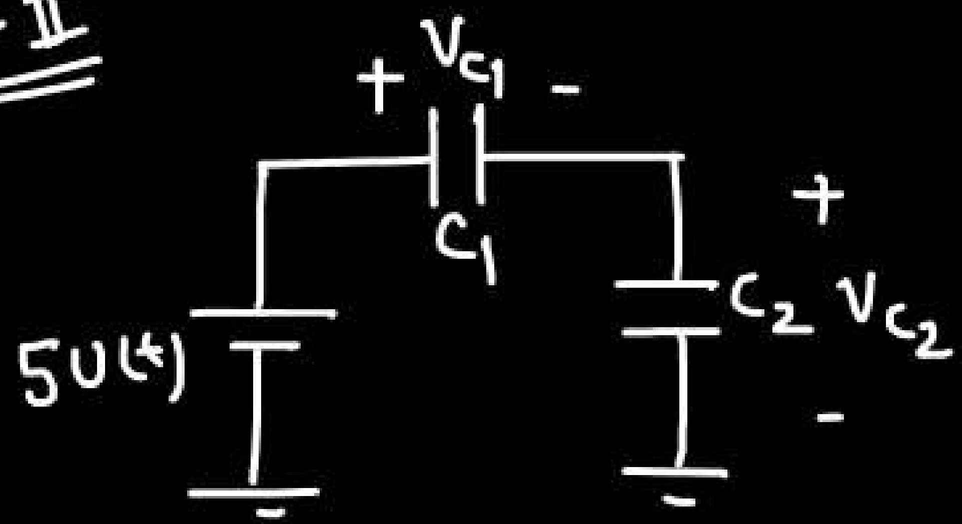
$$= C_1 \times \frac{5C_2}{C_1+C_2}\delta(t)$$

$$\boxed{i_c = \frac{5C_1C_2}{C_1+C_2}\delta(t)}$$





M - II



C_1 and C_2 is series

$\Downarrow$

current same $\Rightarrow$ charge same

$$Q_1 = Q_2$$

$$C_1 V_{C_1} = C_2 V_{C_2} \quad \text{— (1)}$$

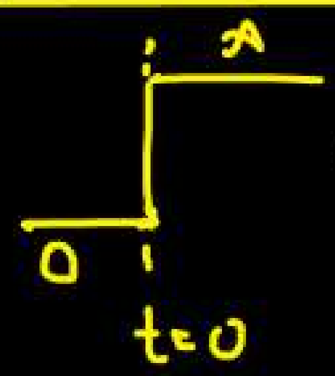
$$5u(t) = V_{C_1} + V_{C_2}$$

$$5u(t) = \frac{C_2 V_{C_2}}{C_1} + V_{C_2}$$

$$\boxed{V_{C_2}(t) = \frac{5C_1}{C_1 + C_2} u(t)}$$

$$\boxed{V_{C_1}(t) = \frac{5C_2}{C_1 + C_2} u(t)}$$

⇒ Important Concepts (For step f^n) :-



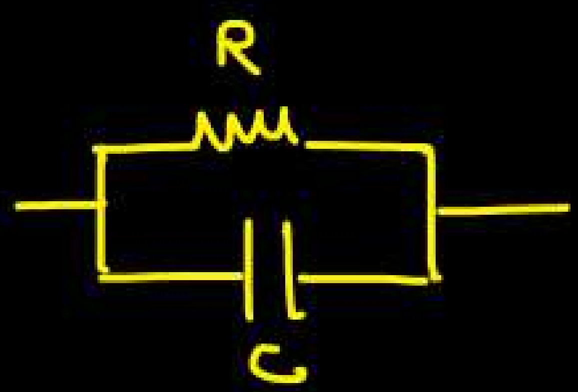
⇝ step f^n

$$u(t) = \begin{cases} 1, & t>0 \\ 0, & t<0 \end{cases}$$

impedance provided by the capacitance

@ $t=0 \Rightarrow \omega=\infty \Rightarrow Z_c = \dfrac{1}{j\omega C} \Rightarrow Z_c = \dfrac{1}{j\infty C} \approx 0 \Rightarrow$ very low

Imp.
N.B. :- For step f^n, @ $t=0$ $(\omega=\infty)$, the cap. very low impedance.



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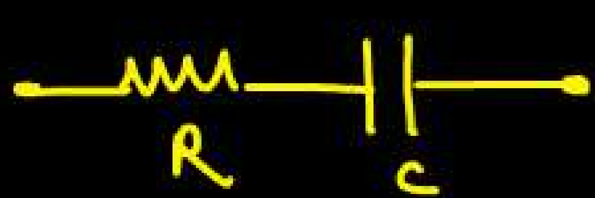
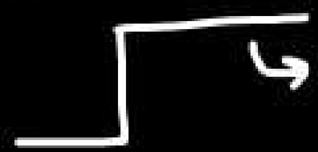


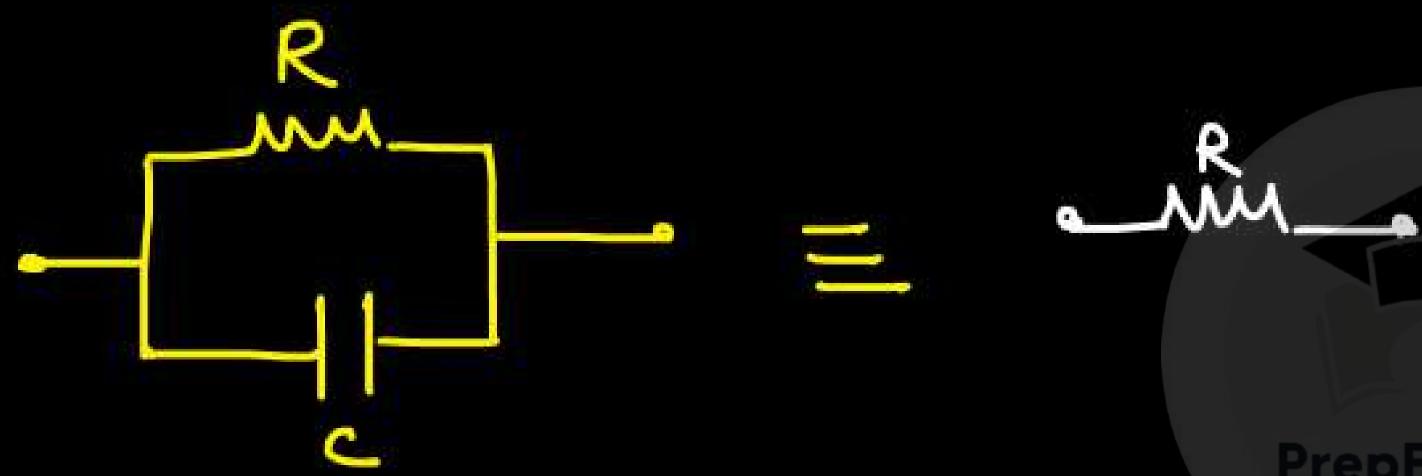
≡

@ $t = \infty$ (steady state) $\Rightarrow$ $\underline{\underline{\omega = 0}}$ $\Rightarrow$ $Z_C = \dfrac{1}{j\omega C} \approx \infty$ $\Rightarrow$ very H



$\hookrightarrow \omega = 0$ (steady state

$\Rightarrow$ N.B. - Cap. provides very High impedance @ steady state



Basic Concept of Laplace Transform:-

(Only for Network Analysis)

Time domain $\rightarrow$ frequency domain

$s = j\omega$

Laplace Transform of $x(t)$

$$X(s) = \int_{-\infty}^{\infty} x(t)\, e^{-st}\, dt$$

$$L[x(t)] = X(s)$$

☆ $L[u(t)] = ?$

$x(t) = u(t)$

$L[x(t)] = X(s)$

$$X(s) = \int_{-\infty}^{\infty} x(t)\, e^{-st}\, dt$$

$$X(s) = \int_{-\infty}^{\infty} u(t)\, e^{-st}\, dt$$

$$X(s) = \int_{0}^{\infty} 1\, e^{-st}\, dt$$

$$= -\frac{1}{s}\left[e^{-st}\right]_0^{\infty}$$

$$= \frac{-1}{s}\left[e^{-\infty} - e^{0}\right]$$

$$\boxed{X(s) = \frac{1}{s}}$$

$$\mathcal{L}[u(t)] = \frac{1}{s}$$

$$\mathcal{L}[A\,u(t)] = \frac{A}{s}$$

Some Laplace Transforms important to remember:-

1. $L[A\,u(t)] = A/s$
2. $L[A\,r(t)] = A/s^2$
3. $L[A\,\delta(t)] = A$
4. * $L[e^{-at}u(t)] = \frac{1}{s+a}$
5. * $L[\cos at\, u(t)] = \frac{s}{s^2+a^2}$
6. * $L[\sin at\, u(t)] = \frac{a}{s^2+a^2}$
7. $L[x_1(t) \pm x_2(t)] = X_1(s) \pm X_2(s)$
8. $L[x(t-t_0)] = e^{-st_0}X(s)$

$$\delta(t) \rightarrow u(t) \rightarrow r(t)$$
$$1 \rightarrow 1/s \rightarrow 1/s^2$$

(9) $L\left[\int_0^t x(t)\cdot dt\right] = \dfrac{X(s)}{s}$

$\int_{-\infty}^{t} \rightarrow 1/s$

(10) $L\left[\dfrac{dx(t)}{dt}\right] = sX(s) - x(0)$

$\dfrac{d}{dt} \rightarrow s$

(11) $L\left[\dfrac{d^2x(t)}{dt^2}\right] = s^2X(s) - s\,x(0) - x'(0)$

$\left\{ x(0) = x(t=0) \neq X(s=0) \right\}$

$x'(0) = \left[\dfrac{d}{dt}x(t)\right]_{t=0}$

(12) $L\left[\dfrac{d^nx(t)}{dt^n}\right] = s^nX(s) - s^{n-1}x(0) - s^{n-2}x'(0) - \cdots - s^0x^{n-1}(0)$

(13) $L\left[e^{-at}x(t)\right] = X(s+a)$

Eg → $L[r(t)] = 1/s^2$

$L[u(t)] = ?$

$$\frac{d}{dt} r(t) = u(t)$$

$$\frac{s}{s^2} = L[u(t)]$$

$$\Rightarrow \boxed{L[u(t)] = 1/s}$$

Eg. $\rightarrow$ $L[u(t)] = 1/s$

$L[e^{-at}u(t)] = \dfrac{1}{s+a}$

(14) $L[t \cdot x(t)] = -\dfrac{d}{ds}X(s)$

Eg. $\rightarrow$ $L[e^{-at}u(t)] = \dfrac{1}{s+a}$

$L[t \cdot e^{-at}u(t)] = -\dfrac{d}{ds}\left[\dfrac{1}{s+a}\right]$

$$\boxed{L[t \cdot e^{-at}u(t)] = \frac{1}{(s+a)^2}}$$

Eg. $\rightarrow$ $L[u(t)] = 1/s$

$L[t\,u(t)] = ?$

or

$L[r(t)] = ?$

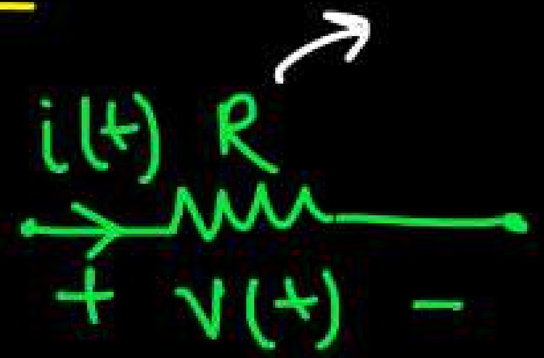
$L[t\,u(t)] = -\dfrac{d}{ds}\left[1/s\right]$

$$\boxed{L[r(t)] = 1/s^2}$$

$\Rightarrow$ Laplace Transforms of Circuit elements:-

① Resistor:-

$$Z_R = R \neq f(t)$$



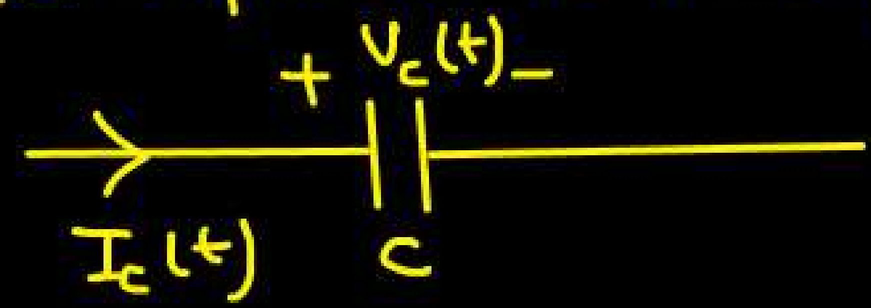
$$v(t) = i(t) \times R$$

$$\frac{v(t)}{i(t)} = R \Rightarrow z(t) = R$$

$$\boxed{Z(s) = R}$$

② Capacitor :-

☆ Assume capacitor is having no initial Voltage.



$V_c(0^-) = 0\,V$

$$I_c(t) = C\frac{dV_c(t)}{dt}$$

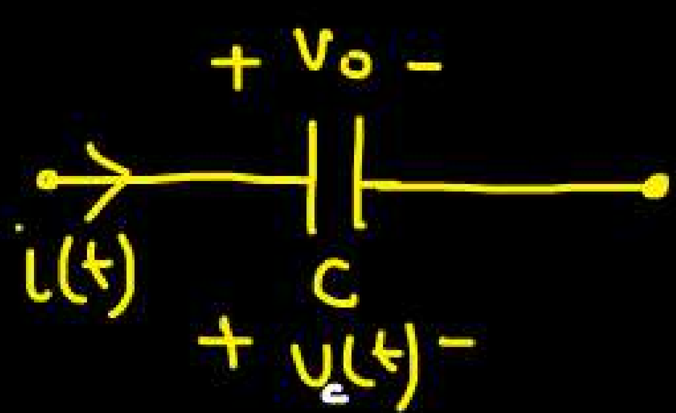
$$I_c(s) = C\left[sV_c(s) - \overset{0}{V_c(0)}\right]$$

$$I_c(s) = CsV_c(s)$$

$$\boxed{\frac{V_c(s)}{I_c(s)} = Z(s) = 1/Cs}$$

→ Impedance provided by the cap. in Laplace Transform.

* Capacitor is having some initial voltage :-



$\Rightarrow V_c(0) = V_0$

$$I_c(S) = C\left[SV_c(S) - V_c(0)\right]$$

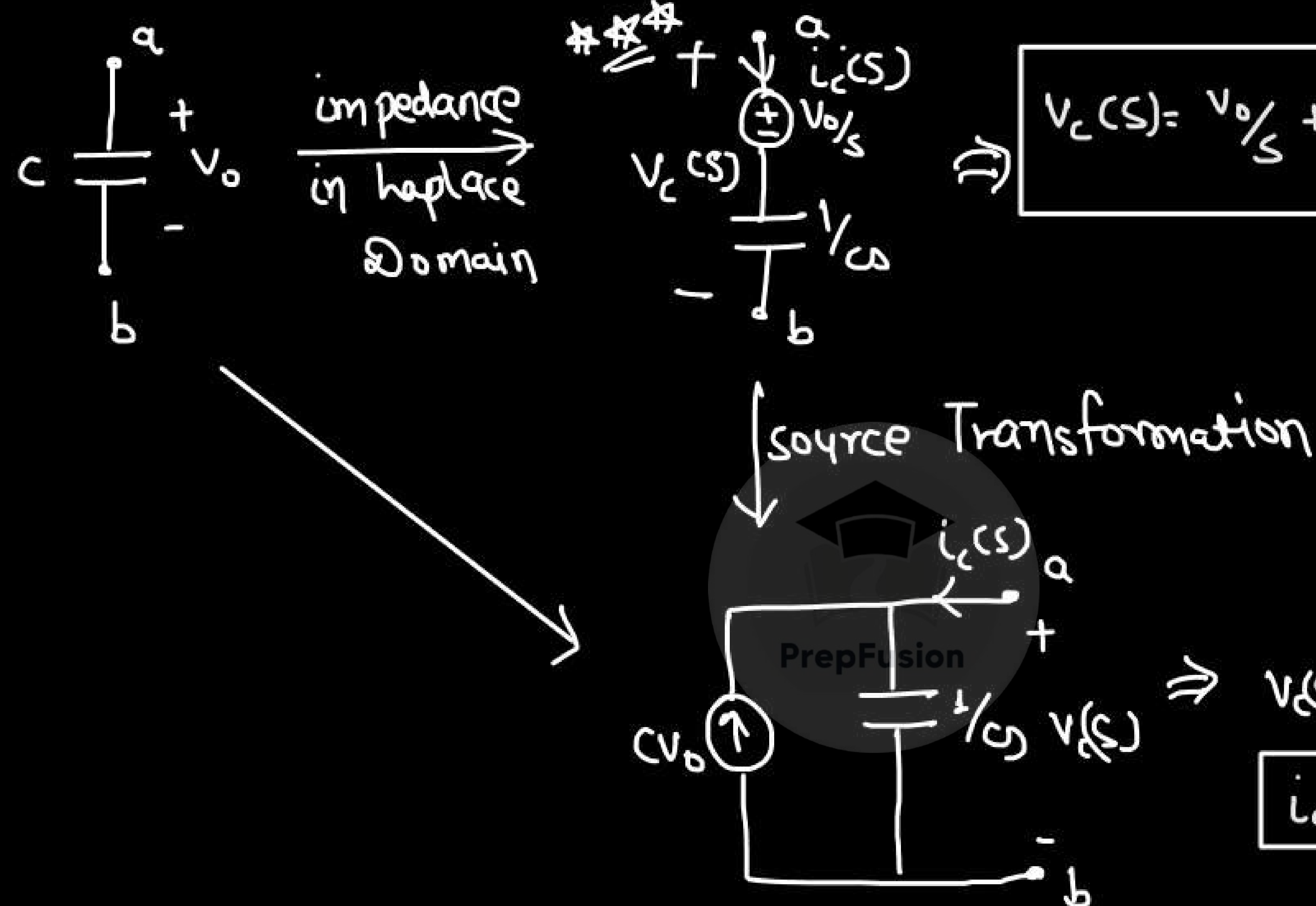
$$I_c(S) = C\left[SV_c(S) - V_0\right]$$

$$I_c(S) = CSV_c(S) - CV_0$$

$$CSV_c(S) = I_c(S) + CV_0$$

$$\boxed{V_c(S) = \underbrace{\frac{I_c(S)}{CS}} + V_0/S}$$

$$\rightarrow \frac{V_c(S)}{I_c(S)} = 1/CS$$



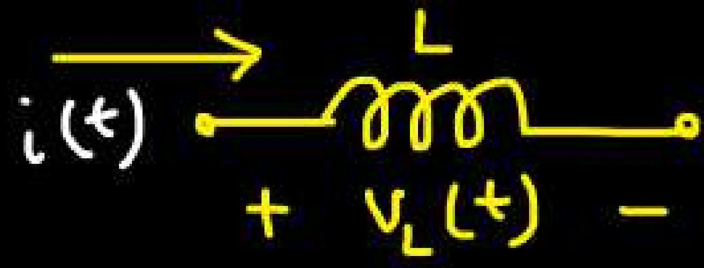
$$\Rightarrow \boxed{V_c(s) = \frac{V_o}{s} + \frac{i_c(s)}{sC}}$$

$$\Rightarrow V_c(s)\,cs = i_c(s) - CV_o$$

$$\boxed{i_c(s) = V_c(s)\,cs + CV_o}$$

③ Inductor :-

* Inductor is having no initial current.



$$V_L(t) = L\frac{di_L(t)}{dt}$$

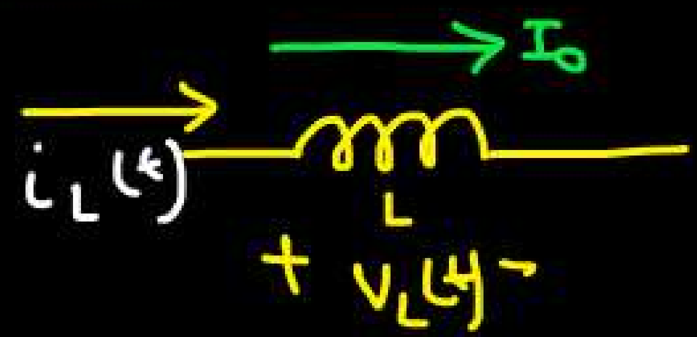
$$V_L(S) = L\left[S I_L(S) - \cancelto{0}{i_L(0)}\right]$$

$$V_L(S) = LS\, I_L(S)$$

$$\boxed{\frac{V_L(S)}{I_L(S)} = Z(S) = LS}$$

→ Impedance provided by the inductor in Laplace domain.

* Inductor is having some initial current

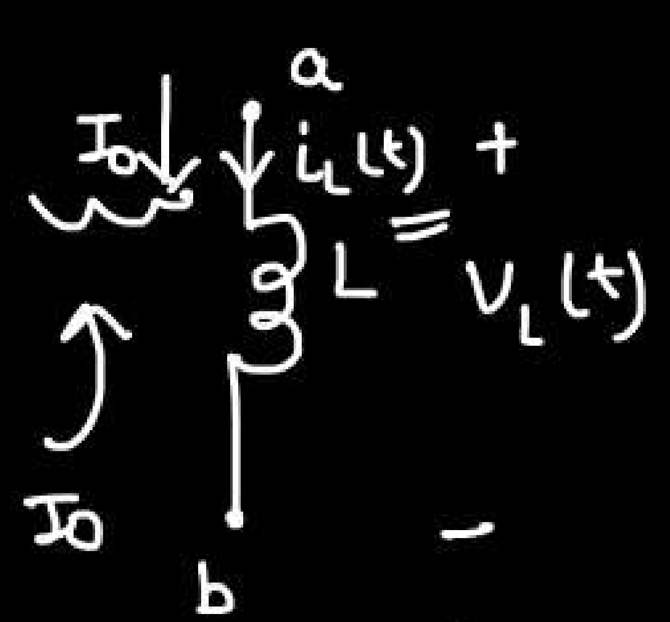


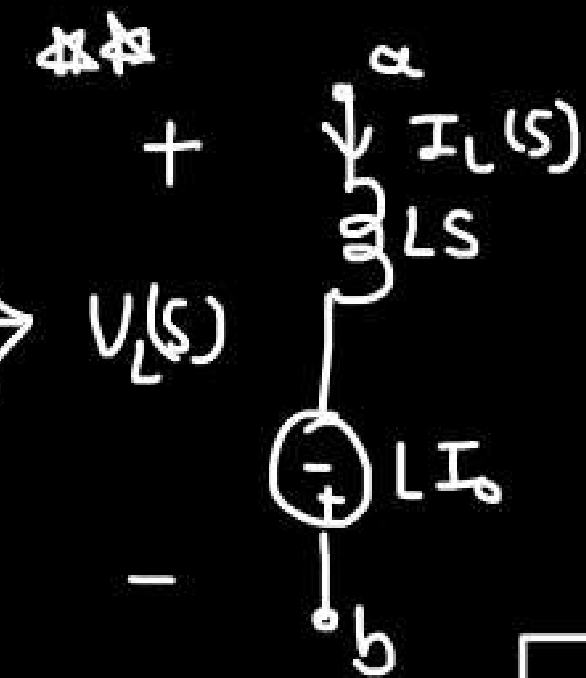
$$V_L(s) = L\left[s I_L(s) - i_L(0)\right]$$

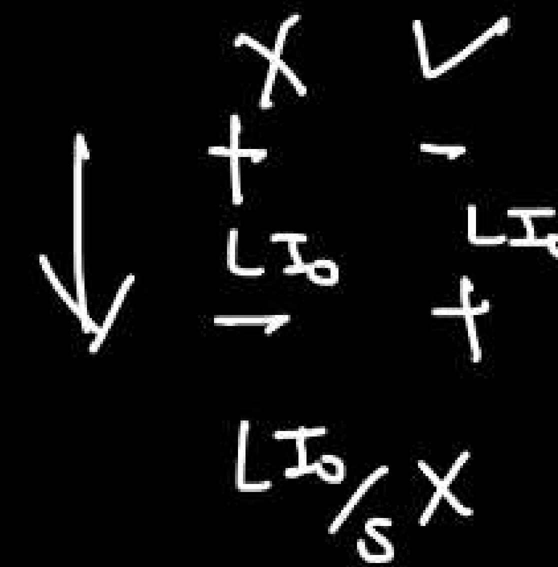
$$V_L(s) = L\left[s I_L(s) - I_0\right]$$

$$\boxed{V_L(s) = Ls\, I_L(s) - L I_0}$$

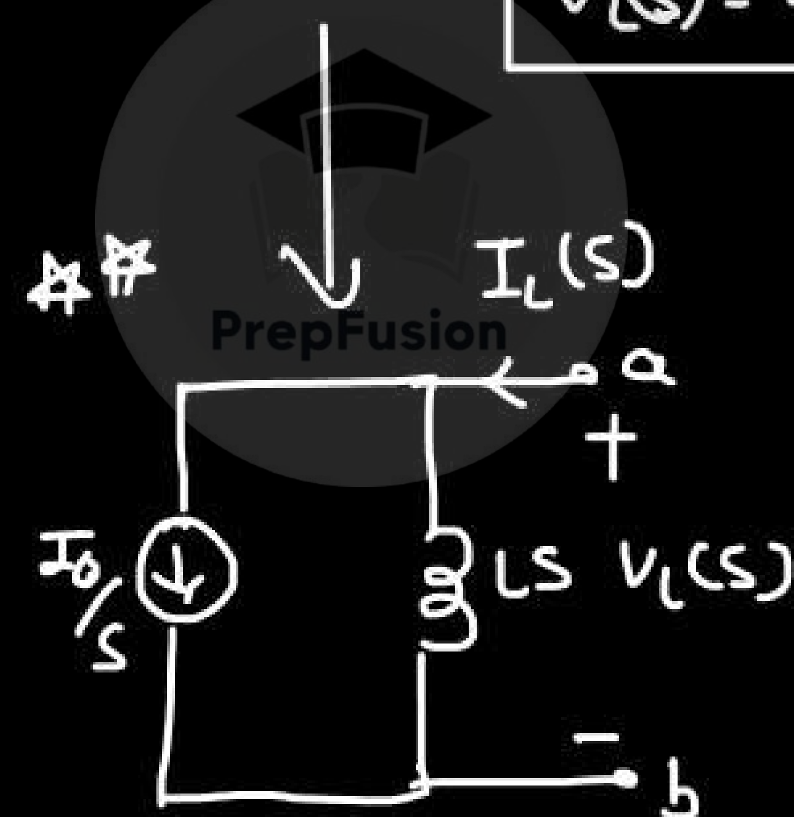
$$\boxed{I_L(s) = \frac{V_L(s)}{Ls} + \frac{I_0}{s}}$$





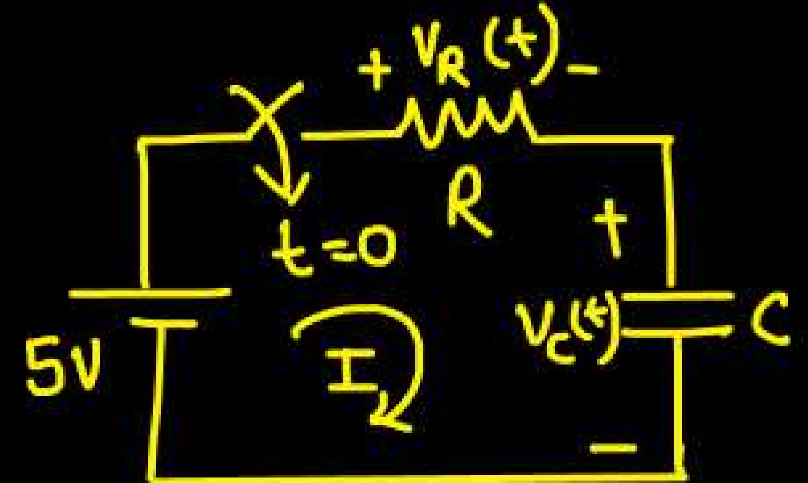


$$\boxed{V_L(s) = I_L(s) - LI_0}$$



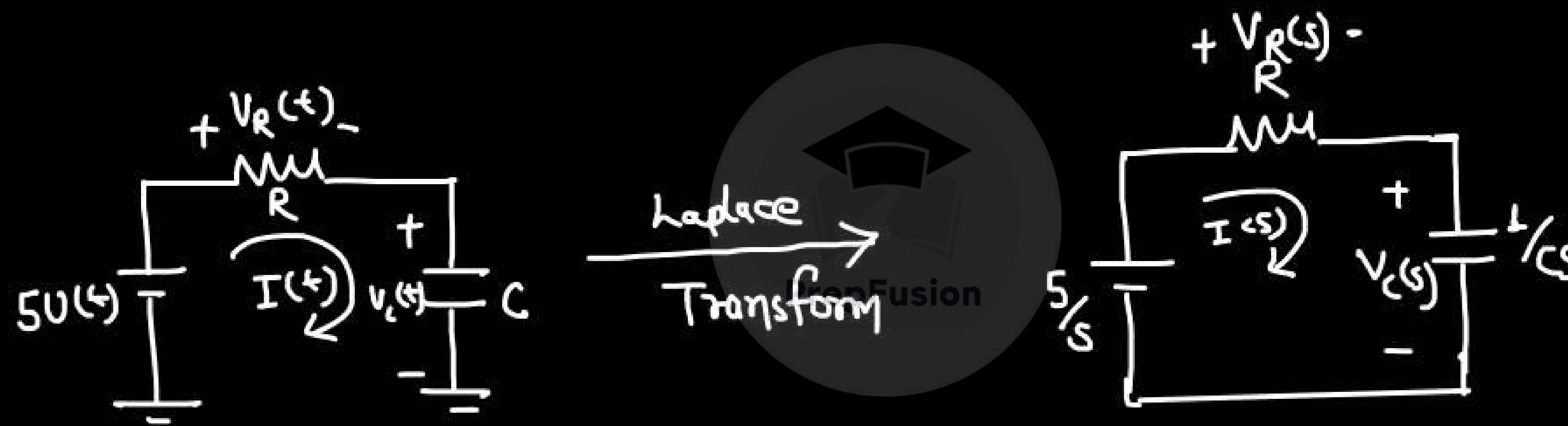
$$\boxed{I_L(s) = \frac{V_L(s)}{Ls} + \frac{I_0}{s}}$$

Q. Solve the ckt using Laplace Transform.



Find $V_C(t)$, $V_R(t)$ & $I(t)$?

→



KVL :-

$$\frac{5}{s} = I(s) \times R + I(s) \times \frac{1}{Cs}$$

$$\frac{5}{s} = I(s)\left[\frac{RCs+1}{Cs}\right]$$

$$\frac{5}{s} = I(s)\left[\frac{RCs+1}{Cs}\right]$$

$$I(s) = \frac{5C}{RCs+1} \qquad (1)$$

$$I(s) = \frac{5C/RC}{s+1/RC}$$

$$I(s) = \frac{5}{R}\left[\frac{1}{s+1/RC}\right]$$

$$\boxed{i(t) = \frac{5}{R}e^{-t/RC}\,u(t)}$$

$$\because \left\{ \mathcal{L}^{-1}\left[\frac{1}{s+a}\right] = e^{-at}u(t) \right\}$$

② $V_R(s)$:-

$$V_R(s) = R \cdot I(s)$$

By eqⁿ ①

$$V_R(s) = \frac{5RC}{RCs+1}$$

$$V_R(s) = \frac{5}{s+1/RC}$$

$$\boxed{v_R(t) = 5e^{-t/RC}\,u(t)}$$

$V_c(s)$:-

$$V_c(s) = \frac{1}{Cs} I(s)$$

$$= \frac{1}{Cs}\left[\frac{5C}{RCs+1}\right]$$

$$V_c(s) = \frac{5}{s(RCs+1)}$$

$$\downarrow$$

$$= \frac{A}{s} + \frac{B}{RCs+1}$$

$$\Rightarrow A(RCs+1) + Bs = 5$$

$$\Rightarrow ARC + B = 0$$

$$A = 5$$

$$B = -5RC$$

$$V_c(s) = \frac{5}{s} - \frac{5RC}{RCs+1}$$

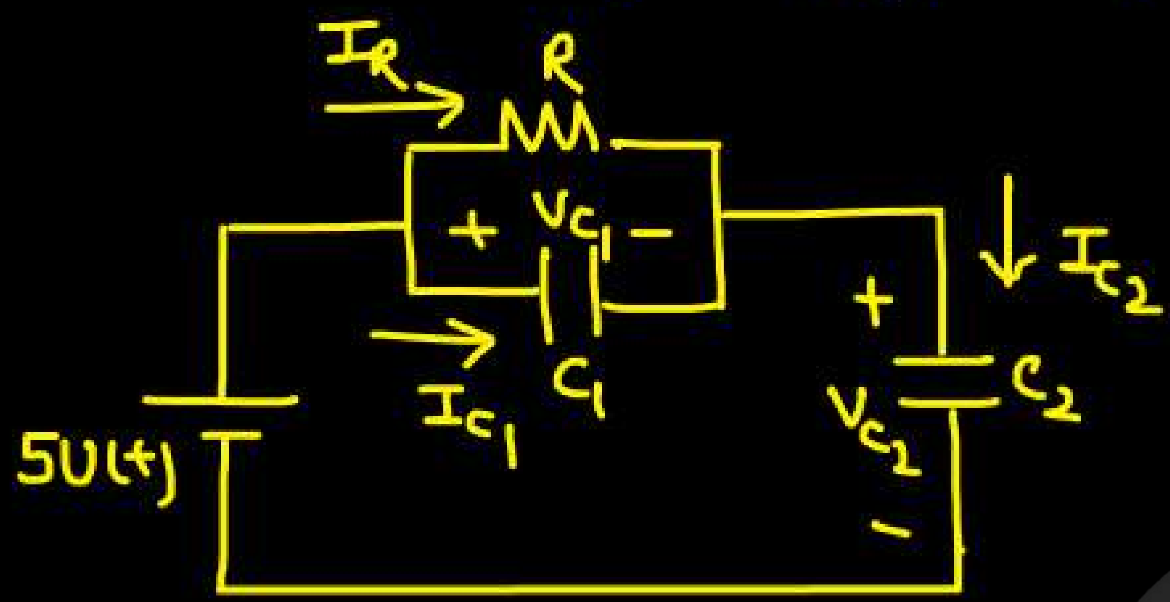
$$V_c(s) = \frac{5}{s} - \frac{5}{s+1/RC}$$

$$v_c(t) = 5u(t) - 5e^{-t/RC}u(t)$$

$$\boxed{v_c(t) = 5\left[1-e^{-t/RC}\right]u(t)}$$

Q. Find V_{C_1}, V_{C_2}, I_{C_1}, I_{C_2}, I_R

(a)

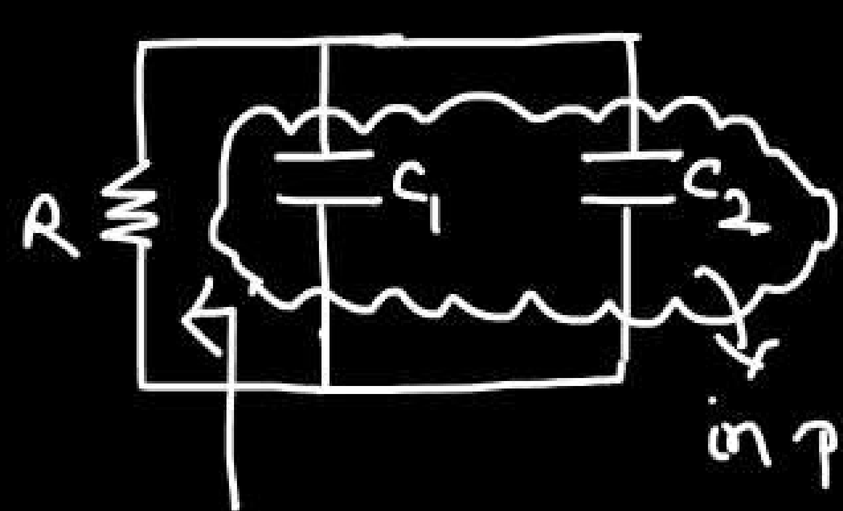


Take $C_1 = C_2 = C$

$R = 1\Omega$

→ Two cap → 2^{nd} order ckt → $\underset{=}{\times}$ NO

Find effective storing element



in parallel

$C_{eff} = C_1 + C_2$

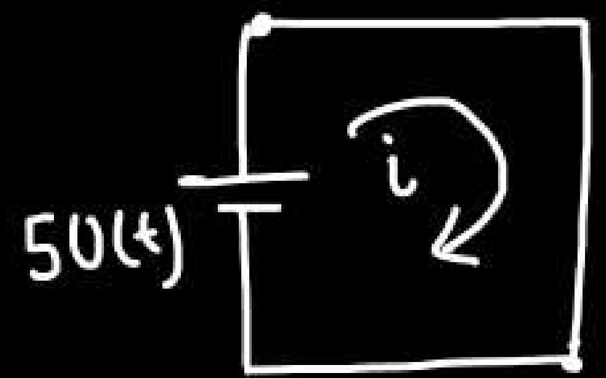
$R_{eq} = R$

$\Rightarrow$ $\boxed{\tau = R(C_1 + C_2)}$

1^{st} order

⇒ Effective storing ele. is only one cap. $(C_1 + C_2)$

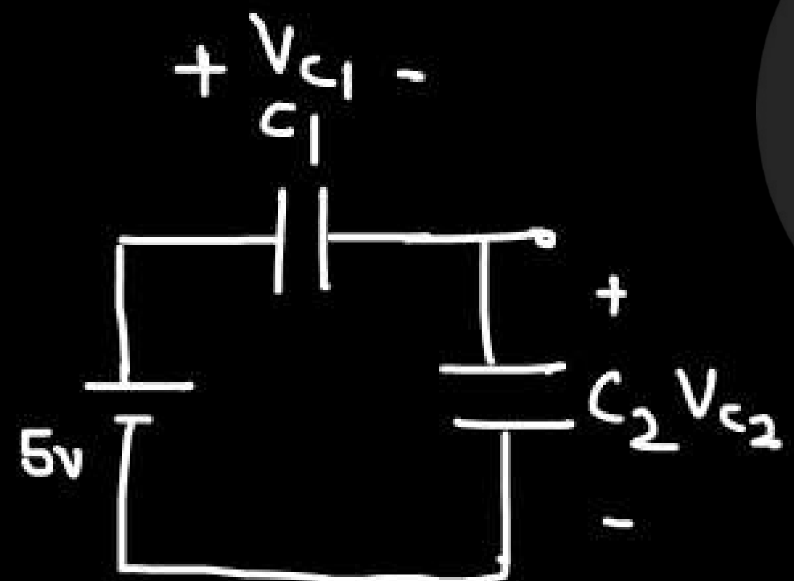
ckt @ $t=0$

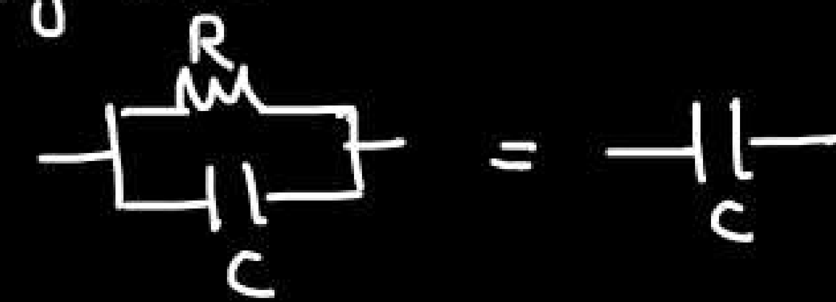


$i = \frac{5}{0} = \infty \Rightarrow$ capacitor voltage will change immediately.

For step i/p:- @ $t=0 \Rightarrow \omega = \infty \Rightarrow Z_c = \frac{1}{j\omega C}$ ~~> very low

@ $t=0$

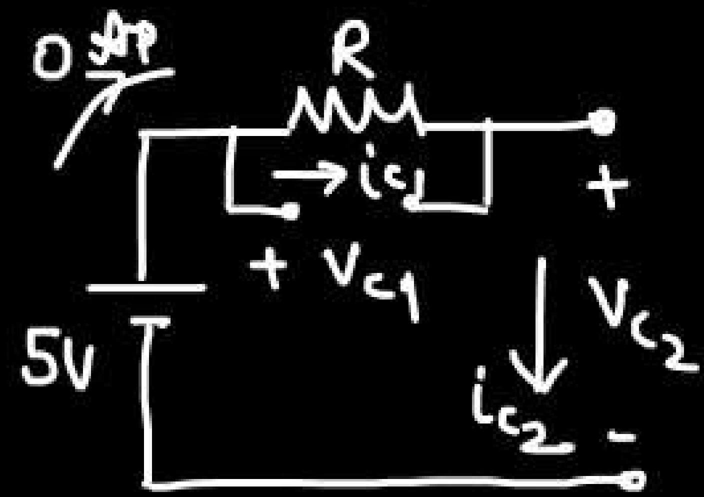




$V_{c_1}(0^-) = 0V$, $V_{c_1}(0^+) = \frac{5C_2}{C_1+C_2}$ V

$V_{c_2}(0^-) = 0V$, $V_{c_2}(0^+) = \frac{5C_1}{C_1+C_2}$ V

@ $t=\infty \Rightarrow$ Cap. acts as o.c.



$V_{c_1}(\infty) = 0V$

$V_{c_2}(\infty) = 5V$

$i_{c_1}(\infty) = i_{c_2}(\infty) = 0$ Amp

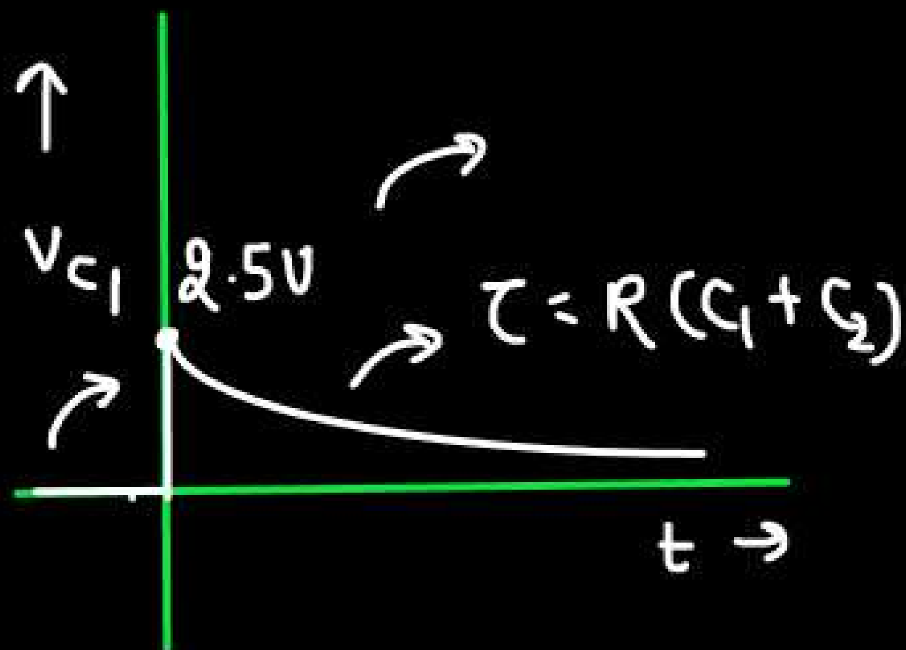
$\Rightarrow V_{c_1}(0^+) = \dfrac{5C_2}{C_1+C_2} = 2.5V$ (taking $C_1 = C_2 = C$) , $V_{c_1}(\infty) = 0V$

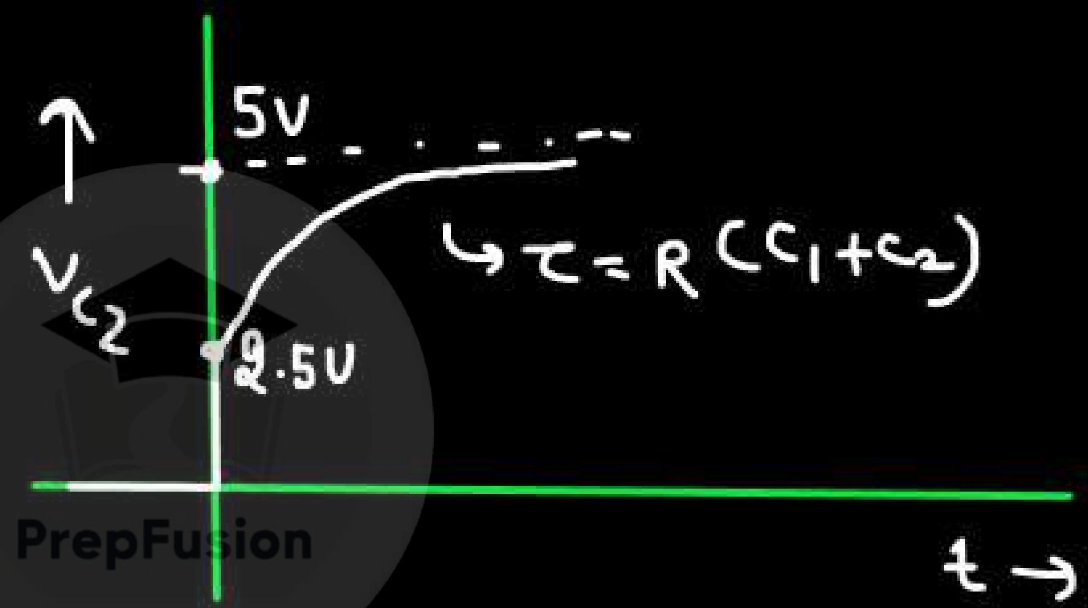
$$\boxed{V_{c_1}(t) = \frac{5C_2}{C_1+C_2} e^{-t/\tau} u(t) = 2.5e^{-t/\tau} u(t)}$$ $\tau = R(C_1+C_2)$

$\Rightarrow V_c(0^+) = \dfrac{5C_1}{C_1+C_2} = 2.5V$, $V_c(\infty) = 5V$

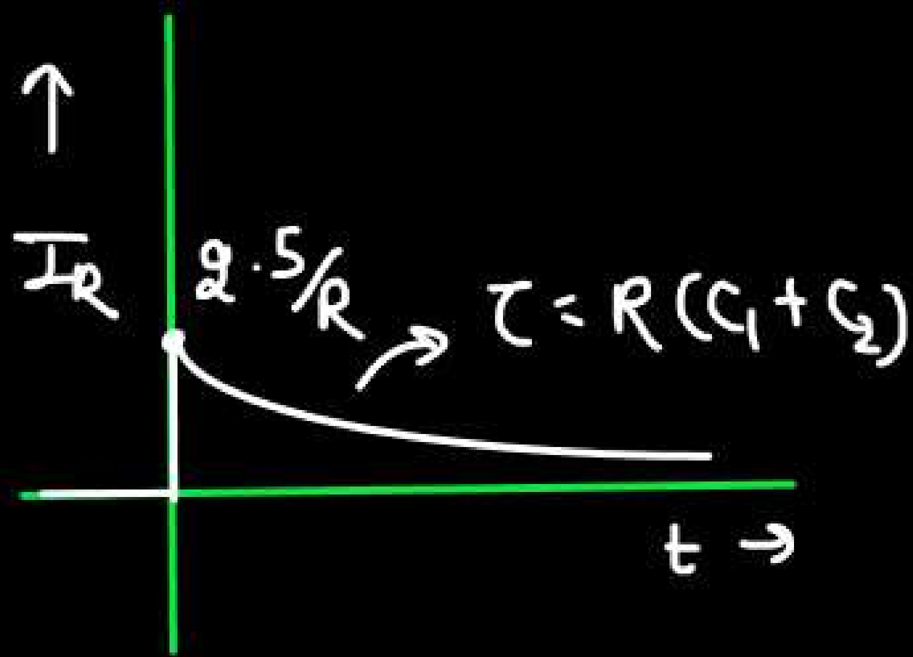
$$V_{c_2}(t) = \left[5 + (2.5 - 5)\, e^{-t/\tau}\right] u(t)$$

$$\boxed{V_{c_2}(t) = \left[5 - 2.5\, e^{-t/\tau}\right] u(t)} \qquad \tau = R(C_1 + C_2)$$





$$\boxed{I_R = \frac{\text{Voltage across resistor}}{R} = \frac{V_{c_1}}{R} = \frac{2.5}{R} e^{-t/\tau} u(t)} \quad \tau = R(C_1 + C_2)$$



$$\boxed{x(t)\cdot\delta(t) = x(0)}$$

$\underline{I_{c_1}\ \&\ I_{c_2} = ?}$

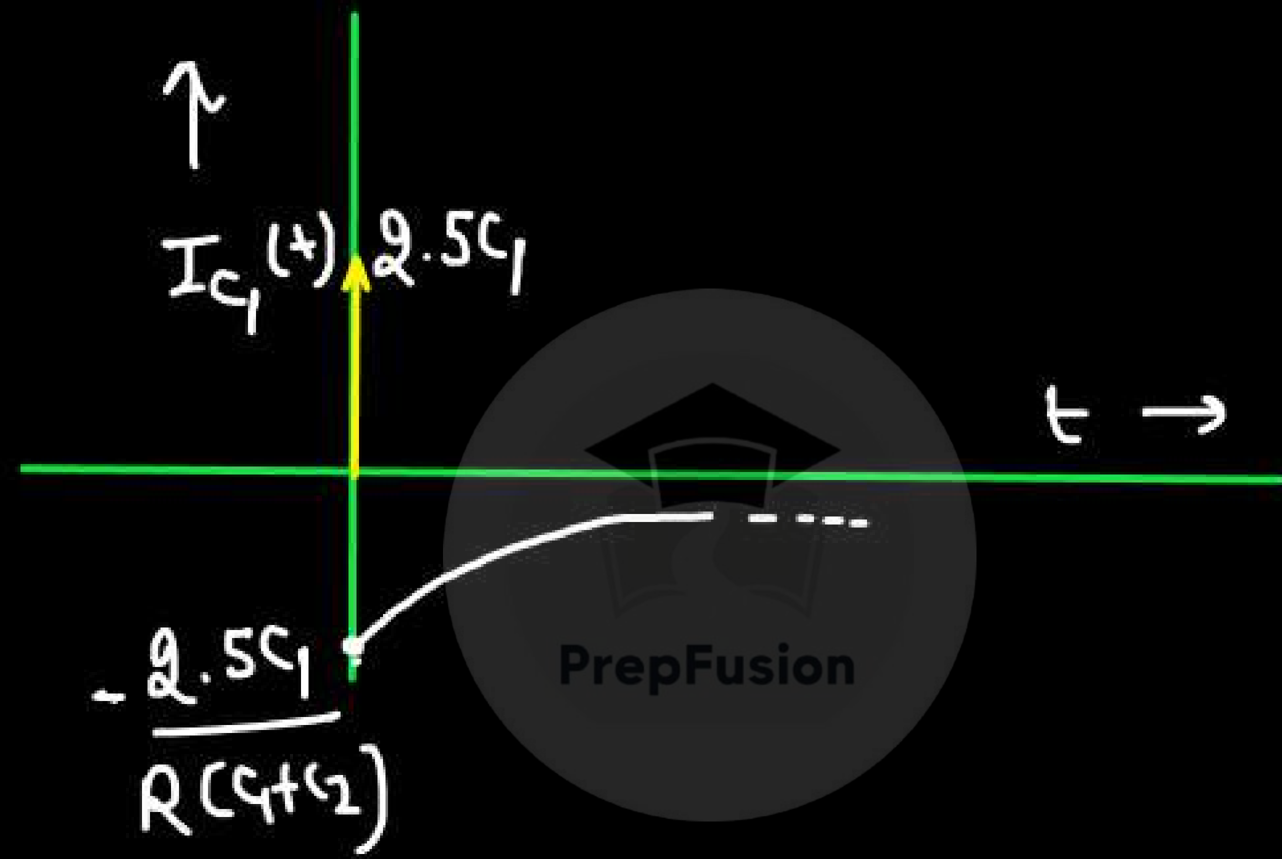
Time domain f^n

$$I_{c_1}(t) = C_1 \frac{dV_{c_1}(t)}{dt} = C_1 \frac{d}{dt}\left[2.5\, \underbrace{e^{-t/\tau}}\, \underbrace{u(t)}\right]$$

$$= 2.5 C_1 \left[e^{-t/\tau}\delta(t) - \frac{e^{-t/\tau}}{\tau} u(t) \right]$$

$$= 2.5 C_1 \left[\delta(t) - \frac{e^{-t/\tau}}{\tau} u(t) \right]$$

$$\boxed{I_{c_1}(t) = 2.5C_1\,\delta(t) - \frac{2.5C_1 e^{-t/\tau}}{R(C_1+C_2)}\,u(t)}$$



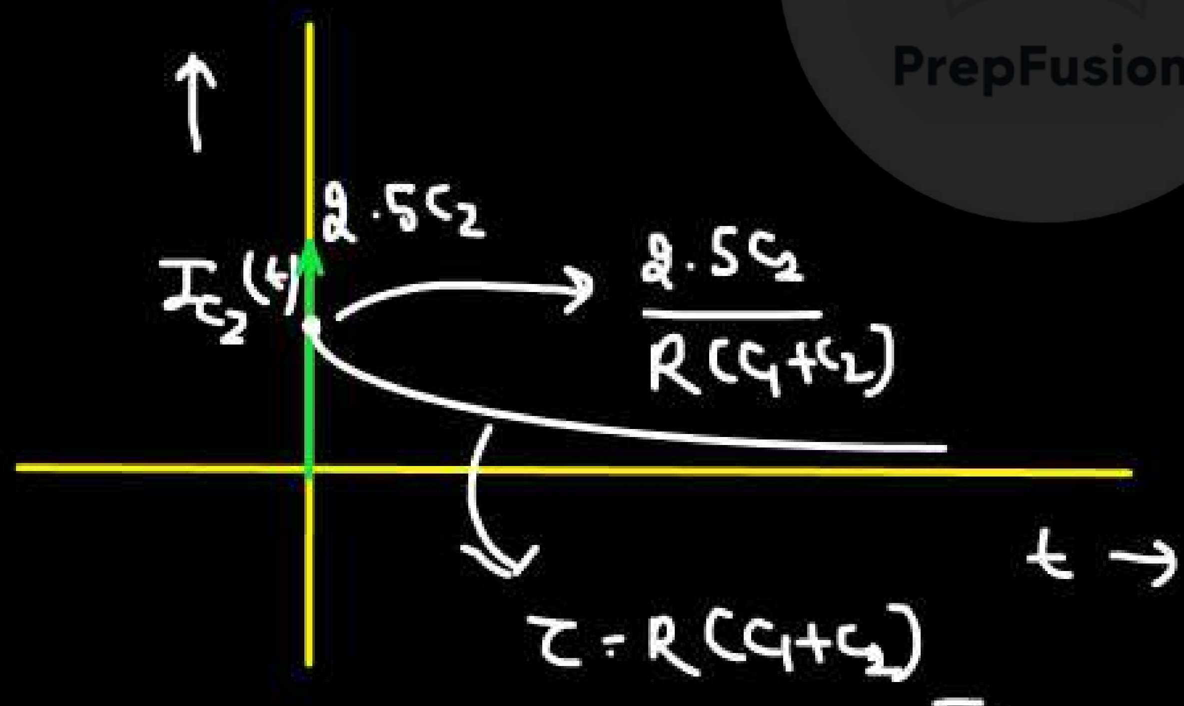
$$I_{c_2}(t) = \frac{C_2\,dV_{c_2}(t)}{dt} = C_2\frac{d}{dt}\left[5 - 2.5e^{-t/\tau}\right]u(t)$$

$$= C_2\frac{d}{dt}\left[5u(t) - 2.5e^{-t/\tau}u(t)\right]$$

$$I_{c_2}(t) = C_2\left[5\delta(t) - 2.5\left(e^{-t/\tau}\delta(t) - \frac{e^{-t/\tau}}{\tau}u(t)\right)\right]$$

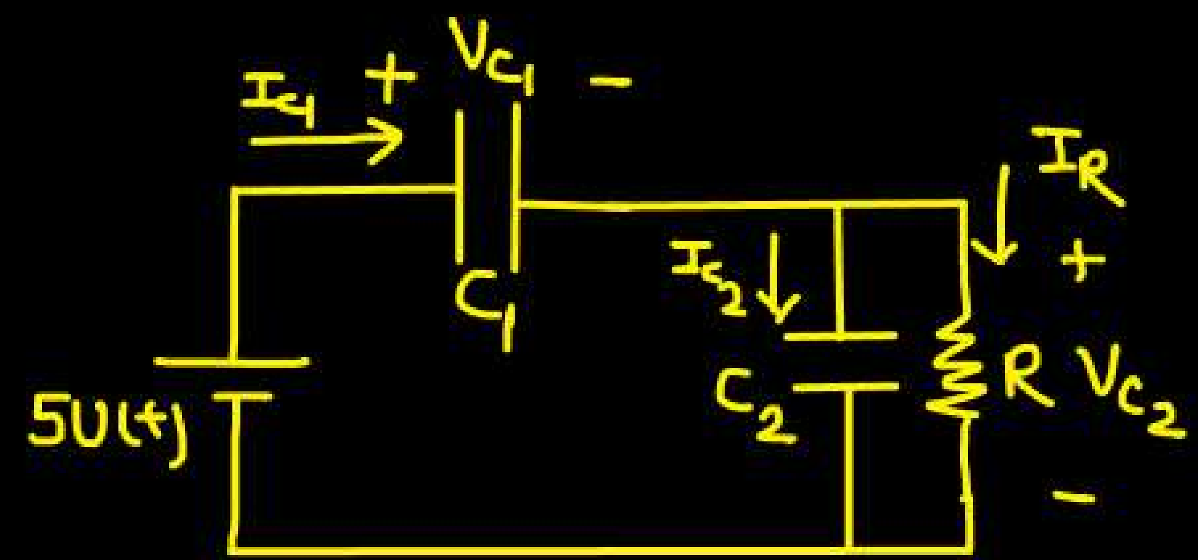
$$I_{c_2}(t) = 5C_2\delta(t) - 2.5C_2\delta(t) + 2.5C_2\frac{e^{-t/\tau}}{\tau}u(t)$$

$$\boxed{I_{c_2}(t) = 2.5C_2\delta(t) + \frac{2.5C_2}{R(C_1+C_2)}e^{-t/\tau}u(t)}$$



Q. Find V_{C_1}, V_{C_2}, I_{C_1}, I_{C_2}, I_R

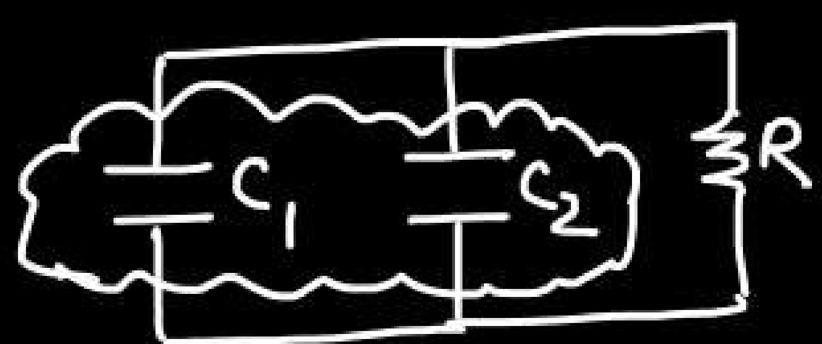
(a)



Take $C_1 = C_2 = C$

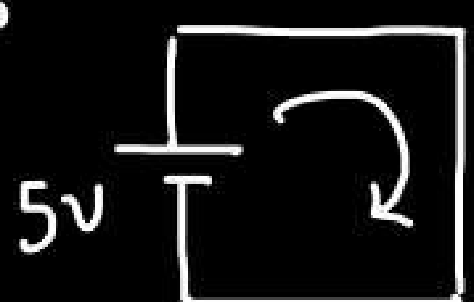
$R = 1\Omega$

$\rightarrow$ order $\rightarrow$ 2^{nd} order ? $\rightarrow$ No:-



$$\boxed{\tau = R(C_1 + C_2)} \rightarrow 1^{st} \text{ order}$$

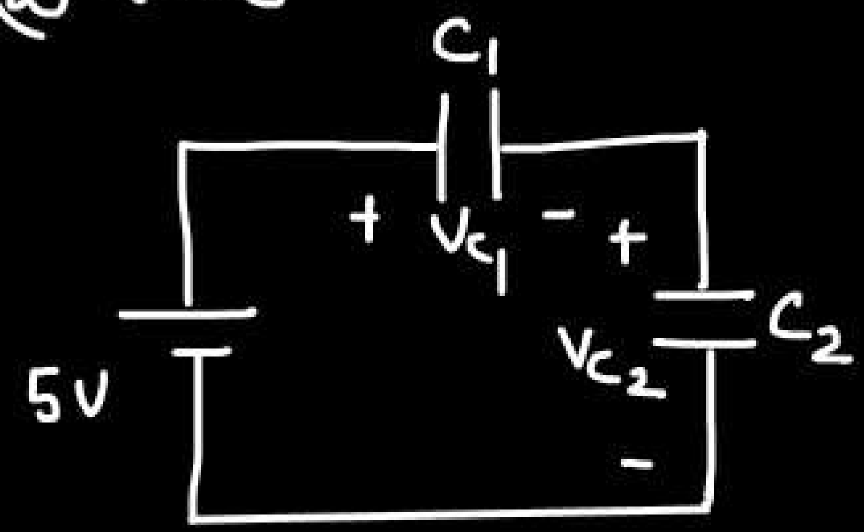
@ $t=0$



$I = \frac{5u(t)}{0} = \infty \rightarrow$ Cap. voltage will change immediately.

$@\ t=0 \Rightarrow \omega = \infty$

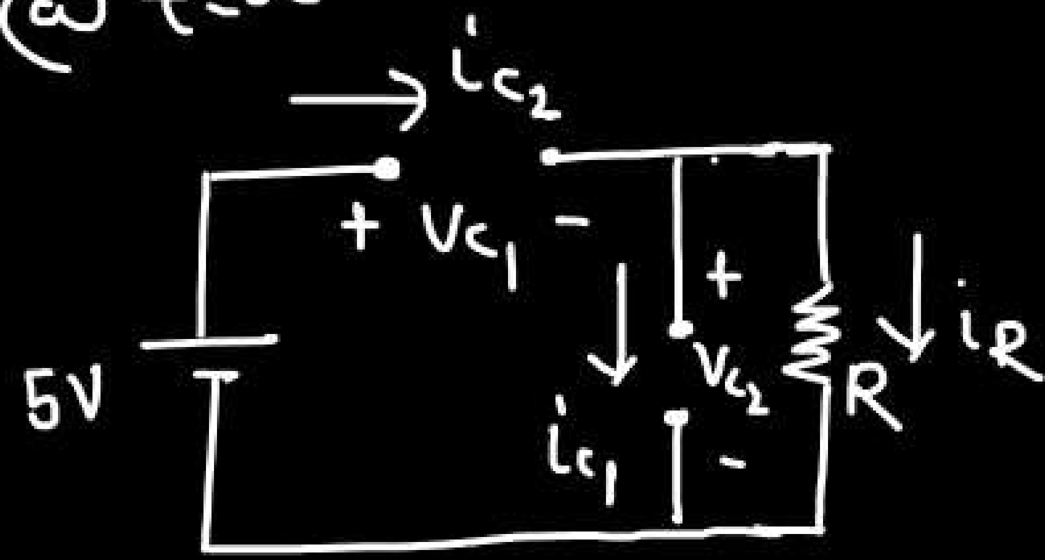
ckt @ $t=0$



$$V_{c_1}(0^+) = \frac{5C_2}{C_1+C_2}$$

$$V_{c_2}(0^+) = \frac{5C_1}{C_1+C_2}$$

ckt @ $t=\infty$



$i_R(\infty) = i_{c_1}(\infty) = i_{c_2}(\infty) = 0$ Amp.

$V_{c_1}(\infty) = 5V$

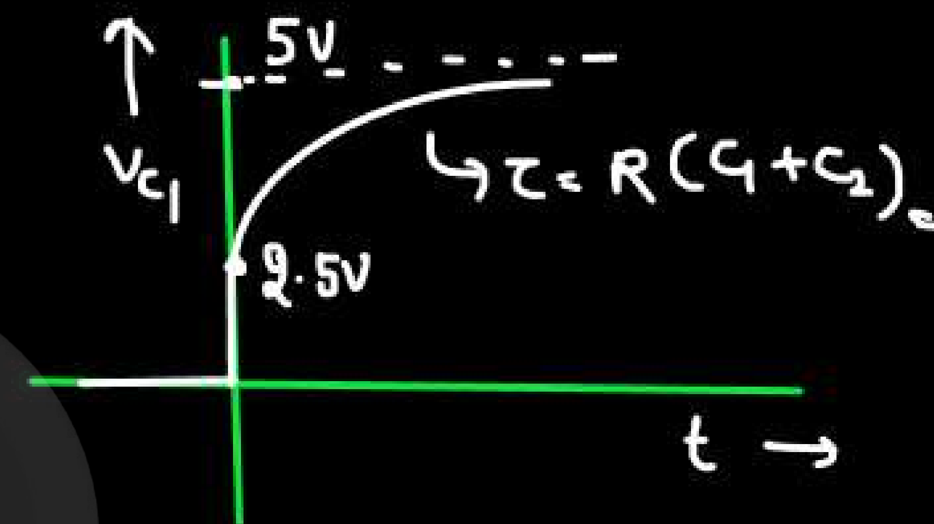
$V_{c_2}(\infty) = 0V$

V_{C_1} :-

$$V_{C_1}(0^+) = \frac{5C_2}{C_1+C_2} = 2.5V \quad (\text{Considering } C_1 = C_2 = C)$$

$$V_{C_1}(\infty) = 5V$$

$$\boxed{V_{C_1}(t) = \left[5 - 2.5e^{-t/\tau}\right]u(t)}$$

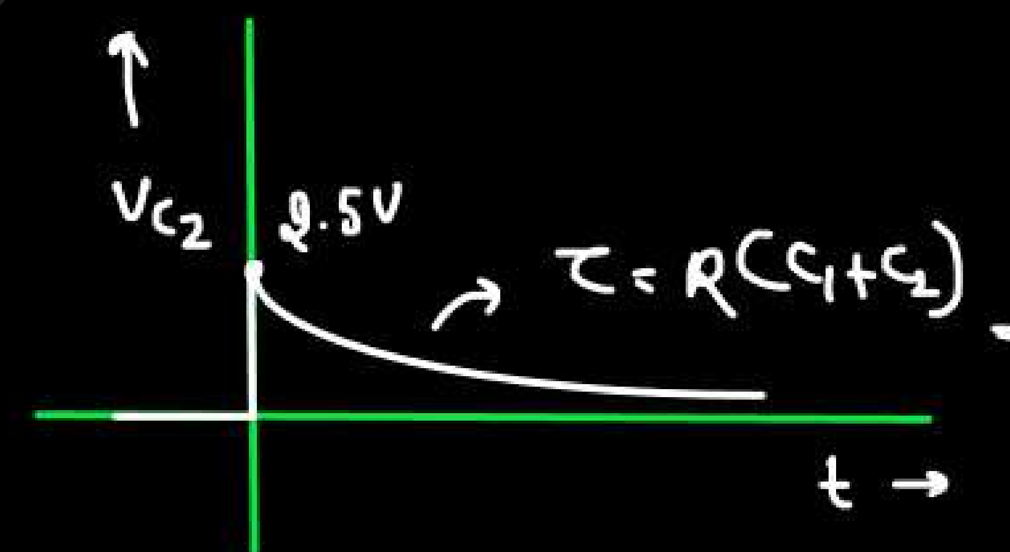


V_{C_2} :-

$$V_{C_2}(0^+) = \frac{5C_1}{C_1+C_2} = 2.5V$$

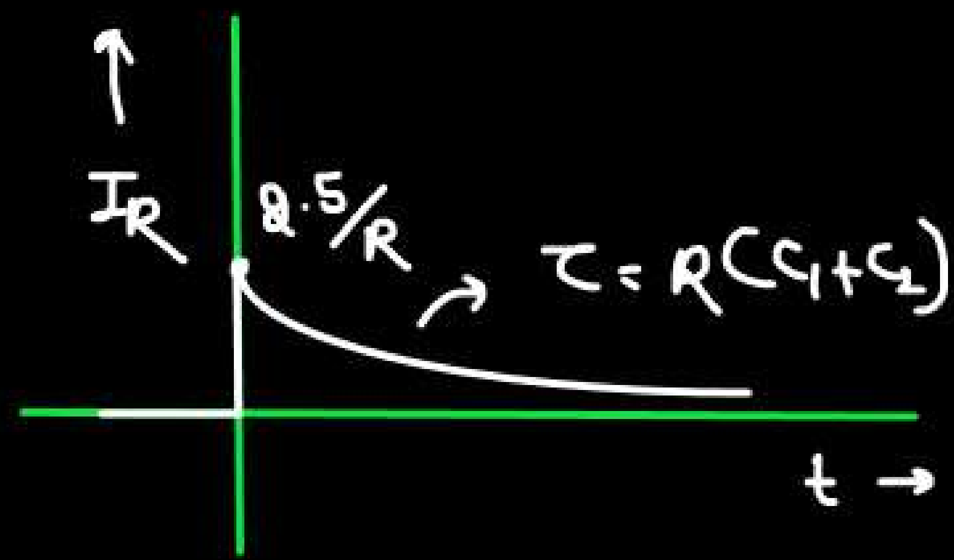
$$V_{C_2}(\infty) = 0V$$

$$\boxed{V_{C_2}(t) = 2.5e^{-t/\tau}u(t)}$$



$\underline{\underline{I_R}}$:-

$$\boxed{I_R = \frac{V_{C_2}}{R} = \frac{2.5}{R} e^{-t/\tau} u(t)}$$



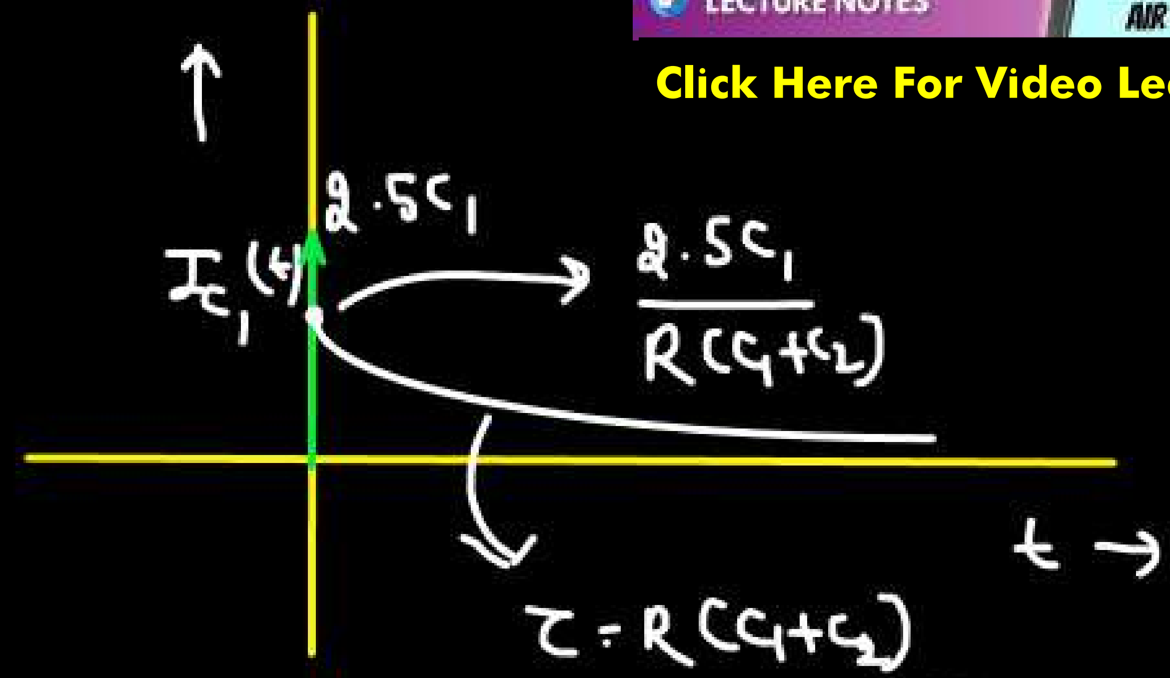
$\underline{I_{C_1}, I_{C_2}} \Rightarrow ?$

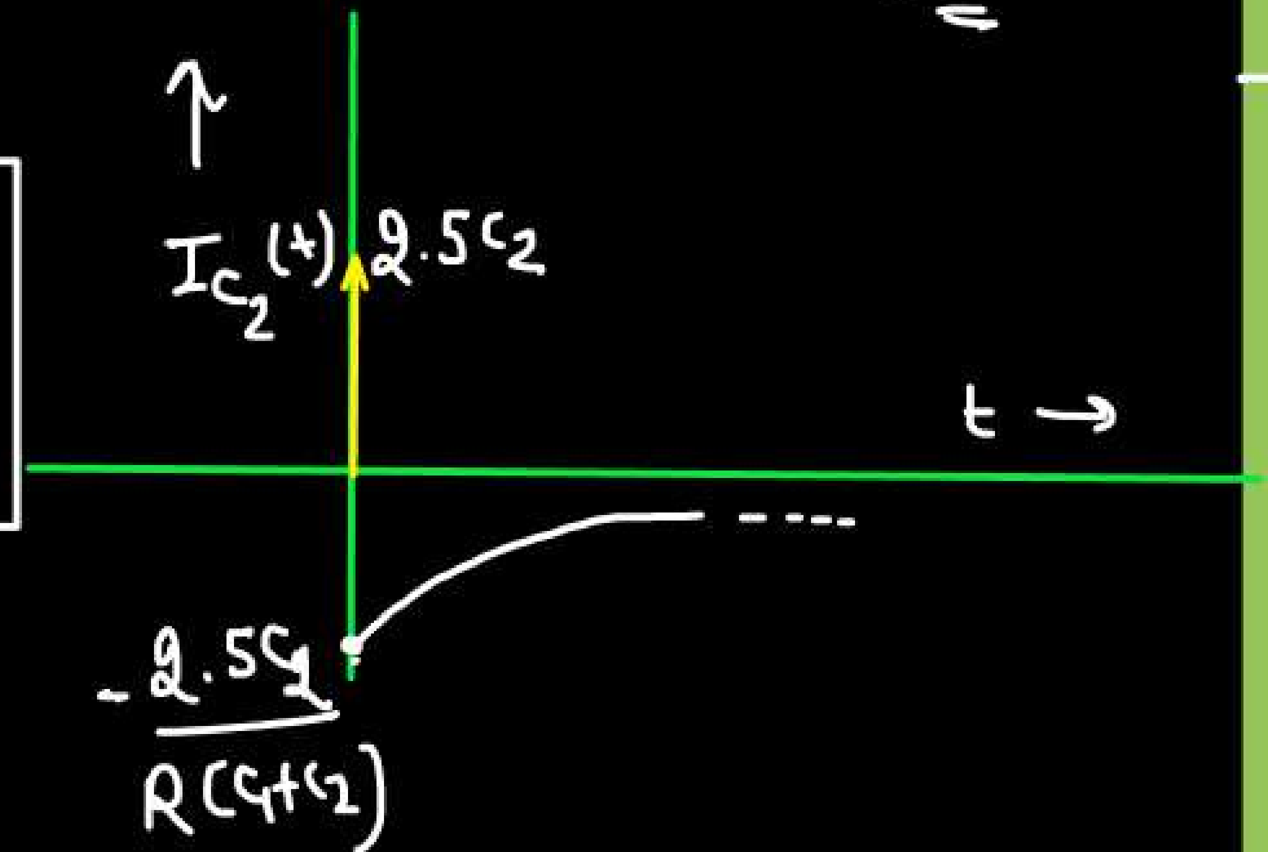
$$I_{c_1} = C_1 \frac{dV_{c_1}(t)}{dt}$$

$$\boxed{I_{c_1}(t) = 2.5\,C_1\,\delta(t) + \frac{2.5\,C_1}{R(C_1+C_2)}\,e^{-t/\tau}\,u(t)}$$

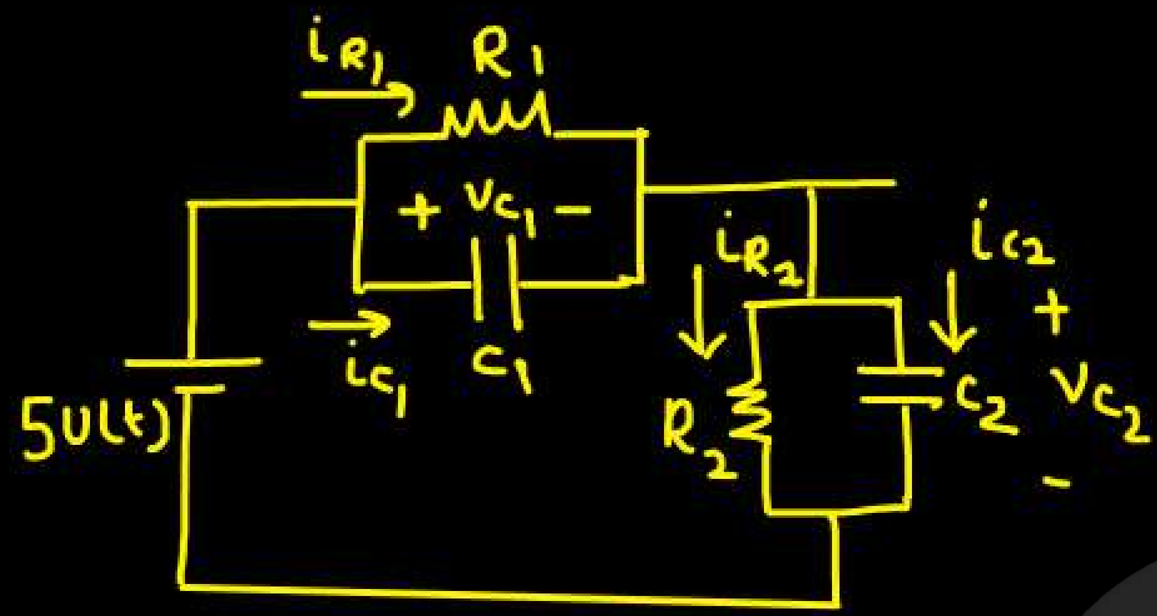
$$I_{c_2} = C_2 \frac{dV_{c_2}(t)}{dt}$$

$$\boxed{I_{c_2}(t) = 2.5\,C_2\,\delta(t) - \frac{2.5\,C_2\,e^{-t/\tau}}{R(C_1+C_2)}\,u(t)}$$





Q.



Comment on all the parameters for three cases

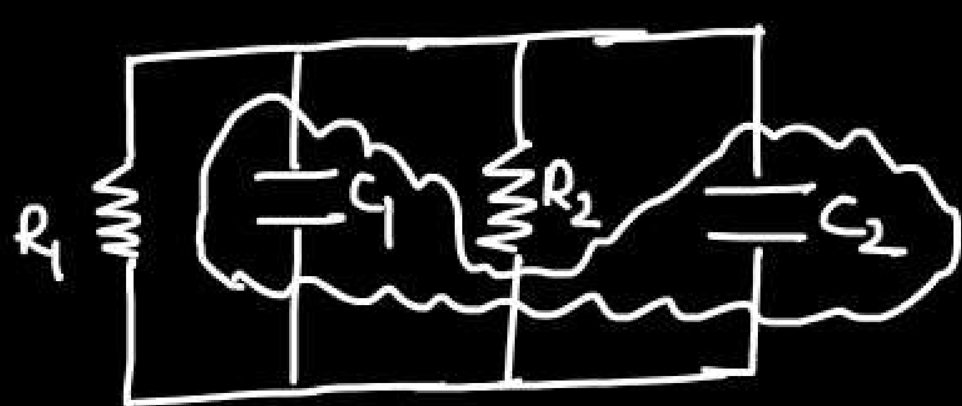
① $R_1C_1 > R_2C_2$

② $R_1C_1 < R_2C_2$

③ $R_1C_1 = R_2C_2$

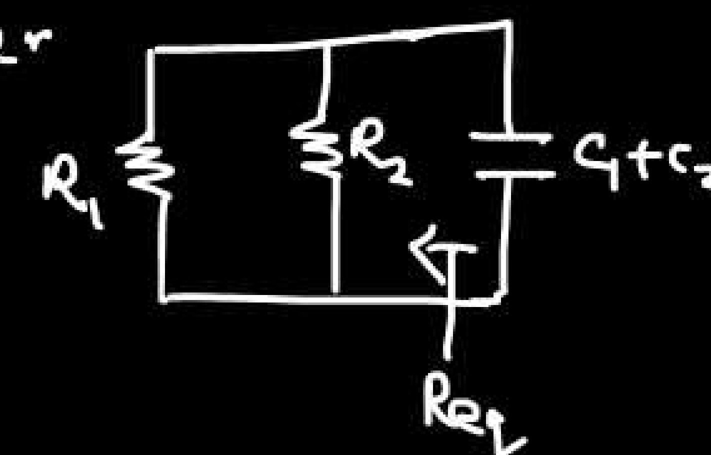
→

order = ?



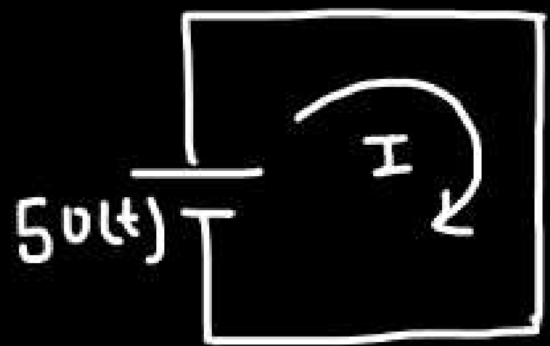
$C_{ef} = C_1 + C_2 \rightarrow 1^{st}$ order

$R_{eq} = R_1 \| R_2 = \frac{R_1R_2}{R_1+R_2}$

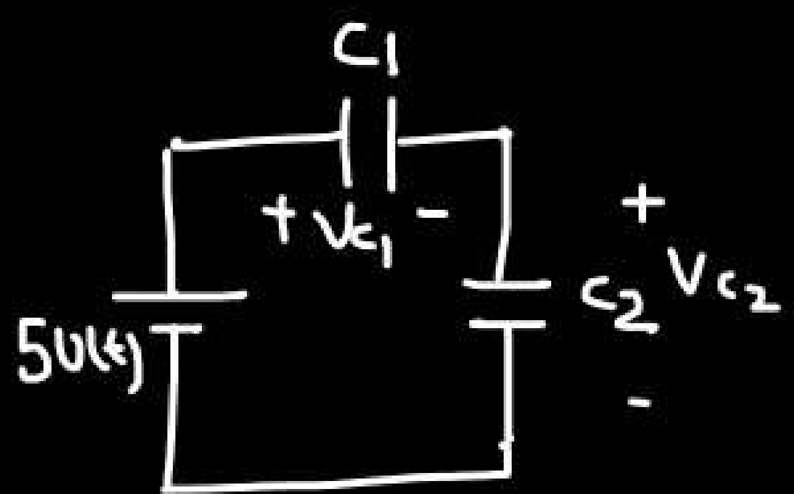


$$\boxed{\tau = \frac{R_1R_2}{R_1+R_2}(C_1+C_2)}$$

@ $t=0$:-



$I = 5/0 = \infty \Rightarrow$ Cap. voltage will change immediately

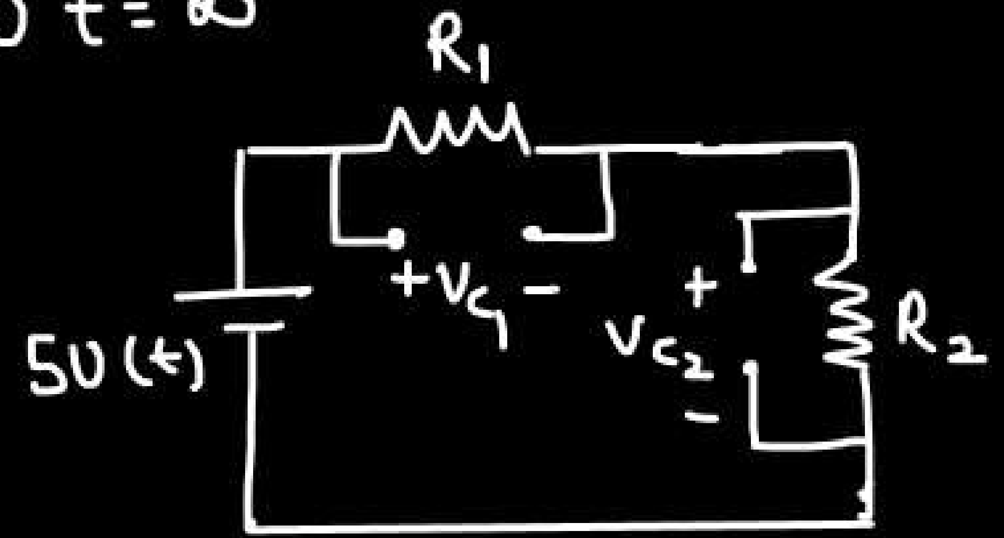


$$\boxed{\begin{aligned} V_{c_1}(0^+) &= \frac{5C_2}{C_1+C_2} \\ V_{c_2}(0^+) &= \frac{5C_1}{C_1+C_2} \end{aligned}}$$

$$= \frac{5}{1+C_1/C_2}$$

$$= \frac{5}{1+C_2/C_1}$$

@ $t = \infty$



$$\boxed{\begin{aligned} V_{c_1}(\infty) &= \frac{5R_1}{R_1+R_2} \\ V_{c_2}(\infty) &= \frac{5R_2}{R_1+R_2} \end{aligned}}$$

$$= \frac{5}{1+\frac{R_2}{R_1}}$$

$$= \frac{5}{1+R_1/R_2}$$

① $R_1C_1 > R_2C_2$

$$\Rightarrow \frac{R_1}{R_2} > C_2/C_1 \quad \Rightarrow \frac{R_2}{R_1} < \frac{C_1}{C_2}$$

$$V_{c_1}(0^+) = \frac{5}{1+C_1/C_2} \quad , \quad V_c(\infty) = \frac{5}{1+R_2/R_1}$$

$$\Rightarrow \boxed{V_{c_1}(0^+) < V_c(\infty)}$$

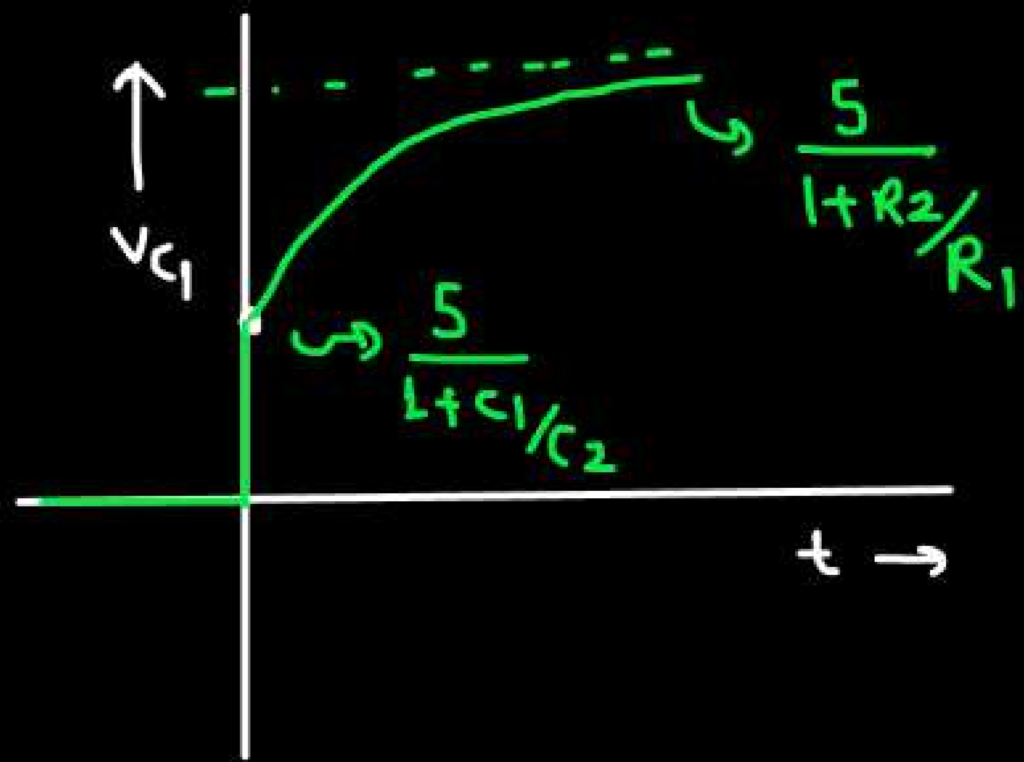
$$V_{c_2}(0^+) = \frac{5}{1+C_2/C_1}$$

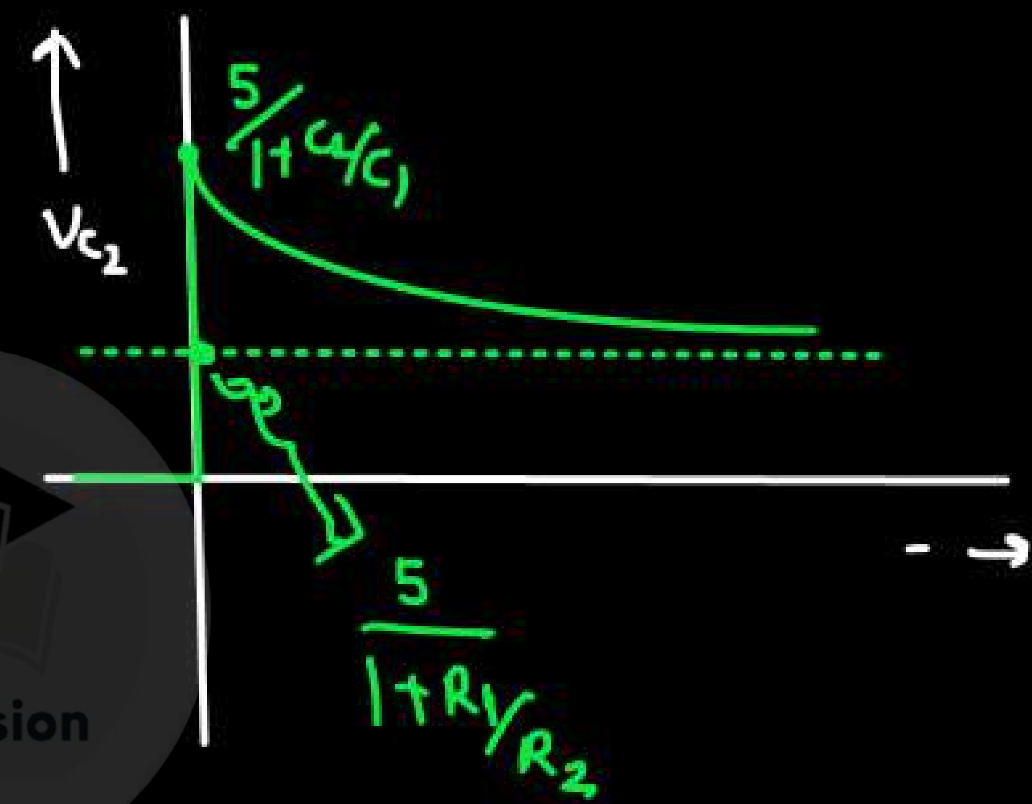
$$V_{c_2}(\infty) = \frac{5}{1+R_1/R_2}$$

$$\boxed{V_{c_2}(0^+) > V_{c_2}(\infty)}$$

$$V_C(t) = V_C(\infty) + [V_C(0) - V_C(\infty)]\, e^{-t/\tau} \quad ; \quad \tau = \frac{R_1 R_2}{R_1 + R_2} (C$$

$(R_1C_1 > R_2C_2)$



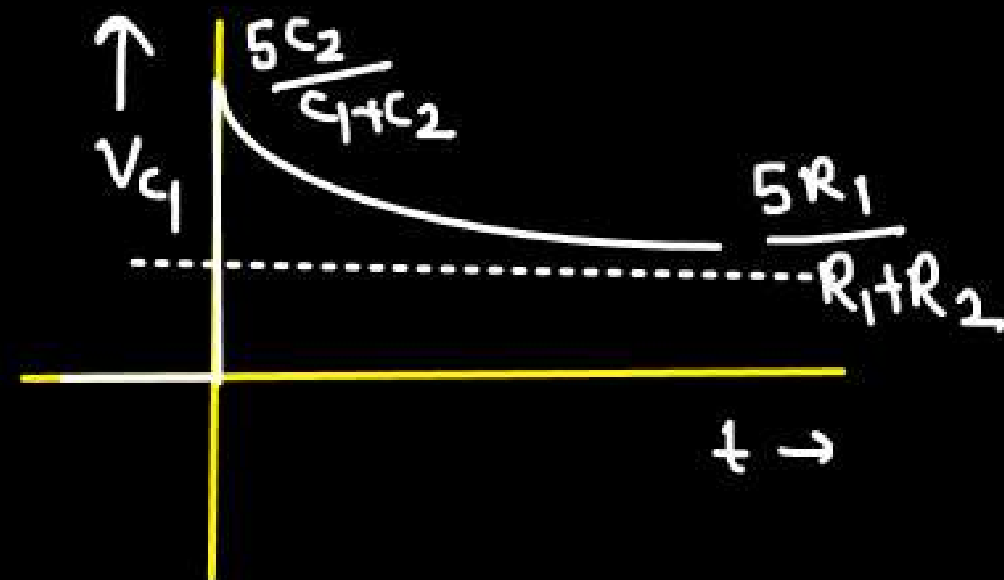


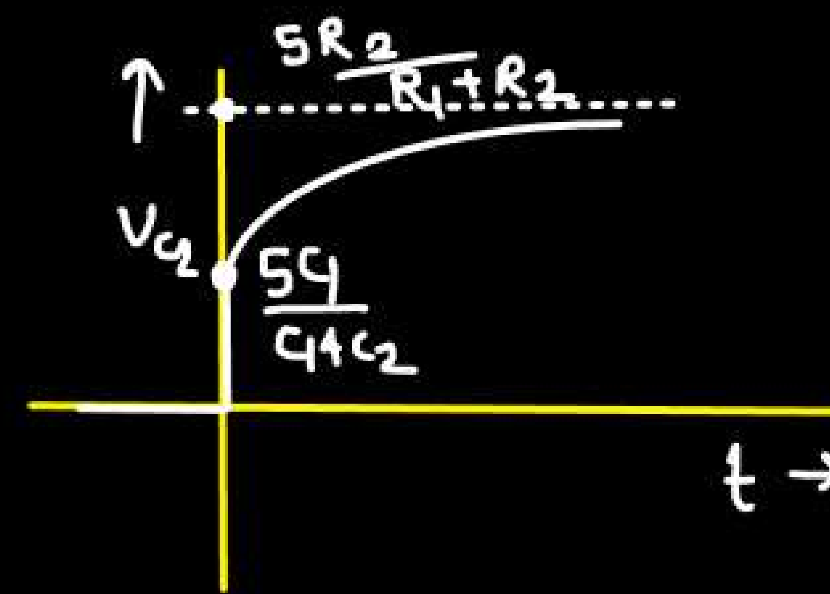
② $R_1C_1 < R_2C_2$

$$\Rightarrow \frac{R_1}{R_2} < \frac{C_2}{C_1} \quad \underline{\underline{OR}} \quad \frac{R_2}{R_1} > \frac{C_1}{C_2}$$

$V_{C_1}(0^+) > V_{C_1}(\infty)$

$V_{C_2}(0^+) < V_{C_2}(\infty)$



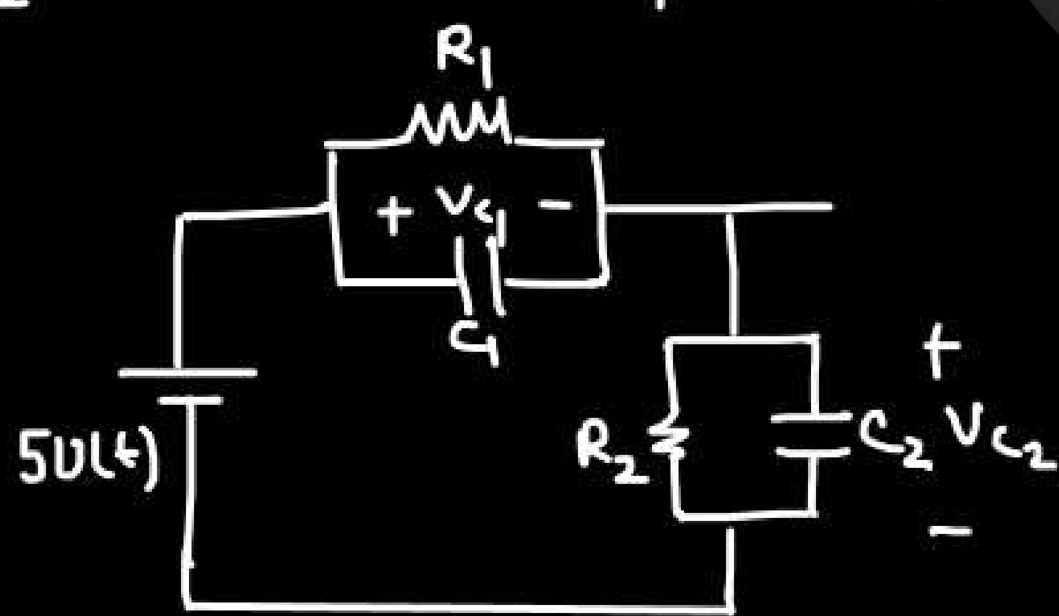


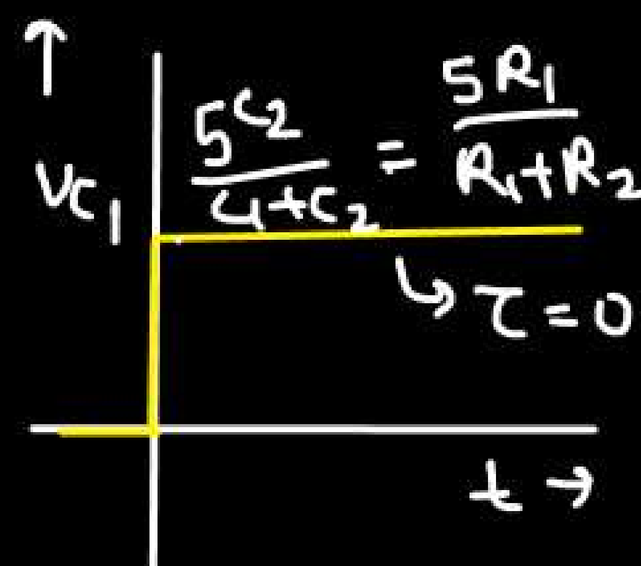
③ $R_1C_1 = R_2C_2$

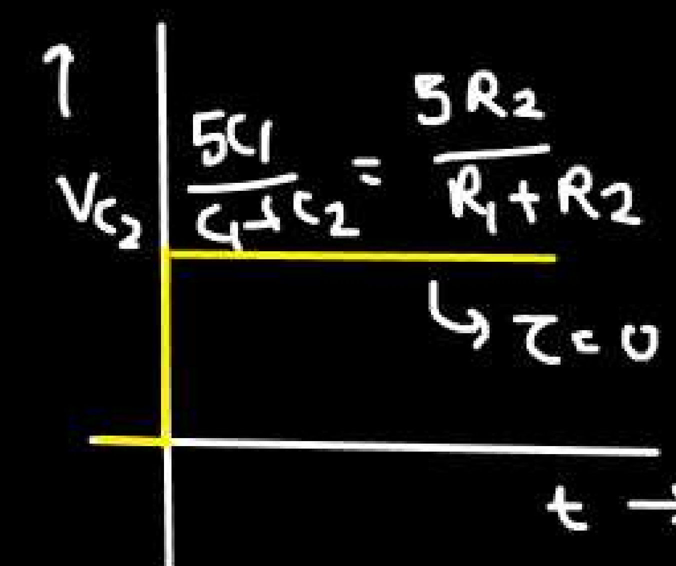
$\Rightarrow \frac{R_1}{R_2} = \frac{C_2}{C_1}$ and $\frac{R_2}{R_1} = \frac{C_1}{C_2}$

$\Rightarrow V_{C_1}(0^+) = V_{C_1}(\infty)$

$V_{C_2}(0^+) = V_{C_2}(\infty)$





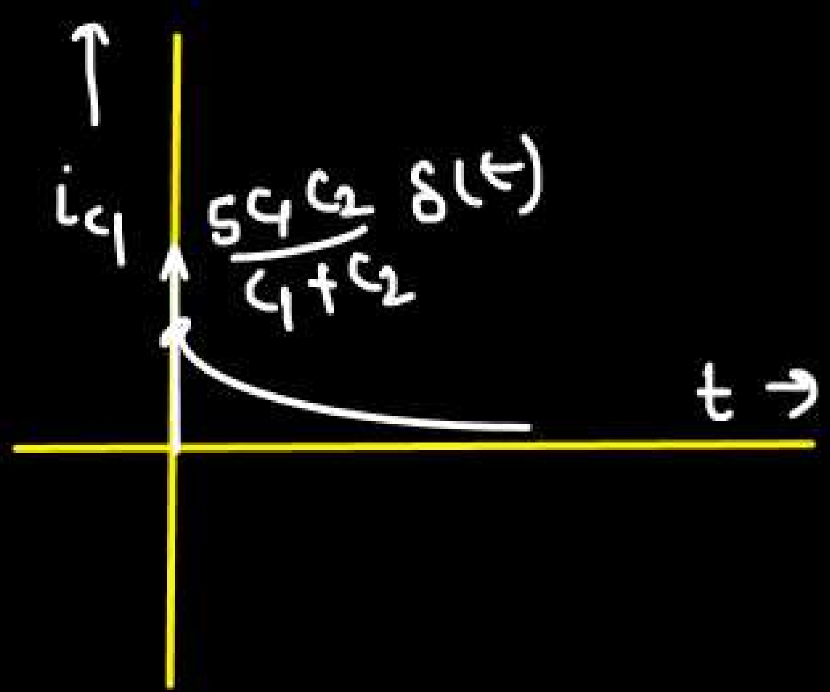


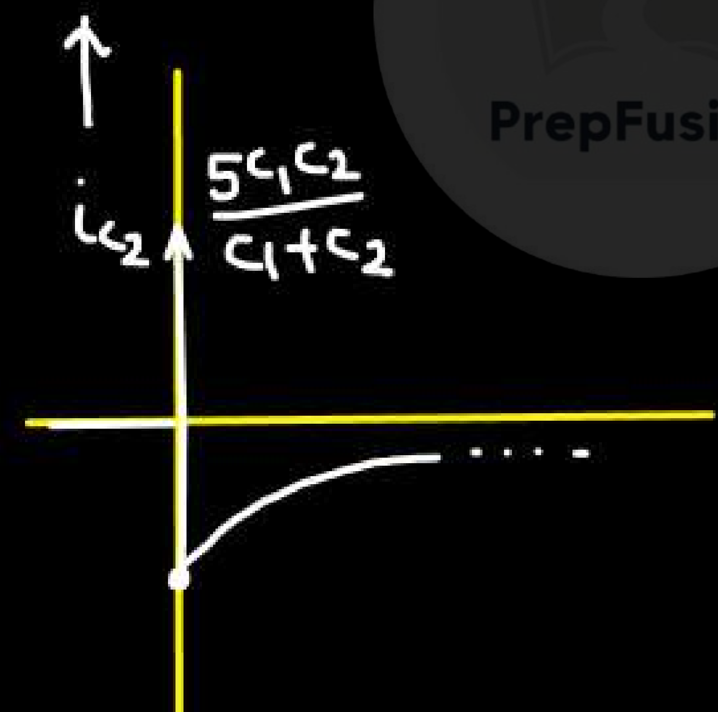
$i_{c_1}, i_{c_2}, i_{R_1}, i_{R_2}$:-

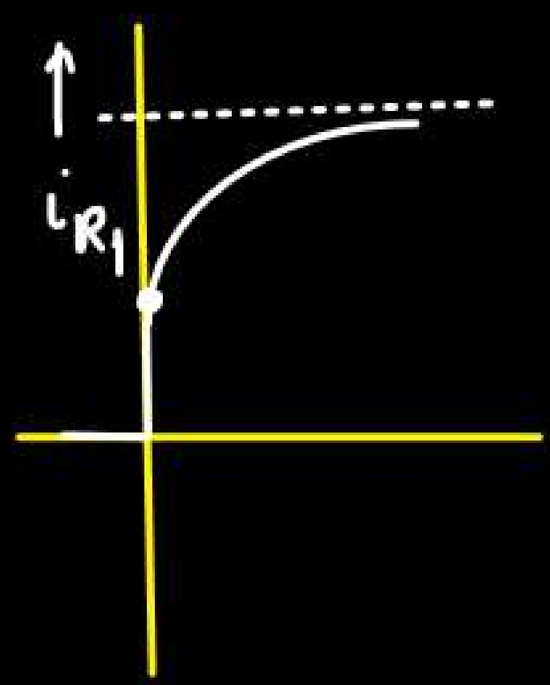
$$i_{c_1} = C_1 \frac{dV_{c_1}}{dt} \quad ; \quad i_{c_2} = C_2 \frac{dV_{c_2}}{dt}$$

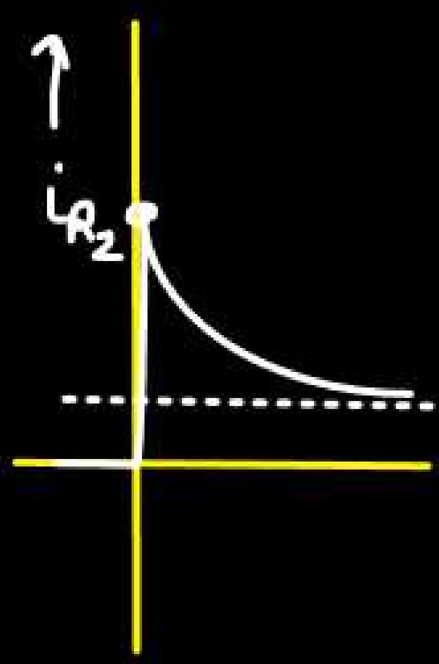
$$i_{R_1} = \frac{V_{c_1}}{R_1} \quad ; \quad i_{R_2} = \frac{V_{c_2}}{R_2}$$

① $R_1C_1 > R_2C_2$

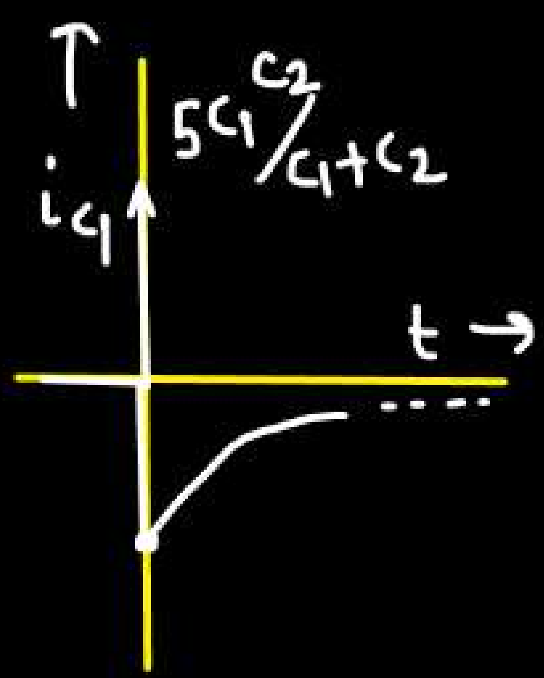


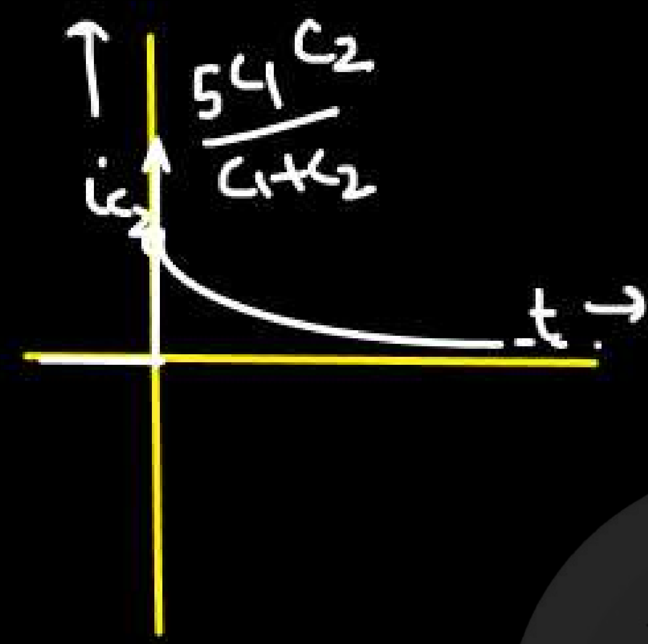


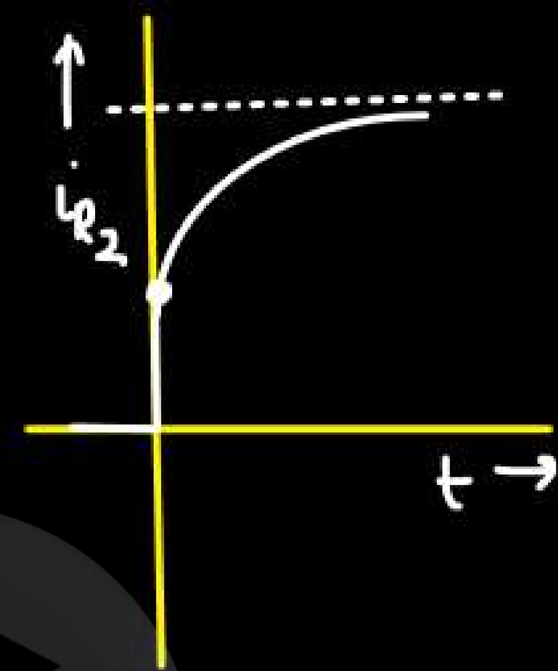




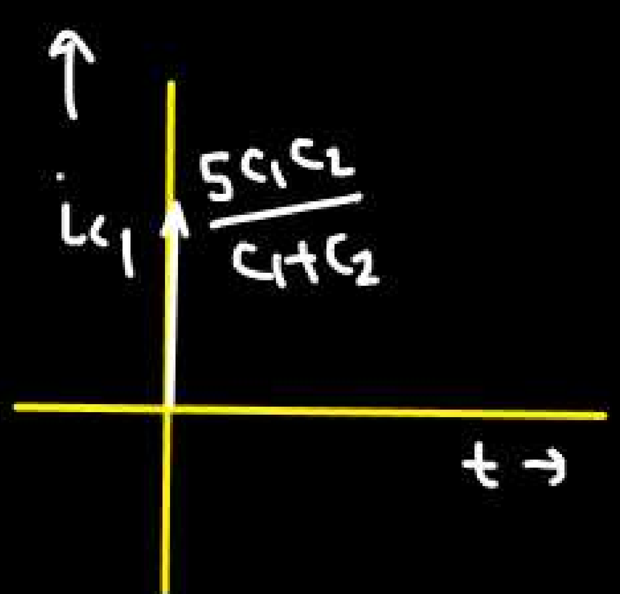
② $R_1C_1 < R_2C_2$

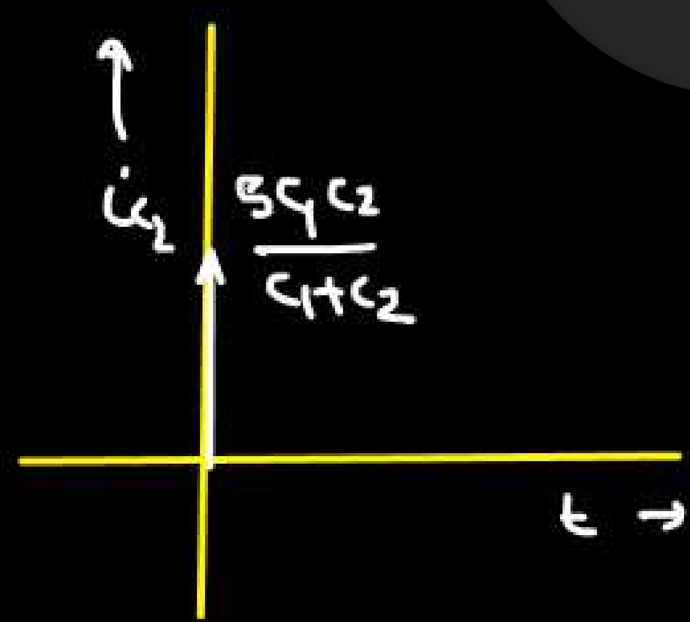


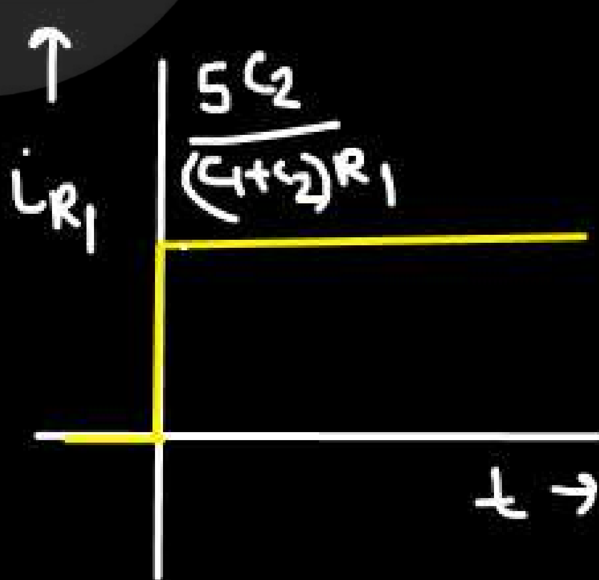


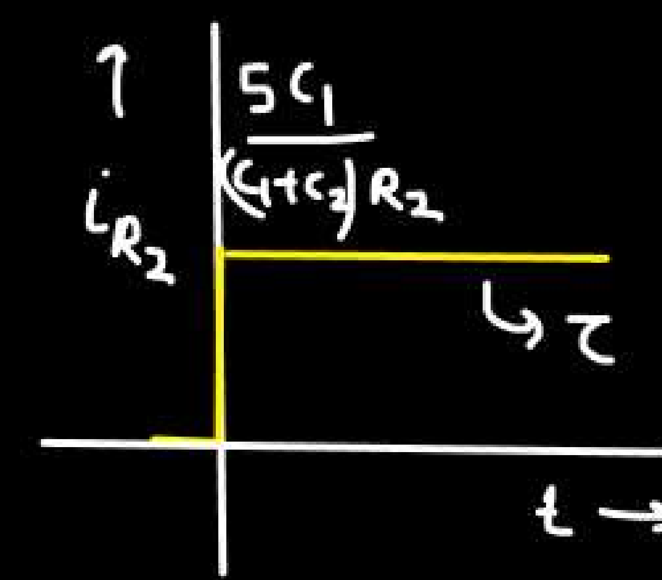


③ $R_1C_1 = R_2C_2$



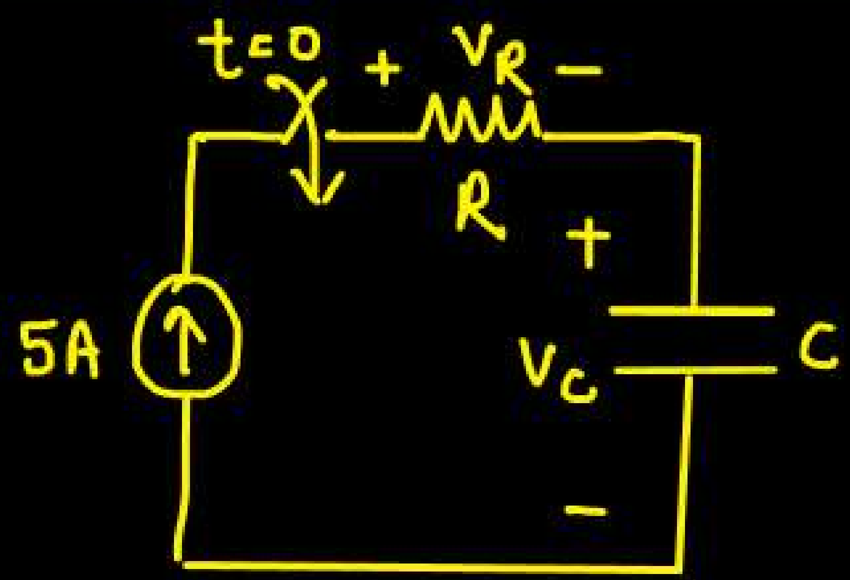




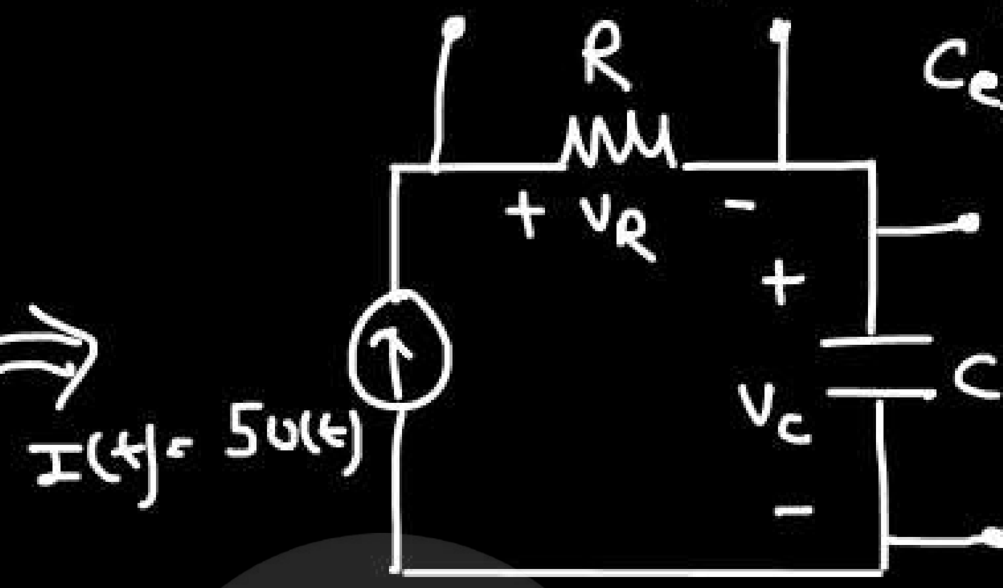


* RC ckt to current i/p :-

Q.



$\Rightarrow$



$R_{eq} = R$

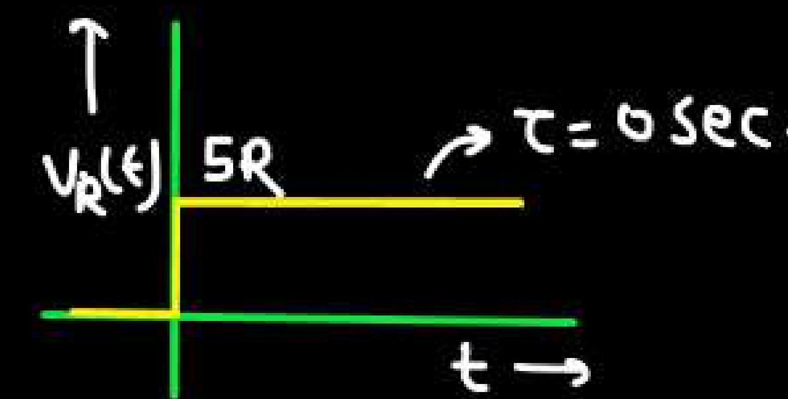
$C_{eff} = 0$

$\tau = 0$ sec.

$C_{eff} = C$

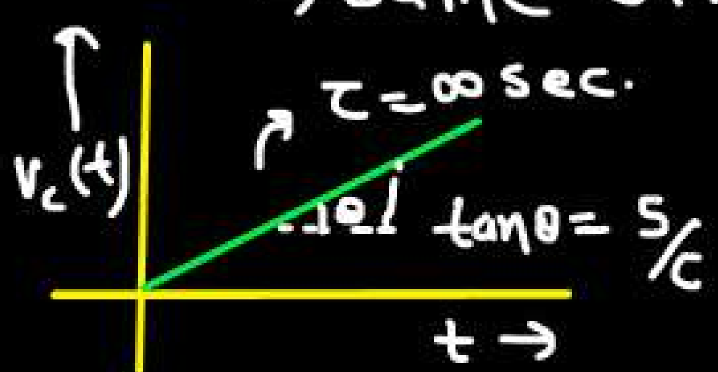
$R_{eq} = \infty$ $\Rightarrow \tau = \infty$ sec.

$$V_R(t) = I(t) \times R = 5R\,u(t)$$



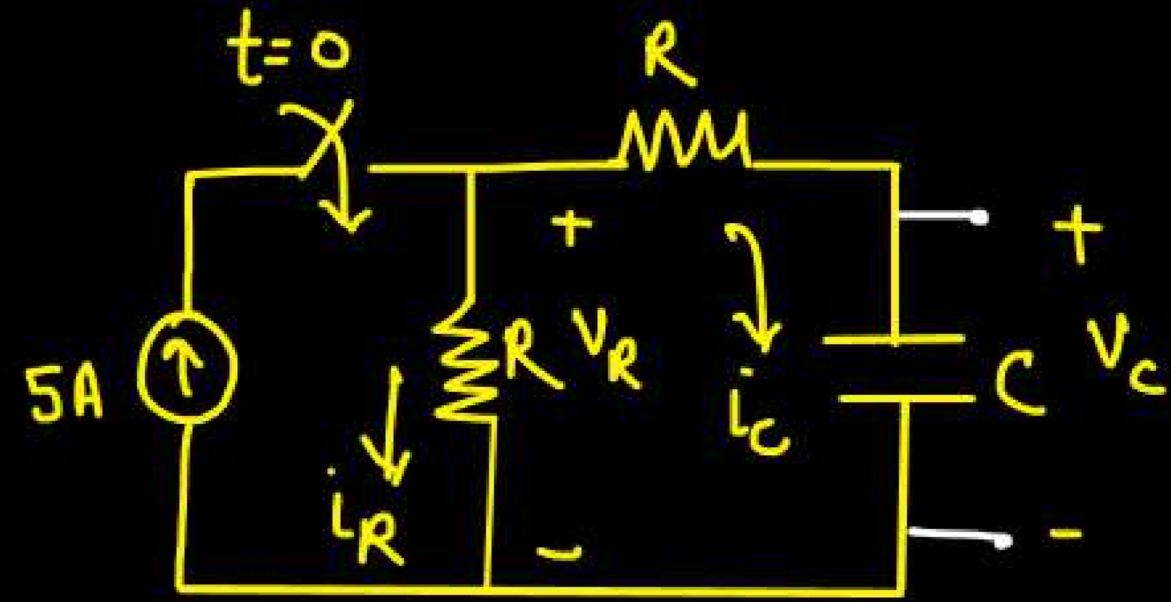
$V_c(t)$:- ?

↳ Same current $5u(t)$ always flows through the cap.

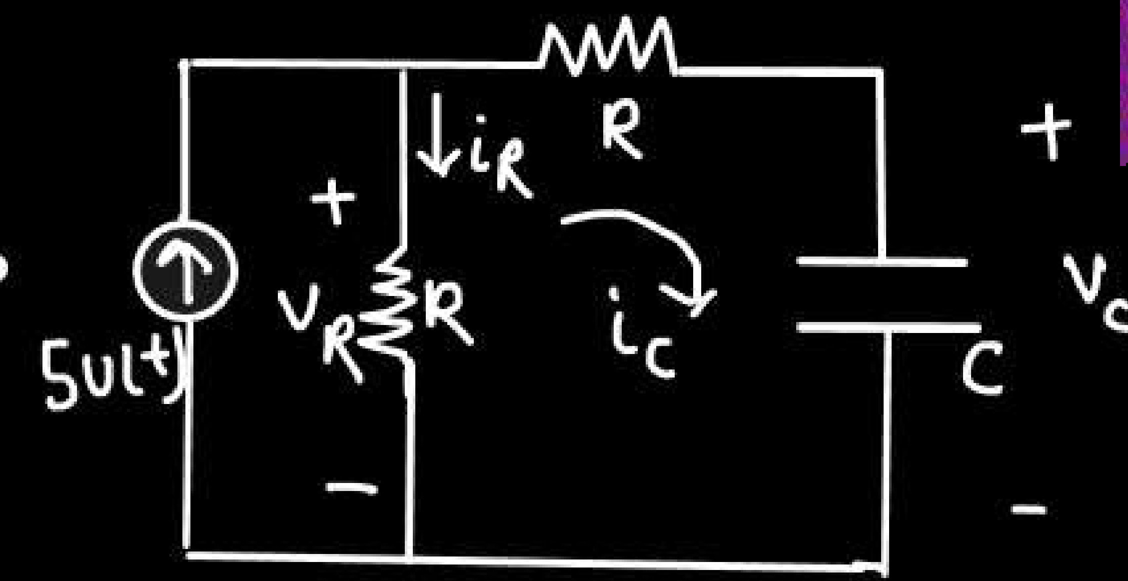


$$V_c(t) = \frac{1}{C}\int_0^t i \cdot dt = \frac{1}{C}\int_0^t 5u(t) \cdot dt = \frac{5}{C} r(t) = \frac{5t}{C} u(t)$$

Q.



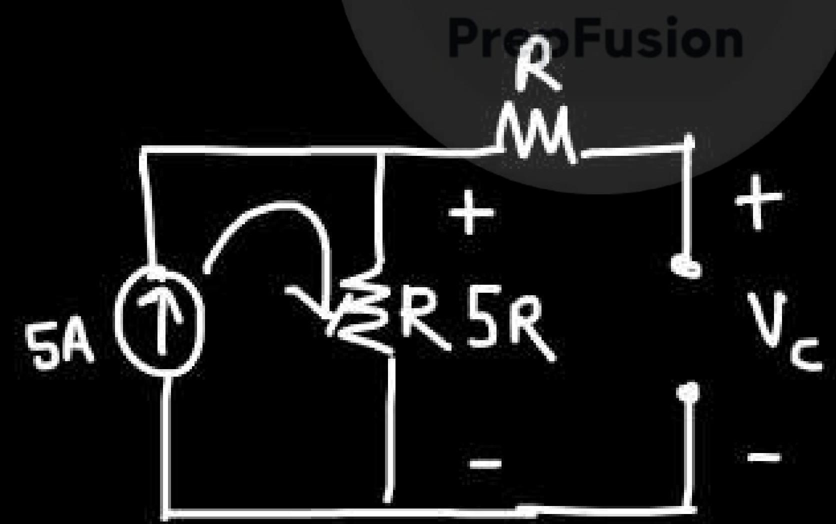
⇒



V_c :-

$V_c(0^+) = 0V$

$V_c(\infty) = 5R$

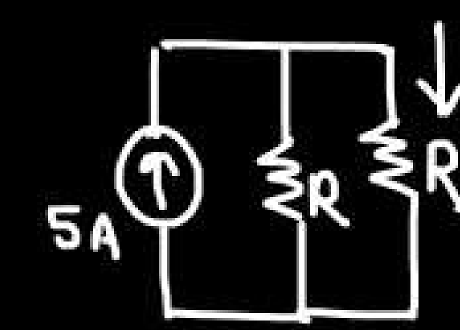


(t=∞)

i_c :-

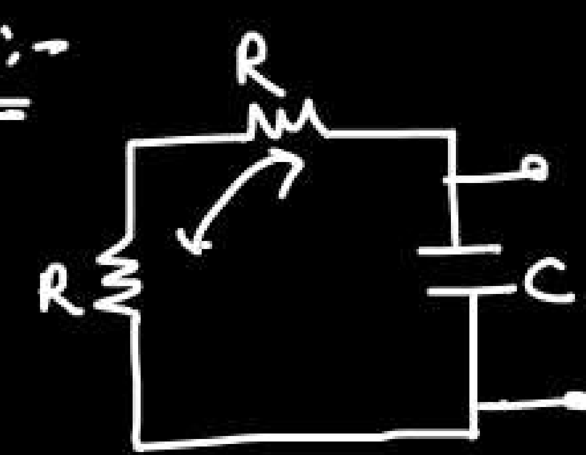
$i_c(0^+) = 2.5$ Amp.

$i_c(\infty) = 0$ Amp.



(t=0)

τ :-



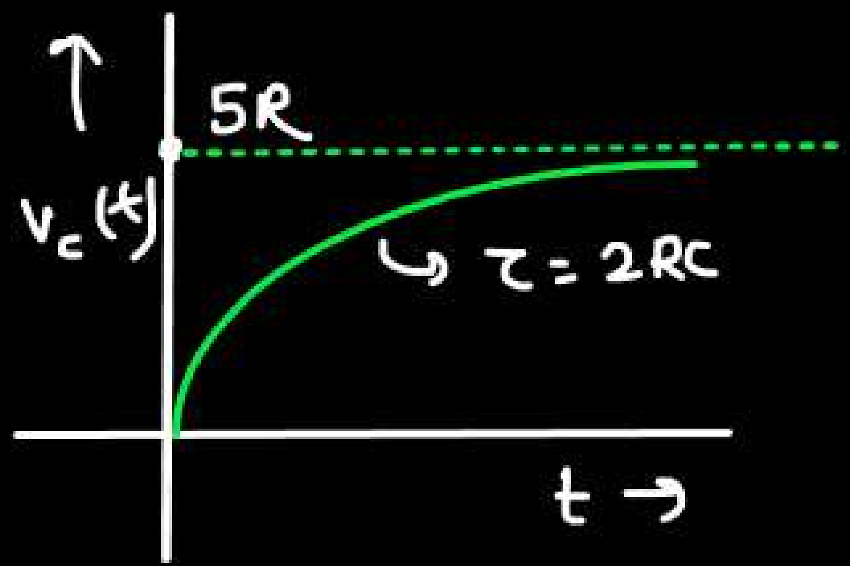
$R_{eq} = 2R$

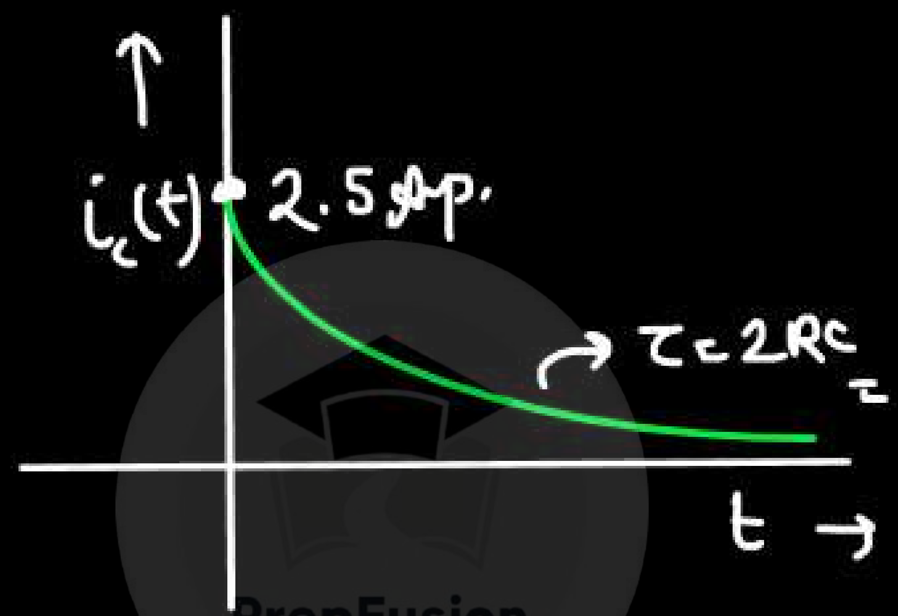
$C_{eff} = C$

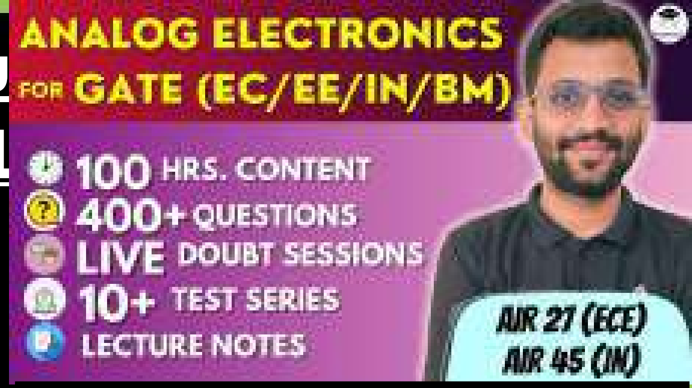
$\tau = 2RC$

$$v_c(t) = 5R\left[1 - e^{-t/\tau}\right]u(t)\ ;\quad \tau = 2RC$$

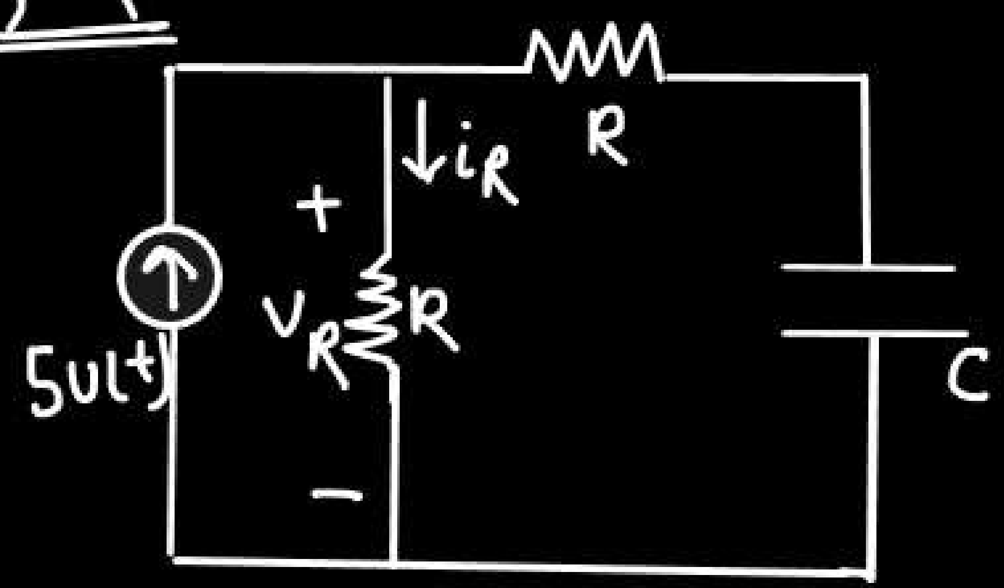
$$i_c(t) = 2.5\,e^{-t/\tau}\,u(t)\ ;\quad \tau = 2RC$$







V_R, I_R:-



$i_R(0^+) = 2.5$ Amp.

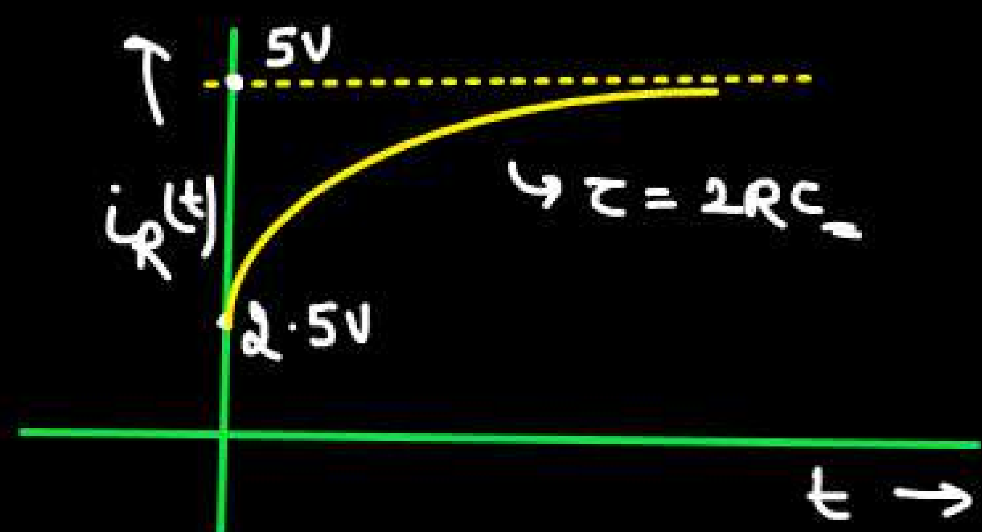
$i_R(\infty) = 5$ Amp.

$V_R(0^+) = 2.5R$

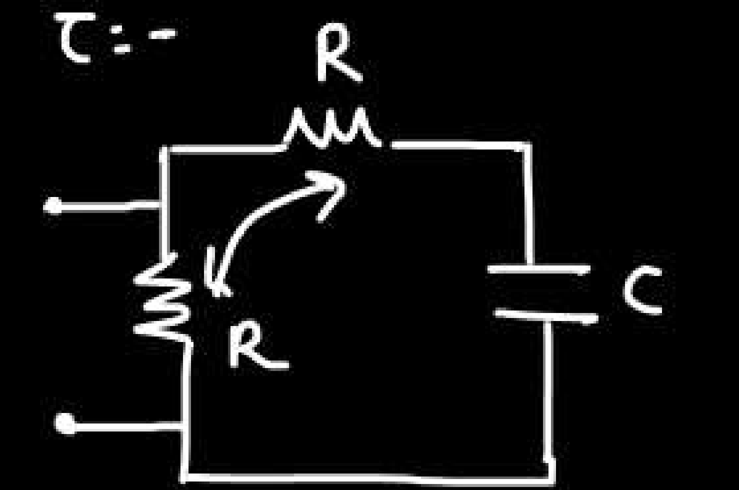
$V_R(\infty) = 5R$

$i_R(t) = 5 - 2.5\, e^{-t/\tau}\, u(t)$; $\tau = 2RC$

$v_R(t) = 5R - 2.5R\, e^{-t/\tau}\, u(t)$; $\tau = 2RC$



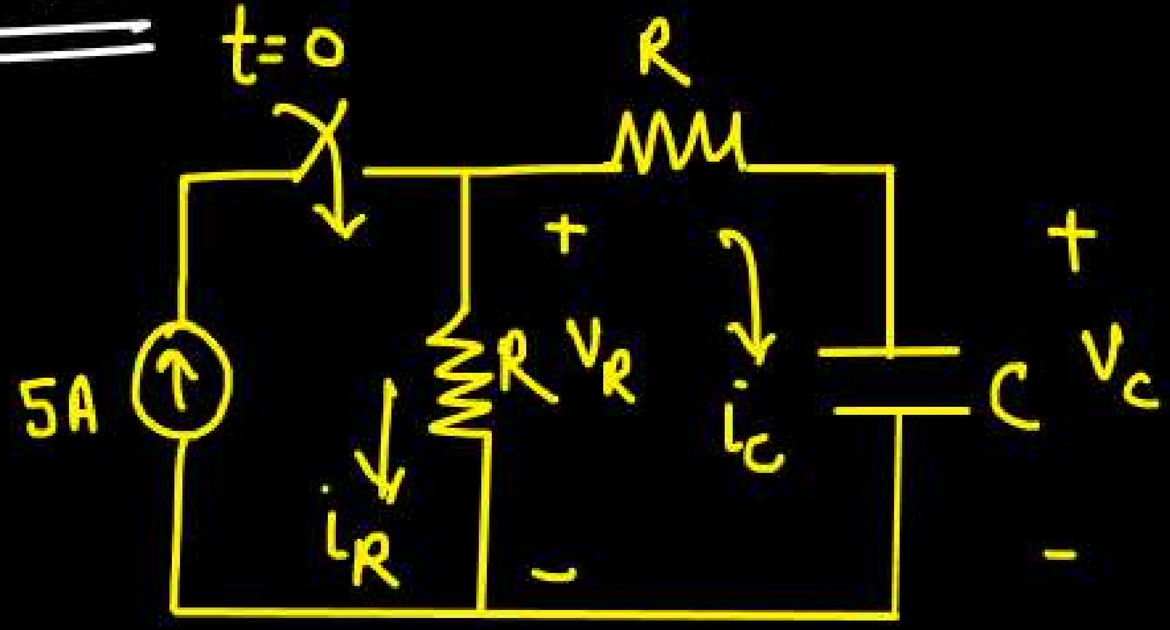
τ:-

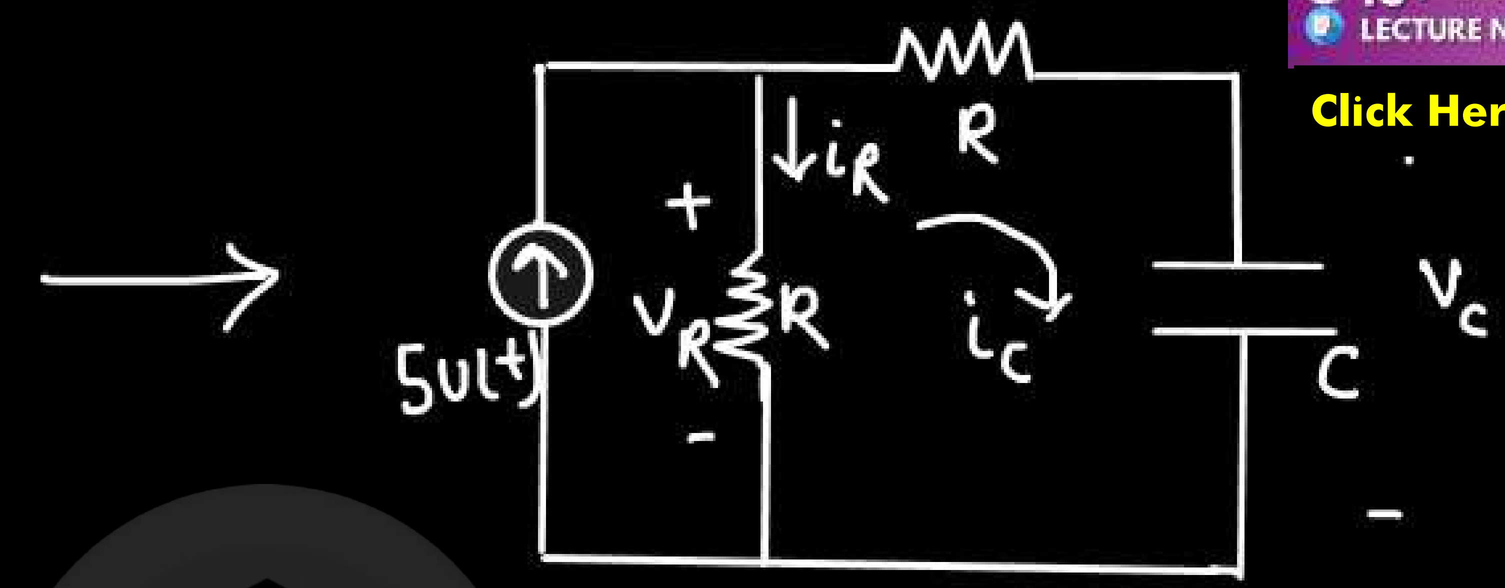


$R_{eq} = 2R$, $C_{eff} = C$

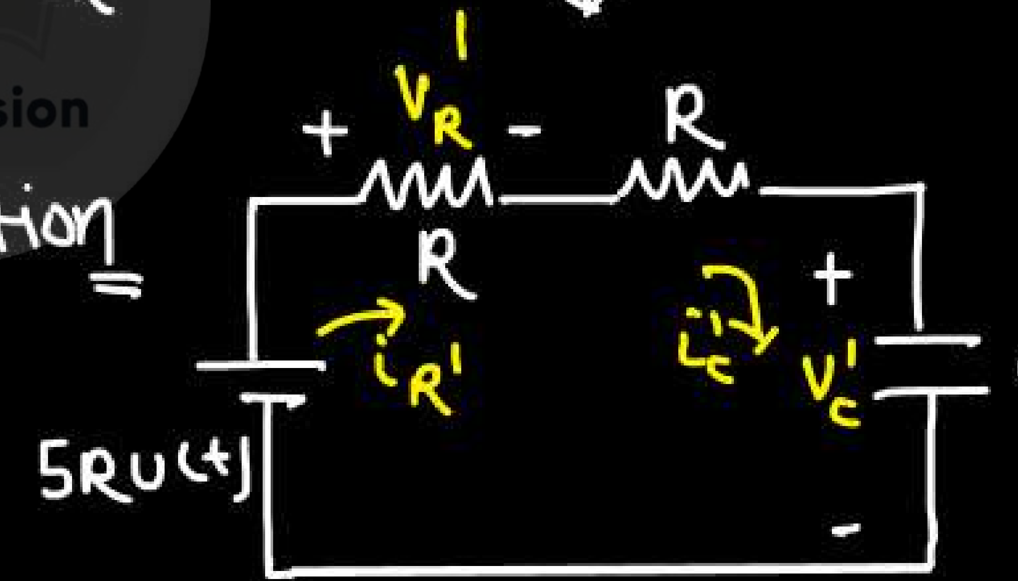
$\tau = 2RC$

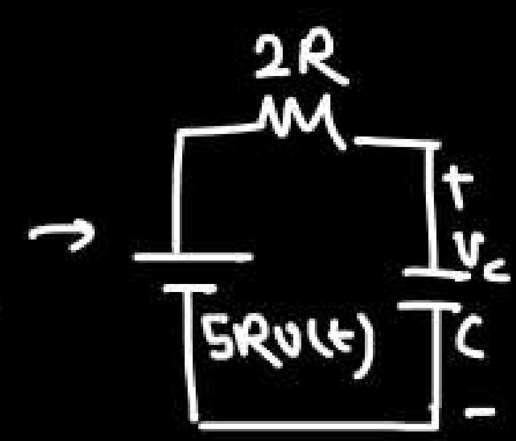
M-II :-





↓ source Transformation



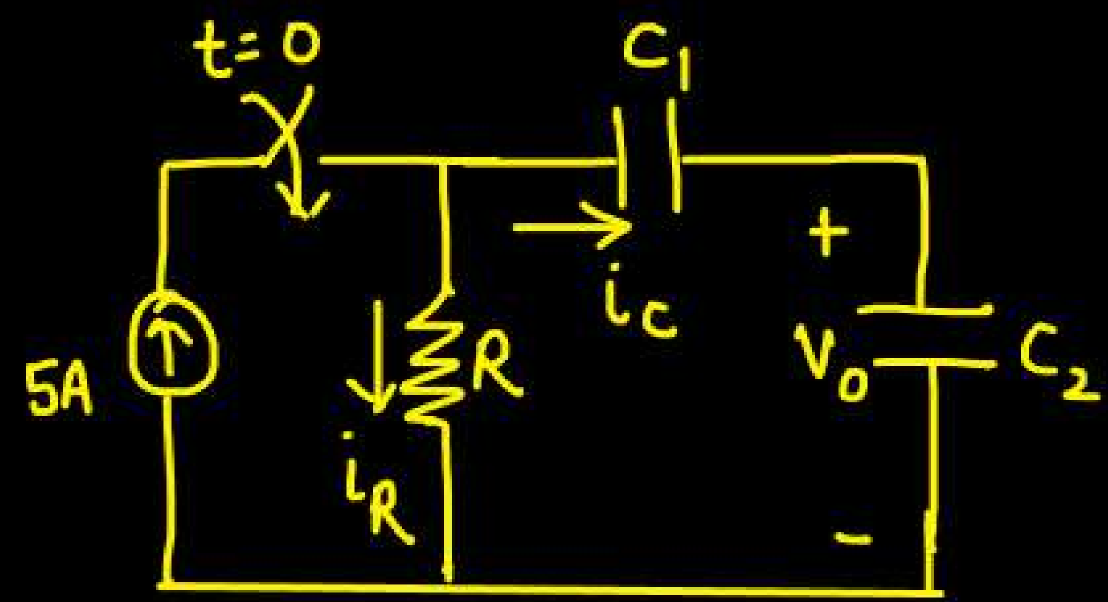


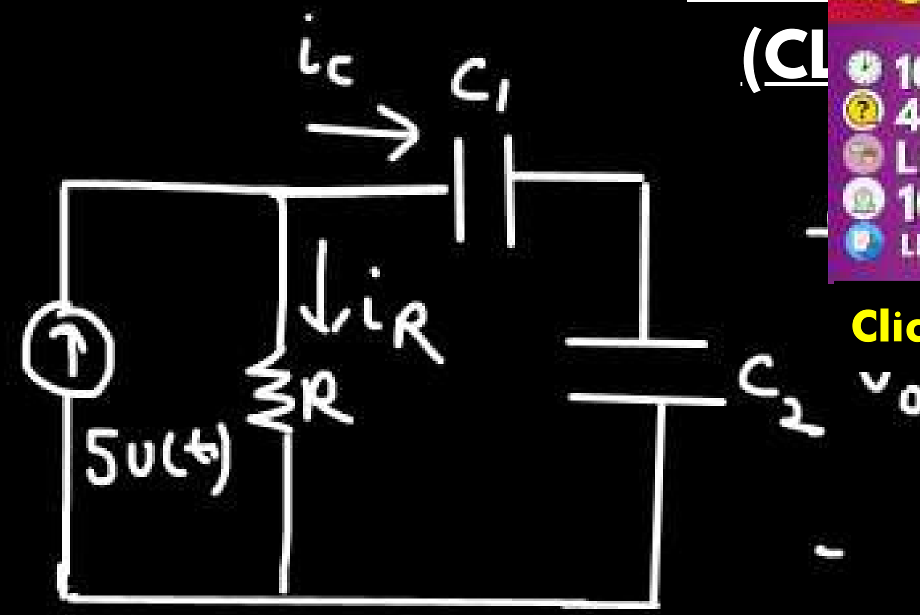
$v_R' = v_R$ ✗
$i_R' = i_R$ ✗ } Can't find v_R & i_R from Source Transformation

$i_c' = i_c$ ✓

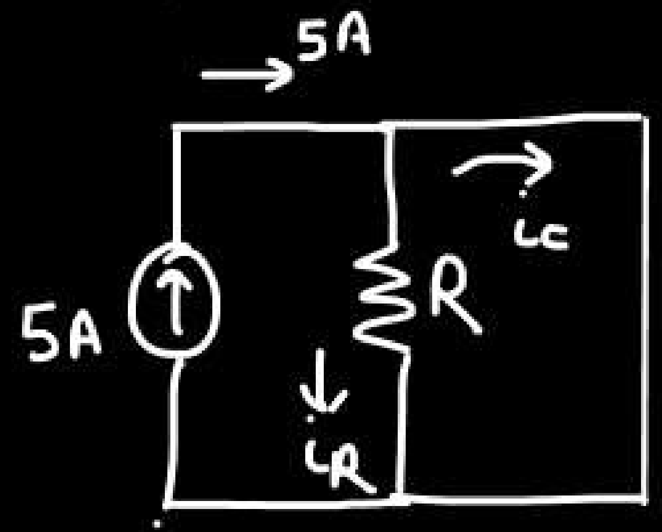
$V_c' = V_c$ ✓

Q.

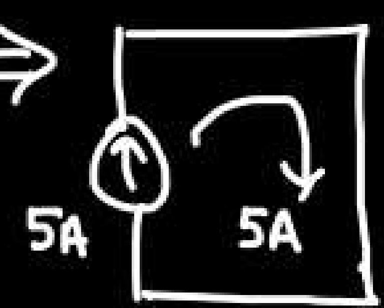




Ckt @ t=0

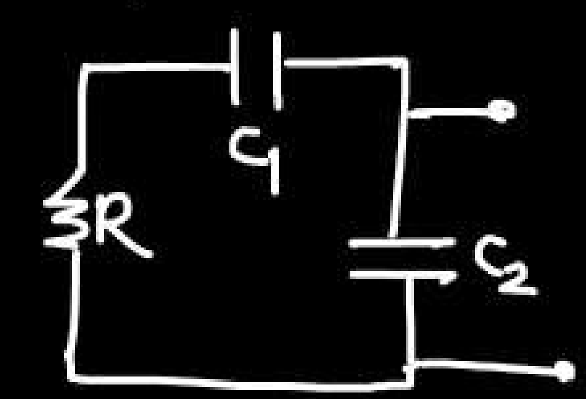


$\Rightarrow$



$i_c(0^+) = 5A$, $V_o(0^+) = 0V$, $i_R(0^+) = 0$ Amp.

$\tau = ?$

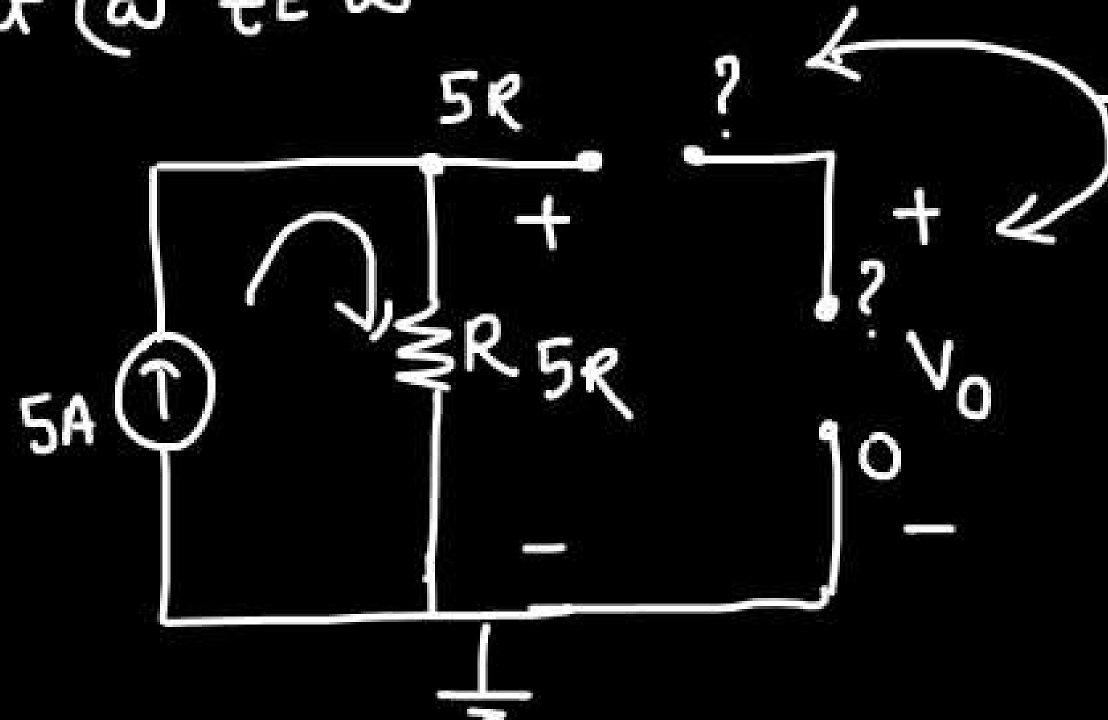


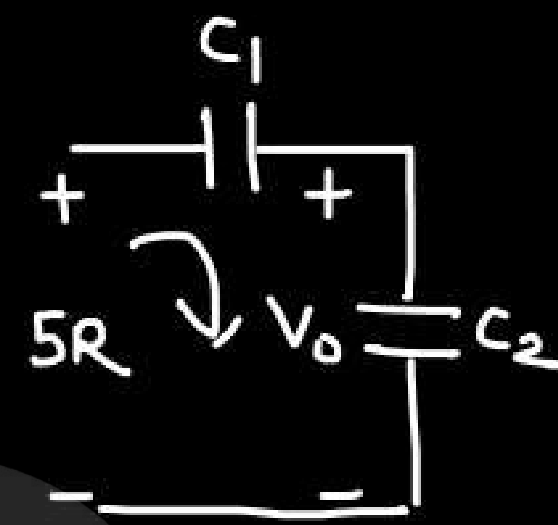
$C_{eff} = \frac{C_1 C_2}{C_1 + C_2}$

$R_{eq} = R$

$\tau = \frac{R C_1 C_2}{C_1 + C_2}$

ckt @ $t = \infty$



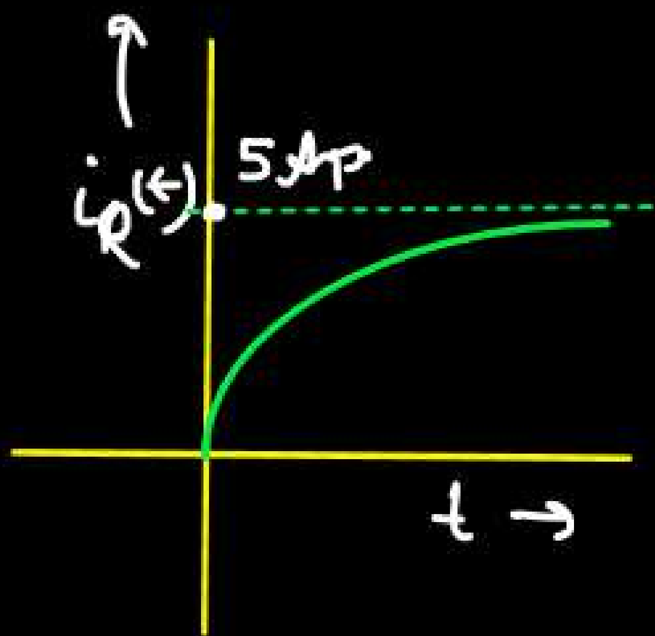


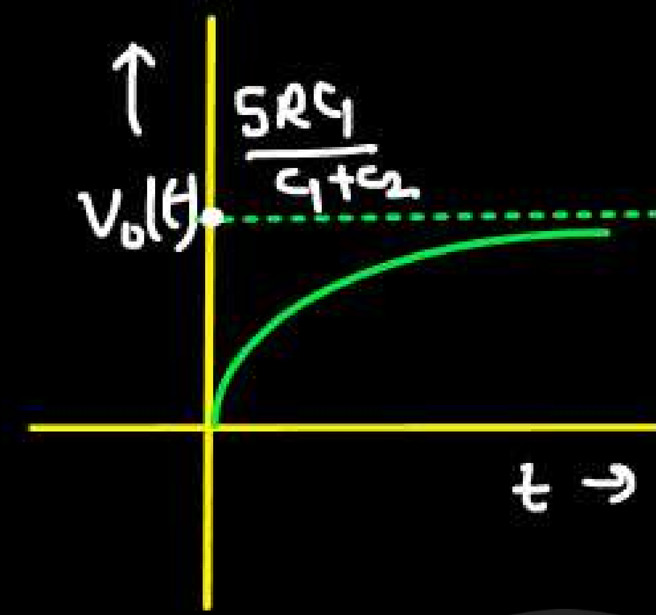
$$V_0(\infty) = \frac{5RC_1}{C_1 + C_2}, \quad i_C(\infty) = 0 \text{ Amp.}, \quad i_R(\infty) = 5 \text{ Amp.}$$

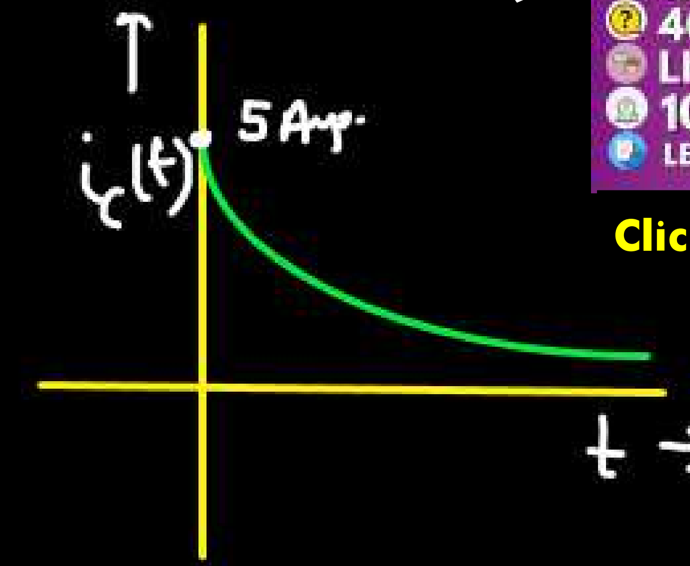
$$i_C(t) = 5e^{-t/\tau}\,u(t) \text{ Amp.}$$

$$V_0(t) = \frac{5RC_1}{C_1+C_2}\left[1 - e^{-t/\tau}\right]u(t) \text{ V}$$

$$i_R(t) = 5\left[1 - e^{-t/\tau}\right]u(t) \text{ Amp.}$$

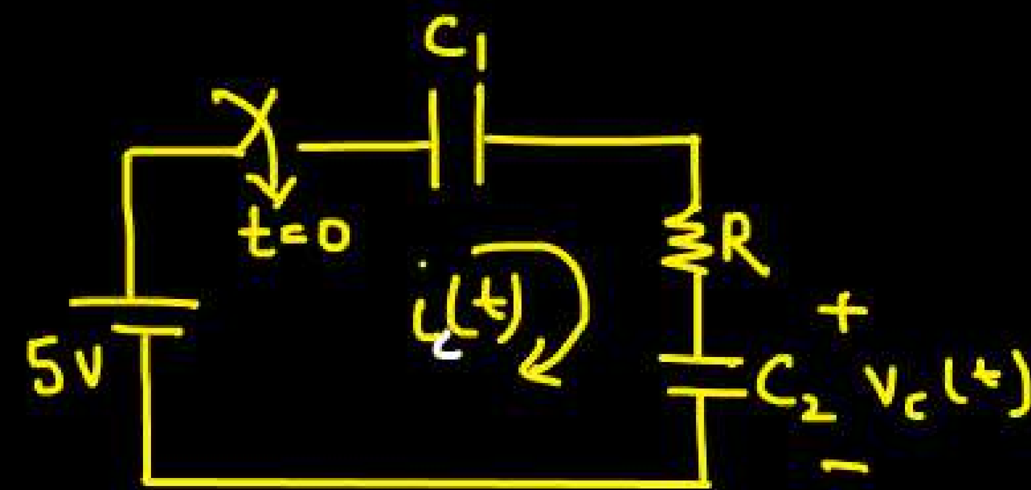

5 Ap
$i_R(t)$
t →

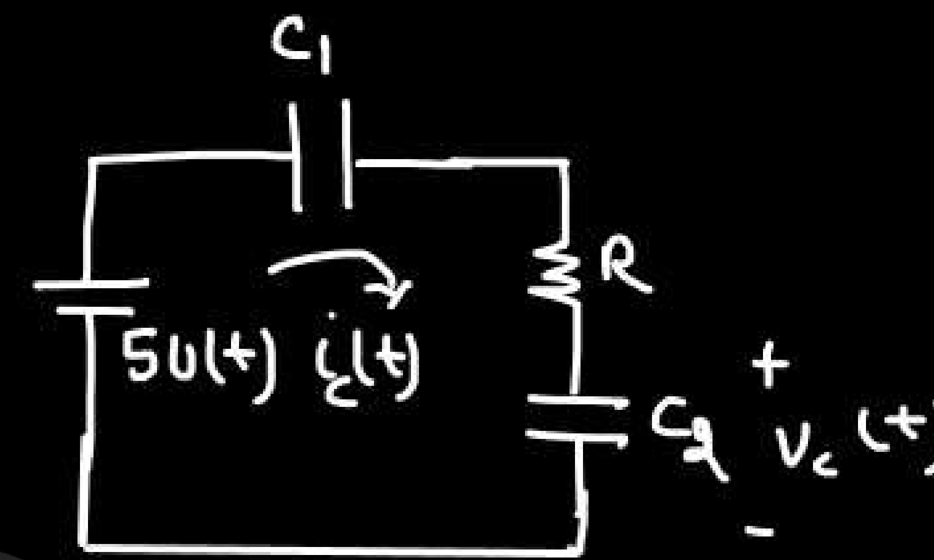

$\frac{5RC_1}{C_1+C_2}$
$V_0(t)$
t →


5 Amp.
$i_C(t)$
t →

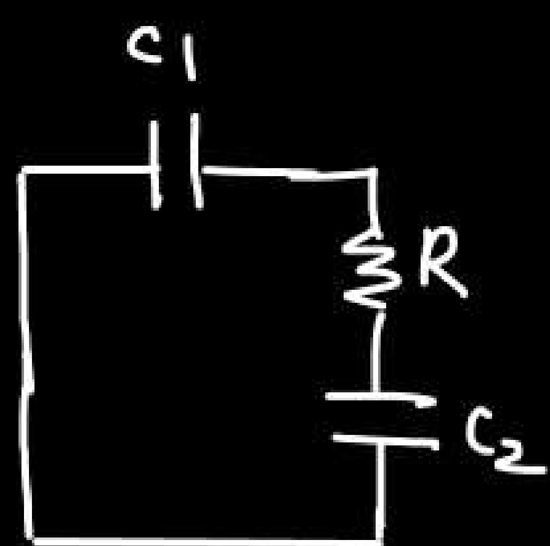
More Examples of RC ckts:-

Q.





→ $\tau = ?$



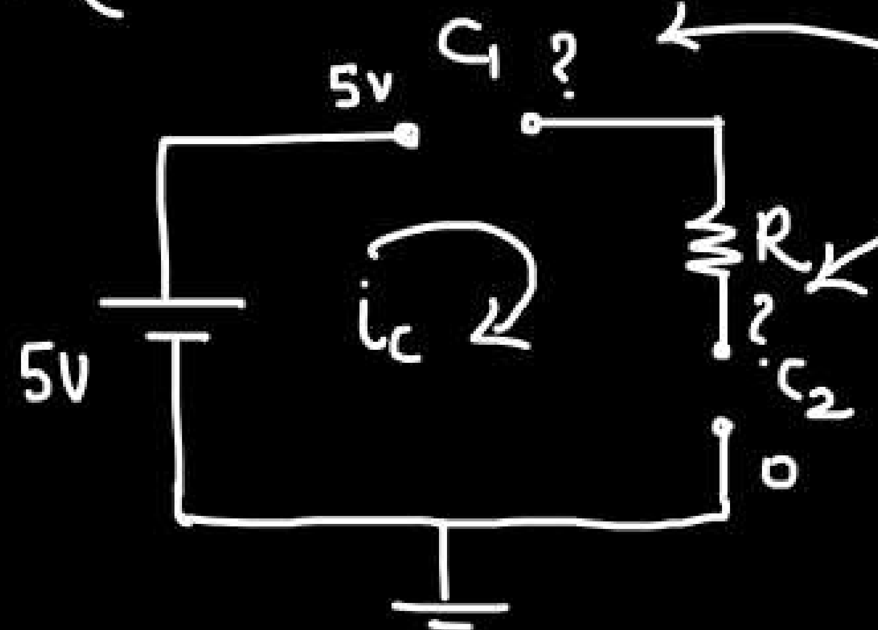
$R_{eq} = R$

$C_{eff} = \dfrac{C_1 C_2}{C_1 + C_2}$

$$\boxed{\tau = \frac{R C_1 C_2}{C_1 + C_2}}$$

$i(0^+) = \dfrac{5}{R}$ Ap. ; $v_c(0^+) = 0\ V$

ckt @ $t=\infty$

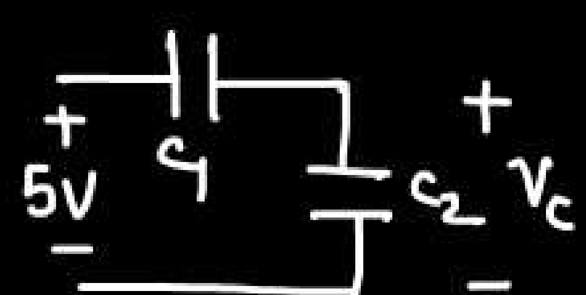


open ended nodes

$i_c(\infty) = 0$ Amp.

@ $t=\infty \Rightarrow$ steady state $\Rightarrow \omega = 0 \Rightarrow Z_c = \dfrac{1}{j\omega C} \Rightarrow$ impedance by capacitor is very High

equivalent ckt @ $t=\infty$



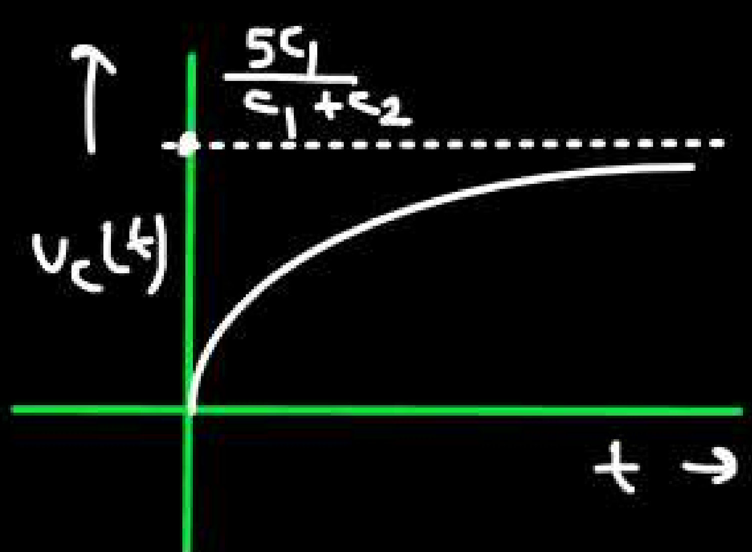
$$V_c(\infty) = \frac{5C_1}{C_1 + C_2}$$

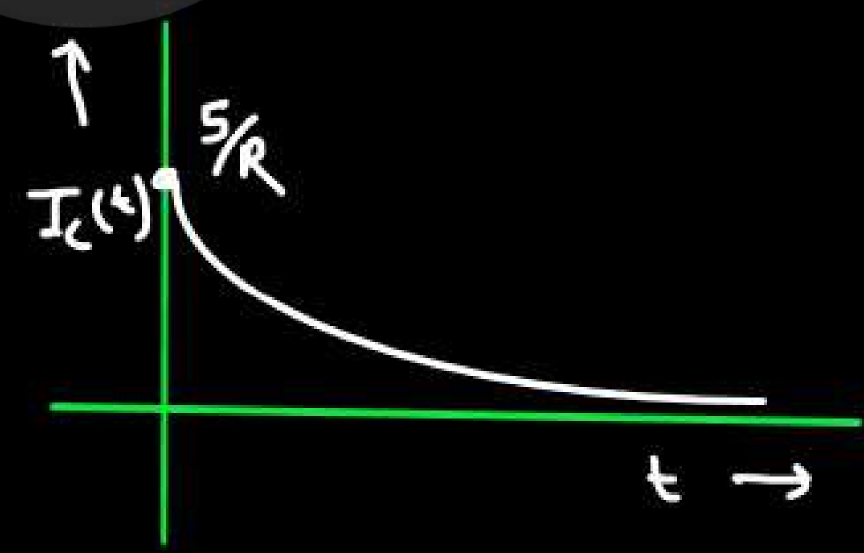
$V_c(0^+) = 0\,V \quad ; \quad V_c(\infty) = \dfrac{5C_1}{C_1+C_2}$

$I_c(0^+) = 5/R \text{ Amp.} \quad ; \quad I_c(\infty) = 0 \text{ Amp.}$

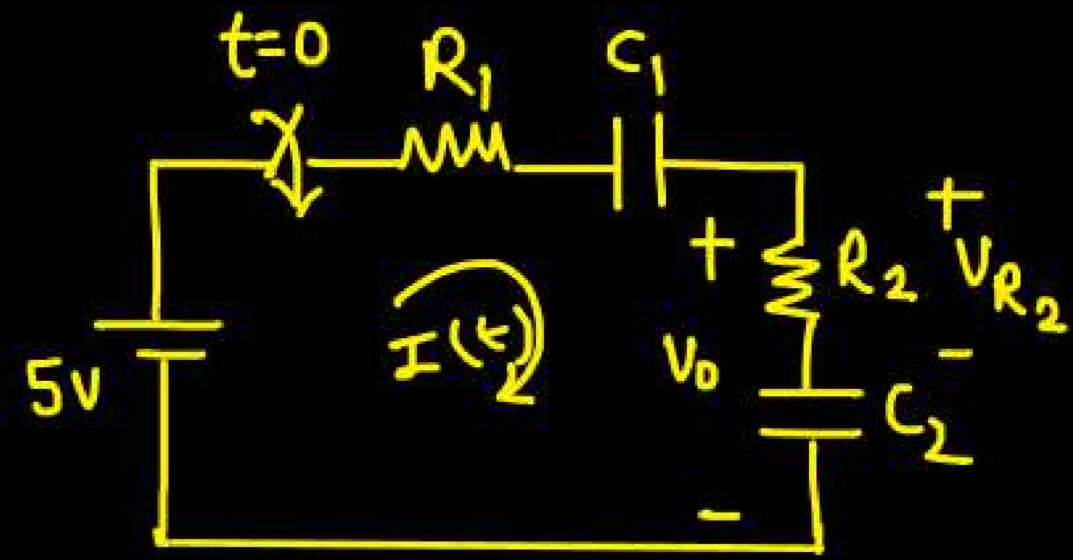
$$V_c(t) = \frac{5C_1}{C_1+C_2}\left(1 - e^{-t/\tau}\right)u(t) \quad ; \quad \tau = \frac{R C_1 C_2}{C_1+C_2}$$

$$I_c(t) = \frac{5}{R} e^{-t/\tau} u(t)$$





Q.



→

$\tau = ?$

$R_{eq} = R_1 + R_2$

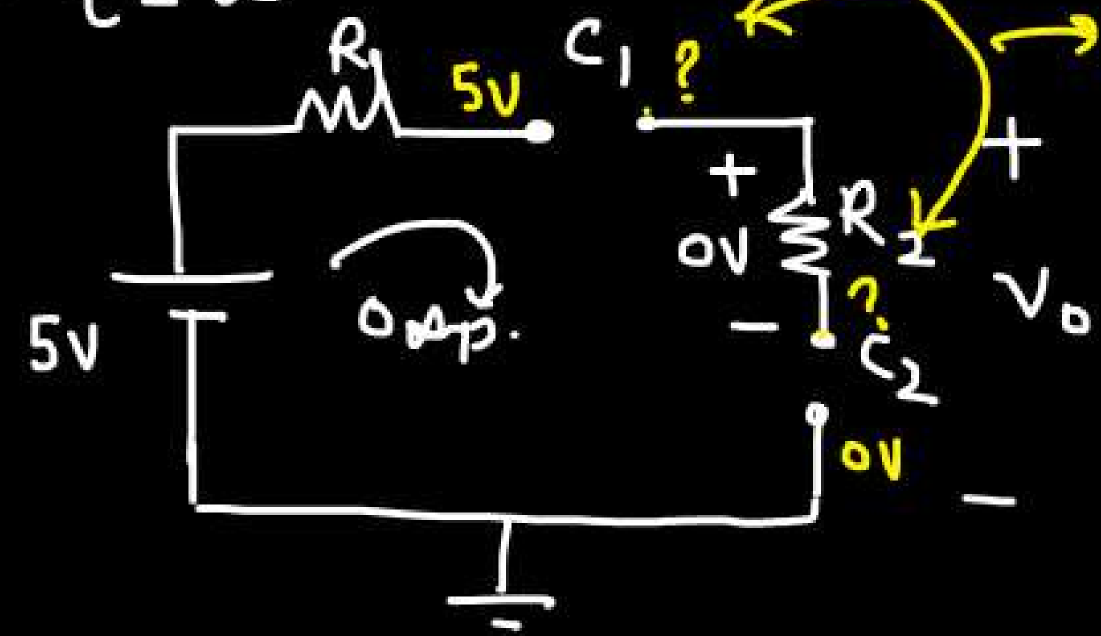
$C_{eff} = \dfrac{C_1 C_2}{C_1 + C_2}$

$$\boxed{\tau = (R_1 + R_2)\dfrac{C_1 C_2}{C_1 + C_2}}$$

at t=0:-

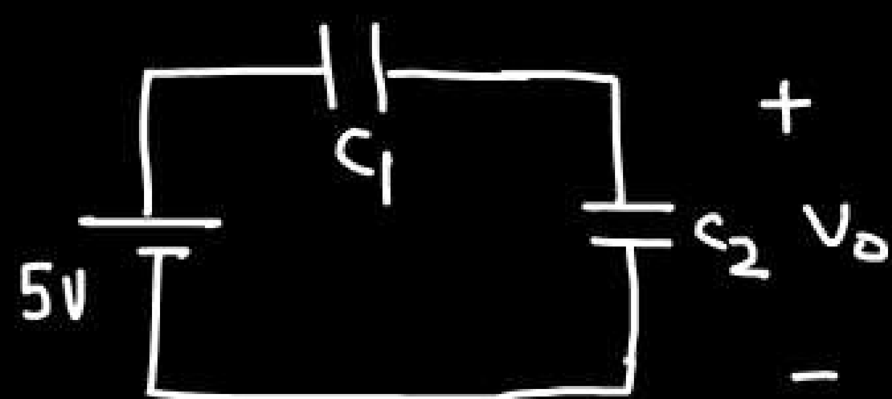
$I(0^+) = \dfrac{5}{R_1 + R_2}$; $V_0(0^+) = \dfrac{5R_2}{R_1 + R_2}$; $V_{R_2}(0^+) = \dfrac{5R_2}{R_1 + R_2}$

at $t = \infty$



open ended nodes

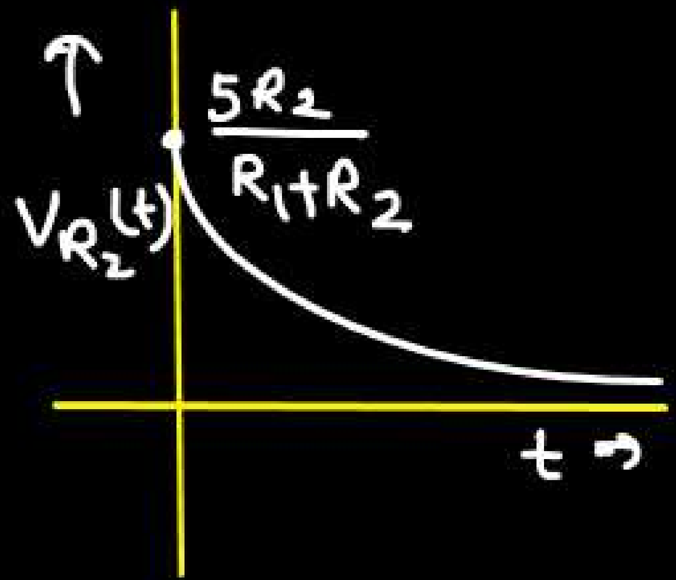
@ $t = \infty \Rightarrow \omega = 0 \Rightarrow$

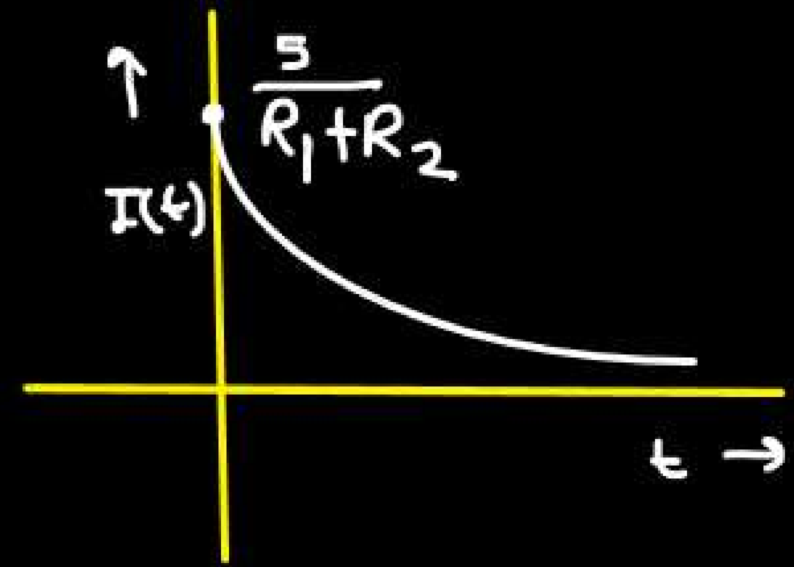


$$V_{R_2}(\infty) = 0\ V$$

$$V_o(\infty) = \frac{5C_1}{C_1 + C_2}$$

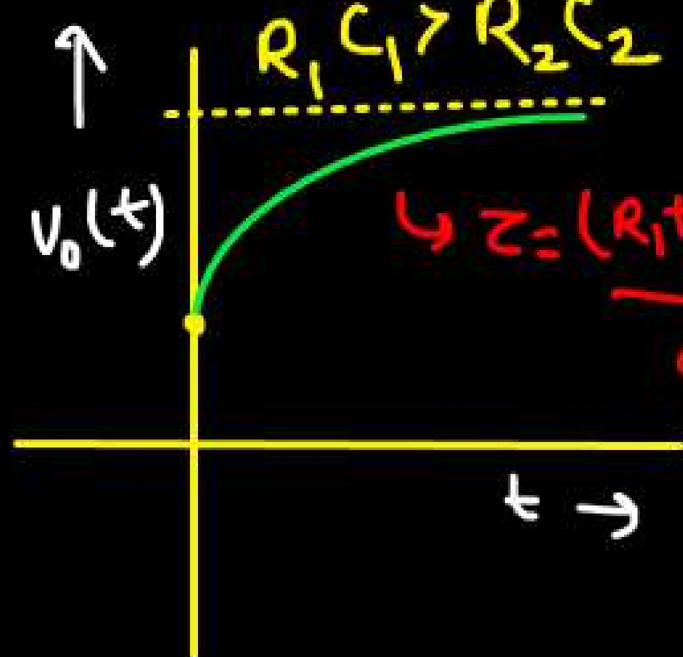
$$I(\infty) = 0 \text{ Amp.}$$



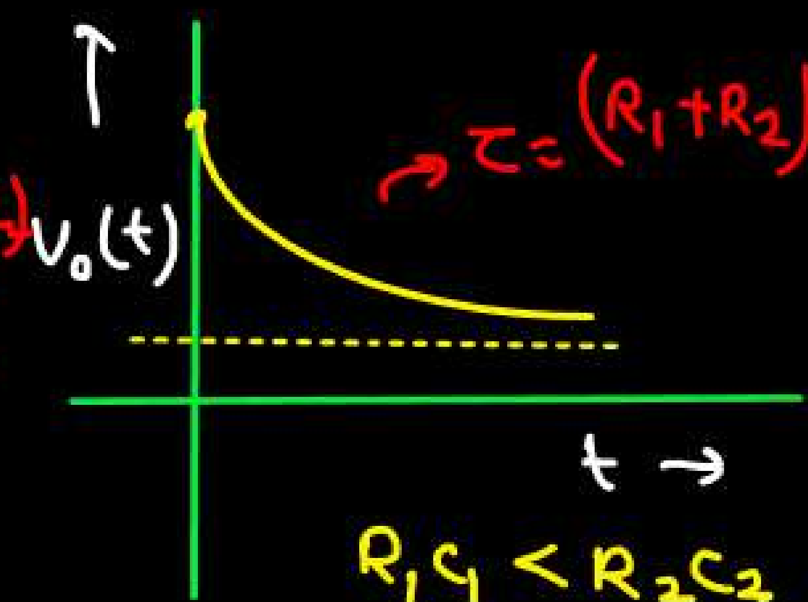


$$V_0(0^+) = \frac{5R_2}{R_1+R_2} = \frac{5}{1+R_1/R_2}$$

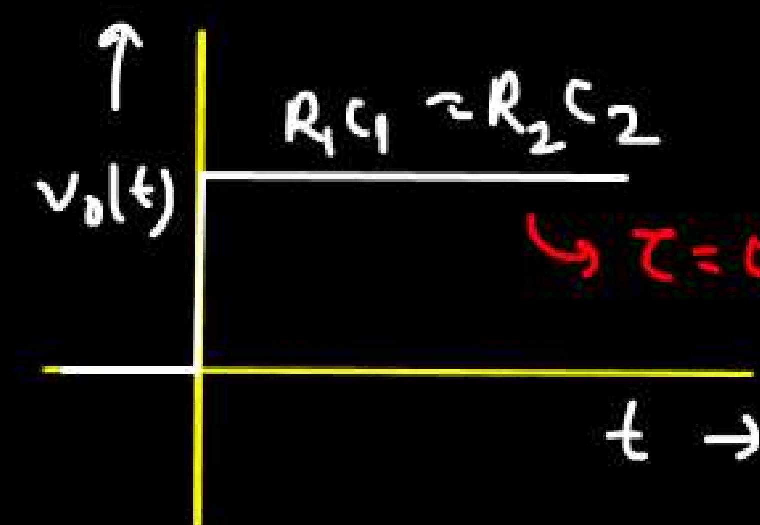
$$V_0(\infty) = \frac{5C_1}{C_1+C_2} = \frac{5}{1+C_2/C_1}$$



$\tau = (R_1+R_2)\left(\frac{C_1C_2}{C_1+C_2}\right)$

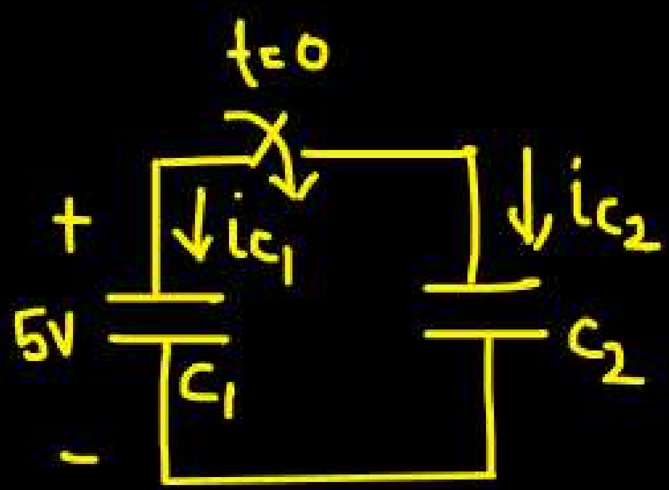


$\tau = (R_1+R_2)\left(\frac{C_1C_2}{C_1+C_2}\right)$

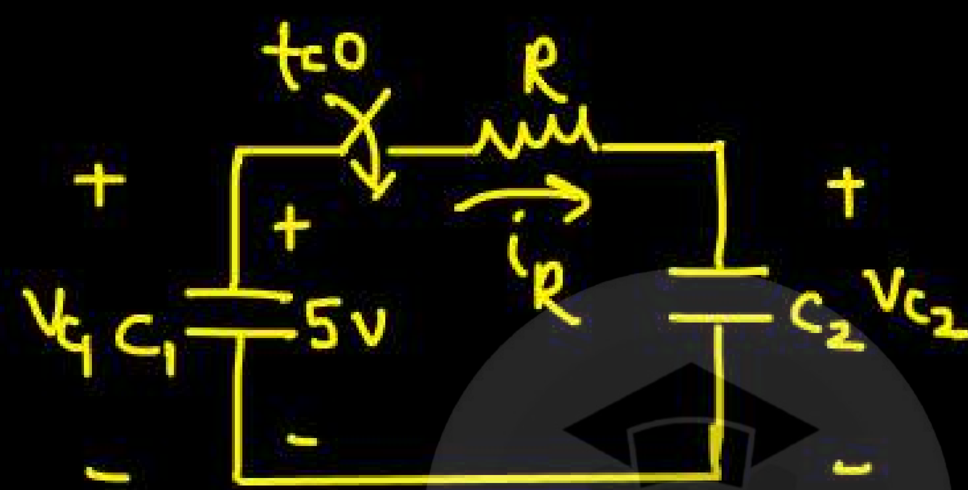


$\tau = 0$ Sec.

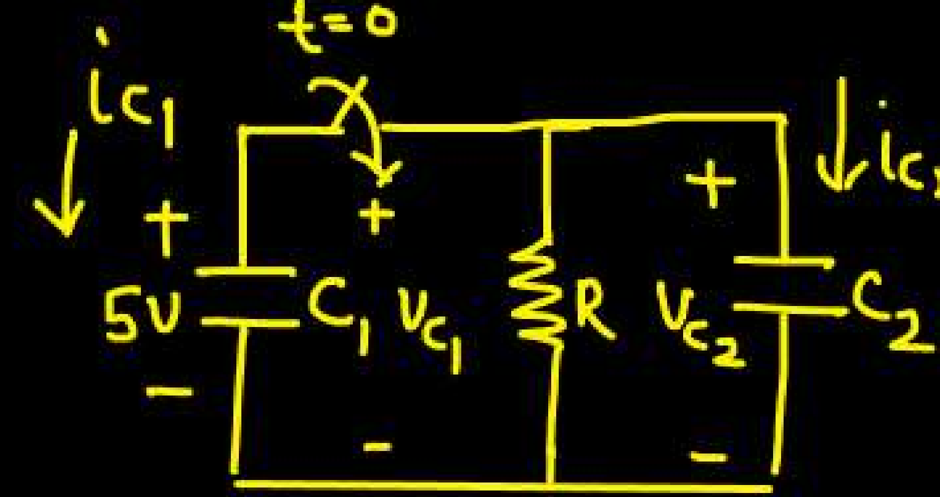
Q. In the given ckt cap. C_1 is already charged to 5V. Find V_{C_1}, V_{C_2}, V_R, i_{C_1}, i_{C_2} and i_R.



(a)

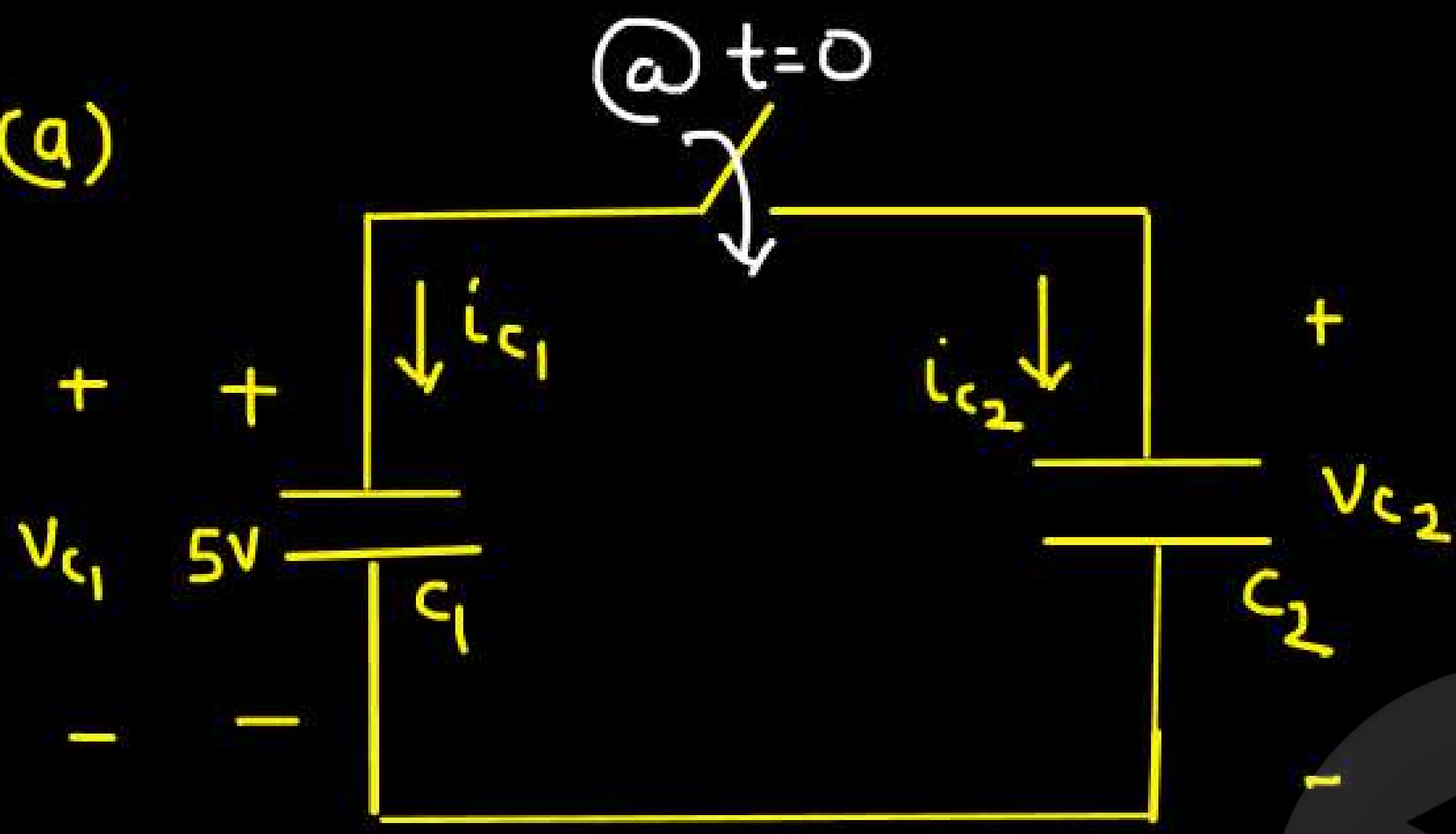


(b)

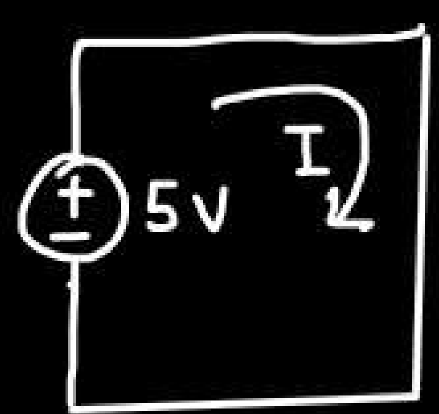


(c)

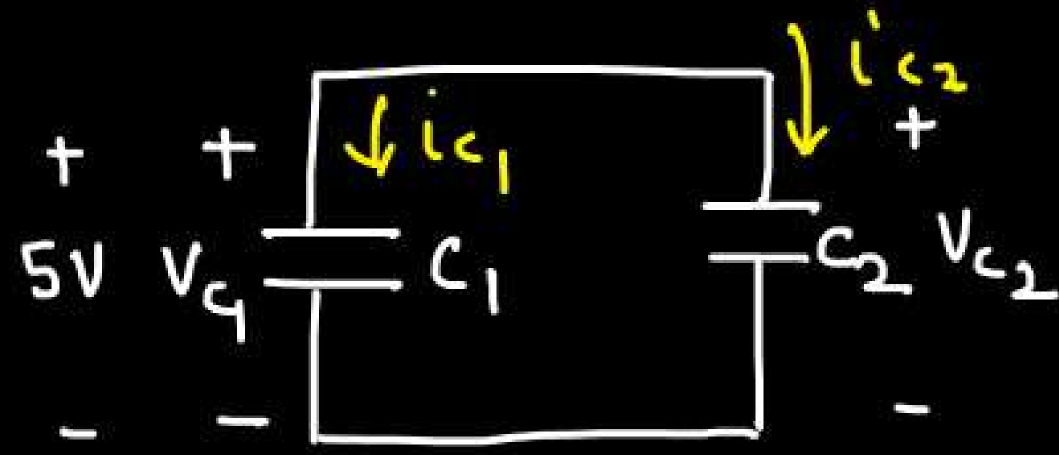
(a)



Ckt @ t=0



$I = \frac{5}{0} = \underline{\infty} \Rightarrow$ impulse current ⇒ sudden change in cap. voltage



Charge conservation;

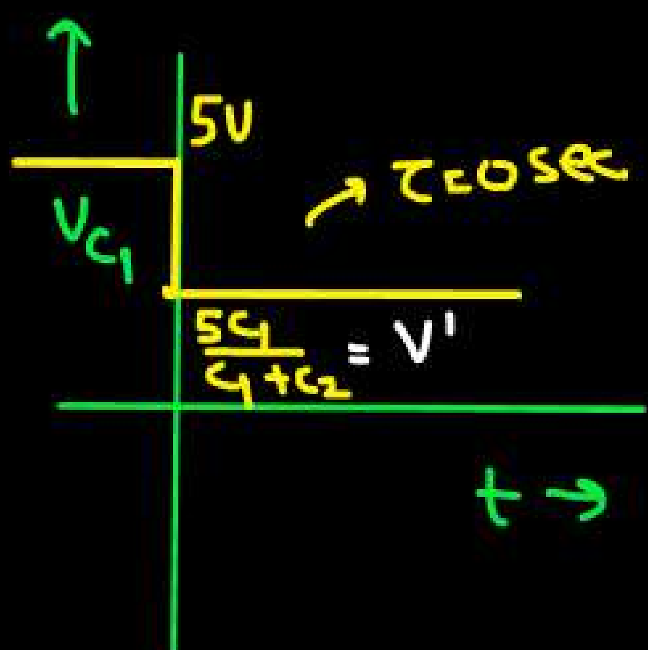
Charge before switching = charge after switching

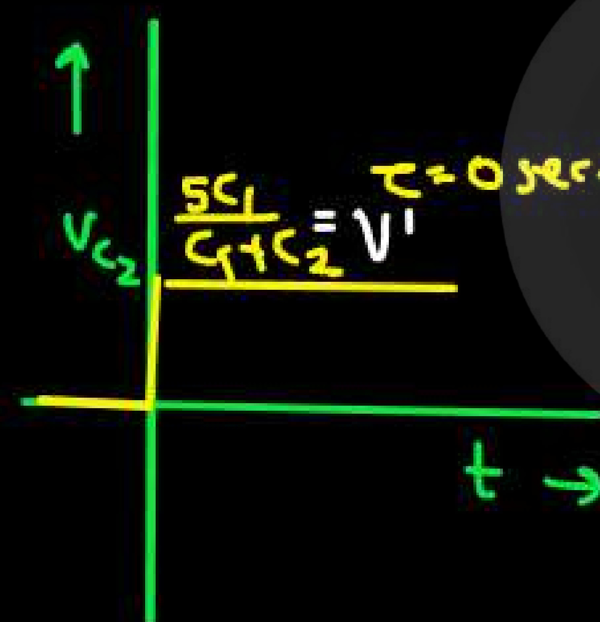
$$5C_1 = C_1 V_{c_1} + C_2 V_{c_2}$$

after switching, $V_{c_1} = V_{c_2} = V_c$

$$5C_1 = (C_1 + C_2) V_c$$

$$\boxed{V_c = \frac{5C_1}{C_1 + C_2}}$$





$$i_{c_1} = -i_{c_2}$$

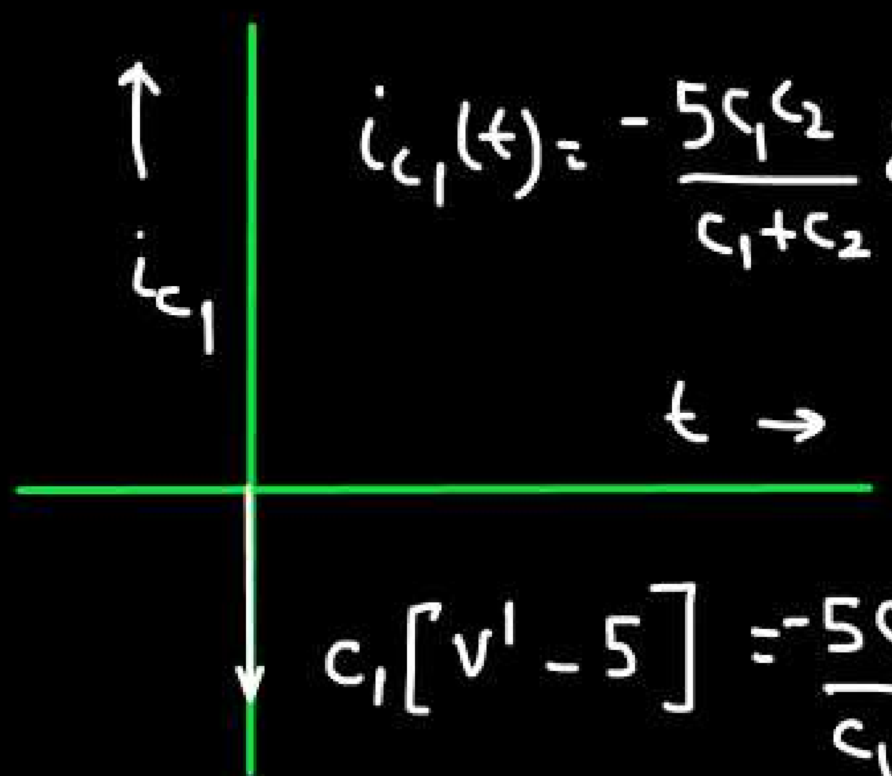
N.B. :-

$$C_1 V_1 + C_2 V_2 = (C_1 + C_2) V_0$$

$$V_0 = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$$

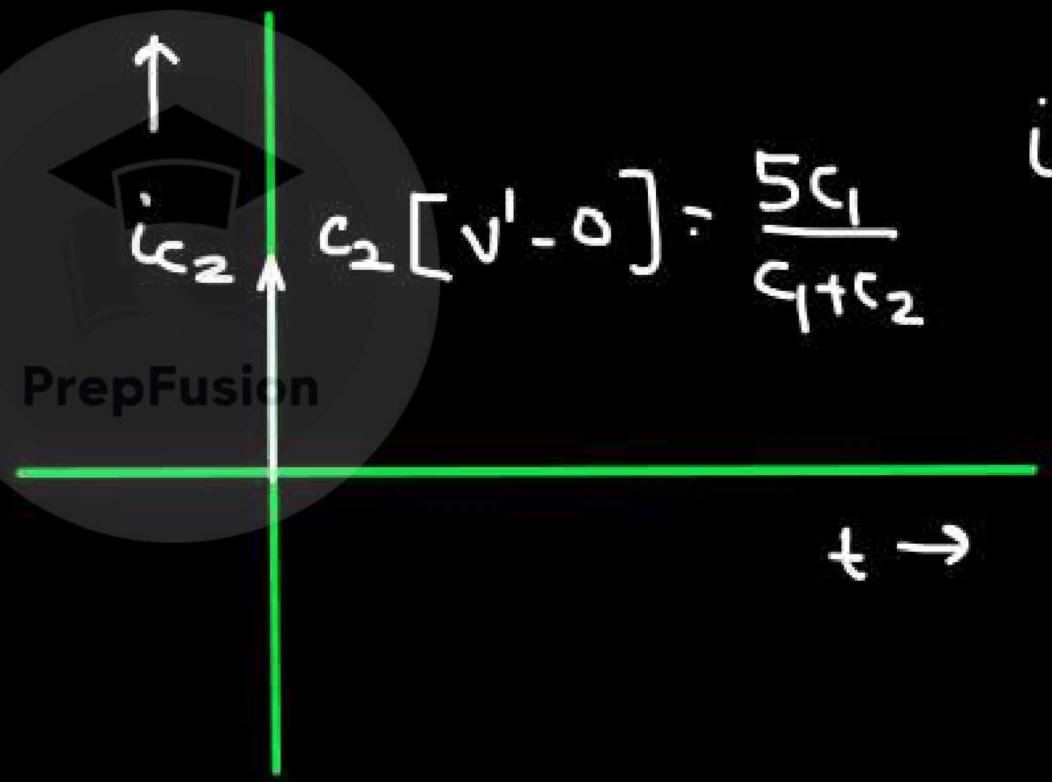
C_1 cap. is getting discharged ⇒ Current flowing out of the cap. (i_{c_1} → nega

C_2 cap. is getting charged ⇒ Current flowing into the cap. (i_{c_2} → positive)



$$i_{c_1}(t) = -\frac{5C_1C_2}{C_1+C_2}\delta(t)$$

$$C_1[V'-5] = -\frac{5C_1C_2}{C_1+C_2}$$

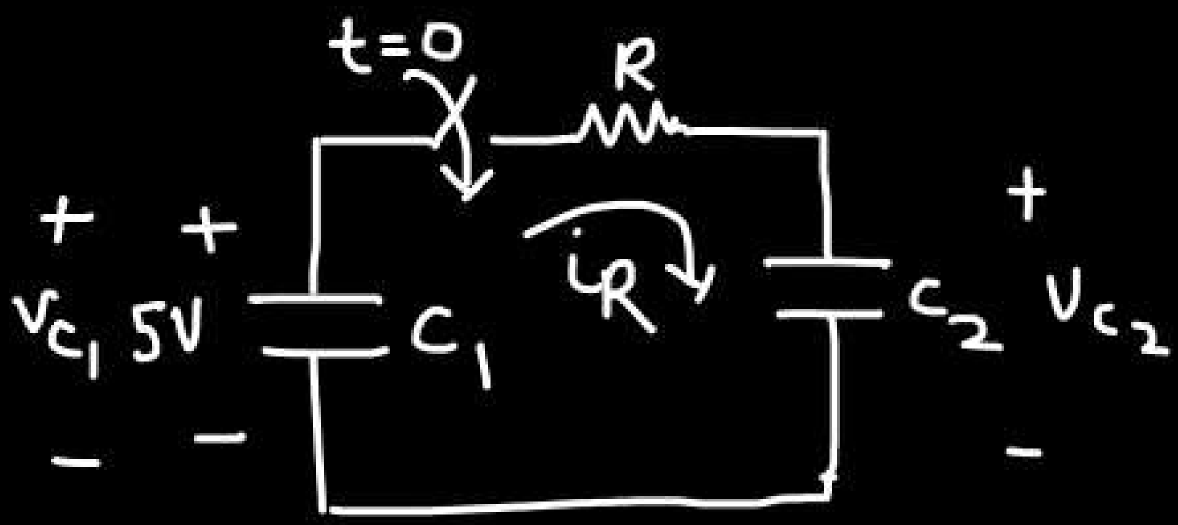


$$C_2[V'-0] = \frac{5C_1}{C_1+C_2}$$

$$i_{c_2}(t) = \frac{5C_1}{C_1+C_2}\delta(t)$$

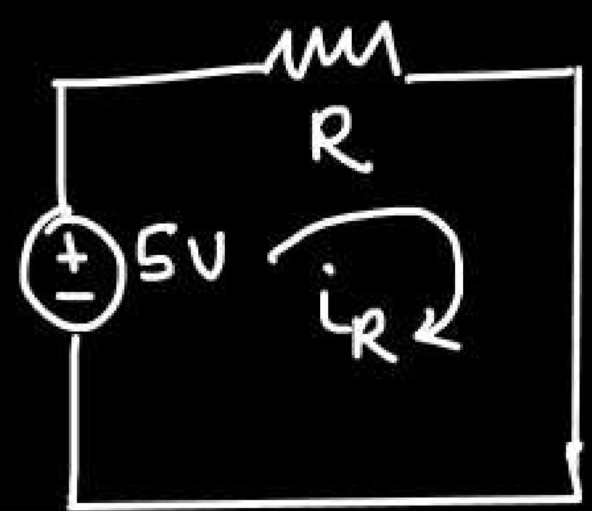
$$\boxed{i_{c_1} = -i_{c_2}}$$

$$\boxed{V' = \frac{5C_1}{C_1+C_2}}$$



(b)

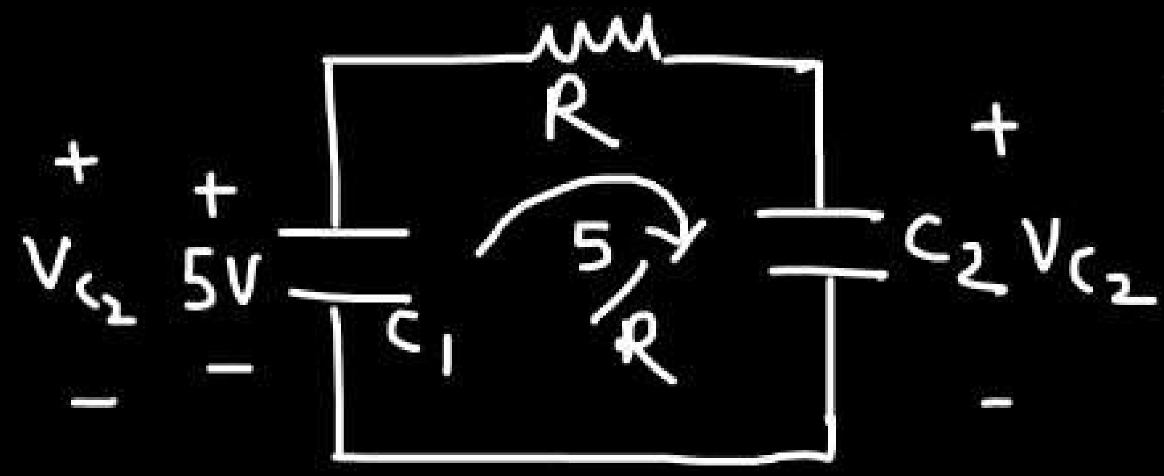
ckt @ t=0



$i_R(0^+) = 5/R$ amp $\neq \infty$

$V_{C_1}(0^+) = 5V$, $V_{C_2}(0^+) = 0V$

after $t = 0^+$



$\Rightarrow$ $5/R$ current charges c_2 and discharges c_1

$\Downarrow$

This charging and discharging will go on unit $i_R = 0$

$\Downarrow$

if $V_{c_1} = V_{c_2} = V_c \Rightarrow i_R = 0$ ~~cap~~.

$\Downarrow$

no current through cap.

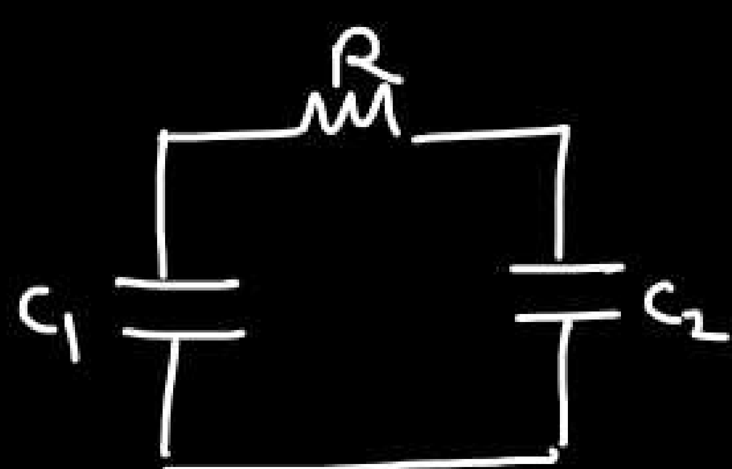
$\Rightarrow$ @ steady state $V_{c_1}(\infty) = V_{c_2}(\infty) = V_c$

Apply charge conservation;

$$5C_1 = (C_1 + C_2)V_c$$

$$\boxed{V_c = \frac{5C_1}{C_1 + C_2}} = V_{c_1}(\infty) = V_{c_2}(\infty)$$

$\tau = ?$

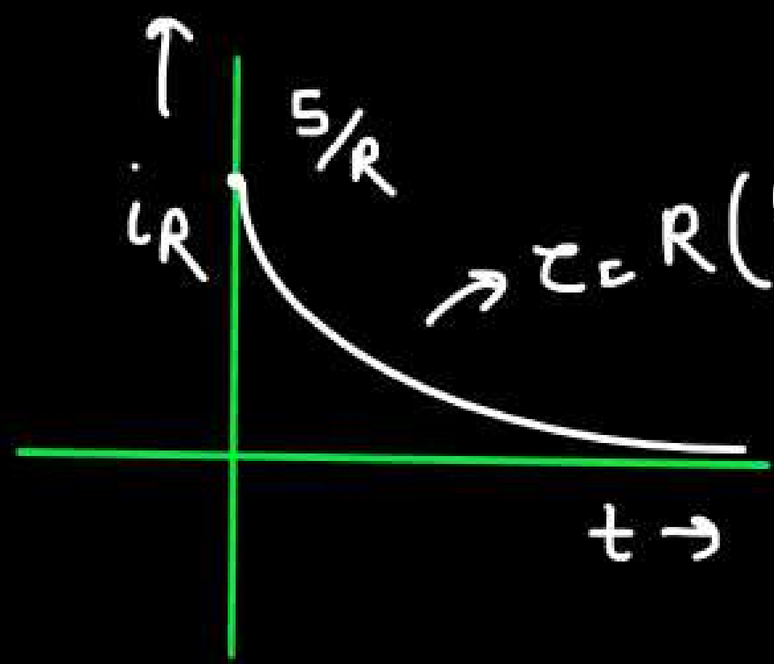


$$C_{eff} = \frac{C_1 C_2}{C_1 + C_2}$$

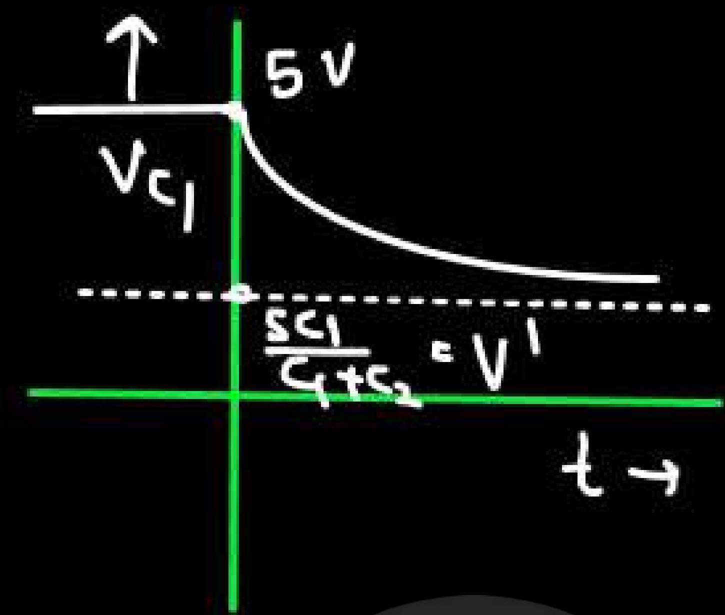
$$R_{eq} = R$$

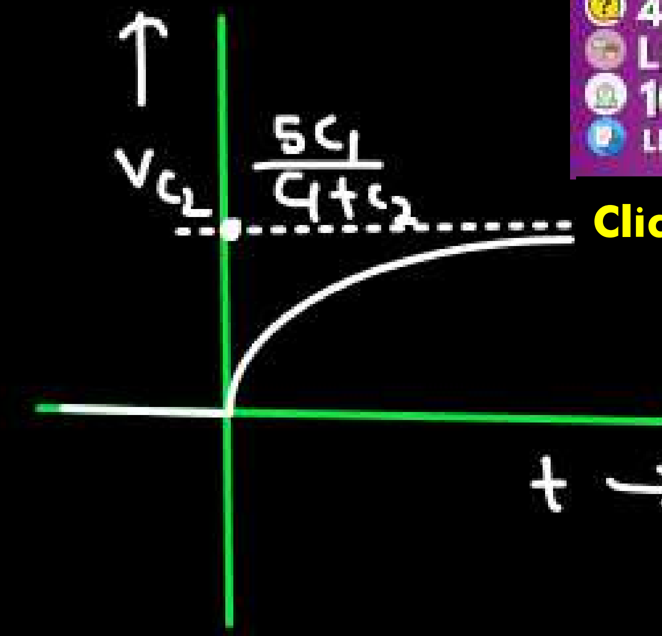
$$\boxed{\tau = \frac{R C_1 C_2}{C_1 + C_2}}$$

$I_R(\infty) = 0$ Amp.



$\tau = R\left(\frac{C_1 C_2}{C_1+C_2}\right)$

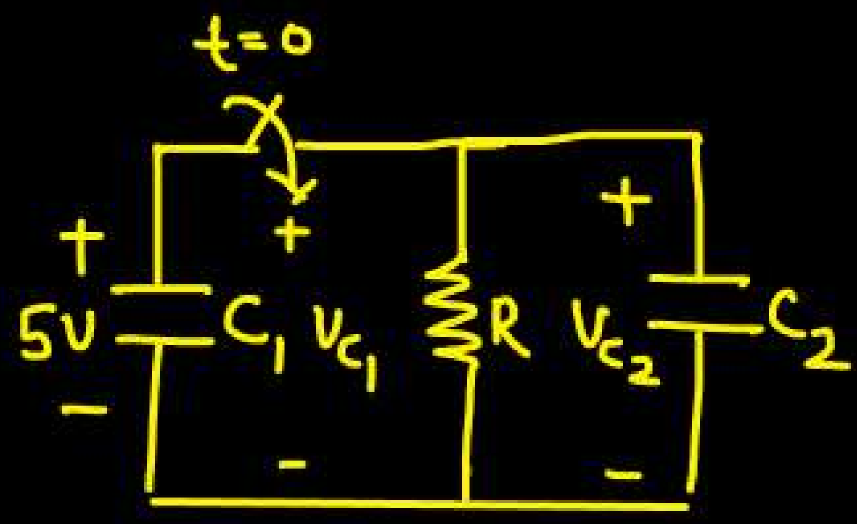




$$i_R = \frac{5}{R} e^{-t/\tau} u(t)$$

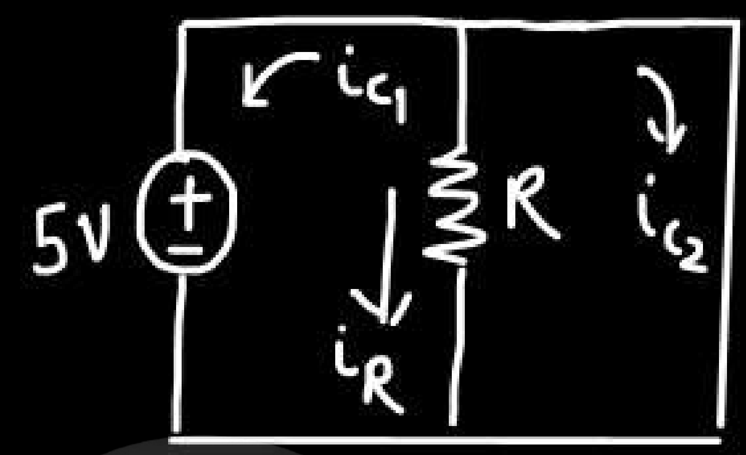
$$v_{c_1}(t) = \left[V' + (5 - V') e^{-t/\tau}\right] u(t) \;;\quad v_{c_2} = \frac{5C_1}{C_1+C_2}\left(1 - e^{-t/\tau}\right) u(t)$$

$$= \left[\frac{5C_1}{C_1+C_2} + \frac{5C_2}{C_1+C_2} e^{-t/\tau}\right] u(t)$$



(c)

ckt @ t=0



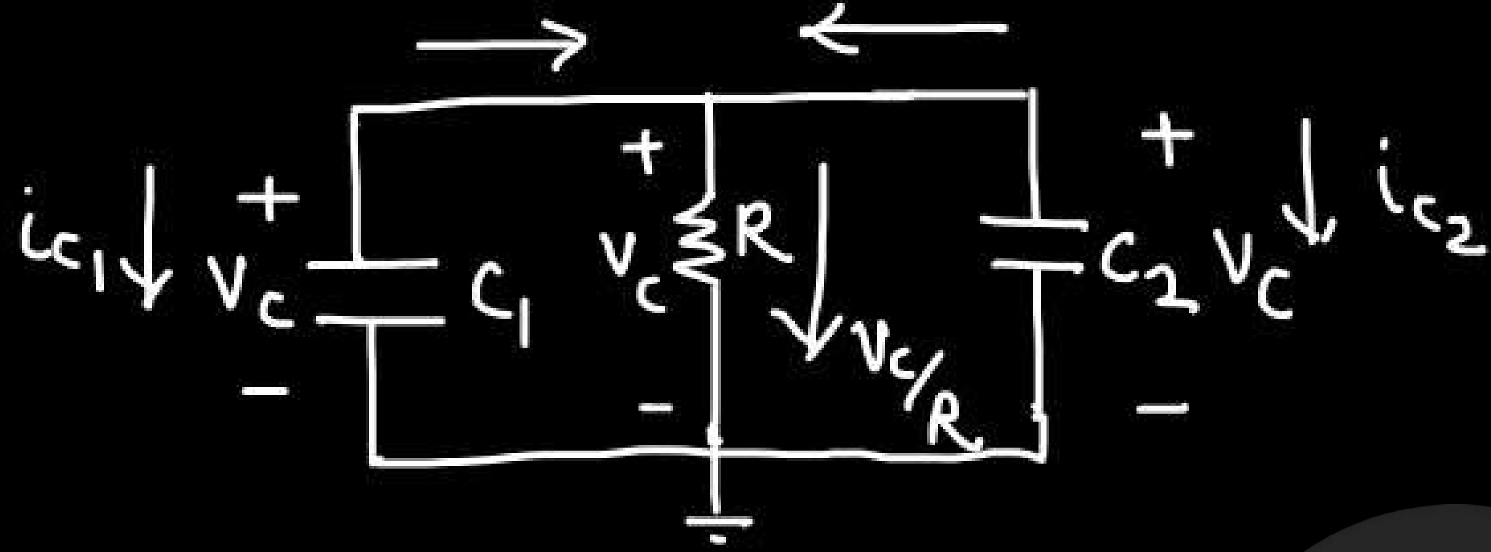
$$i_{c_1} = -i_{c_2} = \frac{5}{0} = \infty \text{ Ap.}$$

↳ impulsive current

@ $t=0^+$; $V_{c_1}(0^+) = V_{c_2}(0^+) = V_C$

$$\boxed{\frac{5C_1}{C_1+C_2} = V_C}$$

after $t = 0^+$



$$i_{c_1}(0^+) = -\frac{V_c}{R} \times \frac{C_1}{C_1+C_2}$$

$$i_{c_2}(0^+) = -\frac{V_c}{R} \times \frac{C_2}{C_1+C_2}$$

$$i_R(0^+) = V_c/R$$

From both of the cap., current is flowing outward

$\Downarrow$

Both of the cap. are getting discharged.

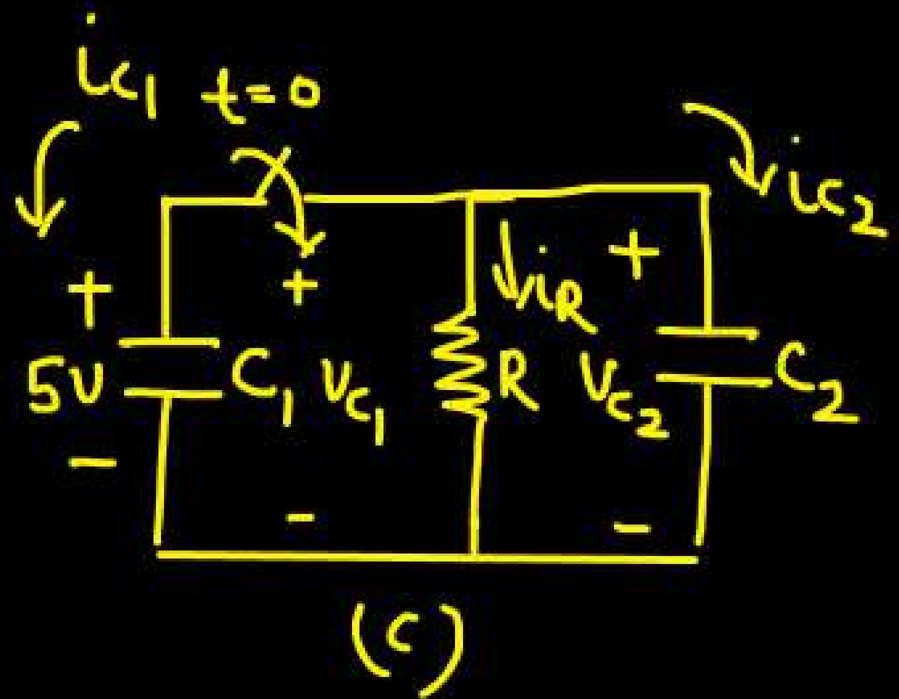
$\Downarrow$

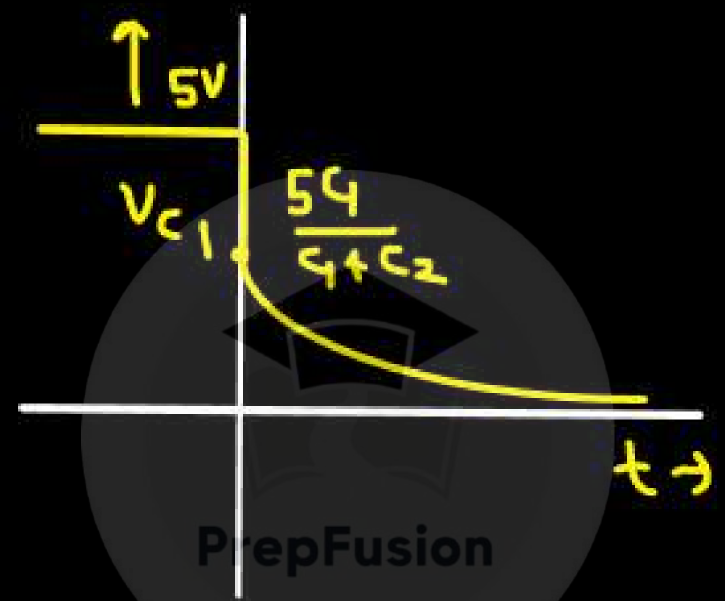
The cap. will charge until i_{c_1} and i_{c_2} goes to zero

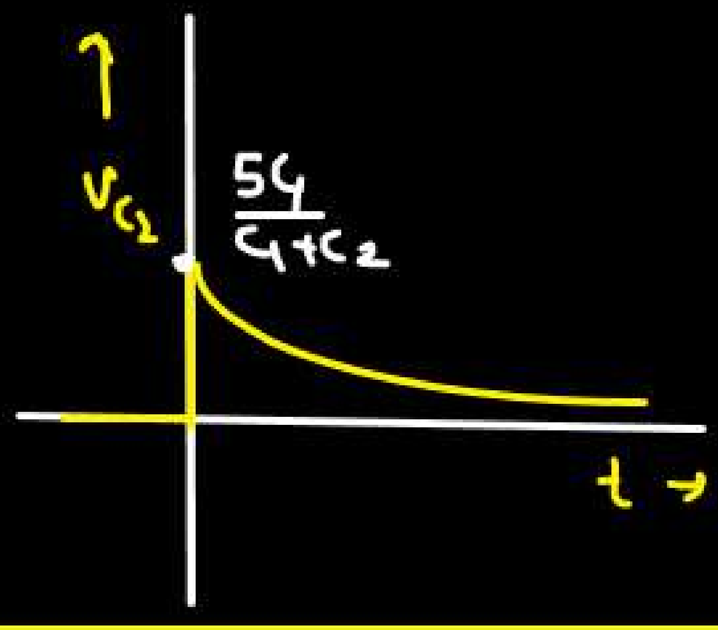
$\Rightarrow$ if i_{c_1} and i_{c_2} goes to zero $\Rightarrow$ i_R goes to zero

@ steady state;

$$V_{C_1}(\infty) = V_{C_2}(\infty) = V_R(\infty) = 0V$$



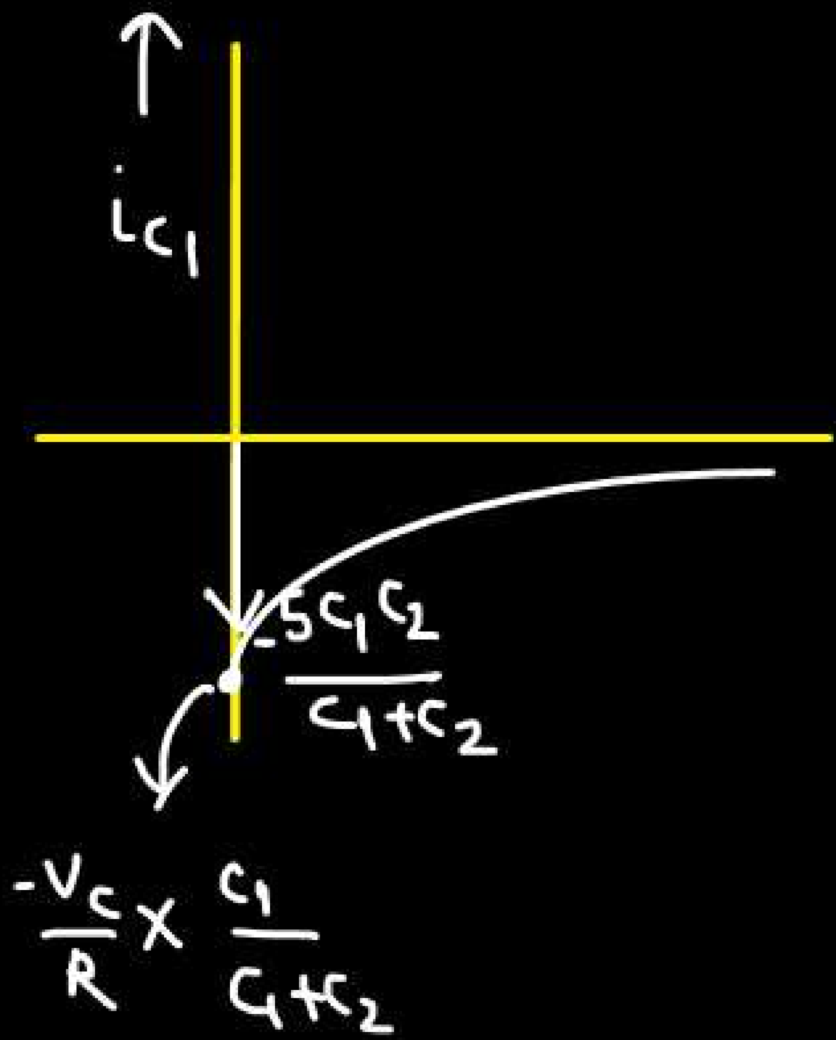


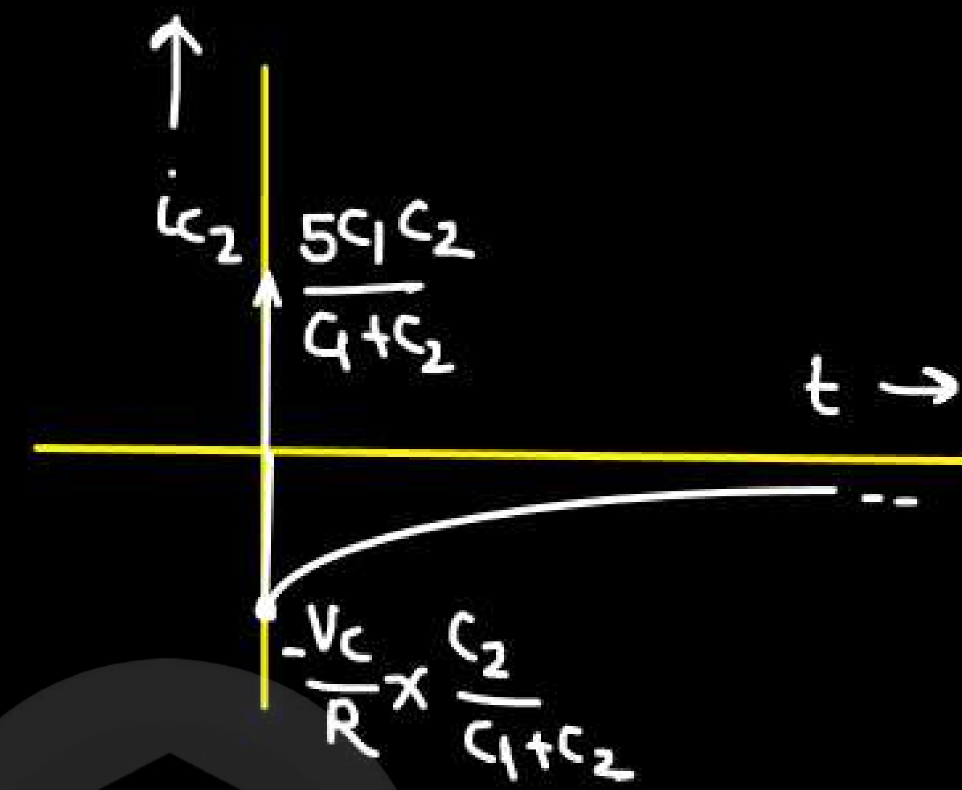


$$\boxed{\tau = R(C_1+C_2)}$$

$$\boxed{V_{C_2}(t) = \frac{5C_1}{C_1+C_2} e^{-t/\tau} u(t)}$$

$$\boxed{V_{C_1}(t) = 5u(-t) + \frac{5C_1}{C_1+C_2} e^{-t/\tau} u(t)}$$





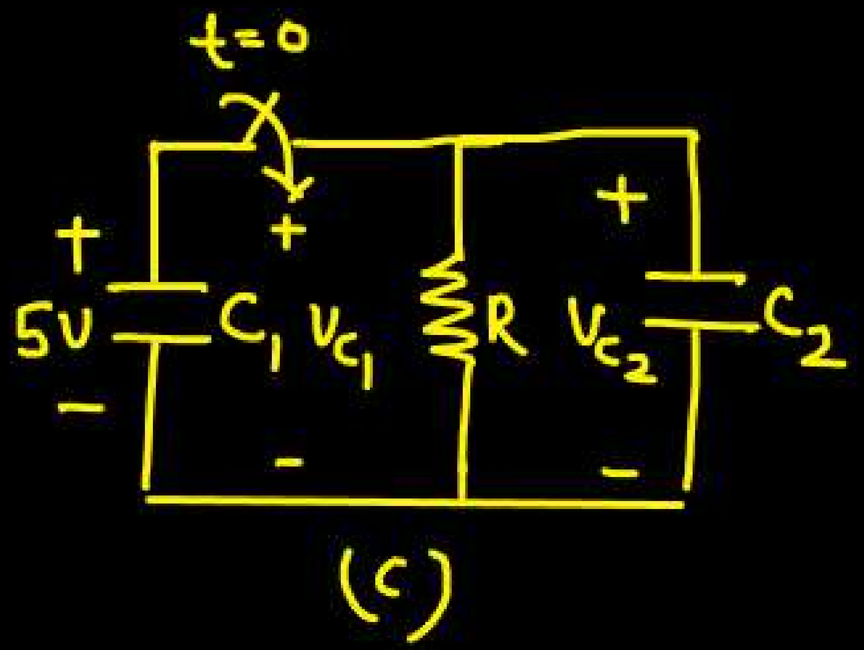
$$i_{c_2}(t) = \frac{5C_1C_2}{C_1+C_2}\delta(t) - \frac{V_c}{R} \times \frac{C_1}{C_1+C_2} e^{-t/\tau} u(t)$$

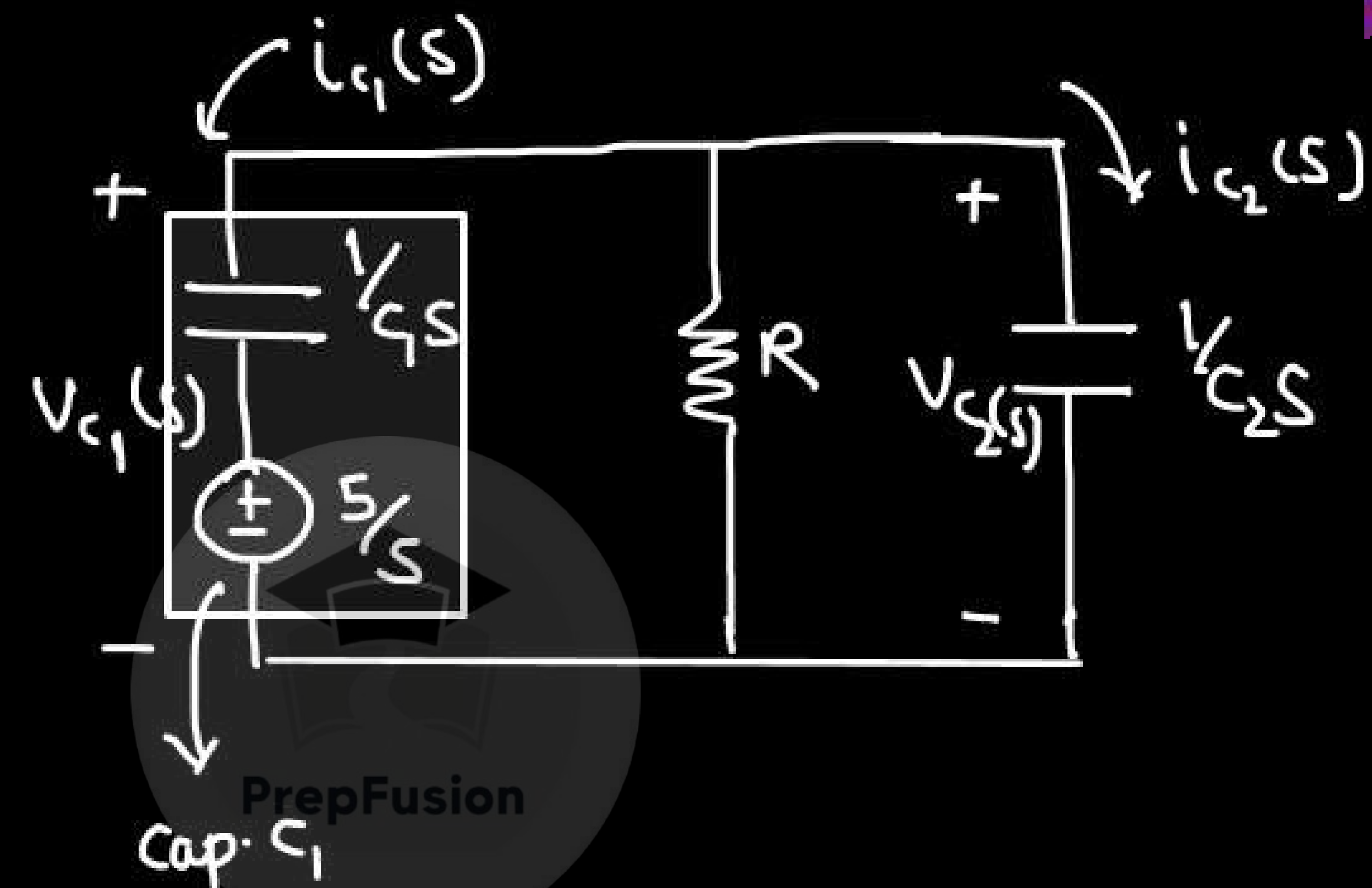
$$V_c = \frac{5C_1}{C_1+C_2}$$

$$i_{c_1}(t) = -\frac{5C_1C_2}{C_1+C_2}\delta(t) - \frac{V_c}{R} \times \frac{C_1}{C_1+C_2} e^{-t/\tau} u(t)$$

$$i_R(t) = \frac{5C_1}{R(C_1+C_2)} e^{-t/\tau} u(t)$$

↳ solving the ckt by Laplace Transform:-





$$\frac{V_{c_1}(s) - 5/s}{1/C_1 s} + \frac{V_{c_1}(s)}{R} + \frac{V_{c_1}(s)}{1/C_2 s} = 0$$

$$\Rightarrow V_{c_1}(s) = \_\_\_ \quad -$$

Slope @ $t=0^+$ in RC ckts:-

Q. Given $x(t) = 6t^2 + 3t$

find $\left[\frac{dx(t)}{dt}\right]_{t=0^+}$ or $\frac{dx(0^+)}{dt}$ or $x'(0^+)$.

→ $$\boxed{\begin{aligned} x(0) &= 6(0)^2 + 3(0) \\ &= 0 \\ \frac{dx(0)}{dt} &= x'(0) = 0 \end{aligned}}$$ X wrong

$$\frac{dx(t)}{dt} = 12t + 3$$

$$\left[\frac{dx(t)}{dt}\right]_{t=0^+} = 12(0) + 3 = 3$$

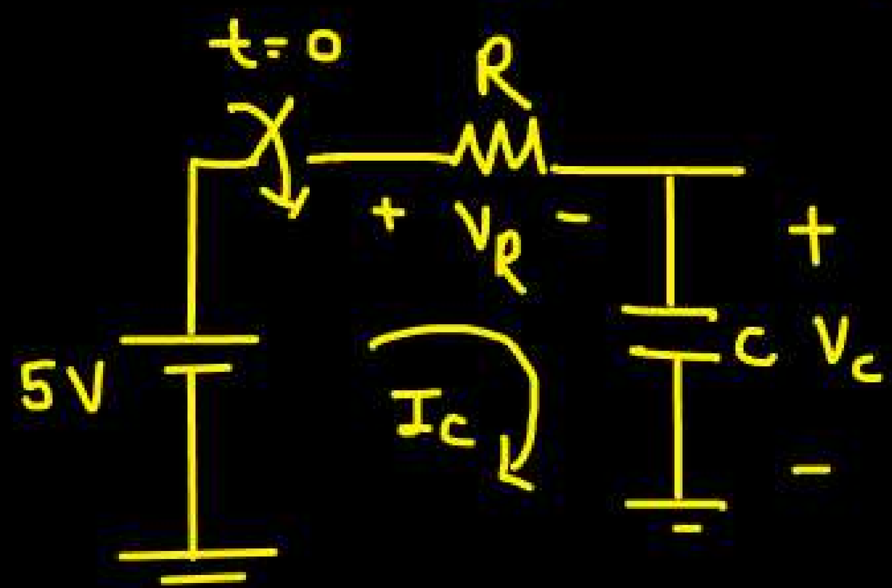
$$\left[\frac{dx(t)}{dt}\right]_{t=0^+} = \frac{dx(0^+)}{dt} = x'(0^+) = 3$$

N.B.- Even if $x(0) = 0$

then $x'(0^+)$ may not be zero

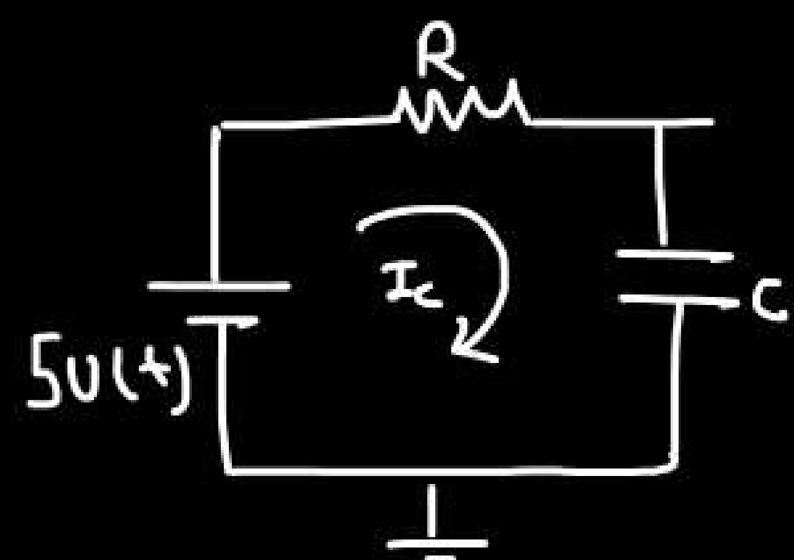
Here; $x(0) = 0$ but $x'(0^+) = 3$

Q. Find $V_R'(0^+)$, $V_c'(0^+)$, $I_c'(0^+) = ?$



where $V_R'(0^+) = \left[\dfrac{dV_R(t)}{dt}\right]_{t=0^+}$

→



$$5u(t) = I_c(t)\cdot R + \frac{1}{C}\int I_c(t)\cdot dt$$

Differentiating both sides

$$5\delta(t) = R\frac{dI_c(t)}{dt} + \frac{I_c(t)}{C}$$

at $t=0^+$,

$$5\,\delta(0^+) = R\,\frac{dI_c(0^+)}{dt} + \frac{I_c(0^+)}{C}$$

$$\left\{ \delta(t) = \begin{cases} \infty, & t \\ 0, & t \end{cases} \right.$$

$$\delta(0^+) = 0$$

$$0 = R\,\frac{dI_c(0^+)}{dt} + \frac{5}{RC} \qquad \left\{ I_c(0^+) = 5/R \right\}$$

$$\boxed{\frac{dI_c(0^+)}{dt} = \frac{-5}{R^2C}}$$

M-II

$$u(t) = \begin{cases} 1, & t > 0 \\ 0, & t < 0 \end{cases}$$

$$I_c(t) = \frac{5}{R} e^{-t/RC}\,u(t)$$

$$\frac{dI_c(t)}{dt} = \frac{5}{R}\left[e^{-t/RC}\,\delta(t) - \frac{e^{-t/RC}}{RC}\,u(t)\right]$$

$$u(0^+) = 1$$

$$\frac{dI_c(0^+)}{dt} = \frac{5}{R}\left[0 - \frac{1}{RC}\,u(0^+)\right] = -\frac{5}{R^2C}$$

$$\frac{dV_R(0^+)}{dt} : \rightarrow$$

$$5u(t) = V_R(t) + \frac{1}{C}\int_0^t I_c(t)\,dt$$

Differentiating on both sides

$$5\delta(t) = \frac{dV_R(t)}{dt} + \frac{I_c(t)}{C}$$

at $t = 0^+$

$$0 = \frac{dV_R(0^+)}{dt} + \frac{5}{RC}$$

$$\boxed{\frac{dV_R(0^+)}{dt} = -\frac{5}{RC}}$$

M-II

$$V_R(t) = 5e^{-t/RC}u(t)$$

$$\frac{dV_R(t)}{dt} = 5\left[e^{-t/RC}\delta(t) - \frac{e^{-t/RC}}{RC}u(t)\right]$$

$$\boxed{\frac{dV_R(0^+)}{dt} = \frac{-5}{RC}}$$

$$\frac{dV_c(0^+)}{dt} :-$$

$$5u(t) = I_c(t)R + V_c(t) \qquad I_c(t) = C\frac{dV_c(t)}{dt}$$

$$5u(t) = RC\frac{dV_c(t)}{dt} + V_c(t)$$

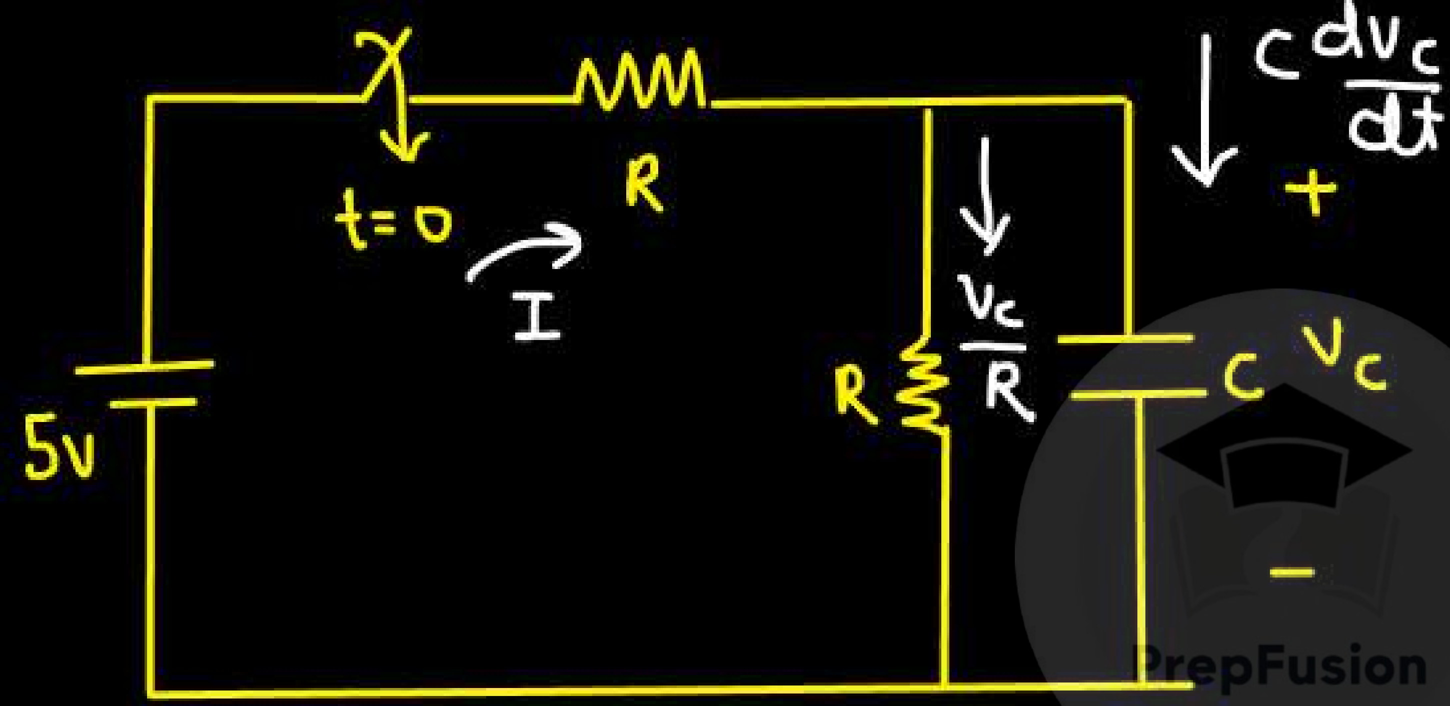
for $t = 0^+$

$$5u(0^+) = RC\frac{dV_c(0^+)}{dt} + V_c(0^+) \qquad \left\{ \begin{array}{l} V_c(0^+) = 0V \\ u(0^+) = 1 \end{array} \right\}$$

$$5 = RC\frac{dV_c(0^+)}{dt}$$

$$\boxed{\frac{dV_c(0^+)}{dt} = \frac{5}{RC}}$$

Q. find $\left[\frac{dv_c(t)}{dt}\right]_{t=0^+}$



→ $5u(t) = I(t)R + v_c(t)$ — (1)

Task:- replace 'I' in terms of 'v_c'

$$I(t) = \frac{v_c(t)}{R} + C\frac{dv_c(t)}{dt} \quad \text{— (2)}$$

By eq^n 1 and 2

$$5u(t) = \left[\frac{V_c(t)}{R} + C\frac{dV_c(t)}{dt}\right]R + V_c(t)$$

$$5u(t) = V_c(t) + RC\frac{dV_c(t)}{dt} + V_c(t)$$

$$5u(t) = 2V_c(t) + RC\frac{dV_c(t)}{dt}$$

at $t = 0^+$

$$5u(0^+) = 2V_c(0^+) + RC\frac{dV_c(0^+)}{dt}$$

$$\left\{\begin{array}{l} V_c(0^+) = 0\,V \\ u(0^+) = 1 \end{array}\right\}$$

$$5 = RC\frac{dV_c(0^+)}{dt}$$

$$\boxed{\frac{dV_c(0^+)}{dt} = \frac{5}{RC}}$$

M - II

$$v_c(t) = 2.5\left(1 - e^{-t/\tau}\right)u(t) \;;\; \tau = RC/2$$

$$\frac{dv_c(t)}{dt} = 2.5\left[\left(1 - e^{-t/\tau}\right)\delta(t) + \frac{e^{-t/\tau}}{\tau}u(t)\right]$$

$$\frac{dv_c(0^+)}{dt} = 2.5\left[0 + \frac{1}{\tau}\right]$$

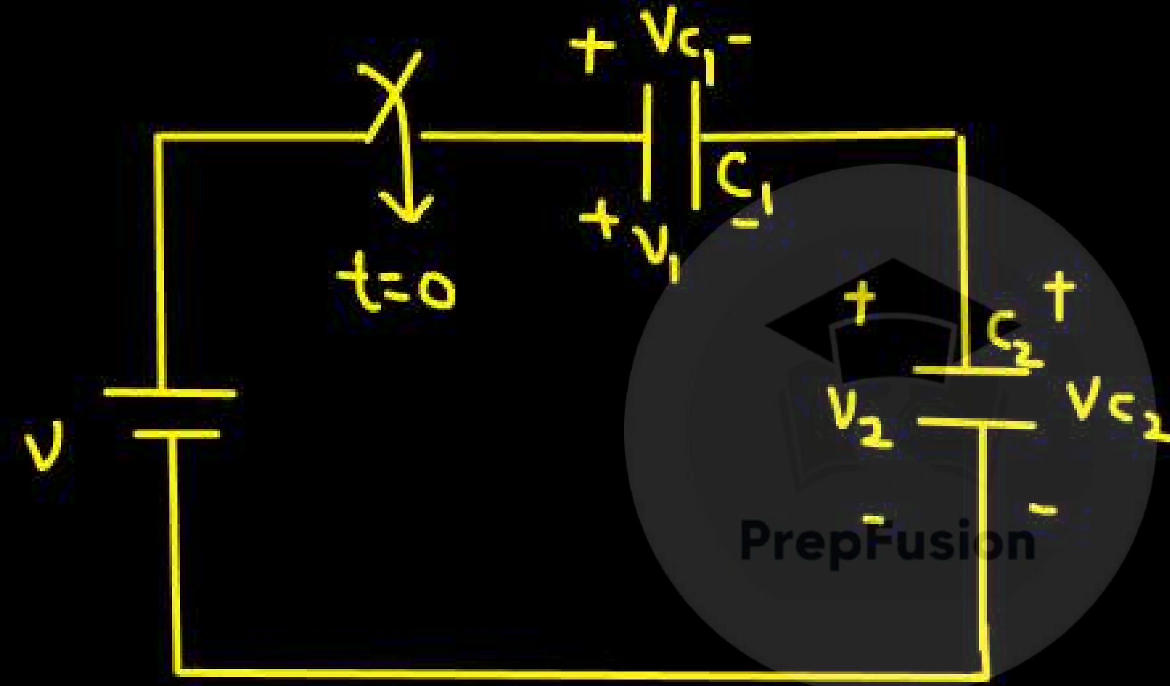
$$= \frac{2.5(2)}{RC}$$

$$\boxed{\frac{dv_c(0^+)}{dt} = \frac{5}{RC}}$$

Switch capacitors :-

★ Given; initial voltage across capacitor $C_1 = V_1$

initial voltage across capacitor $C_2 = V_2$

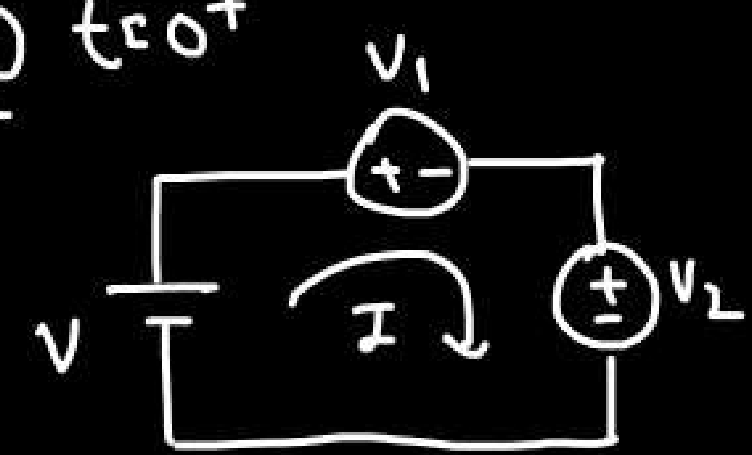


Find steady state value of V_{C_1} & V_{C_2}.

→ $V_{C_1}(0^-) = V_1$

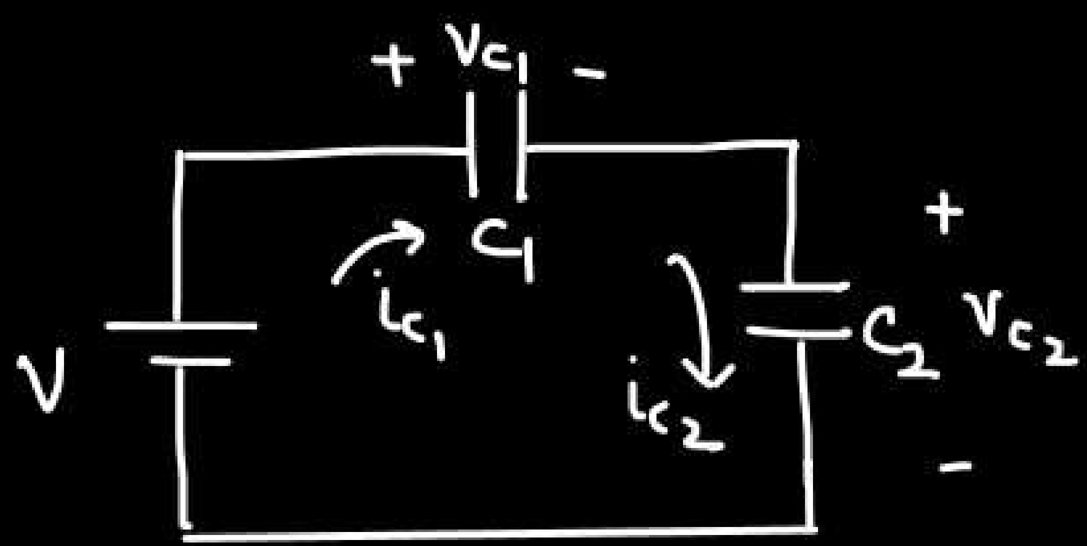
$V_{C_2}(0^-) = V_2$

ckt @ $t=0^+$



$$I = \frac{(V - V_1 - V_2)}{0} = \infty$$

↳ impulse current



since, both cap. are connected in series

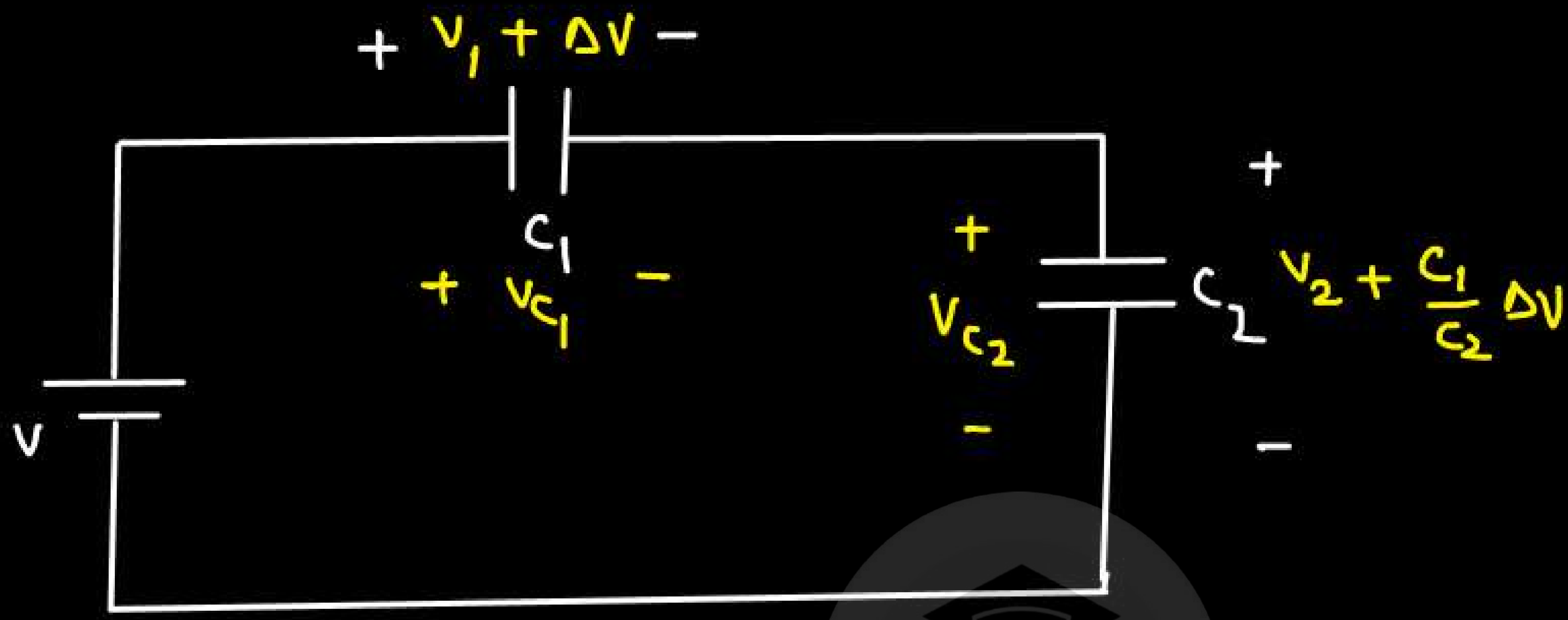
$$i_{C_1} = i_{C_2}$$

$$C_1 \frac{dV_{C_1}}{dt} = C_2 \frac{dV_{C_2}}{dt} \qquad \{\text{change in charge will be the same}\}$$

$$C_1 \Delta V_{C_1} = C_2 \Delta V_{C_2}$$

Because of voltage source V, if the change in V_{C_1} is ΔV

the change in V_{C_2} will be $\frac{C_1}{C_2} \Delta V$



Applying KVL:-

$$V = V_{c_1} + V_{c_2}$$

$$V = V_1 + \Delta V + V_2 + \frac{C_1}{C_2}\Delta V$$

$$V - V_1 - V_2 = \left(\frac{C_1 + C_2}{C_2}\right)\Delta V \Rightarrow \boxed{\Delta V = \left(\frac{C_2}{C_1 + C_2}\right)(V - V_1 - V_2)}$$

$$V_{c_1} = V_1 + \Delta V$$

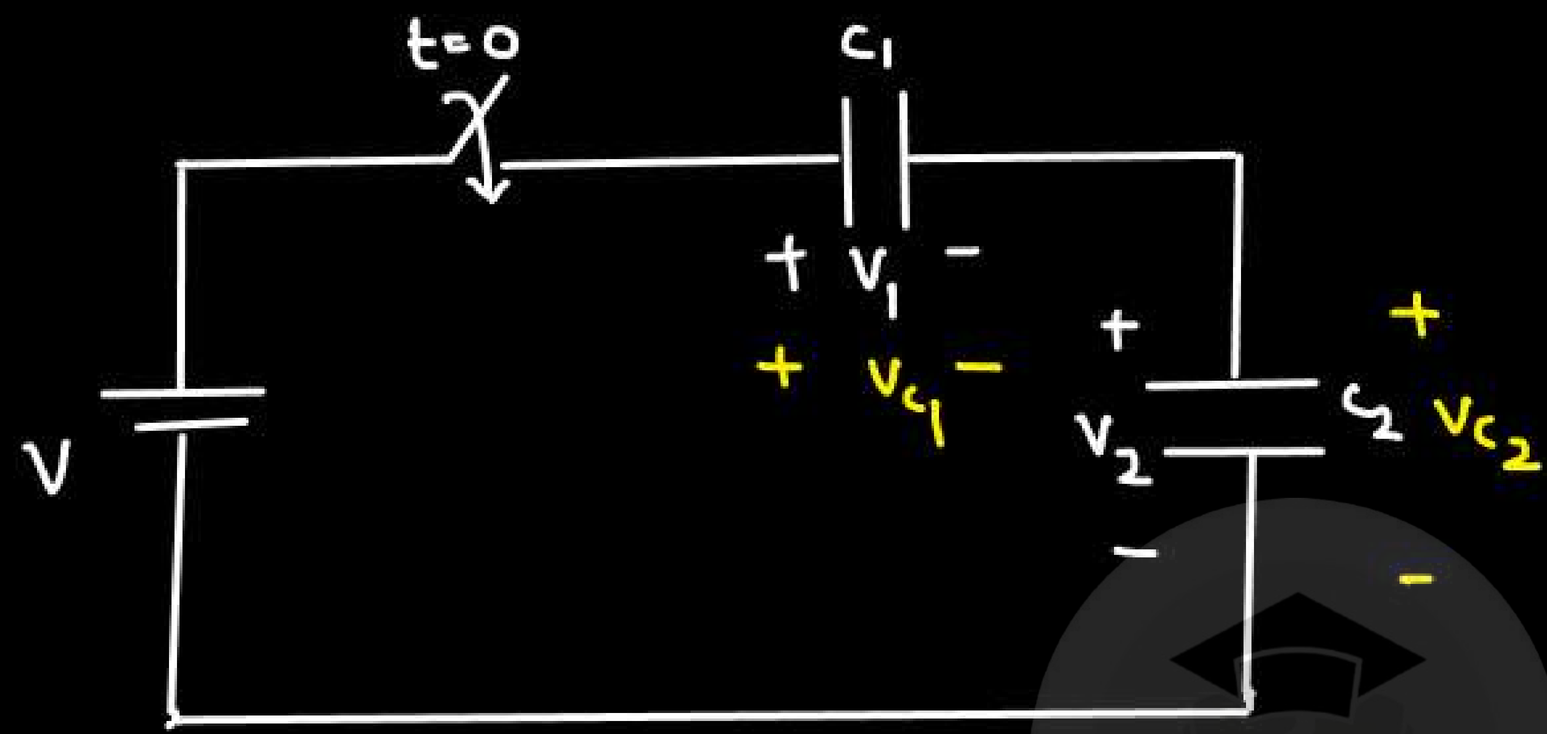
$$\boxed{V_{c_1} = V_1 + \left(\frac{C_2}{C_1 + C_2}\right)\left(V - V_1 - V_2\right)}$$

$$V_{c_2} = V_2 + \frac{C_1}{C_2}\Delta V$$

$$V_{c_2} = V_2 + \frac{C_1}{C_2}\left(\frac{C_2}{C_1 + C_2}\right)\left(V - V_1 - V_2\right)$$

$$\boxed{V_{c_2} = V_2 + \frac{C_1}{C_1 + C_2}\left(V - V_1 - V_2\right)}$$

How will you write steady state V_{c_1} & V_{c_2} in one step?



$$V_{c_1} = V_1 + (V - V_1 - V_2)\frac{C_2}{C_1 + C_2}$$

$$V_{c_2} = V_2 + (V - V_1 - V_2)\frac{C_1}{C_1 + C_2}$$

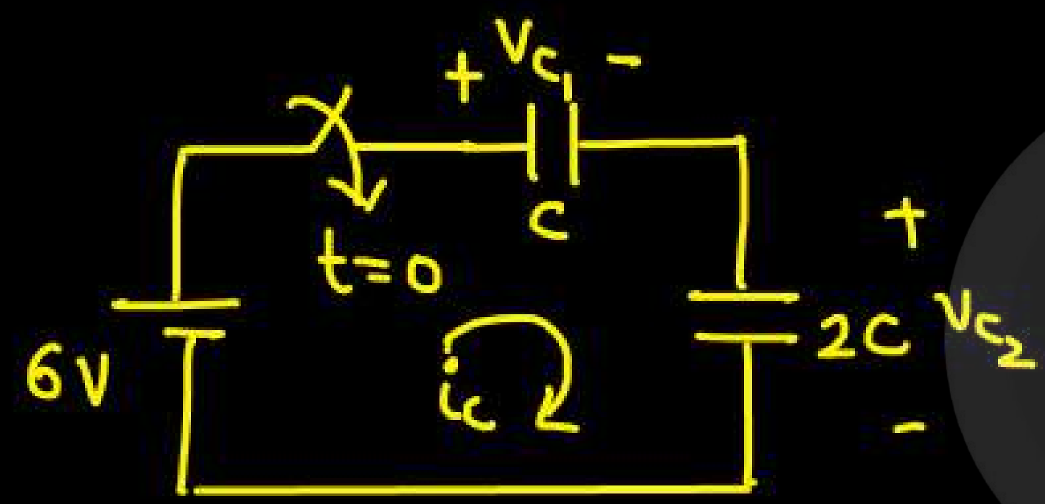
Question :-

Q. Find $V_{c_1}(0^+)$ and $V_{c_2}(0^+)$.

Draw the waveform of i_c.

$V_{c_1}(0^-) = 2V$

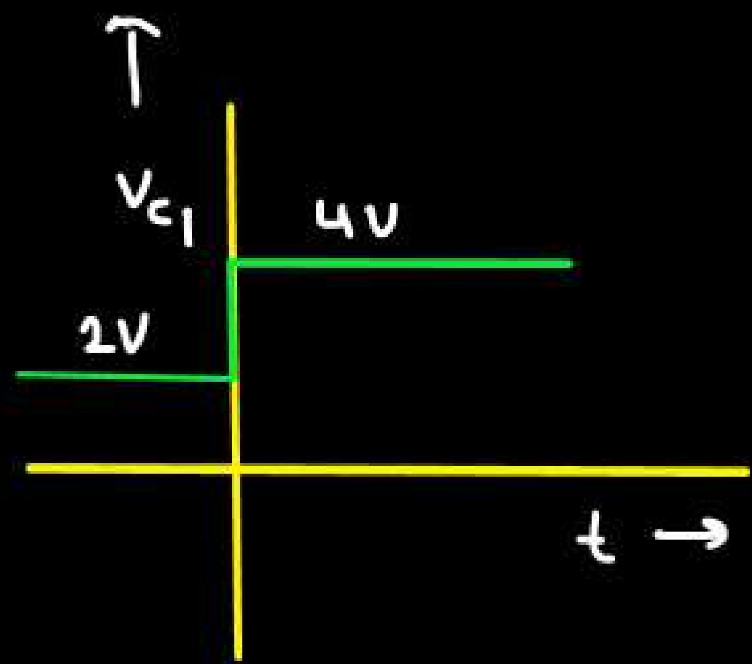
$V_{c_2}(0^-) = 1V$

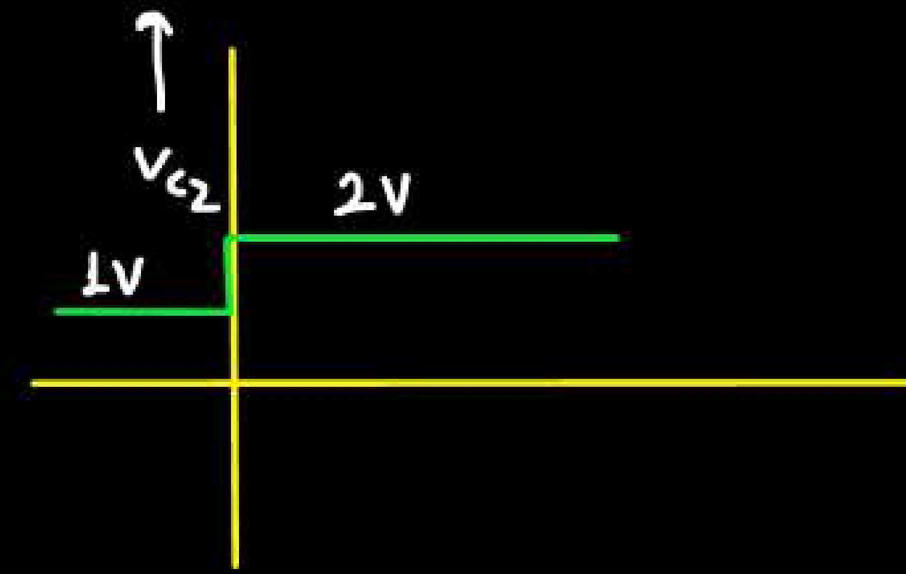


$\rightarrow$ $$V_{c_1}(0^+) = 2 + (6-2-1)\frac{2C}{3C}$$

$$= 4V$$

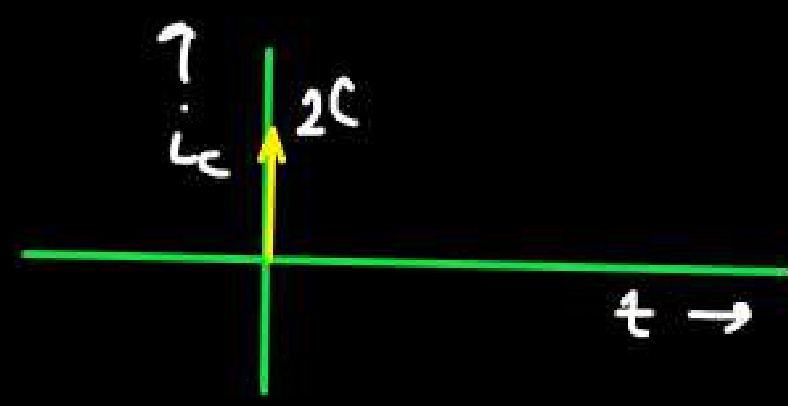
$$V_{c_2}(0^+) = 1 + (6-2-1)\frac{C}{3C} = 2V$$





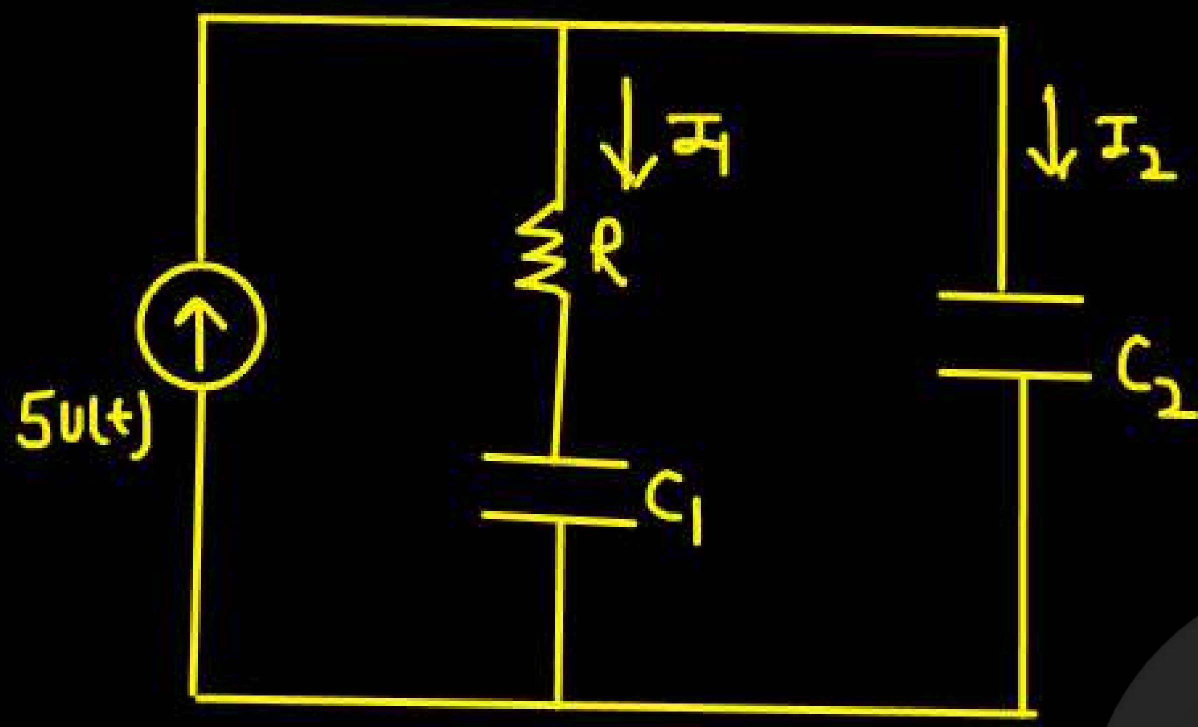
$$i_{c_1} = i_{c_2} = i_c$$

$$i_c = C_1 \frac{dV_{c_1}}{dt} = \underbrace{C \frac{dV_{c_1}}{dt}}_{= 2C\,\delta(t)} = C_2 \frac{dV_{c_2}}{dt} = \underbrace{2C \frac{dV_{c_2}}{dt}}_{= 2C\,\delta(t)}$$



$$i_c(t) = 2C\,\delta(t)$$

Q.



Find expression for I_1 &

→ $\underline{\underline{\tau = ?}}$

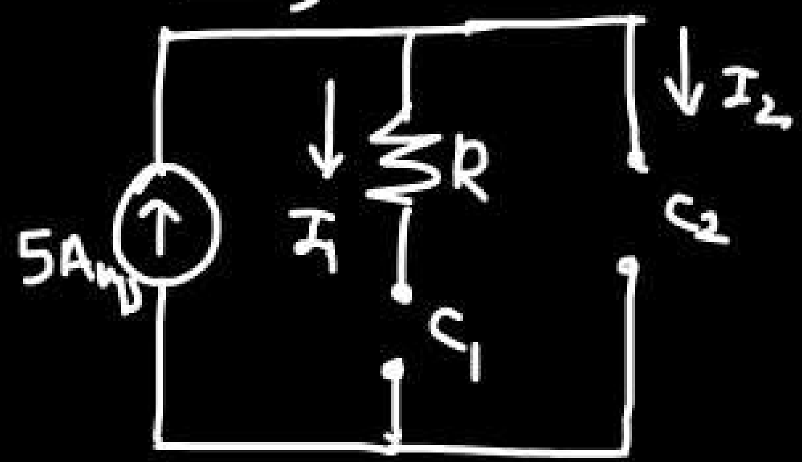
$$\boxed{\tau = \frac{R(C_1 C_2)}{C_1 + C_2}}$$

@ $t=0^+$

$I_1(0^+) = 0$ Amp.

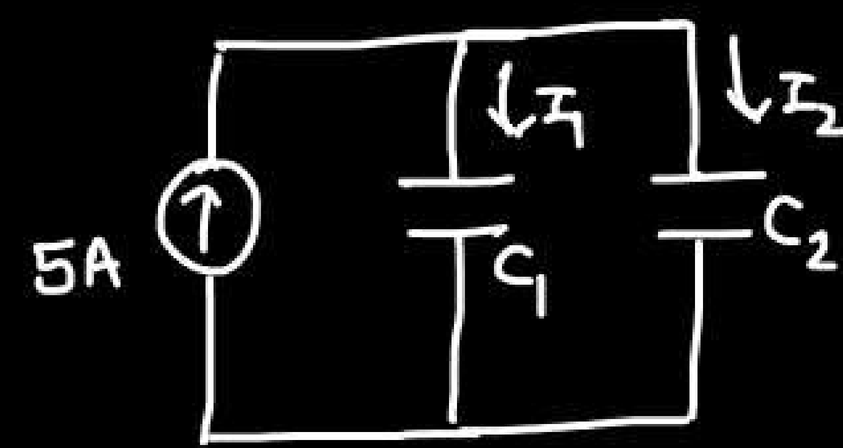
$I_2(0^+) = 5$ Amp.

@ $t=\infty$



$5 = I_1 + I_2$

$t=\infty \Rightarrow \omega = 0 \Rightarrow X_c \rightarrow$ very High



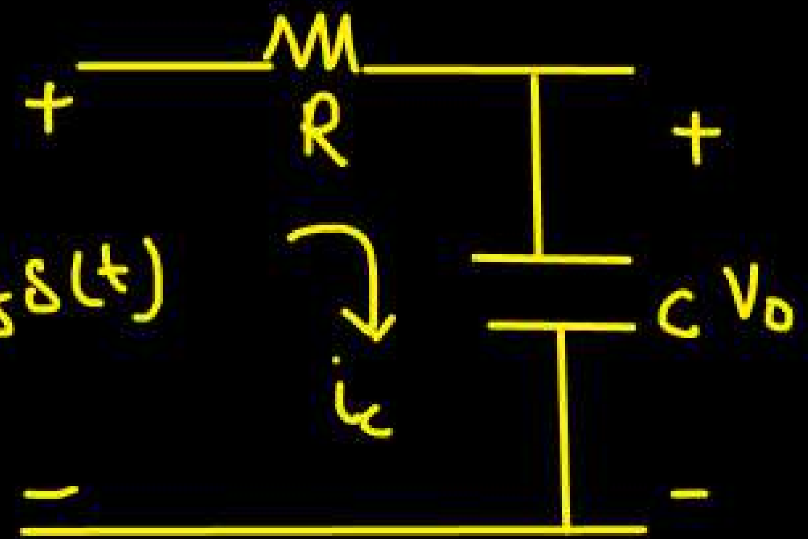
$$I_1(\infty) = \frac{5C_1}{C_1+C_2}$$

$$I_2(\infty) = \frac{5C_2}{C_1+C_2}$$

$$I_1(t) = \frac{5C_1}{C_1+C_2}\left[1 - e^{-t/\tau}\right]u(t)\ ; \quad \tau = R\left(\frac{C_1C_2}{C_1+C_2}\right)$$

$$I_2(t) = \left[\frac{5C_2}{C_1+C_2} + \frac{5C_1}{C_1+C_2}e^{-t/\tau}\right]u(t)$$

RC ckt with impulse voltage i/p:-

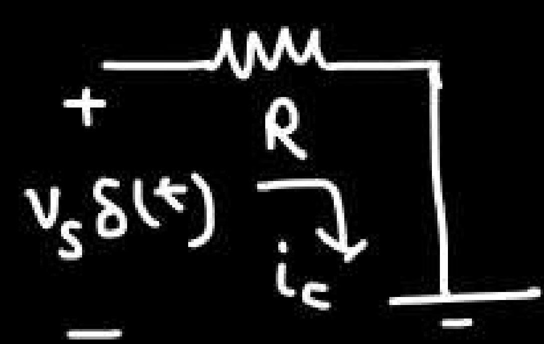


Draw V_o waveform.

Draw i_c waveform.

$$\left\{ \begin{array}{l} \text{emf} = \dfrac{d\phi}{dt} \\ (V \times S) = \text{flux} \end{array} \right.$$

@ $t=0$:→ cap. will shorted



$$i_c(0) = \frac{V_s\,\delta(t)}{R} \rightarrow \text{impulse current}$$

$$V_c(0^- \rightarrow 0) = \frac{1}{C}\int_{0^-}^{0} i_c(t)\,dt = \frac{1}{C}\int_{0^-}^{0} \frac{V_s}{R}\,\delta(t)\cdot dt$$

$$V_c(0) = \frac{V_s}{RC}\int_{0^-}^{0} \delta(t)\cdot dt$$

$$= \frac{V_s}{RC}\left[u(t)\right]_{0^-}^{0}$$

$$= \frac{V_s}{RC}\left[u(0) - u(0^-)\right]$$

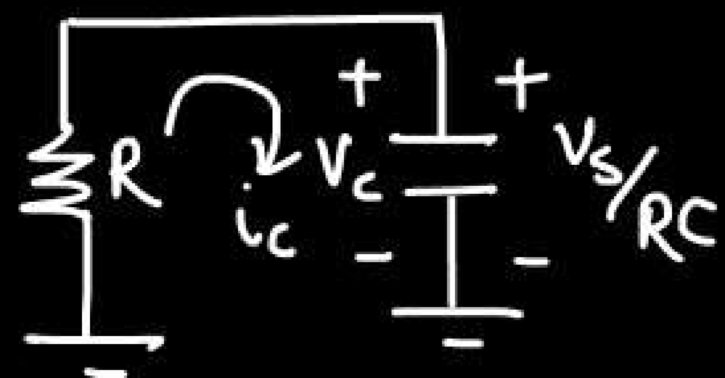
$$V_c(0) = \frac{V_s}{RC}\left[1 - 0\right]$$

$$\boxed{V_c(0) = \frac{V_s}{RC}}$$

ckt @ $t = 0^+$

$V_i(t) = V_s\,\delta(t)$ will be zero after $t = 0$

$V_i(0^+) = 0\,V$



$\frac{V_s}{RC}$ voltage will be discharged with time const. RC.

$V_c(\infty) = 0V$

$$\boxed{V_c(t) = \frac{V_s}{RC} e^{-t/\tau} u(t)} \; ; \; \tau = RC$$

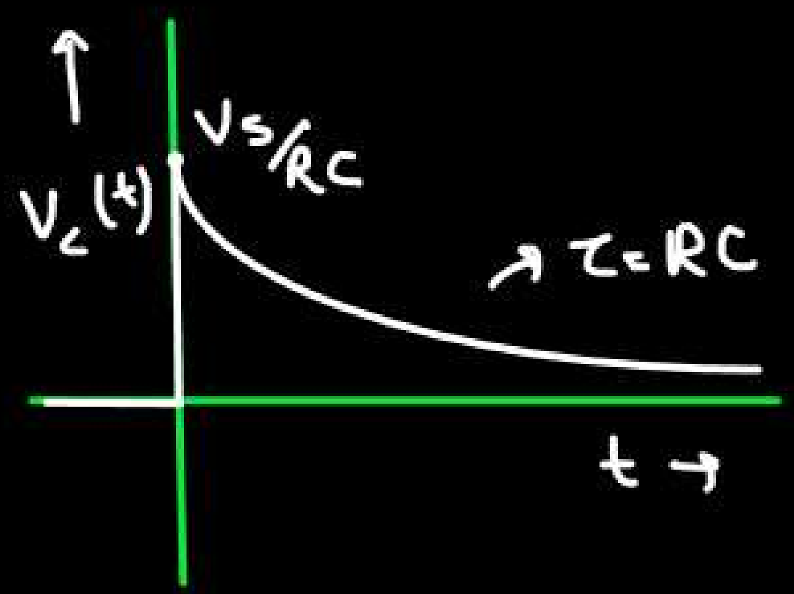
$\underline{\underline{i_c:-}}$

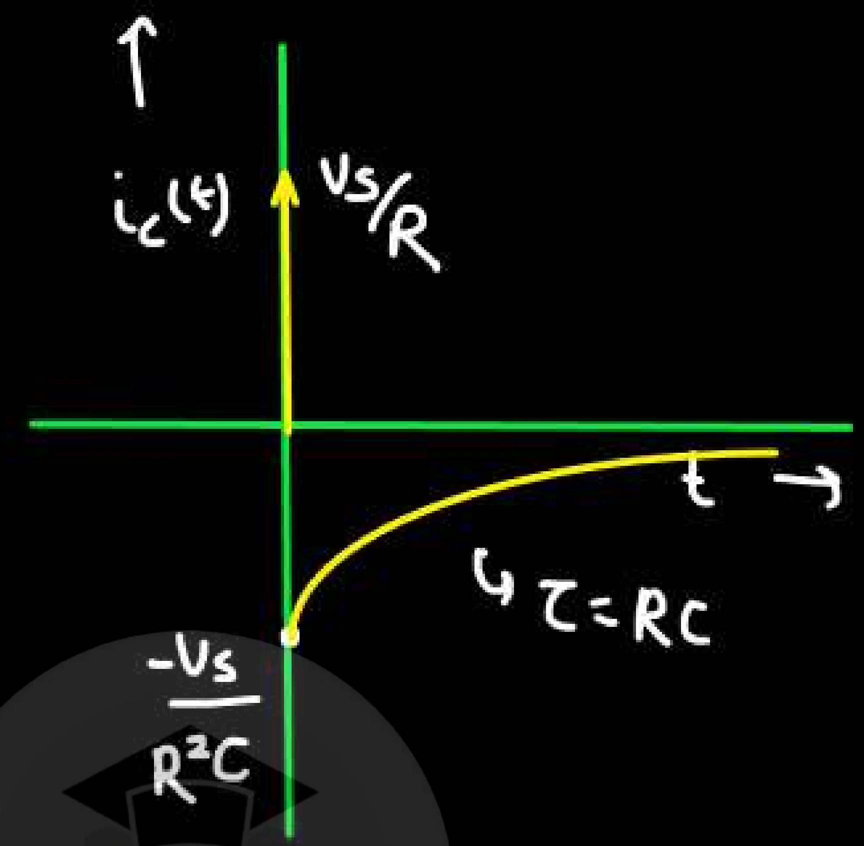
$$i_c(0) = \frac{V_s}{R}\delta(t)$$

$$i_c(0^+) = -\frac{V_s}{R^2C}$$

$$i_c(\infty) = 0$$

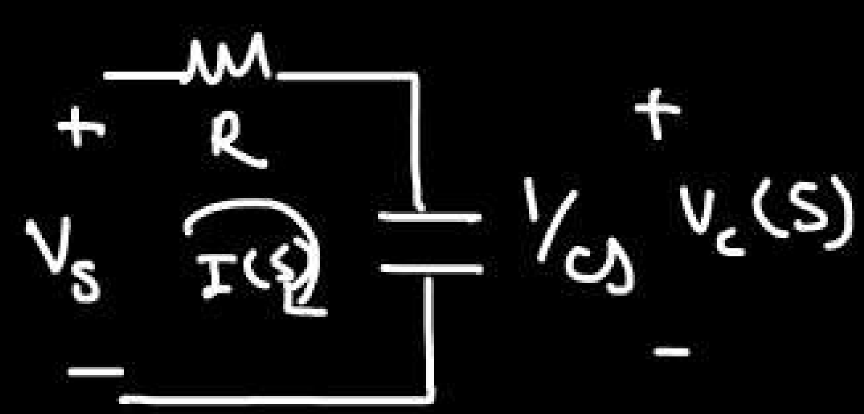
$$\boxed{i(t) = \frac{V_s}{R}\delta(t) - \frac{V_s}{R^2C} e^{-t/\tau} u(t)} \quad \tau = RC$$





M-II :-

By Laplace Transform :-



$$v_i(t) = V_s\,\delta(t)$$

$$V_i(S) = V_s$$

$$I(s) = \frac{V_s}{R + \frac{1}{Cs}}$$

$$I(s) = \frac{V_s Cs}{RCs + 1}$$

$$= \frac{CV_s}{RC}\left(\frac{RCs+1-1}{RCs+1}\right)$$

$$I(s) = \frac{CV_s}{RC}\left[1 - \frac{1}{RCs+1}\right]$$

$$I(s) = \frac{V_s}{R} - \frac{V_s}{R^2C} \times \frac{1}{s + \frac{1}{RC}}$$

$$i(t) = \frac{V_s}{R}\delta(t) - \frac{V_s}{R^2C} e^{-t/RC} u(t)$$

$$\left\{ \begin{aligned} L^{-1}[A] &= A\,\delta(t) \\ L^{-1}\left[\frac{1}{s+a}\right] &= e^{-at} u(t) \end{aligned} \right\}$$

$$V_c(S) = \frac{1/CS}{1/CS + R} \times V_s$$

$$= \frac{1}{RCS+1} \times V_s$$

$$V_c(s) = \frac{V_s}{RC}\left[\frac{1}{s+1/RC}\right]$$

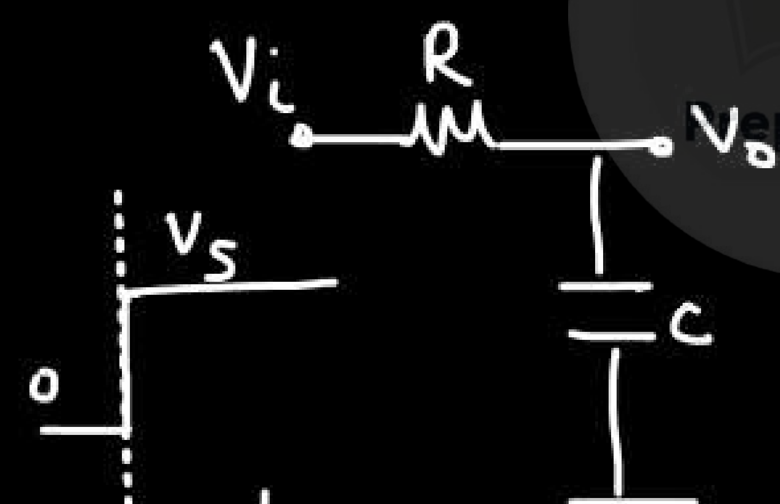
$$\boxed{v_c(t) = \frac{V_s}{RC} e^{-t/RC} u(t)}$$

M-III :-

$$\text{step i/p} \longrightarrow \boxed{\text{LTI s/s}} \longrightarrow \text{step response}$$

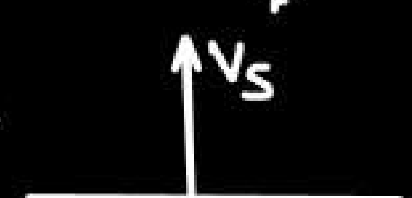
step i/p $\xrightarrow{\text{differentiate}}$ impulse i/p

step response $\xrightarrow{\text{differentiate}}$ impulse response



Differentiate

$v_i(t) = V_s\,\delta(t)$



step response:-

$$v_o(t) = V_s\left(1 - e^{-t/\tau}\right)u(t)$$

$\downarrow$ Differentiate

impulse response

$$\text{impulse response} = \frac{d}{dt}\left[V_s\left(1-e^{-t/\tau}\right)u(t)\right]$$

$$= \underbrace{V_s\left(1-e^{-t/\tau}\right)\delta(t)}_{\Downarrow\ 0} + \frac{V_s e^{-t/\tau}}{\tau}u(t)$$

★★★

$$\boxed{\text{impulse response} = \frac{V_s}{RC}e^{-t/\tau}u(t)}$$

$$\text{impulse response for current} = \frac{d}{dt}\left[\text{step response for current}\right]$$

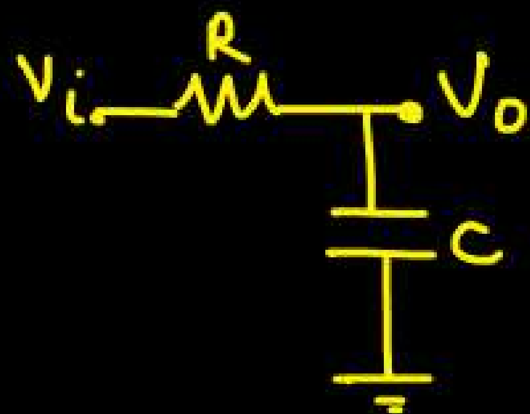
$$= \frac{d}{dt}\left[\frac{V_s}{R}e^{-t/\tau}u(t)\right]$$

$$= \frac{V_s}{R}\left[e^{-t/\tau}\,\delta(t) - \frac{e^{-t/\tau}}{\tau}\,u(t) \right]$$

***

$$\boxed{\text{impulse current response} = \frac{V_s}{R}\,\delta(t) - \frac{V_s}{R^2 C}\,e^{-t/\tau}\,u(t)}$$

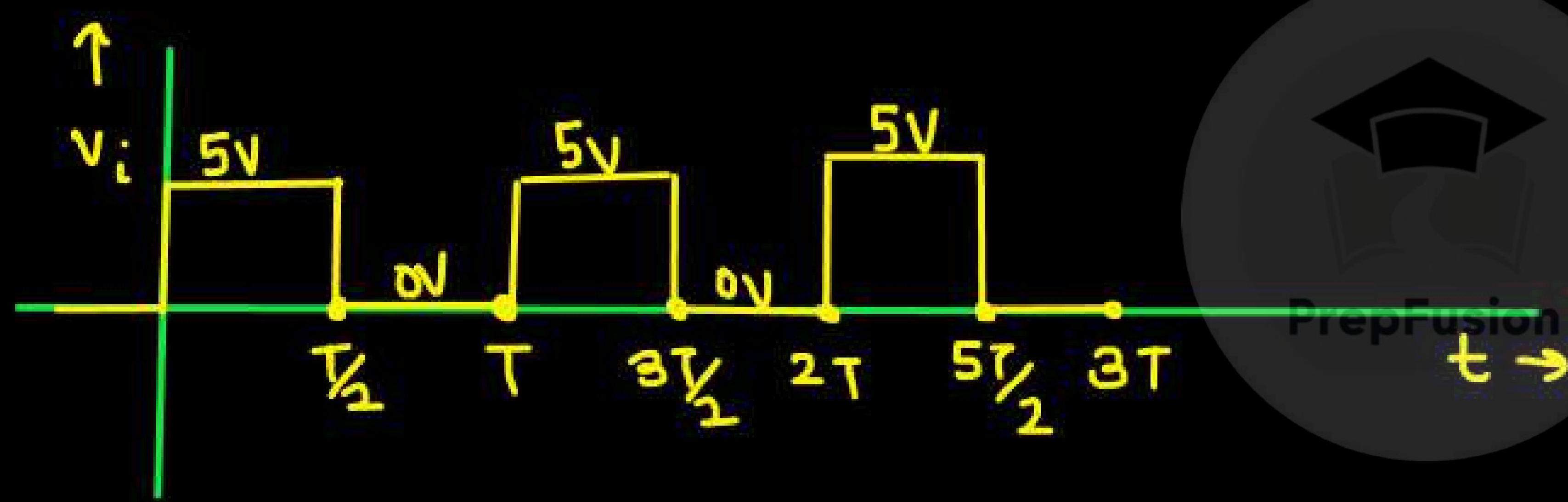
★ RC ckts with pulse-wave input:-



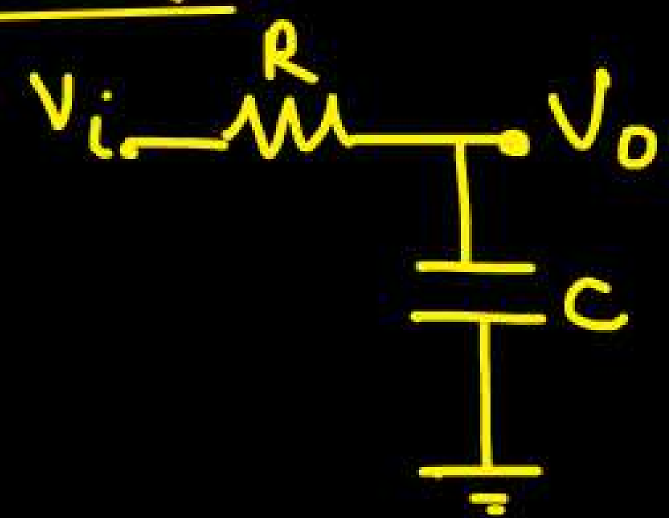
Draw V_o waveform

① $T >> RC$

② $T << RC$



① $T >> RC$:-



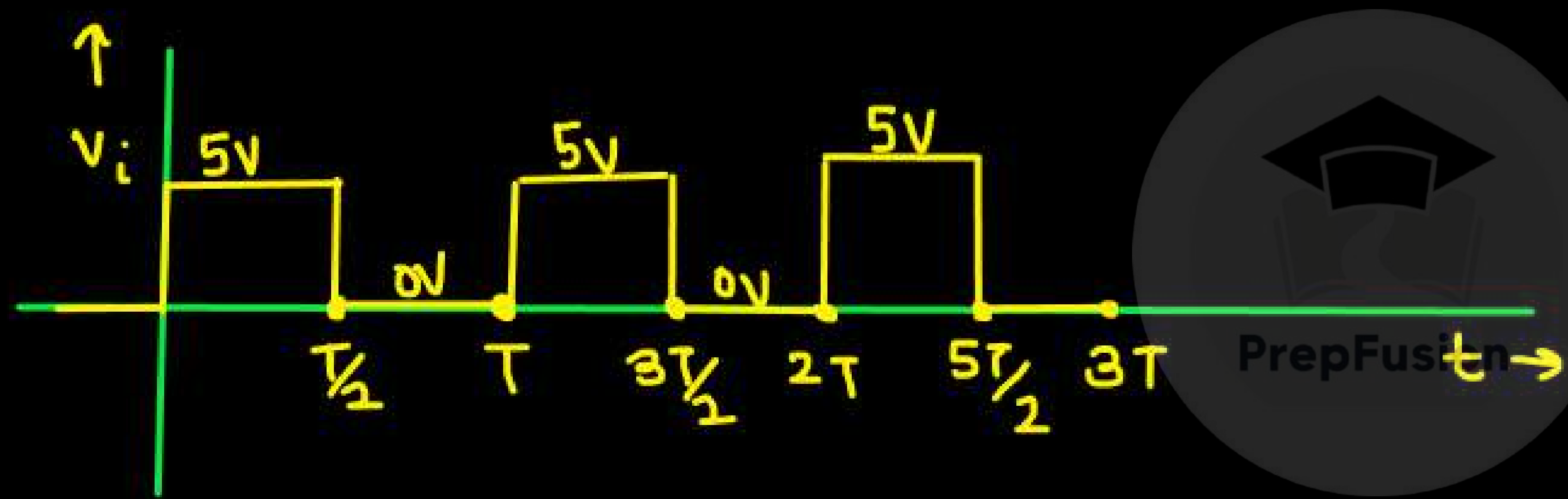
Let,

$R = 2\Omega$, $C = 1F$

$RC = 2$ sec.

$T = 20$ sec.

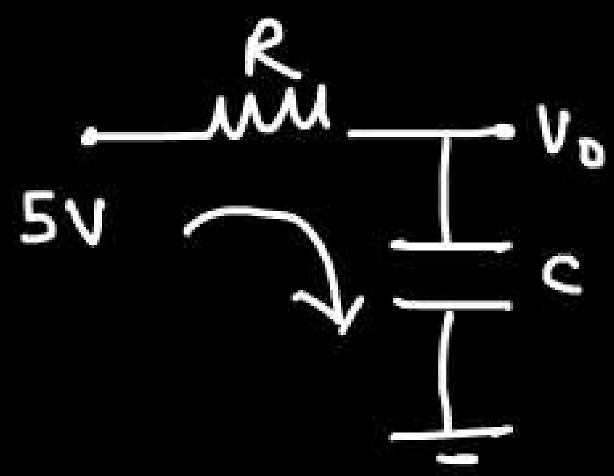
This would be given



→ Given : $T >> RC$

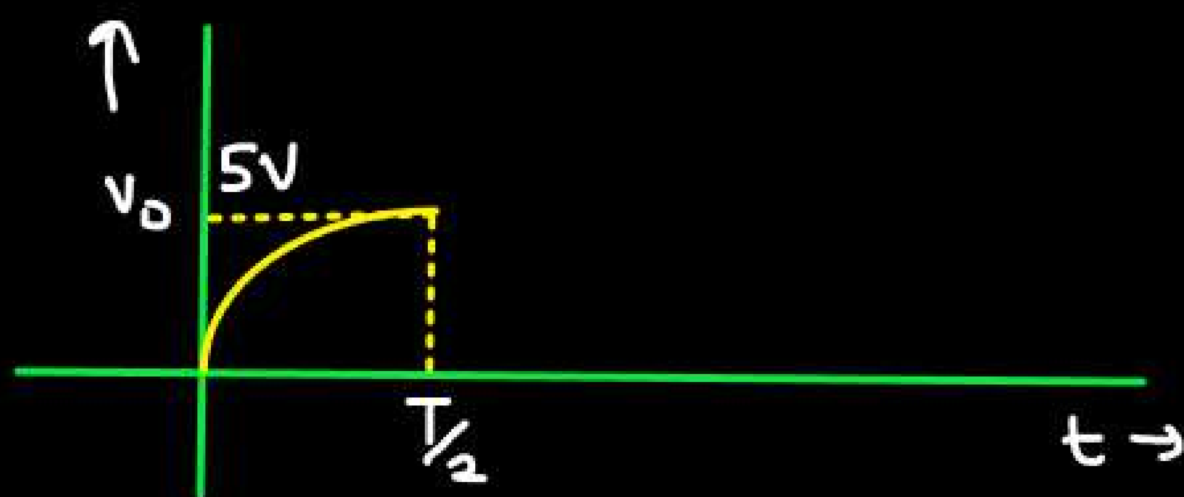
Time period is very large than the time constant for $0 < t < T/2$

$$V_i = 5V$$



since τ is very large. The cap. will have enough time to get charged to 5V.

$$V_c(T/2) = 5V$$

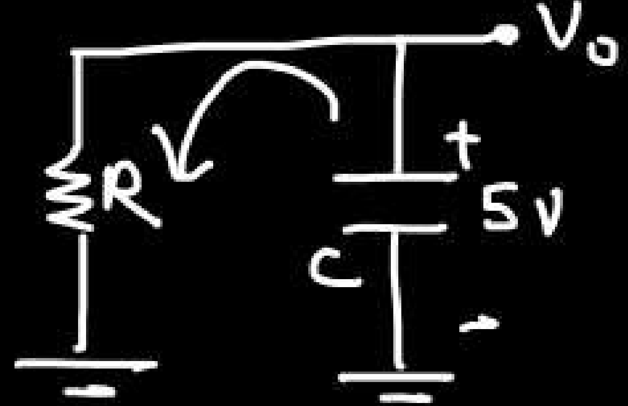


for $T/2 < t < T$

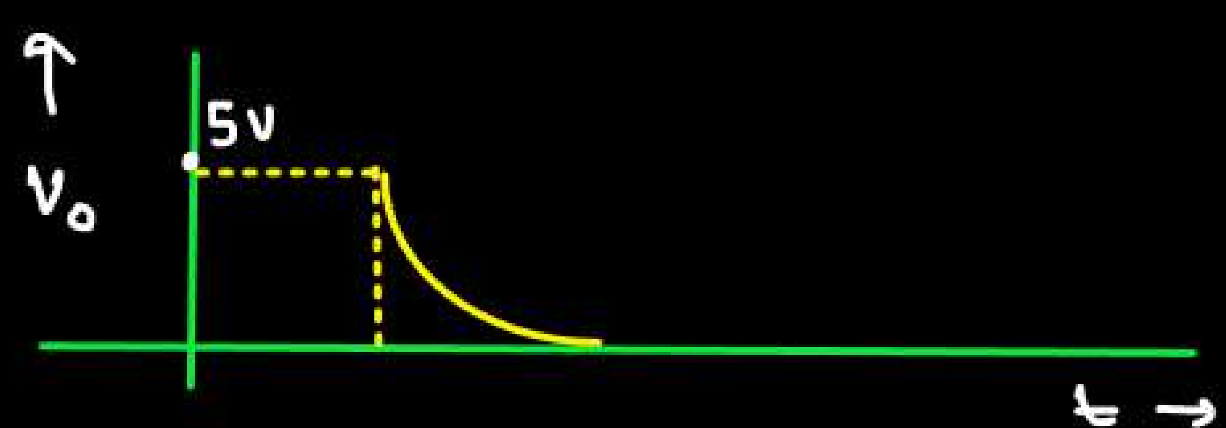
$V_i = 0V$

$V_c(T/2) = V_c(T/2^+) = 5V$

But i/p is gone.



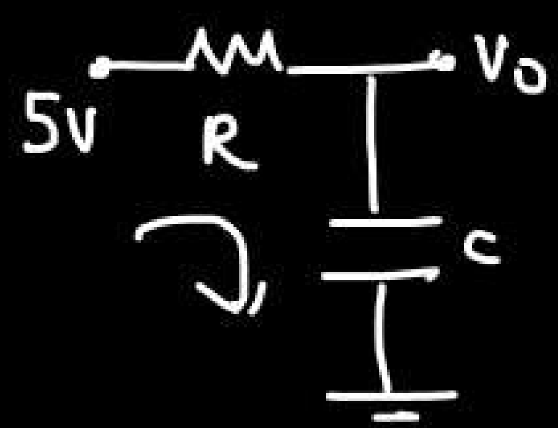
$\Rightarrow$ cap. will get completely discharged.
(Because T is very large)



For $T \leq t < 3T/2$

$$V_c(T) = 0 = V_c(T^+)$$

$V_i = 5V$



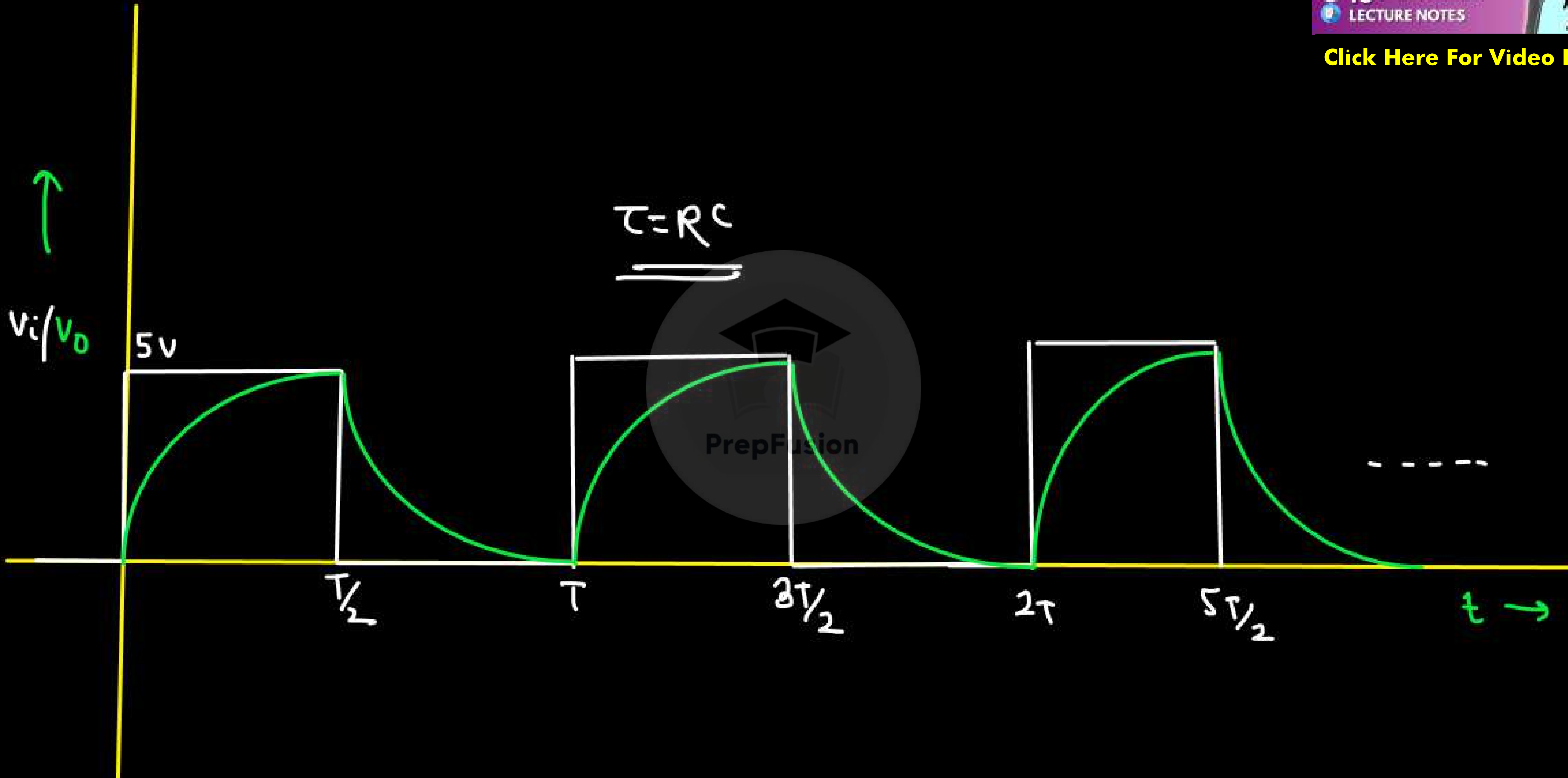
cap will again charge to 5V.

$$V_c(3T/2) = 5V$$

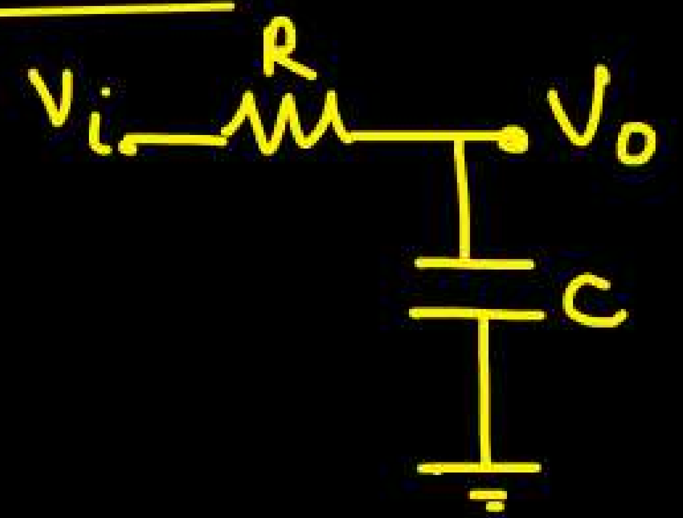
For $3T/2 \leq t < T$

$V_i = 0V$, $V_c(3T^+/2) = 5V \Rightarrow$ The cap. will discharge to 0V.

This cycle goes on.


$\tau = RC$
V_i/V_o
5V
T/2
T
3T/2
2T
5T/2
t
PrepFusion

① $T \ll RC$:-

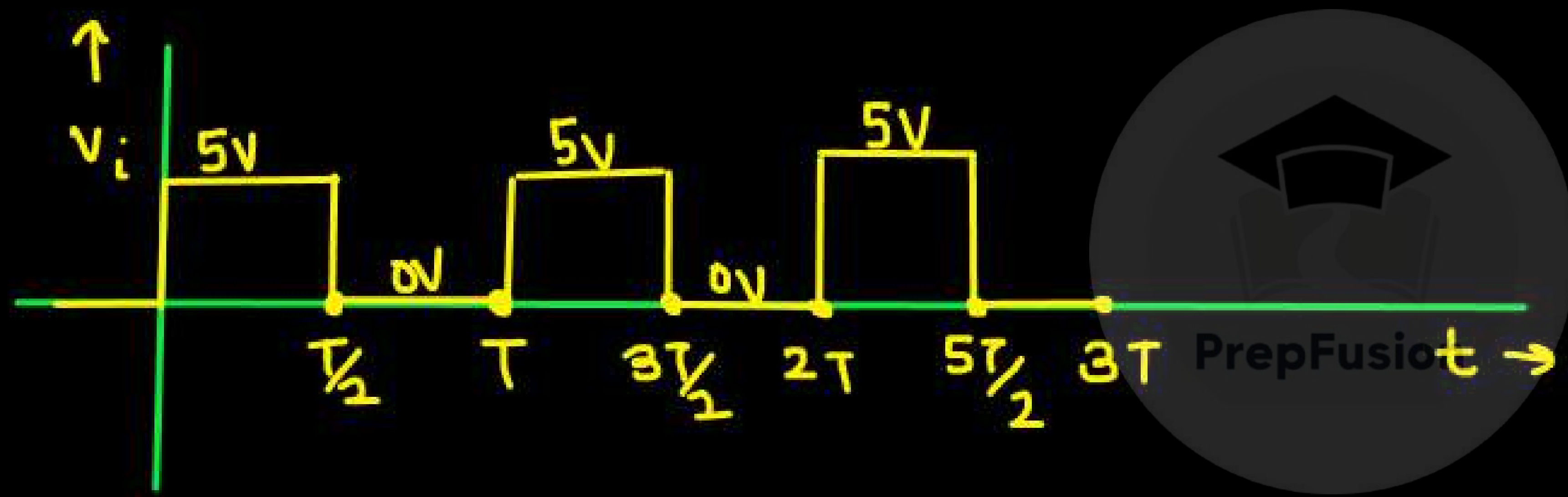


$RC = 2$ sec.

$T = 1$ sec.

$T/2 = 0.5$ sec.

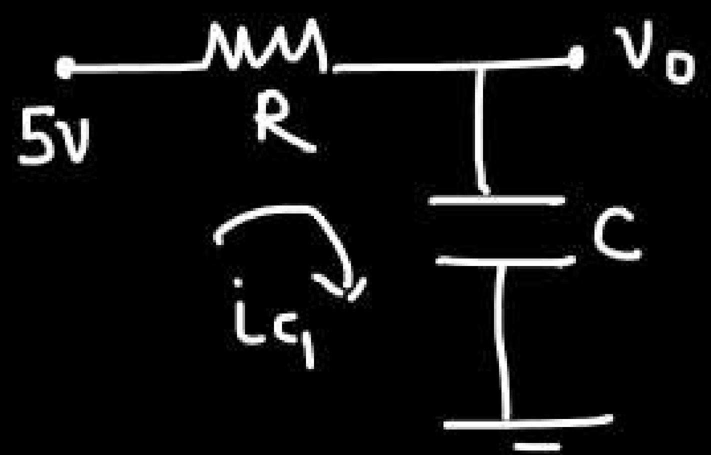
would be given.



For $0 < t < T/2$

$V_i = 5V$

$T \ll RC$



now since T is less and time constant is large.

$\Rightarrow$ cap will try to charge upto 5V but will not be able to reach there.

↳ depending on the values of T and RC,

let $V_c(T/2) = 1$ V

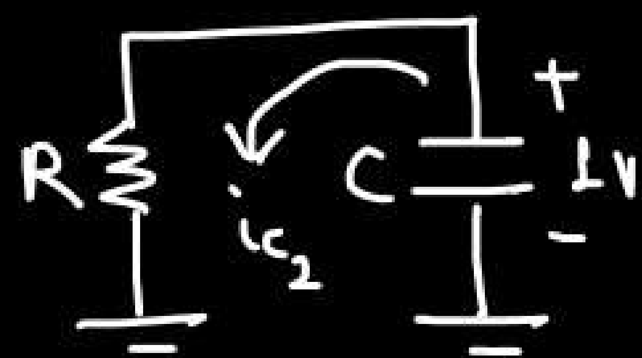
$i_{c_1}(0^+) = 5/R$

↳ charging current

for $T/2 < t < T$

$$V_i = 0\text{ V}$$

$$V_c(T/2^+) = 1\text{ V}$$

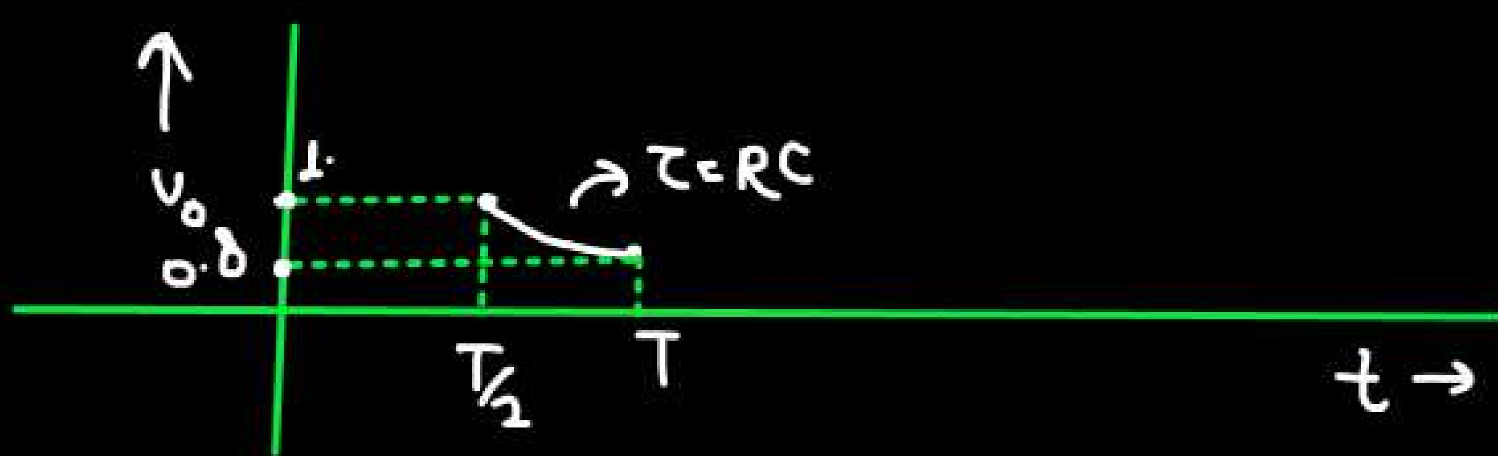


since T is very less, C will not be able to discharge to zero.

$$V_c(T) = 0.8\text{ V}$$

$$i_{c_2}(T/2^+) = 1/R \text{ A}$$

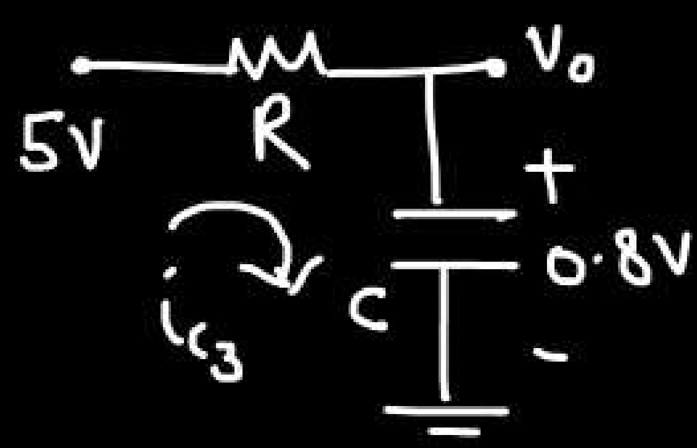
↳ discharging current



For $T \le t < 3T/2$

$V_i = 5V$

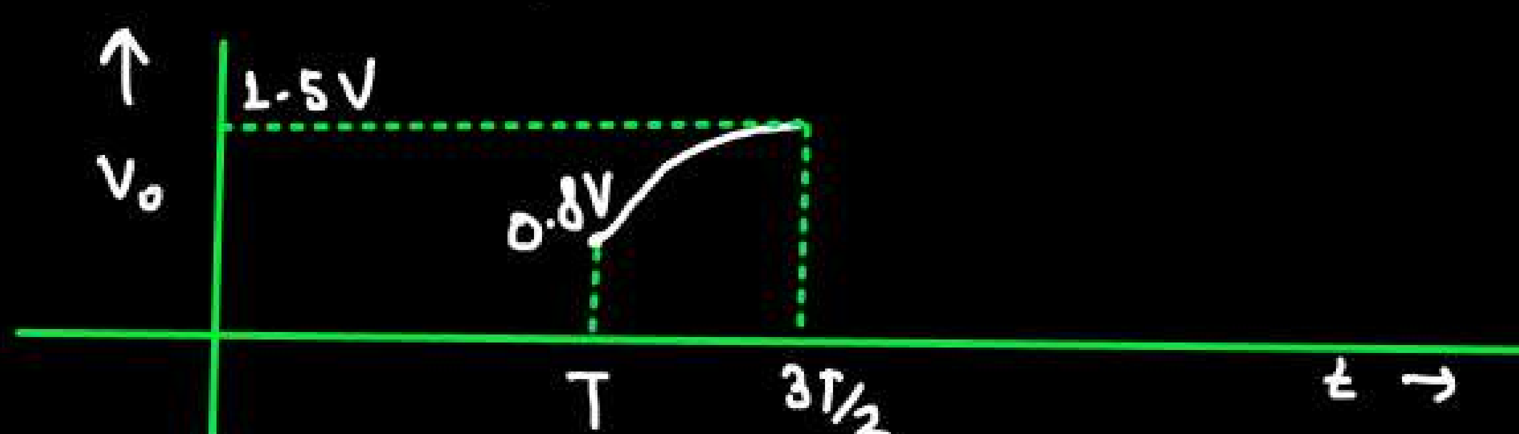
$v_c(T^+) = 0.8\ V$



The cap. will try to charge but can't reach upto 5 V.

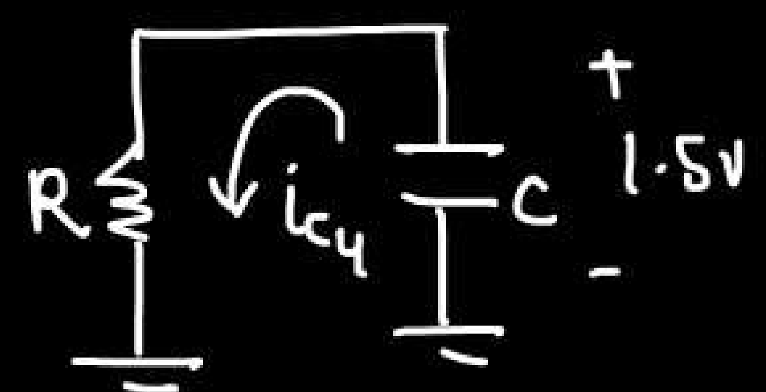
Let; $v_c(3T/2^+) = 1.5V$

$i_{c_3}(T^+) = \frac{4.2}{R} \rightarrow$ charging current



For $3T/2 \le t < 2T$

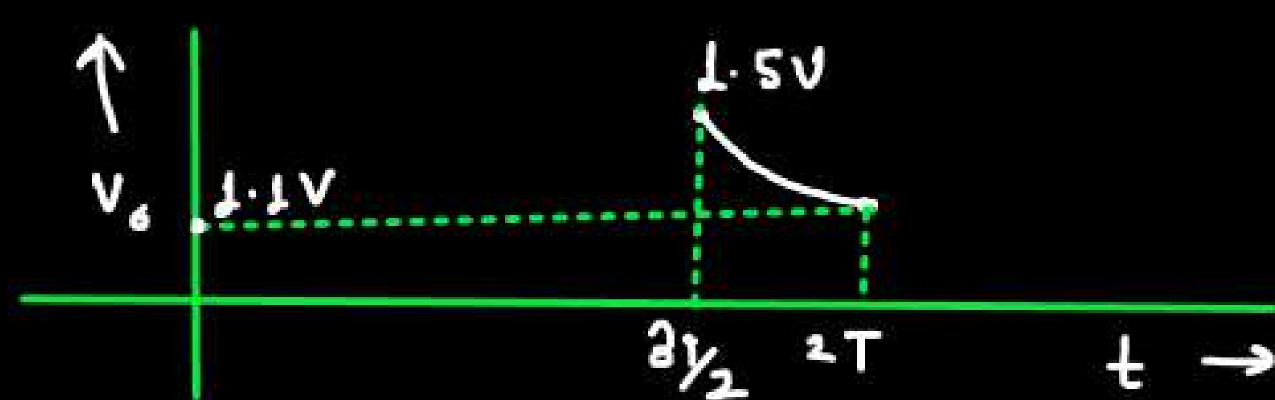
$V_i = 0$; $V_c(3T/2^{+}) = 1.5V$



V_c will try to go till zero voltage but can't reach there.

$i_{c_4}(3T/2^{+}) = 1.5/R \rightarrow$ discharging

$V_c(T) = 1.1V$



For $2T < t \le 5T/2$

$$i_{C_5}(2T^+) = \frac{5-1.1}{R} = 3.9/R \rightarrow \text{charging current}$$

Let cap. charges from 1.1V to 1.6V

For $5T/2 < t \le 3T$

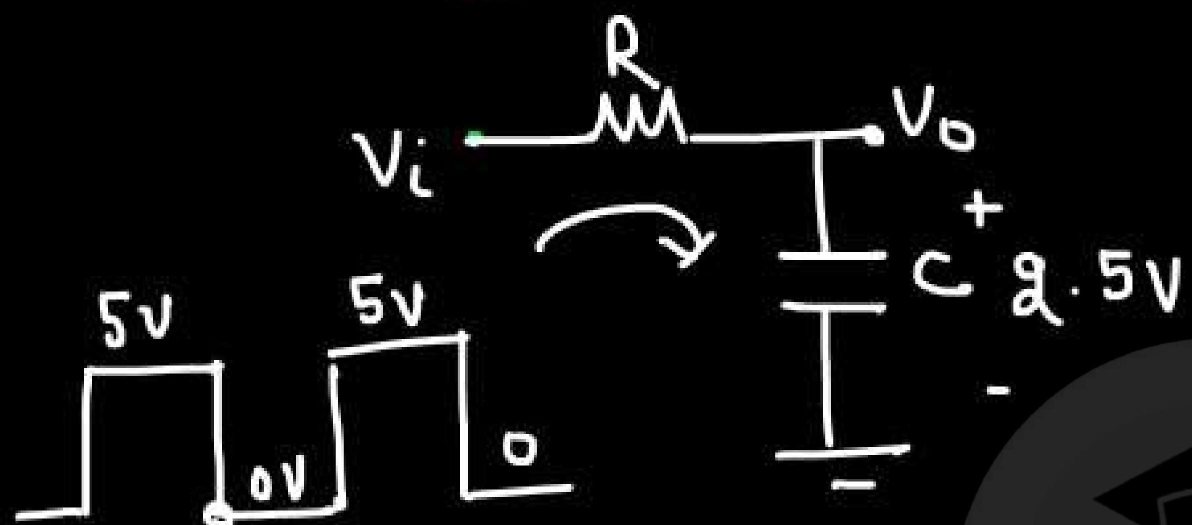
$$i_{C_c}(5T/2^+) = \frac{1.6}{R} \rightarrow \text{discharging current}$$

charging current $\Rightarrow \frac{5}{R} \rightarrow \frac{4.2}{R} \rightarrow \frac{3.9}{R}$ $\Rightarrow$ with continuous cycle, charging current $\downarrow$

discharging current $\Rightarrow \frac{1}{R} \rightarrow \frac{1.5}{R} \rightarrow \frac{1.6}{R}$ discharging current $\uparrow$

at some time;

charging current = discharging current = $2.5/R$



when $V_i = 5V$ $\Rightarrow$ $i_c = 2.5/R$ $\rightarrow$ charging current

when $V_i = 0V$ $\rightarrow$ $i_c = -2.5/R$ $\rightarrow$ discharging current

$\Downarrow$

steady state

V_c (steady state) $\approx 2.5V$

You
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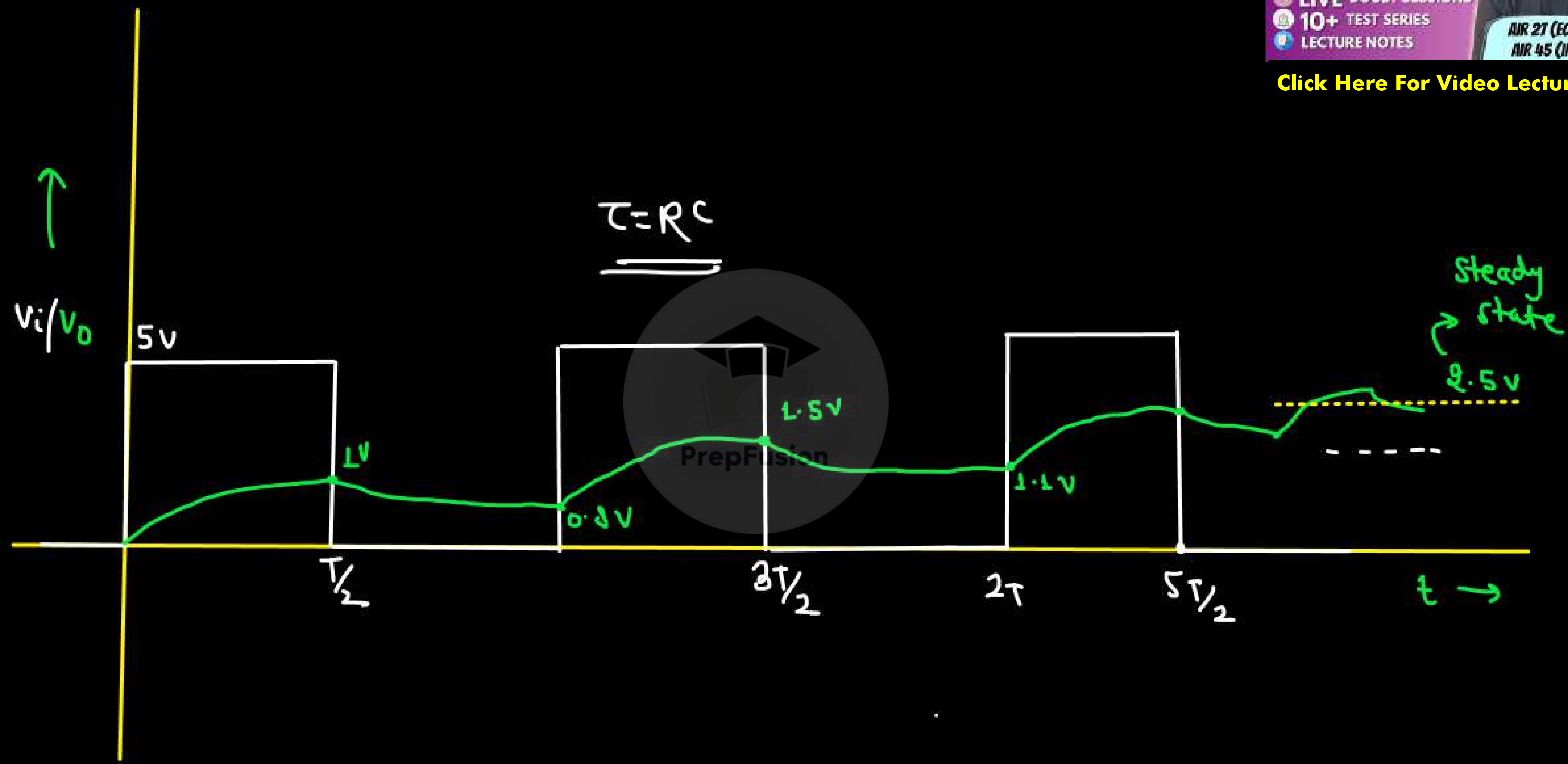
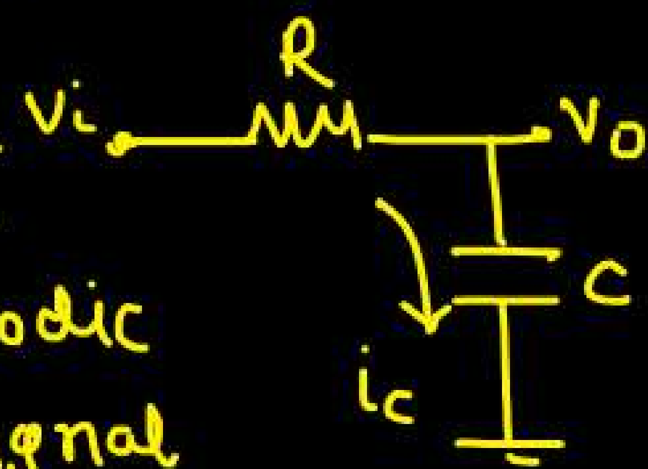
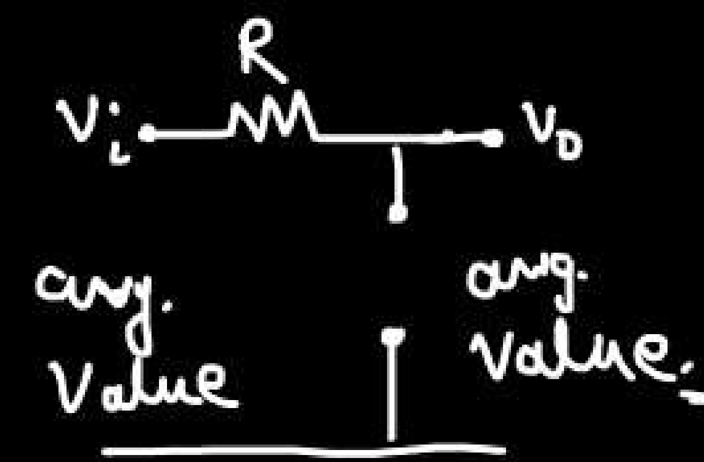


conclusion



periodic signal

$\xrightarrow[\text{state}]{\text{steady}}$

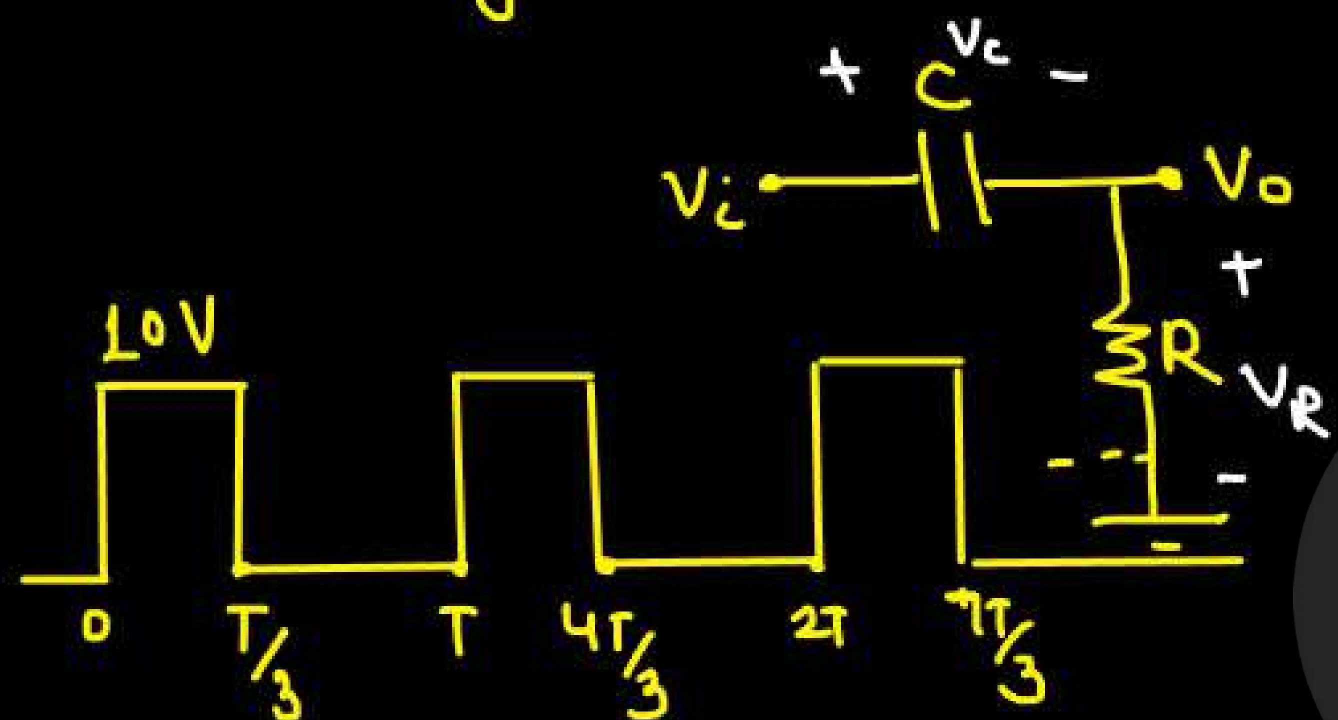


$$\rightarrow \left[(V_o)_{avg.}\right]_{s.s.} = \left[V_i\right]_{avg.}$$

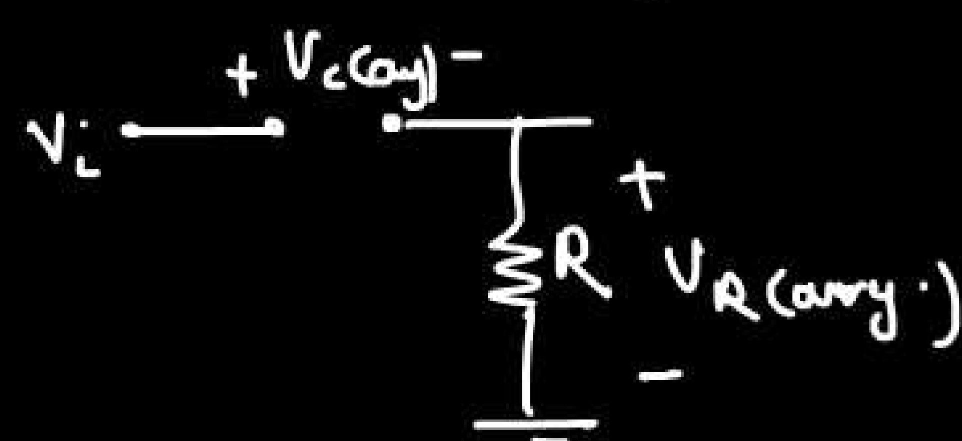
$$\left[(i_c)_{avg.}\right]_{s.s.} = 0 \text{ Amp}$$

$$\left[(V_R)_{avg.}\right]_{s.s.} = 0V \quad \left\{ (V_R)_{avg.} = (i_c)_{avg.} \times R \right\}$$

Q. Find steady state avg. value of cap. voltage and voltage across resistor.

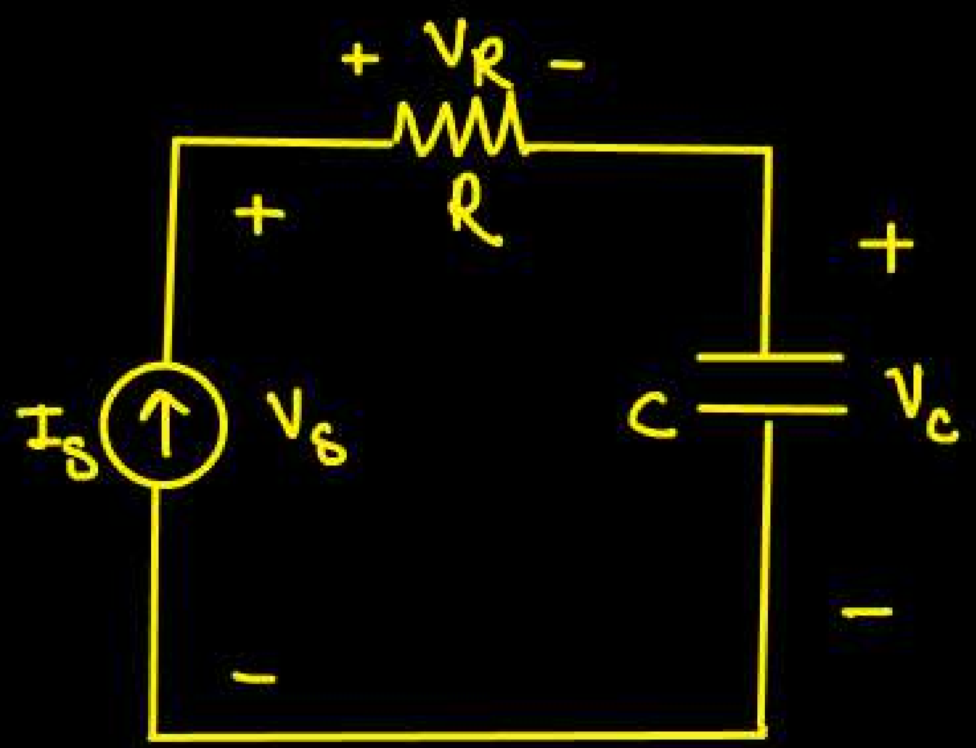


→ @ steady state; $(i_c)_{avg} = 0$ Amp ; $(V_R)_{avg} = 0\,V$



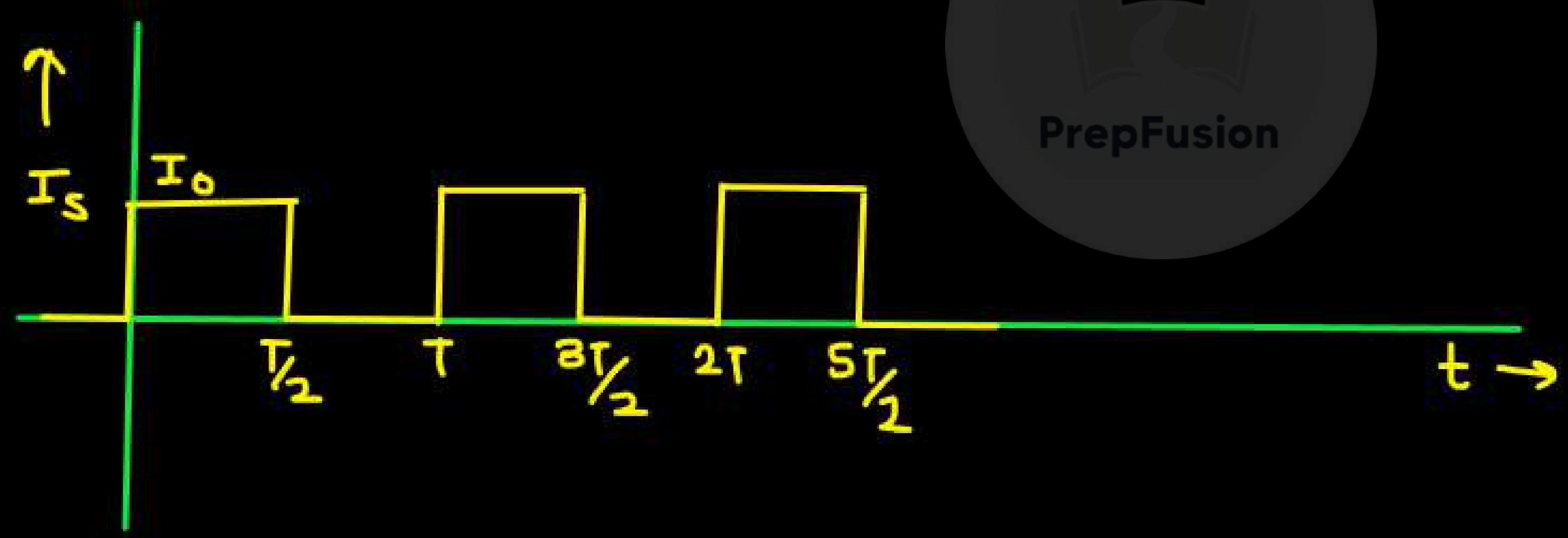
$$(V_c)_{avg} = (V_i)_{avg}$$

$$= \frac{\left(10 \times \frac{T}{3}\right) + \left(0 \times \frac{2T}{3}\right)}{T} = \frac{10}{3}\,V$$

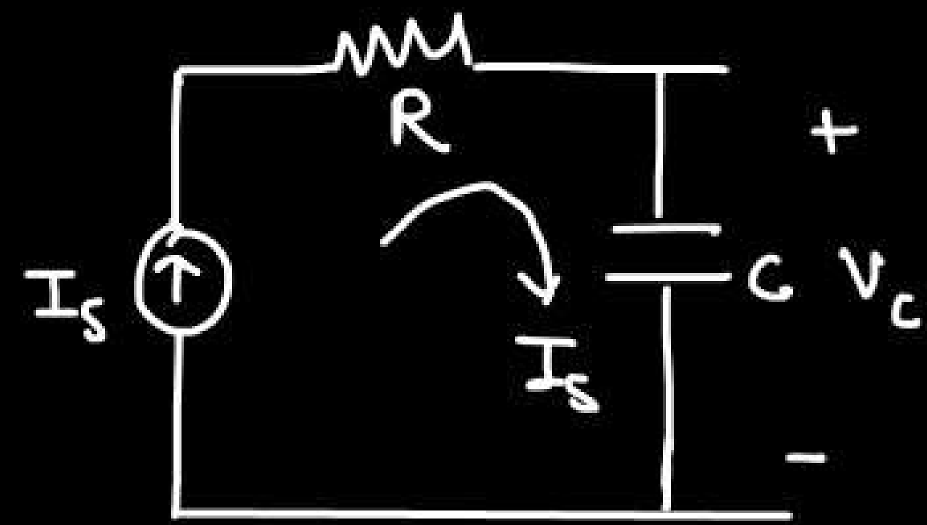


Take $T = RC$

v_c and v_R = ?



→

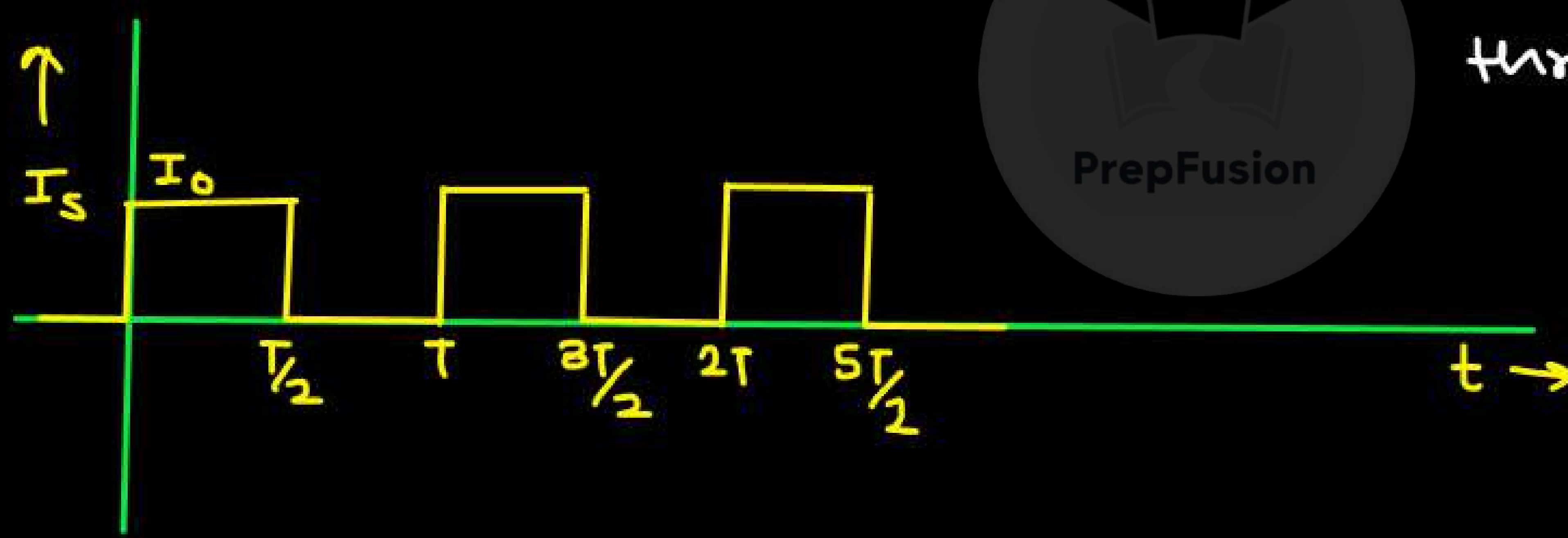


→ I_s current flows through the cap. and resistor forever

⇓

Constant current is flowing through the cap.

$$V_c(t) = \frac{1}{C}\int_0^t I_s \cdot dt$$



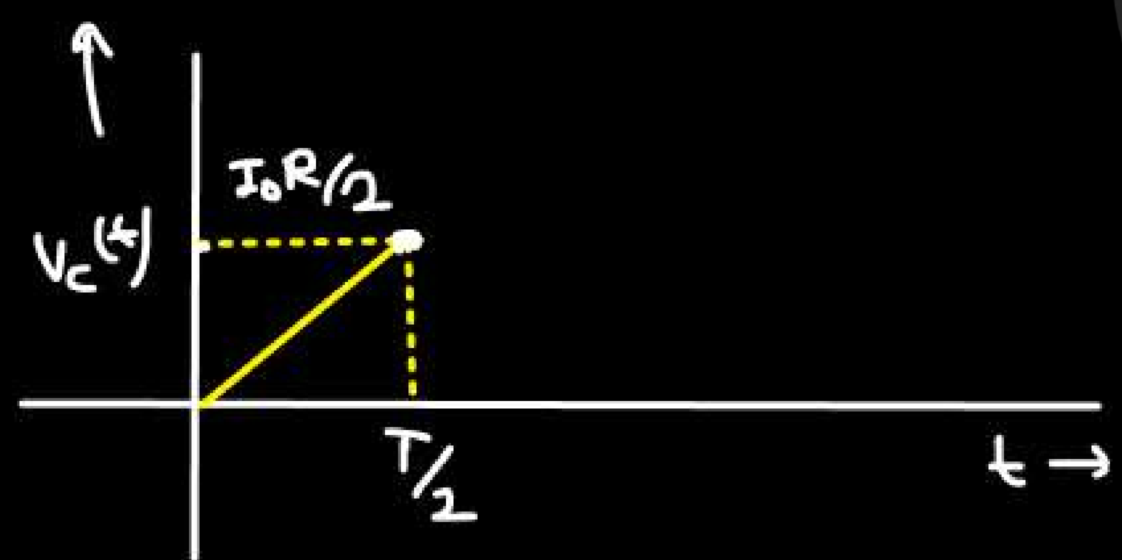
For $0 < t < T/2$

Given $T = RC$

$$V_c(t) = \frac{1}{C}\int_0^t I_S \cdot dt$$

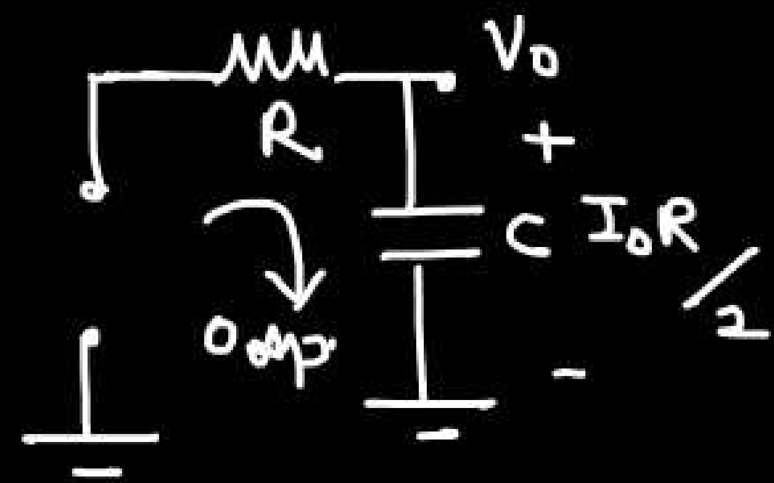
$$= \frac{1}{C}\int_0^t I_0 \, dt$$

$$V_c(t) = \frac{I_0 t}{C} \quad ; \quad V_c(T/2) = \frac{I_0 T}{2C} = \frac{I_0 (RC)}{2C} = \frac{I_0 R}{2}$$

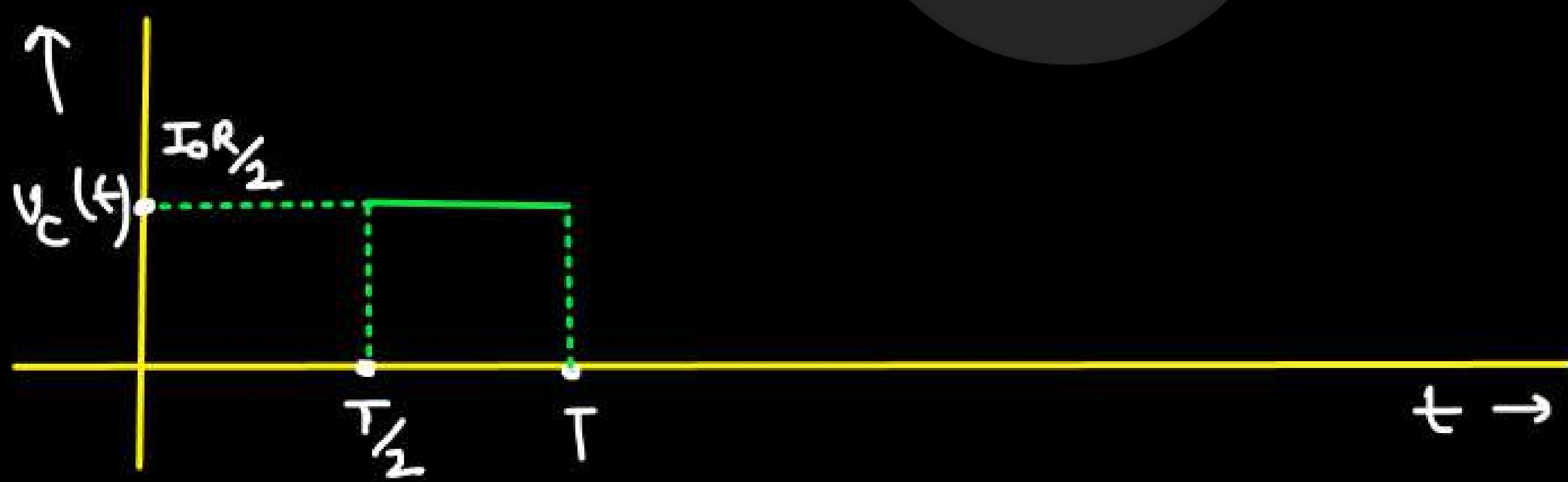


for $T/2 \le t < T$

$I_s = 0$ Amp



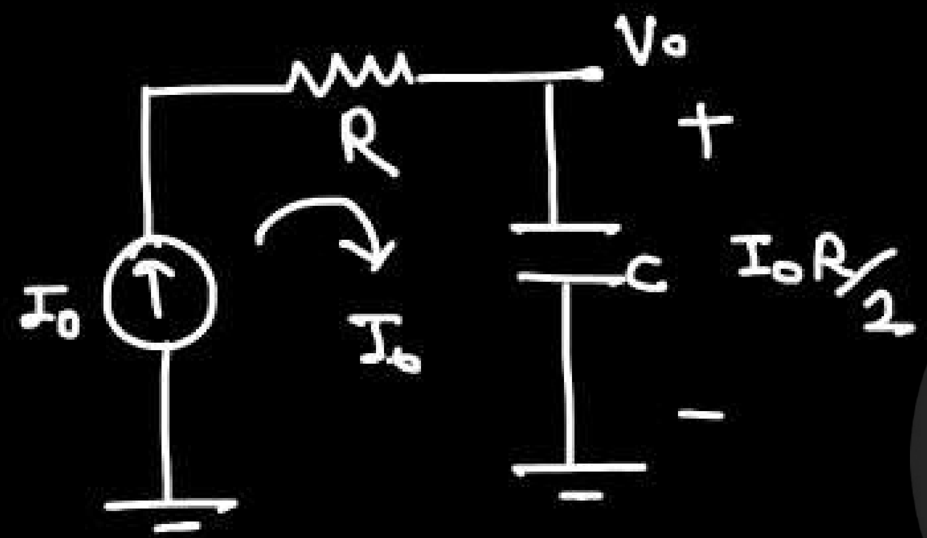
$\Rightarrow$ cap. will neither discharge ; nor charge.



For $T \le t < 3T/2$

$$V_c(T) = I_0R/2$$

$I_s = I_0$ dp.



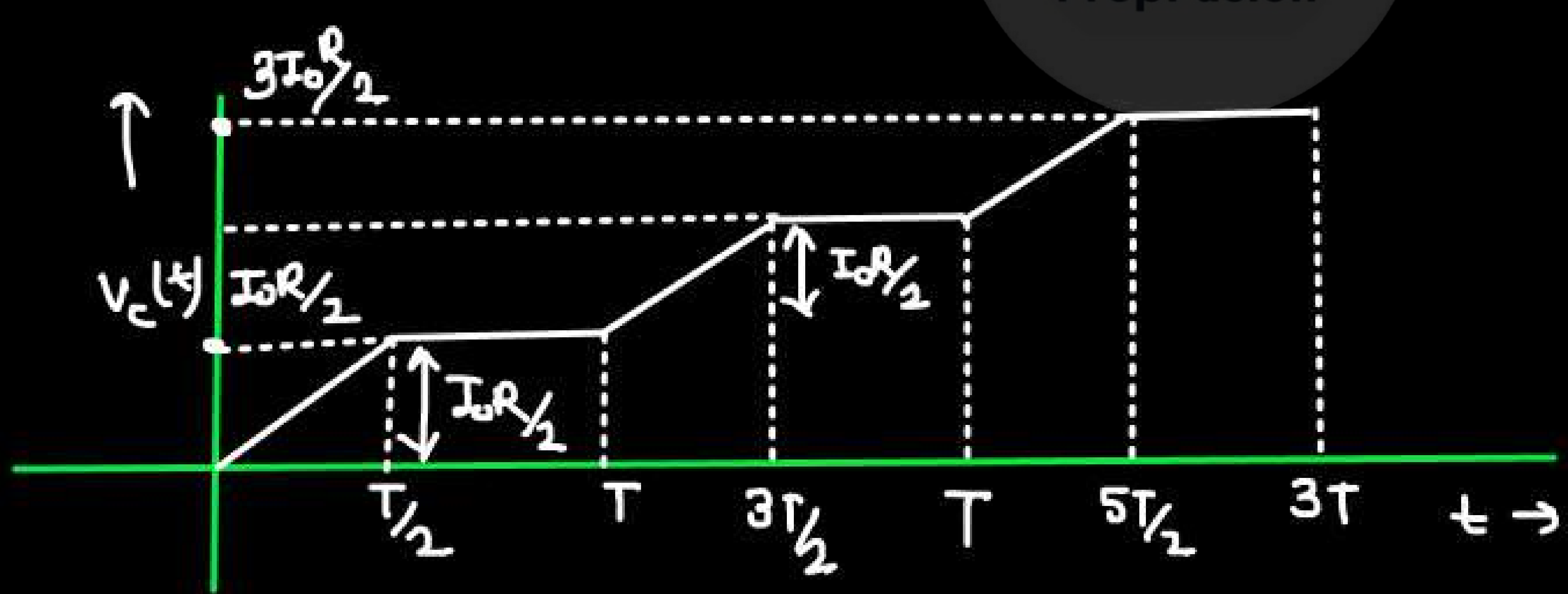
⇒ Cap. will charge.

$$V_c(t) = \frac{I_0R}{2} + \frac{1}{C}\int_T^t I_0 \cdot dt$$

$$= \frac{I_0R}{2} + \frac{I_0}{C}\left[t - T\right]$$

$$V_c(3T/2) = \frac{I_0R}{2} + \frac{I_0}{C}\left[\frac{T}{2}\right]$$

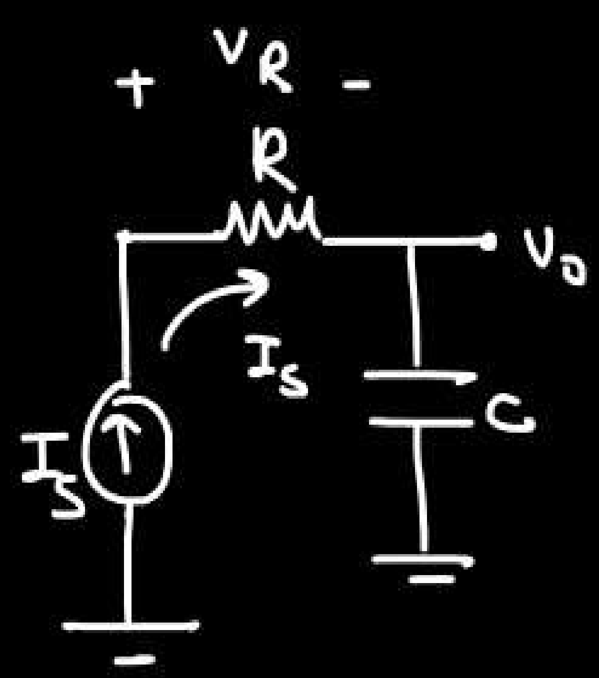
$$= I_0R$$



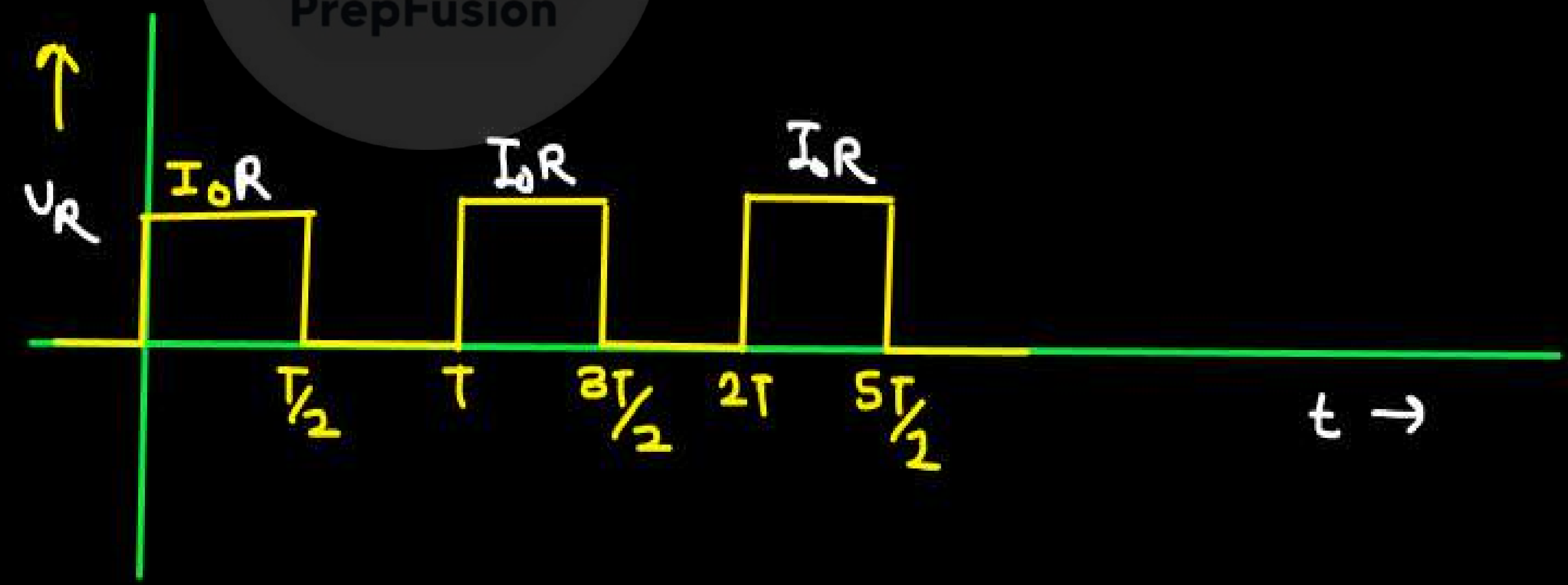
in every cycle, capacitor is developing $\frac{I_0 R}{2}$ voltage.

capacitor voltage after n cycles of i/p $= n \frac{I_0 R}{2}$

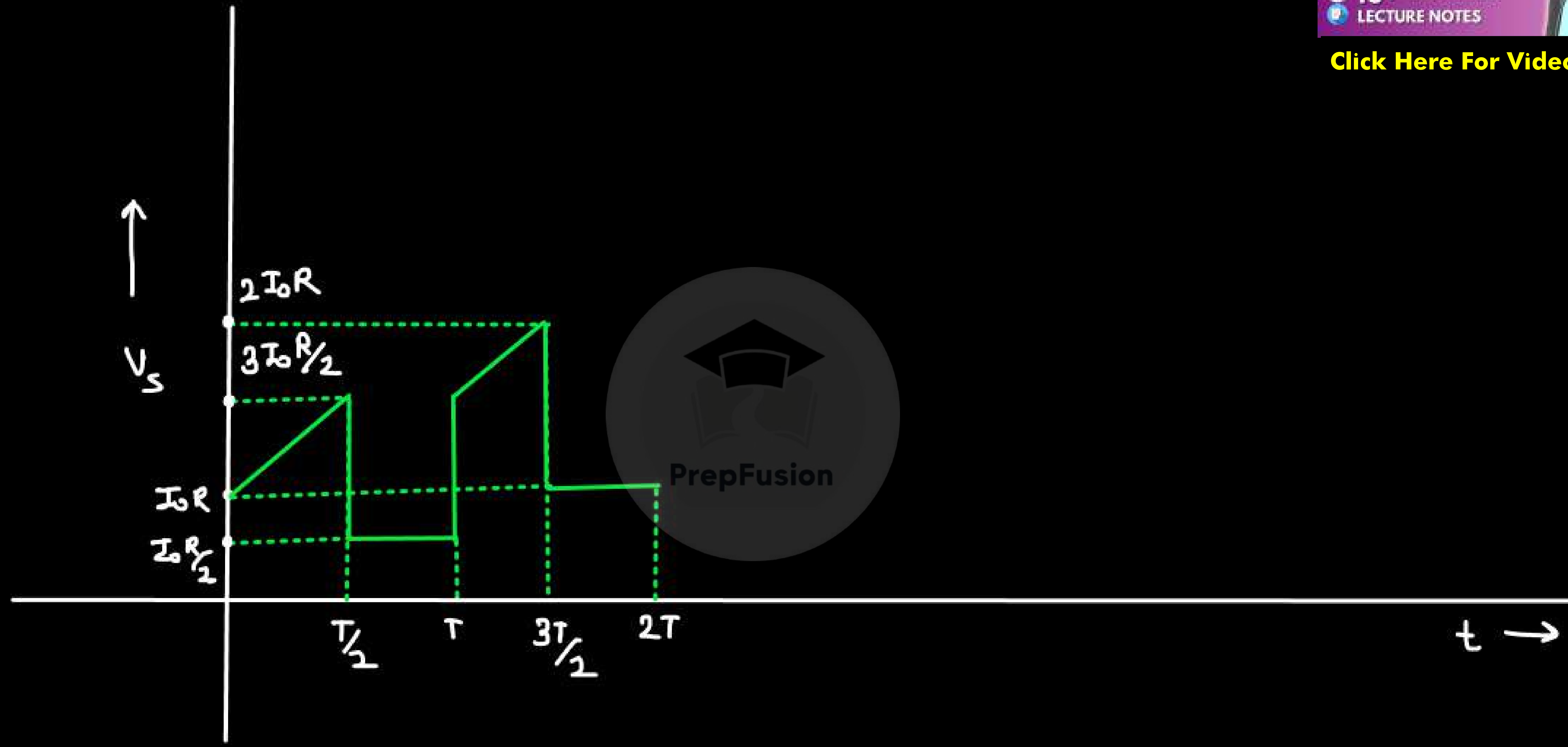
$\underline{\underline{V_R}}$:-



$V_R = I_S R$



$\underline{\underline{V_S}}$:-



★ Initial value and final value Theorem:-

Q. Find the initial and final value of the given f^n:- $f(t) = [1 - e^{-at}]\, u(t)$

→ initial value $(t = 0^+)$:-

$$f(0^+) = [1 - e^{-a(0)}]\, u(0^+)$$

$$= 0$$

Final value / steady state value / DC value $(t = \infty)$:-

$$f(\infty) = [1 - e^{-a(\infty)}]\, u(\infty)$$

$$= 1$$

★ Initial Value Theorem:-

i) Applicable only when $f(t) = 0 \; ; \; t < 0 \quad \Rightarrow \quad f(t) = f_1(t) \cdot u(t)$

ii) $f(t)$ should not contain any impulse or discontinuity at $t = 0^+$

↳ let $L[f(t)] = F(s)$

then initial value $\lim_{t \to 0^+} f(t) = f(0^+) = \lim_{s \to \infty} s \cdot F(s)$

Eg. → ① find initial value for $f(t) = e^{-2t} u(t)$.

→ $f(0^+) = e^{-2(0)} u(0^+)$

$= 1$

$F(s) = \dfrac{1}{s+2}$

$\lim_{t \to 0^+} f(t) = f(0^+) = \lim_{s \to \infty} s \cdot F(s) = \lim_{s \to \infty} \dfrac{s}{s+2} = 1$

Q. $F(s) = \dfrac{s^2+12s+36}{s+6}$ initial value ?

$L[\delta(t)] = 1$

$L[\delta'(t)] = s$

$\rightarrow F(s) = \dfrac{(s+6)^2}{s+6} = s+6$

↳ $f(t) = \delta'(t) + \underbrace{6\delta(t)}$

↳ impulse @ $t=0$

$\Downarrow$

initial value Theorem is not applicable.

Q. $F(s) = \dfrac{s^2+7s+12}{s+2}$

$\rightarrow F(s) = \dfrac{(s+4)(s+3)}{s+2}$

$= \dfrac{(s+2+2)}{s+2}(s+3) = \left(1+\dfrac{2}{s+2}\right)(s+3) = (s+3) + \dfrac{2(s+2+1)}{s+2}$

$$= s+3 + 2\left[1 + \frac{1}{s+2}\right]$$

$$= s+5 + \frac{2}{s+2}$$

$$f(t) = \delta'(t) + \underbrace{5\delta(t)}_{\hookrightarrow \text{impulse @ } t=0} + 2e^{-2t}u(t)$$

$\Rightarrow$ inital value Theorem is not applicable.

N.B.:- In Lalapce transform f^n :- when $\boxed{\text{Degree of Num}^r > \text{Degree of deno}^n}$

$\Downarrow$

Time domain f^n will always have an impulse / differentiation of inpulse (discontinuity @ $t=0$)

$$F(s) = \frac{N(s)}{D(s)}$$

$$\text{Degree}(N(s)) < \text{Degree}(D(s))$$

→ For initial value Theorem to be applicable

Eg → $F(s) = \dfrac{s+6}{s^2+7s+12}$ Find $\lim_{t \to 0^+} f(t)$ or initial value.

→ $$f(0^+) = \lim_{s\to\infty} sF(s) = \lim_{s\to\infty} \frac{s^2+6s}{s^3+7s^2+12s}$$

$$= \lim_{s\to\infty} \frac{s^2}{s^3}$$

$$f(0^+) = \lim_{s\to\infty} \frac{1}{s} = \underline{\underline{0}}$$

Final value Theorem :-

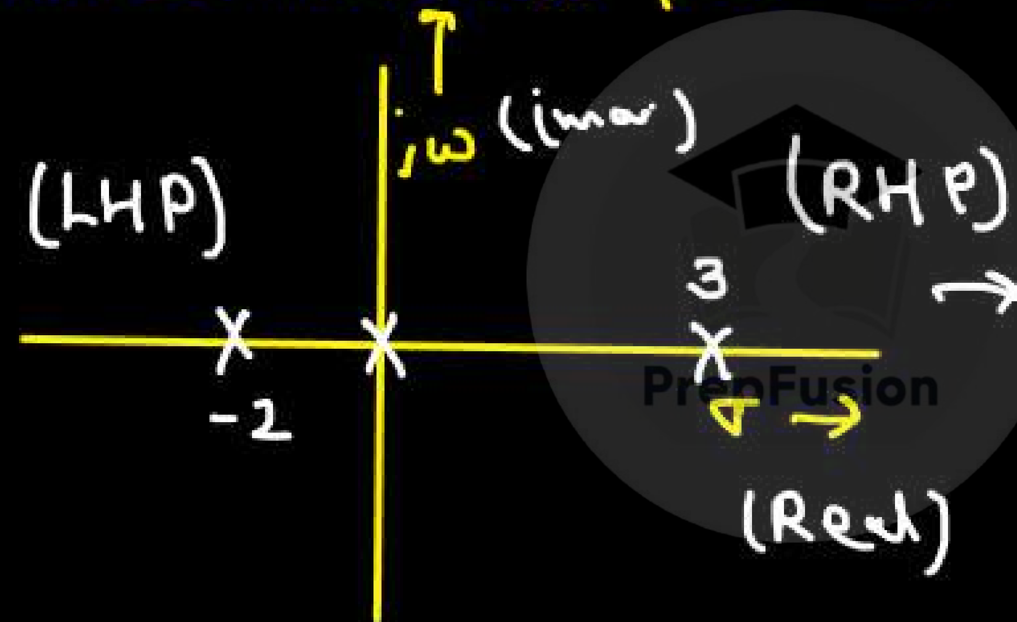
i) Signal should not be unbounded or periodic.

ii) Pole of $F(s)$ should lie in left Half of s-plane.

(iii) $F(s)$ should have max one pole at the origin.

$$F(s) = \frac{1}{s(s+2)(s-3)}$$

Poles: → $-2, 3, 0$



→ can't apply Final value Theorem

s-plane

↳ Final value $\lim_{t \to \infty} f(t) = \lim_{s \to 0} sF(s)$

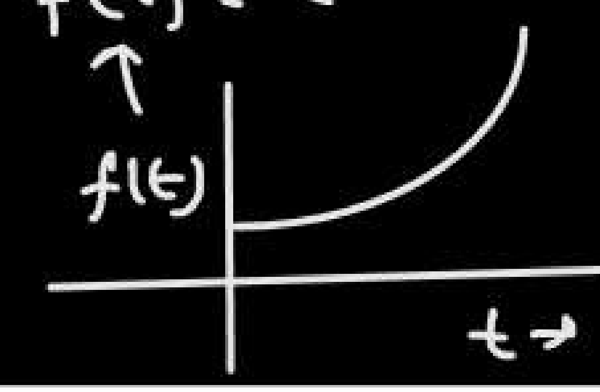
unbounded signal

↓

$\underbrace{f(t) \to \infty}$

@ any point of time

Eg. $f(t) = e^{2t}u(t)$



Q. $f(t) = e^{-2t}u(t)$. Find steady state value.

$$f(\infty) = e^{-\infty}u(\infty) = 0$$

$$F(s) = \frac{1}{s+2}$$

$$f(0) = \lim_{s\to 0} s\cdot F(s) = \lim_{s\to 0} \frac{s}{s+2} = \underline{0}$$

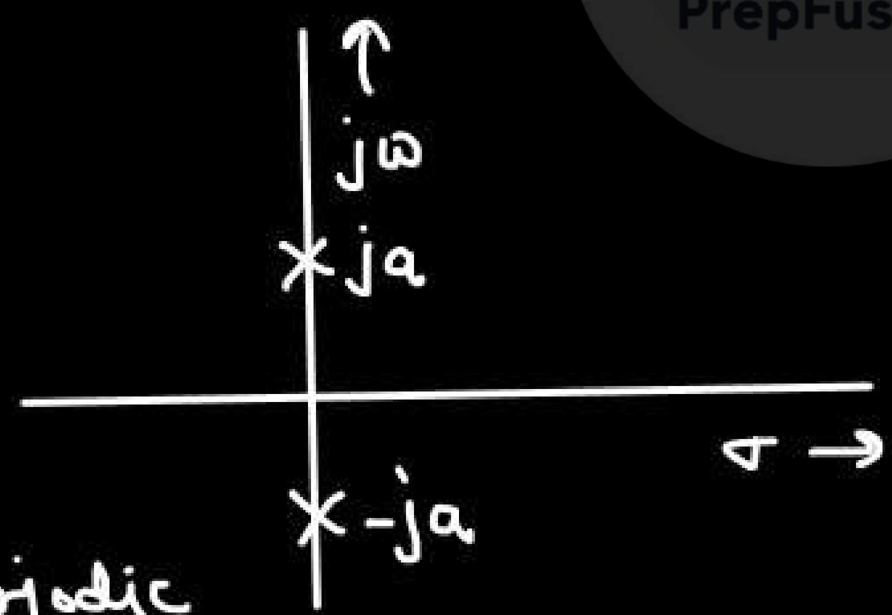
Q. $F(s) = \dfrac{a}{s^2+a^2}$. Find $f(\infty)$.

$\rightarrow$

$$F(s) = \frac{a}{s^2+a^2}$$

$f(t) = \sin at\, u(t)$

↳ periodic



poles → $s^2+a^2=0$

$s = \pm ja$

↳ poles are not in L.H.P.

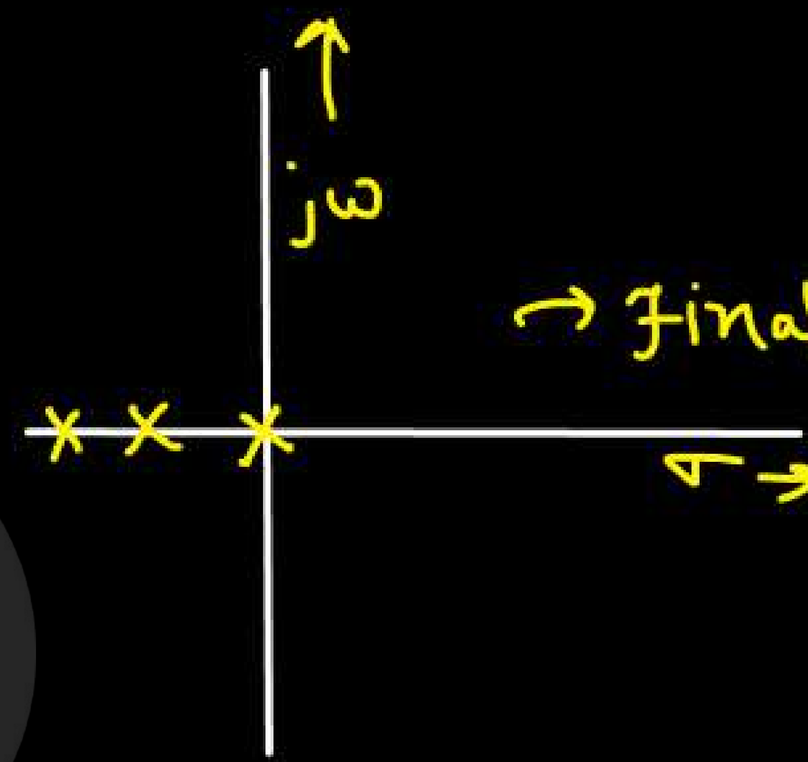
⇓

Final value Theorem not applicable

Eg →

$$F(s) = \frac{s^2+6}{s(s^2+7s+12)}$$

$$= \frac{s^2+6}{s(s+3)(s+4)}$$



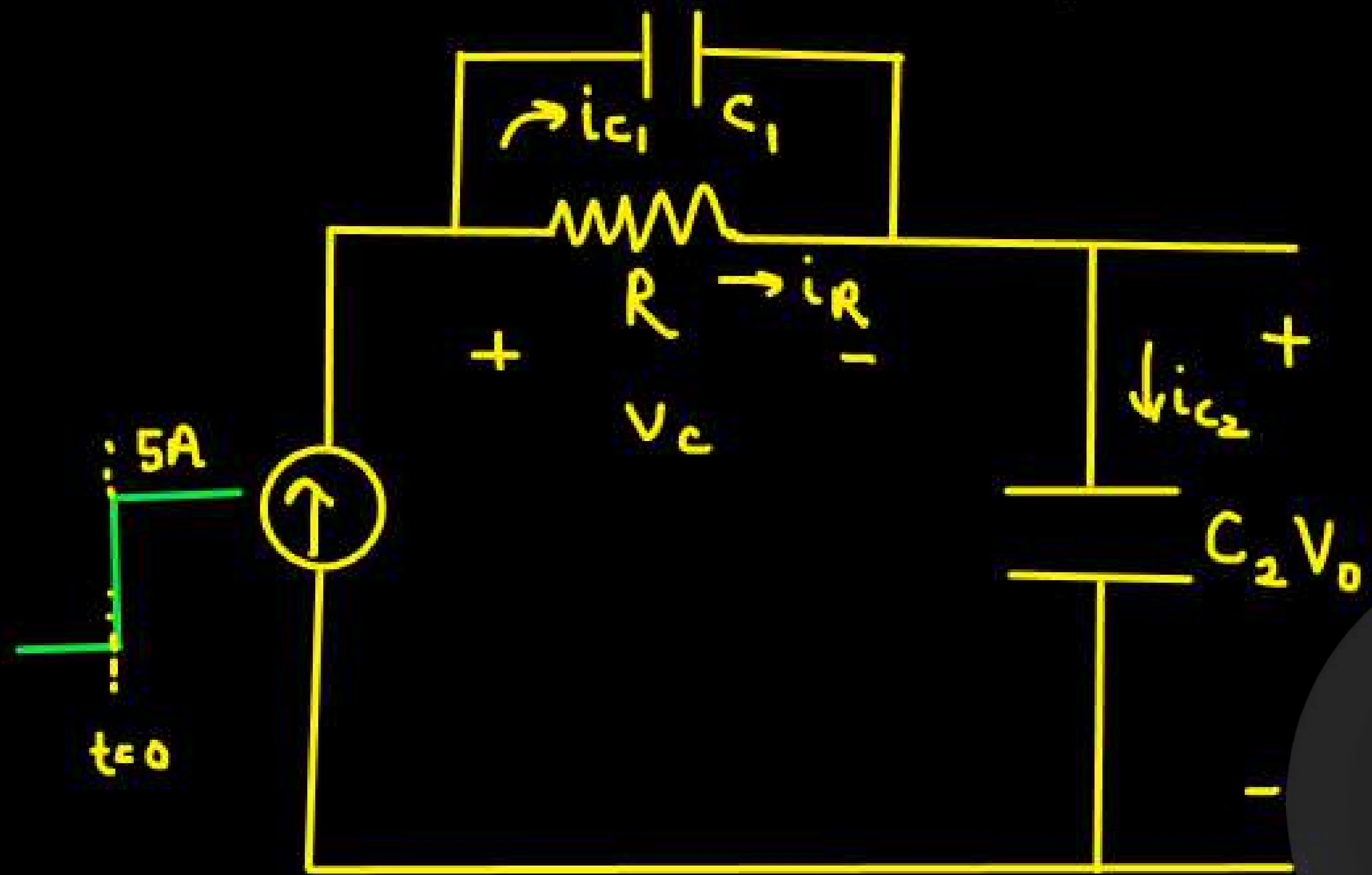
→ Final value Theorem applicable

→ $$f(\infty) = \lim_{s\to 0} s\,F(s) = \lim_{s\to 0} \frac{s^2+6}{(s+3)(s+4)}$$

$$= 6/12 = 1/2$$

* $$\boxed{f(\infty) = 1/2}$$

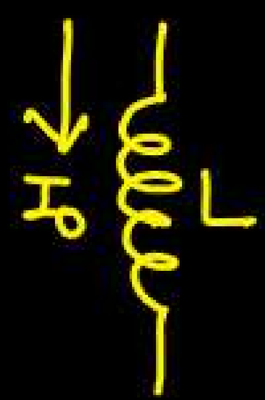
Q. Draw the wave forms.



In-depth analysis of Inductors :-

Inductors :-

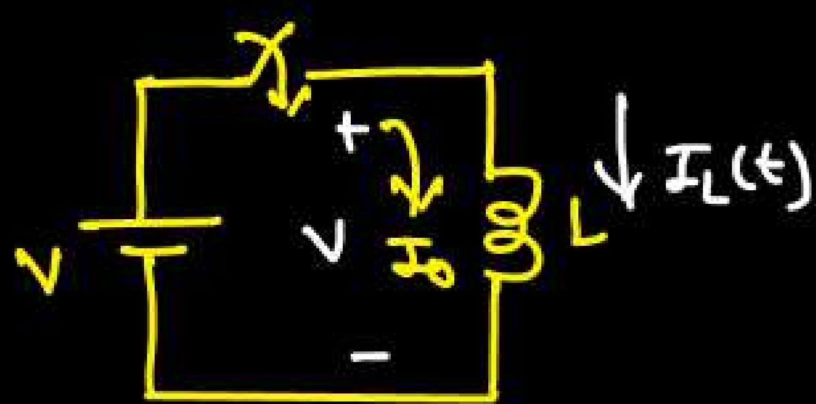
Let's assume inductor is having I_o current initially.



initial flux = LI_o

initial current = I_o

now let's assume, we are forcing some voltage to the inductor.



$$I_L(t) = I_o + \frac{1}{L}\int_{-\infty}^{\infty} V \cdot dt$$

when you force some voltage across inductor, it will develop current.

Properties of inductors :-

① Inductor is a flux storing element.

② When there is a finite voltage across the inductor - (not impulse)

then,

$$\boxed{\begin{aligned} &I_L(t^-) = I_L(t) = I_L(t^+) \\ &\text{But } \; V_L(t^-) \neq V_L(t^+) \end{aligned}}$$

→ {not necessarily equal)

The current across the inductor doesn't change instantaneously but the voltage across the inductor can change instantaneously.

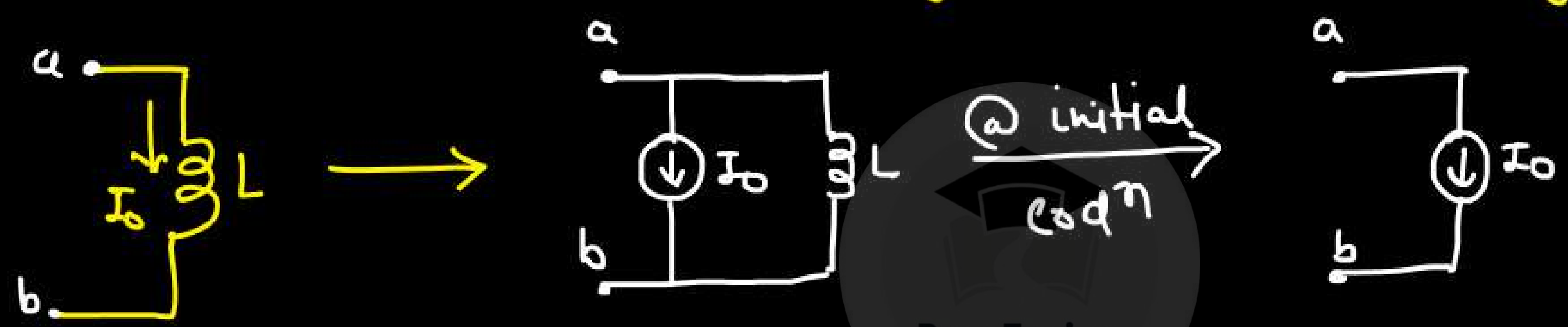
★ Initial and Final Cond^n of an Inductor :-

Zero voltage =

zero current =

★ Initial Cond^n :-

Let's assume inductor is having I_0 current initially.



so, initially an inductor is replaced with

↳ if there was no initial current.

Steady state of Inductor ($t = \infty$) :-

When there is zero voltage across the inductor

⇓

The inductor will not develop further current.

⇓

The inductor has reached it's maximum current.

steady state

So, @ steady state, the current across the inductor will be constant and the voltage across the inductor will be zero.

↳ @ steady state, inductor will be replaced by short ckt.

2^{nd} Analogy:-

@ steady state, I_L = max value it can attain.

$$V_L = L\frac{dI_L(t)}{dt}$$

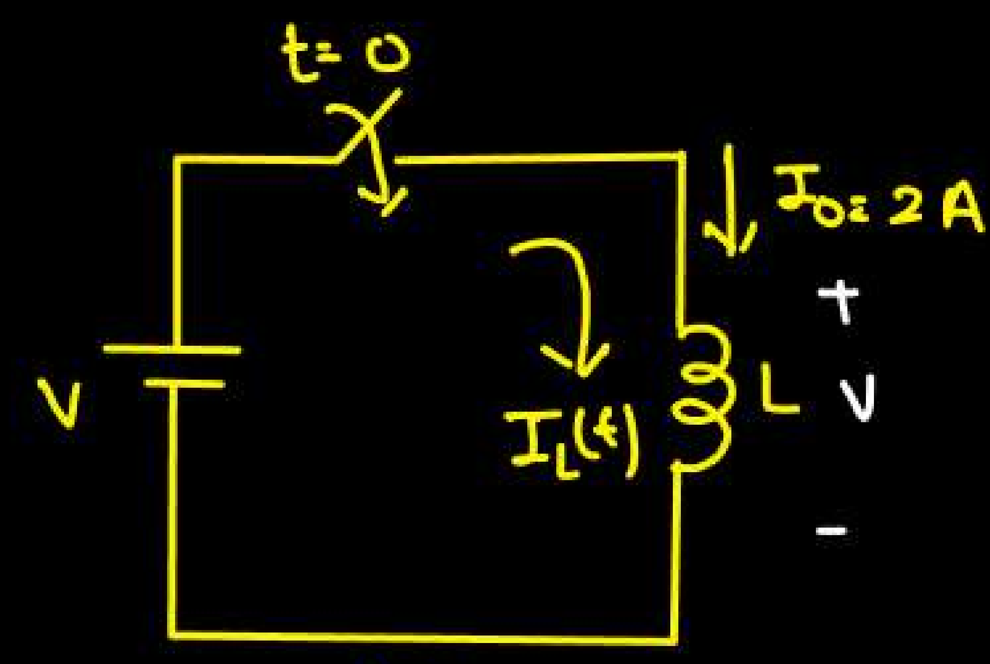
$$I_L = \max \Rightarrow \frac{dI_L(t)}{dt} = 0$$

$$\Rightarrow \boxed{V_L = 0\,V}$$

Summary:-

$$\left.\begin{array}{l} @\ t=0 \Rightarrow \text{inductor will be o.c.} \\ @\ t=\infty \Rightarrow \text{inductor will be s.c.} \end{array}\right\} \text{opposite to that of capacitor}$$

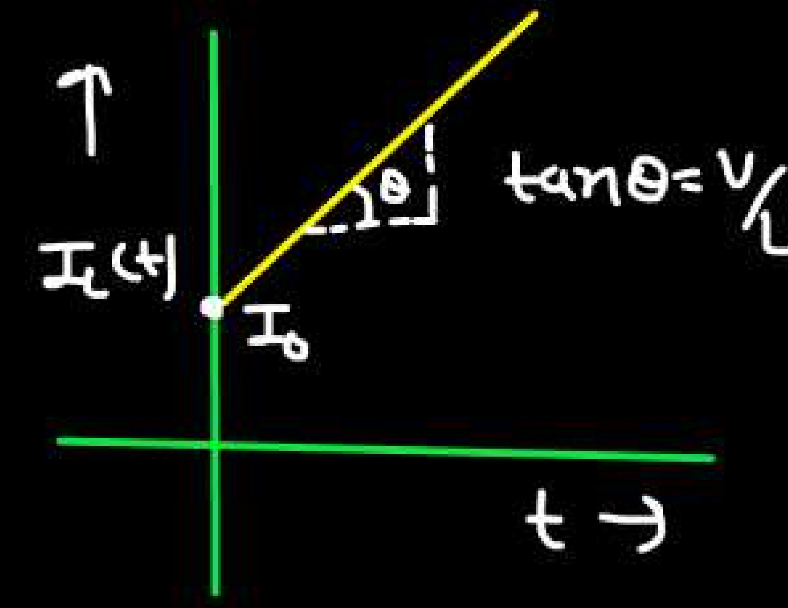
Q. Write eqⁿ for $I_L(t)$.

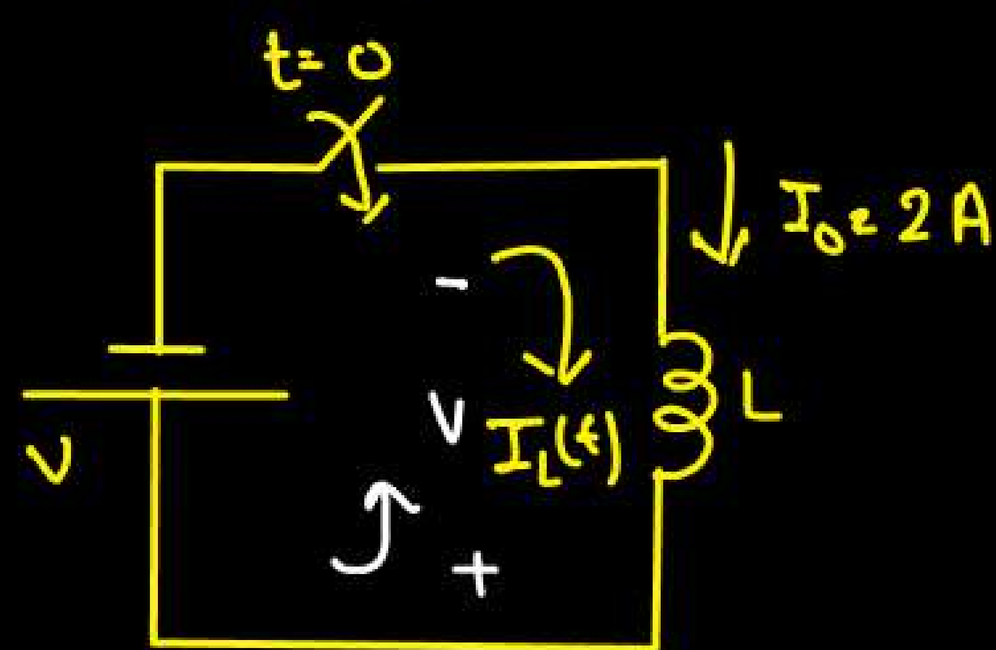


(a)

$$I_L(t) = I_0 + \frac{1}{L}\int_0^t V\,dt$$

$$= I_0 + \frac{Vt}{L} \text{ Amp.}$$

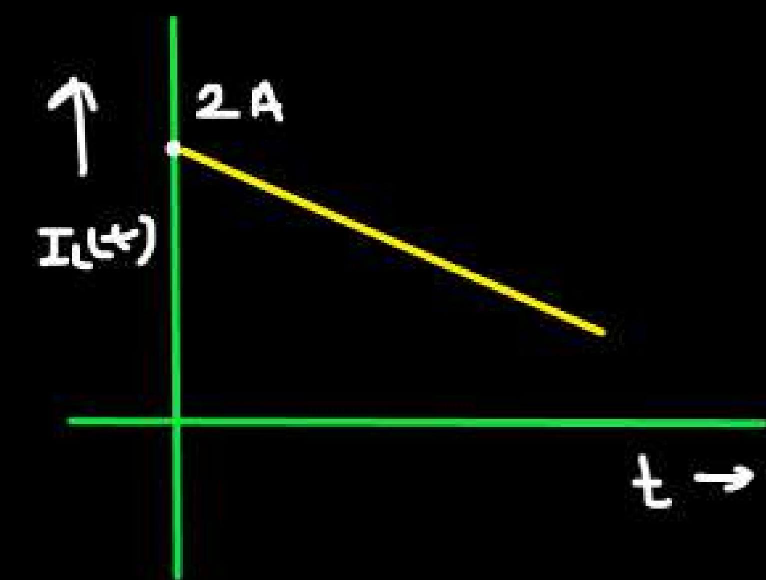


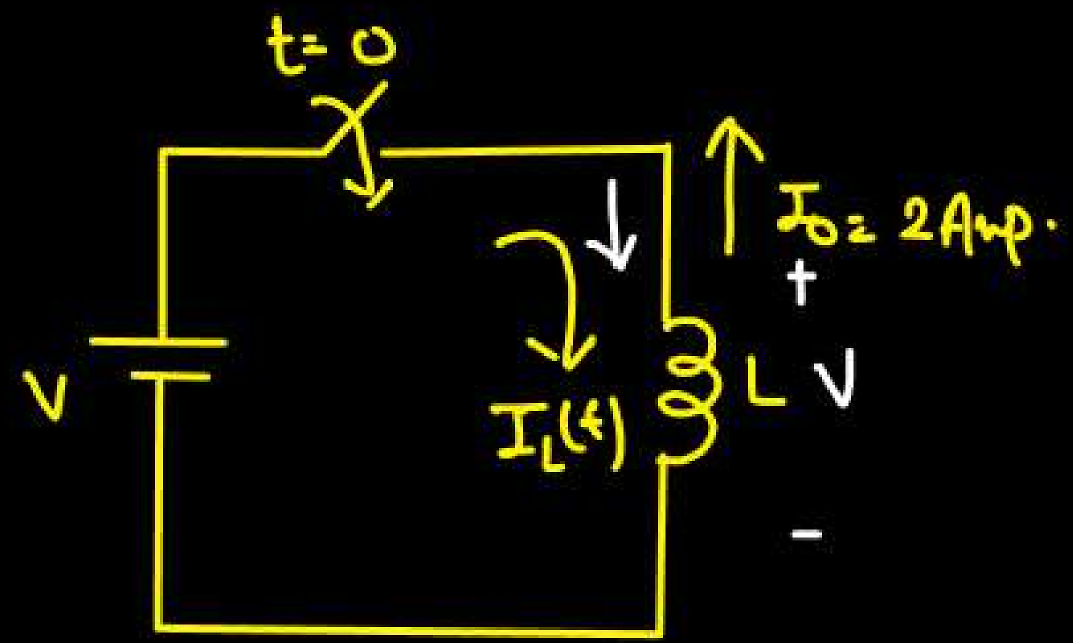


(b)

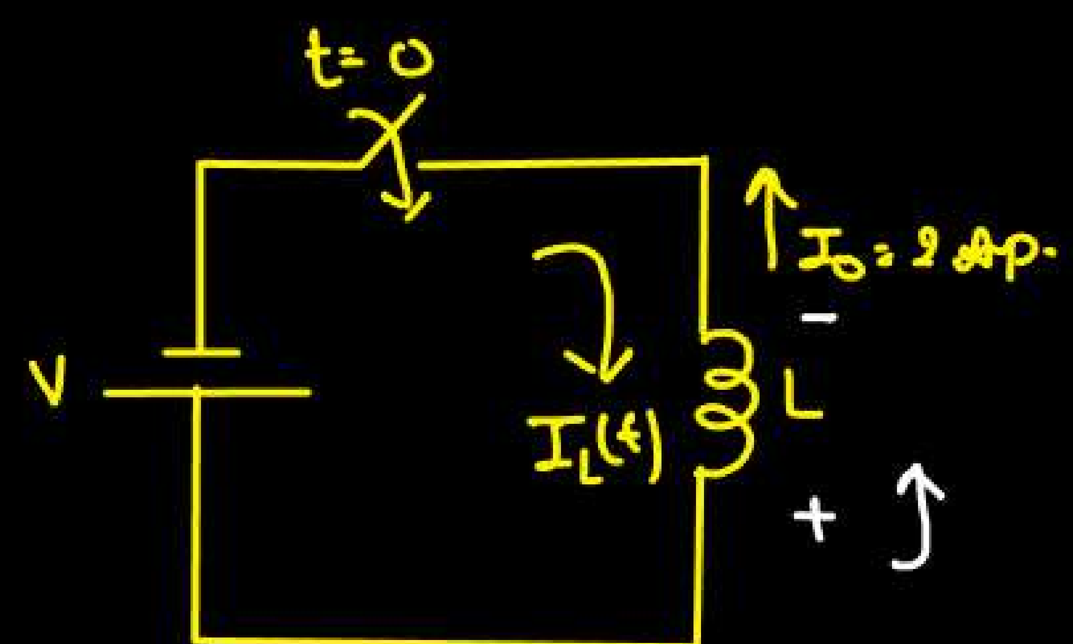
$$I_L(t) = 2 - \frac{1}{L}\int_0^t V\,dt$$

$$= 2 - \frac{Vt}{L} \text{ Amp.}$$





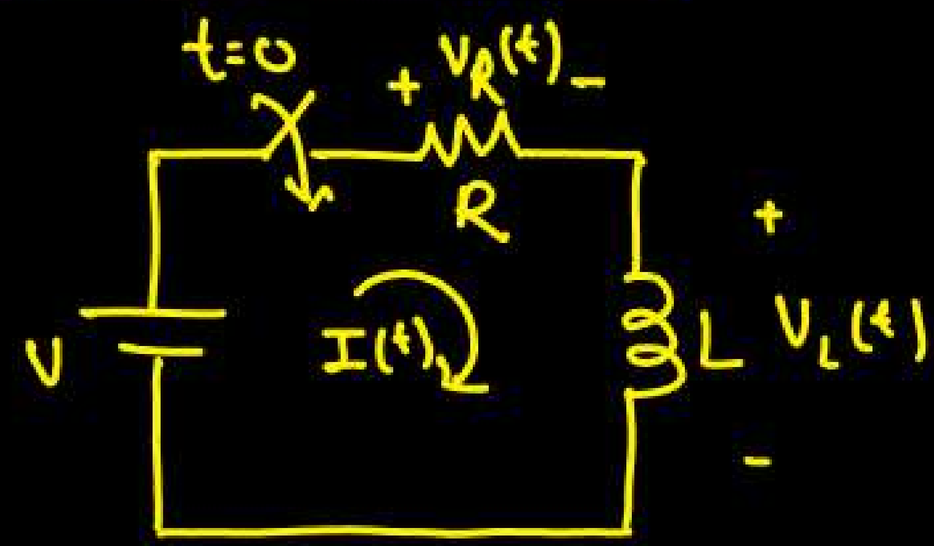
$$I_L(t) = -2 + \frac{Vt}{L} \text{ Amp.}$$



$$I_L(t) = -2 - \frac{Vt}{L}$$

$$= -\left[2 + \frac{Vt}{L}\right] \text{ Amp.}$$

First order RL ckt :-



$V_R(t)$, $V_L(t)$, $I(t) = ?$

Differential eqn :-

I(t) :-

$$V = I(t)\cdot R + L\frac{dI(t)}{dt}$$

$$\left\{ V_L(t) = L\frac{di(t)}{dt} \right\}$$

$V_R(t)$:-

$$V = V_R(t) + \frac{L}{R}\frac{d}{dt}[V_R(t)]$$

$$\left\{ V_L(t) = L\frac{di(t)}{dt} = L\frac{d}{dt}\left[\frac{V_R(t)}{R}\right] \right.$$

$V_L(t)$:-

$$\boxed{V = \frac{R}{L}\int_0^t v_L(t)\cdot dt + V_L(t)}$$

$$\left\{ V_L(t) = \frac{L}{R}\,\frac{d\,[V_R(t)]}{dt} \right.$$

$$\left. \Rightarrow V_R(t) = \frac{R}{L}\int_0^t v_L(t)\cdot dt \right)$$

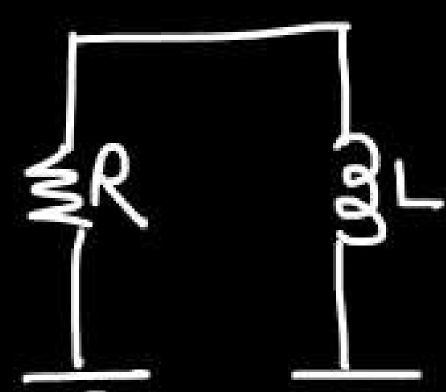
$$0 = \frac{R}{L}V_L(t) + \frac{dV_L(t)}{dt}$$ ← differential eq^n

⇒ So, solve these differential eq^n to get $V_R(t)$, $I(t)$ and $V_L(t)$.

Time constant :-

$$\tau = \frac{L_{eff}}{R_{eq}}$$

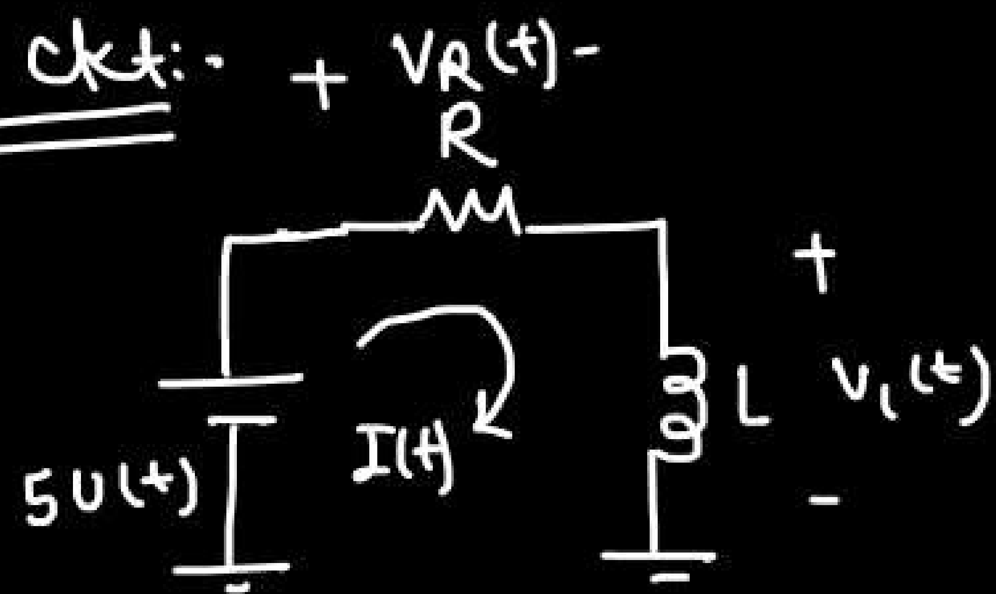
$$\boxed{\tau = \frac{L}{R}}$$



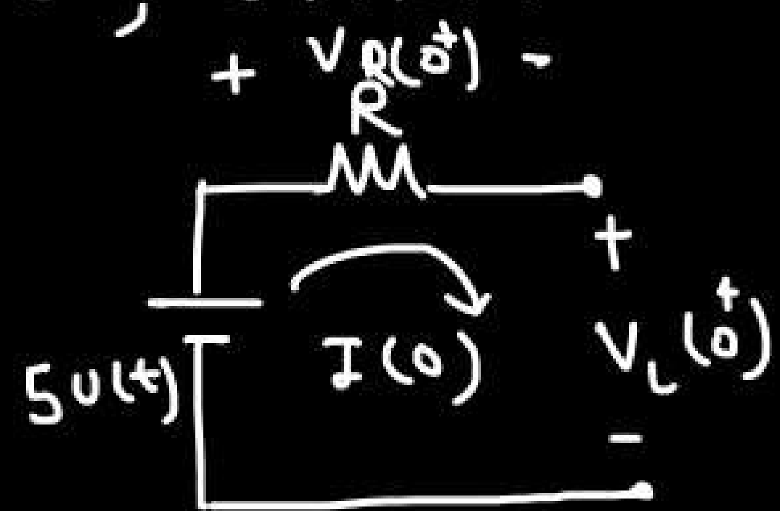
M-II

$$y(t) = y(\infty) + \left[y(0^+) - y(\infty) \right] e^{-t/\tau} \, u(t)$$

given ckt:-



@ $t=0$; inductor → O.C



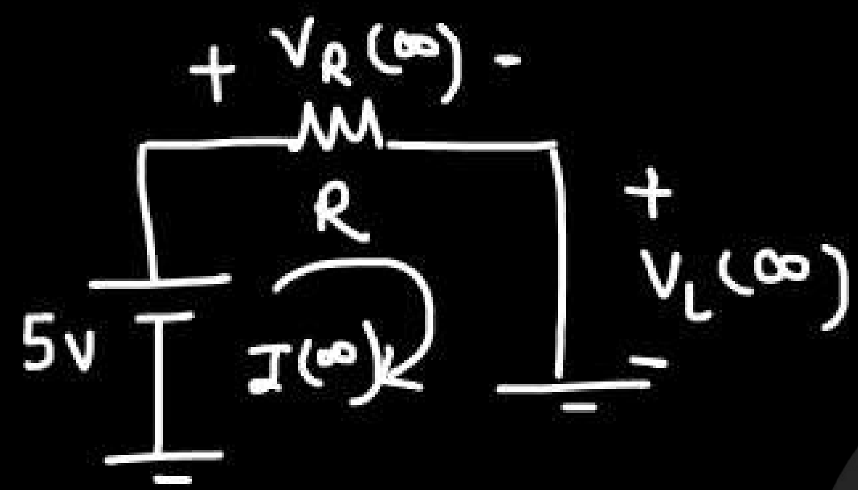
$V_R(0^+) = 0V$

$I(0^+) = 0$ Amp.

$V_L(0^+) = 5V$

@ $\underline{\underline{t = \infty}}$:-

inductor will be shorted.



$I(\infty) = 5/R$

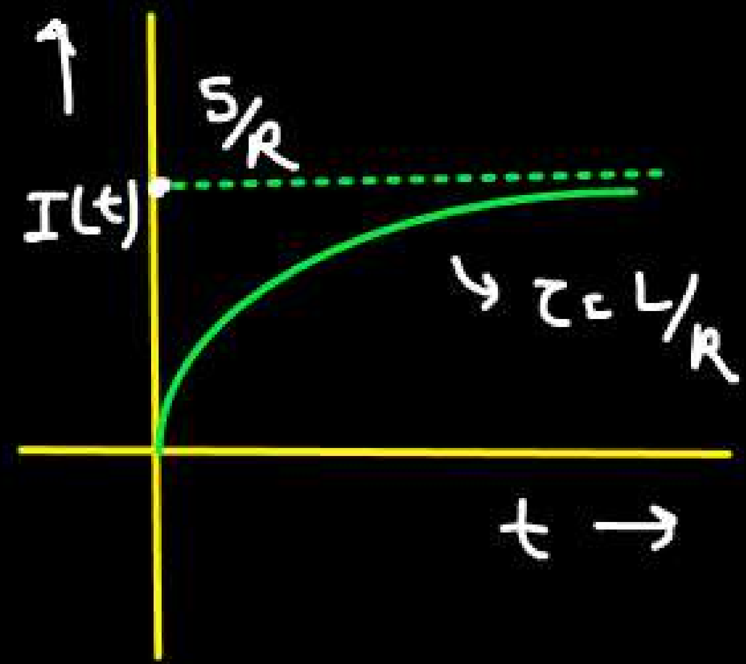
$V_R(\infty) = 5\,V$

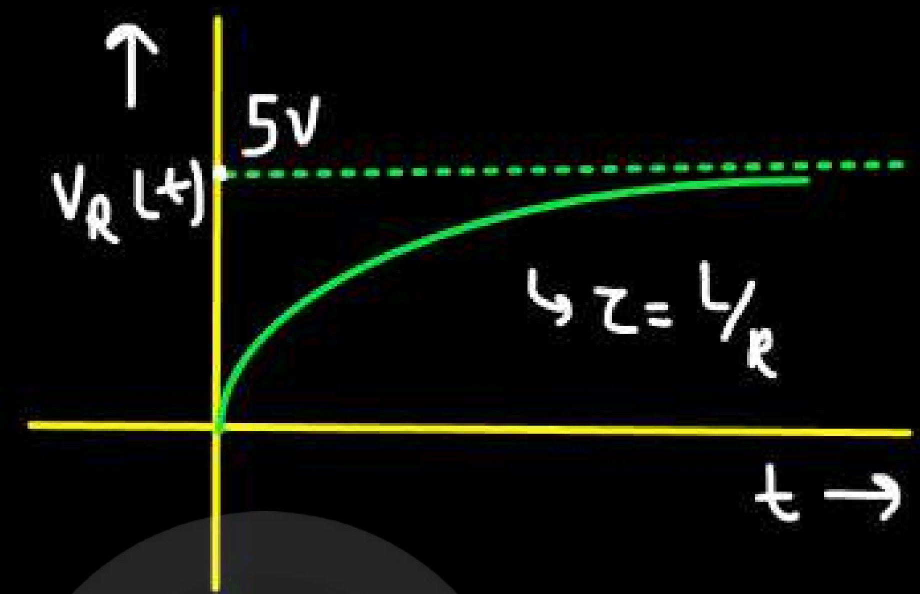
$V_L(\infty) = 0\,V$

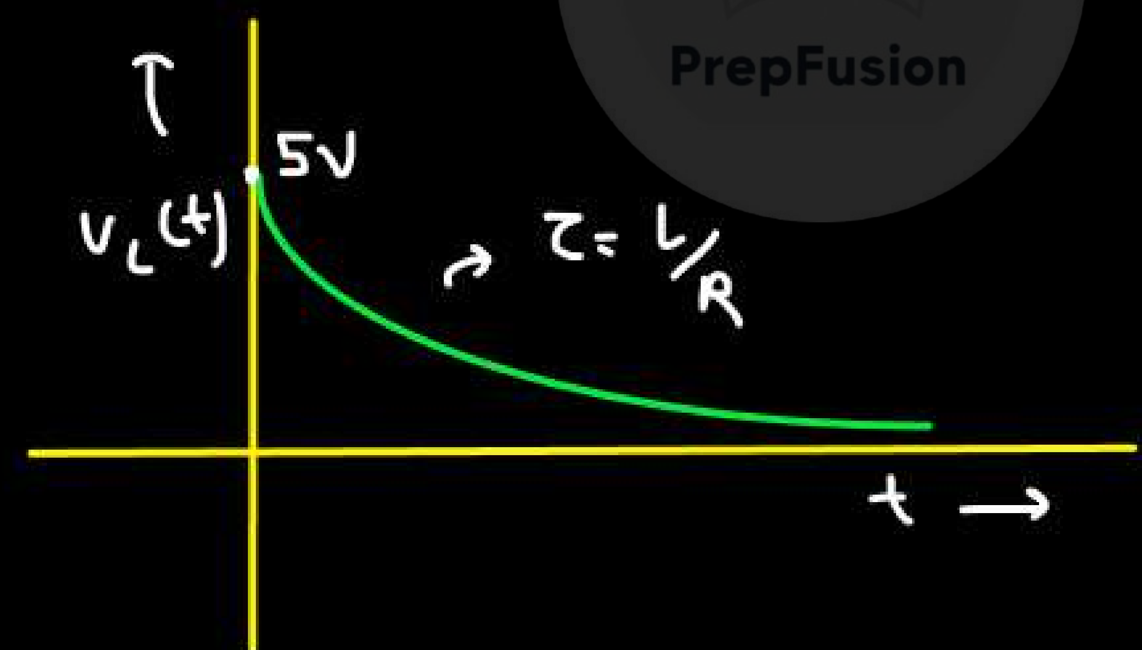
↳ $I(t) = \frac{5}{R}\left[1 - e^{-t/\tau}\right] u(t)$; $\tau = L/R$

$V_R(t) = 5\left[1 - e^{-t/\tau}\right] u(t)$; $\tau = L/R$

$V_L(t) = 5e^{-t/\tau}\, u(t)$; $\tau = L/R$

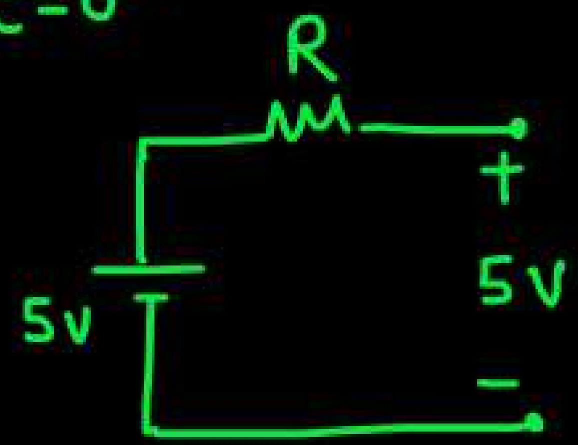

5/R
I(t)
τ = L/R
t →


5V
V_R(t)
τ = L/R
t →


5V
V_L(t)
τ = L/R
t →

What is happening in the ckt :-

@ $t = 0^+$



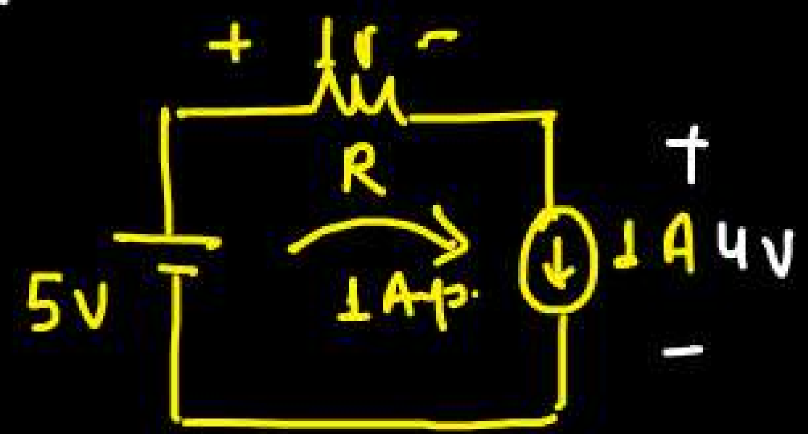
$\Rightarrow$ 5V will come across inductor

$\Downarrow$

it will generate current in inductor

Let's assume @ $t = t_1$, the current through inductor is 1A.

@ $t = t_1$; take $R = 1\Omega$



$\Rightarrow$ now the drop across the inductor has reduced to 4V.

$\Downarrow$

This 4V will also generate some current and the current will increase.

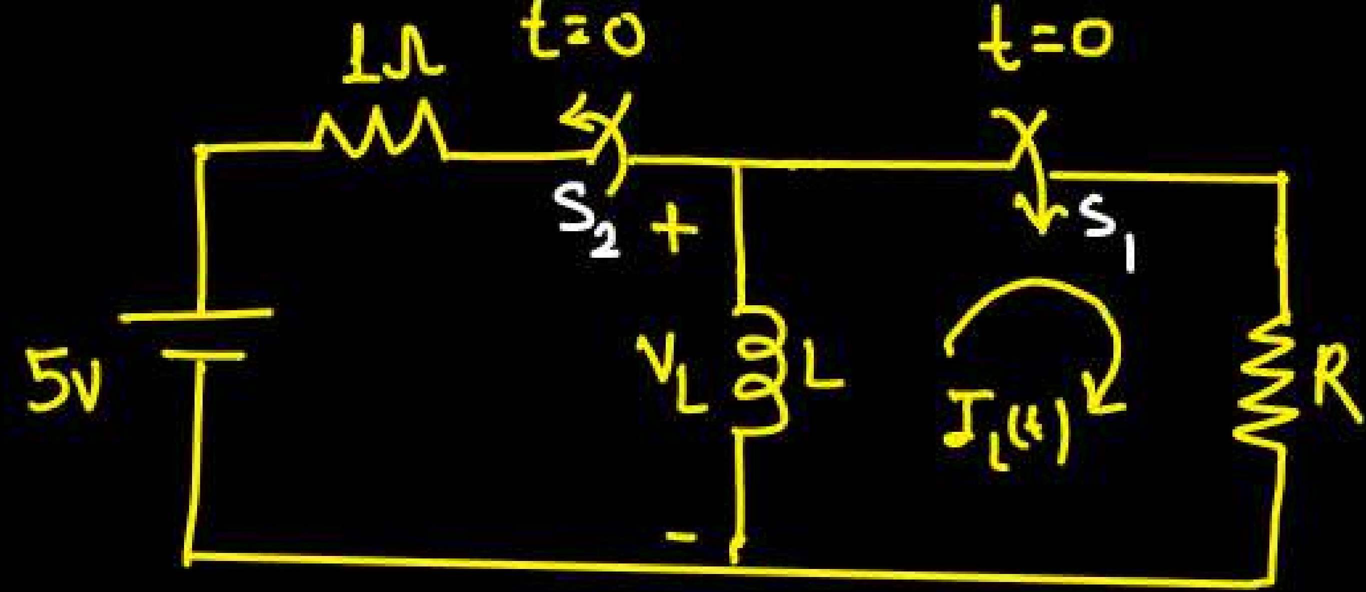
⇒ Slowly the voltage across the inductor is decreasing and the current through the inductor is increasing.

⇒ when $V_L = 0V$ ⇒ The current doesn't increase further.

⇓

That's the steady state.

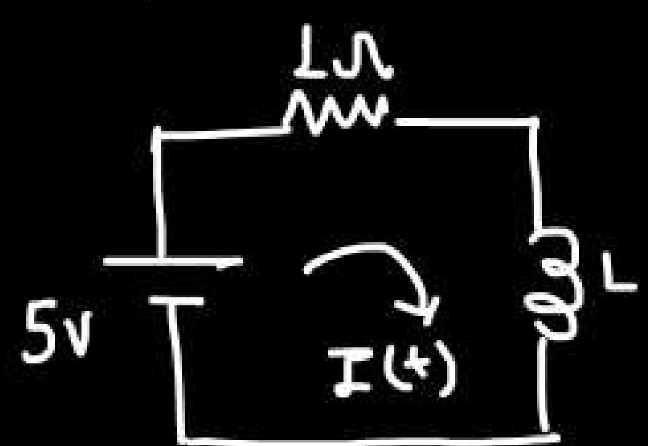
Q.



comment of $I_L(t)$.

→ For $t<0$ $\{-\infty < t < 0\}$

S_1 is open. S_2 is closed.



⇒ switch is closed for $-\infty < t < 0$ (very long time)

⇓

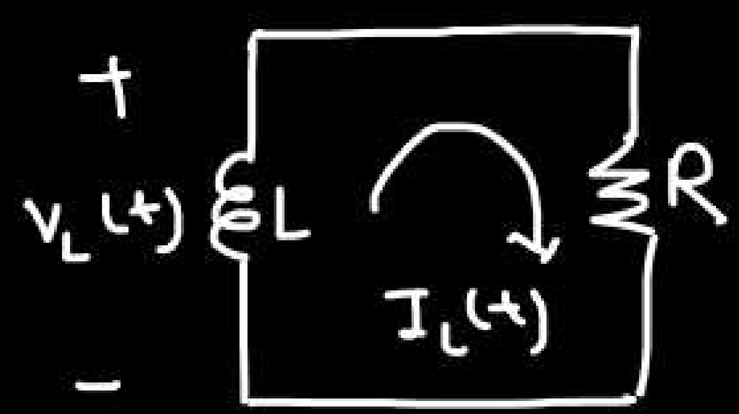
Steady state would have reached.

$\underline{I(0^-) = 5 \text{ Amp.}}$

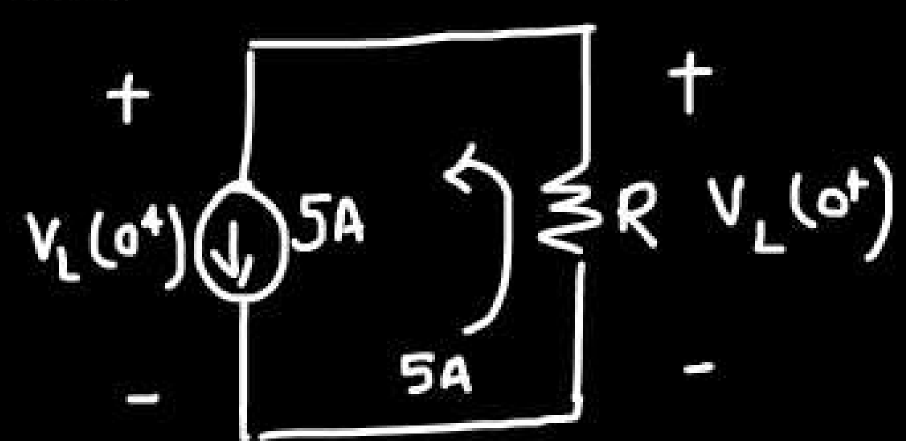
For $t > 0$:-

$$I_L(0^-) = I_L(0) = I_L(0^+) = 5 \text{ Amp.}$$

S_2 is open and S_1 is closed.



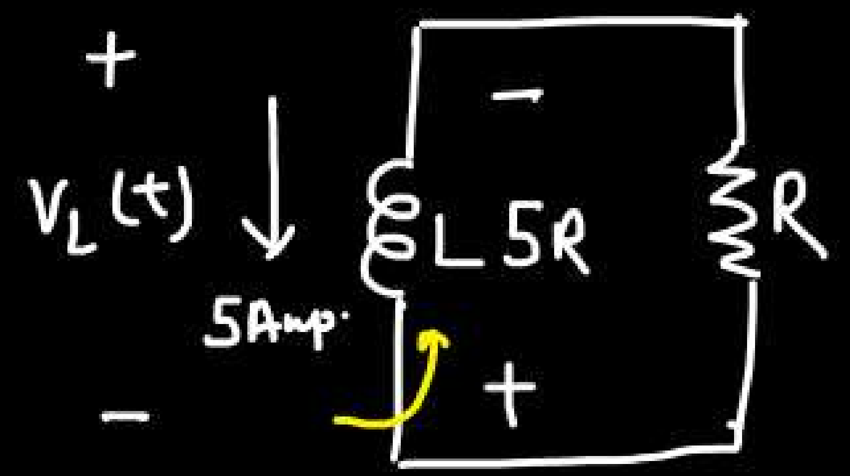
@ $t = 0^+$



$$V_L(0^+) = -5R$$

$$I_L(0^+) = -5 \text{ Amp.}$$

This $-5R$ voltage will come across the inductor.



$\Rightarrow$ This 5R voltage will reduce the current.

$\Downarrow$

current will keep on reducing until $V_L = 0\,V$

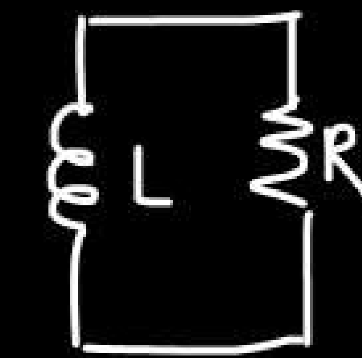
so, @ steady state ; $V_L = 0\,V$

$V_L(\infty) = 0\,V$

$I_L(\infty) = 0\,Amp.$

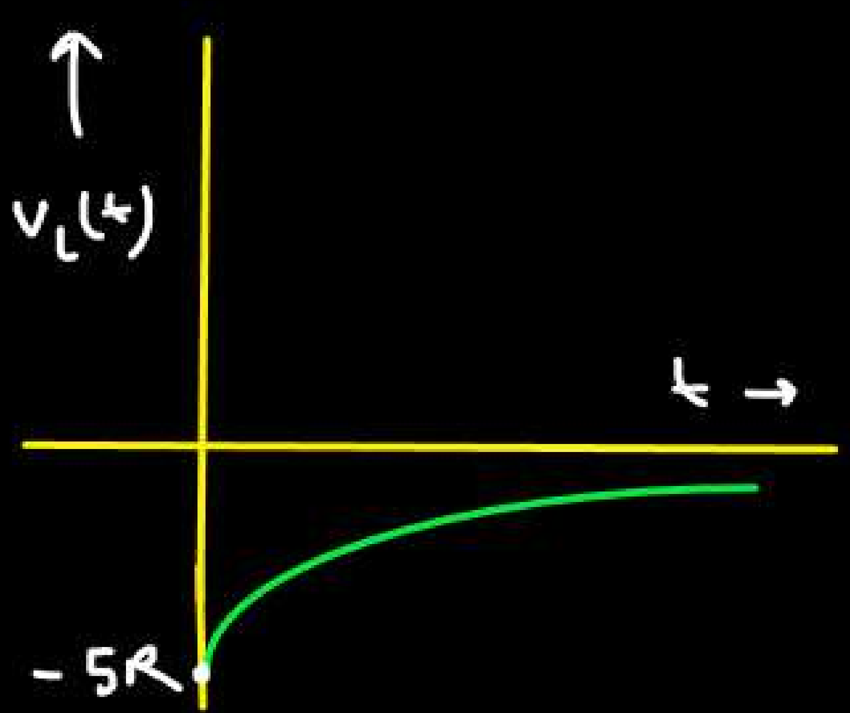
$V_L(0^+) = -5R$; $I_L(0^+) = -5$ Amp

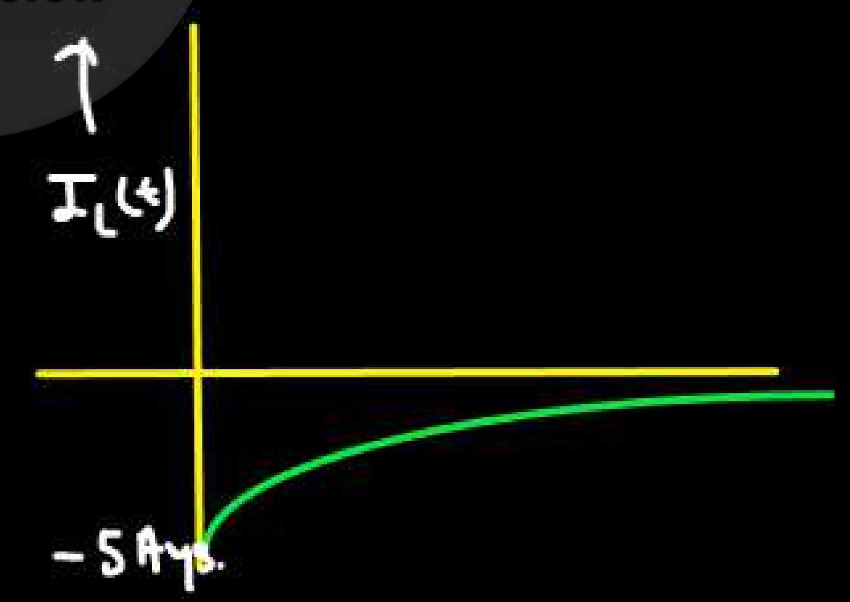
$V_L(\infty) = 0\,V$; $I_L(\infty) = 0$ Ap.



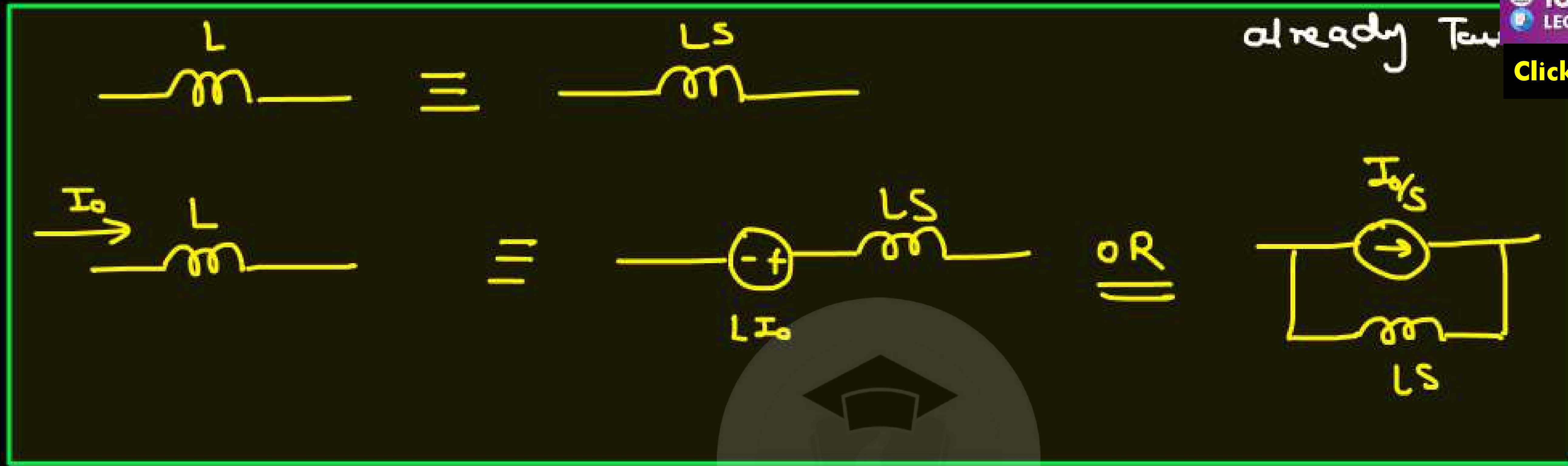
$V_L(t) = -5R\, e^{-t/\tau}\, u(t)$; $\tau = L/R$

$I_L(t) = -5e^{-t/\tau}\, u(t)$; $\tau = L/R$

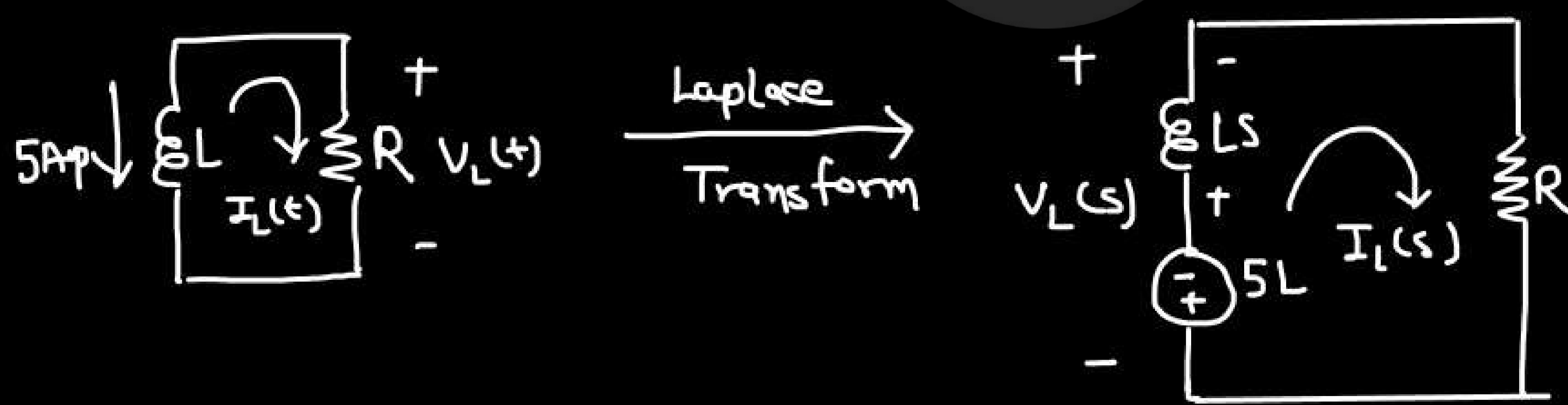




Let's solve by Laplace Transform:-



For $t > 0$



KVL:-

(i) $-5L = I_L(s)\left[Ls + R\right]$

$$I_L(s) = \frac{-5L}{Ls + R}$$

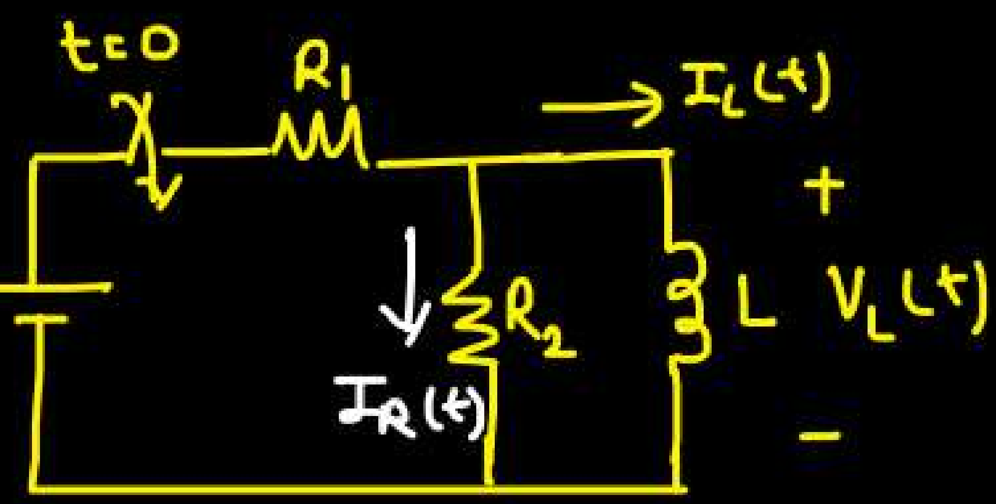
$$I_L(s) = \frac{-5}{s + R/L}$$

$$\boxed{i_L(t) = -5e^{-R/L\,t}\,u(t)}$$

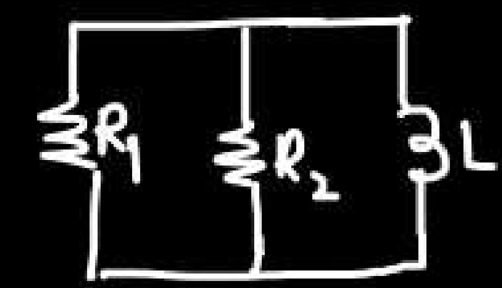
(ii) $V_L(s) = I_L(s)\,R$

$$= \frac{-5R}{s + R/L}$$

$$\boxed{v_L(t) = -5R\,e^{-R/L\,t}\,u(t)}$$

Q. 

comment on $V_L(t)$ & $I_L(t)$



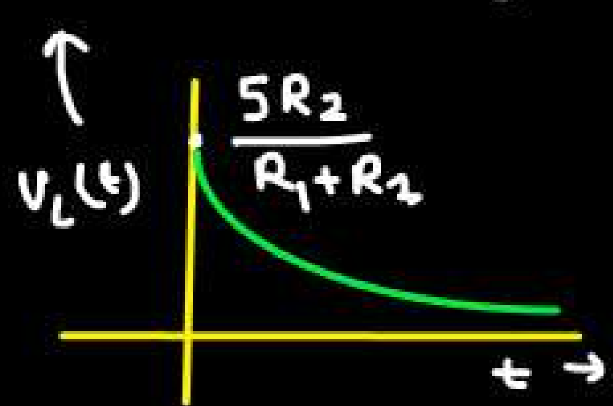
$\tau = \dfrac{L}{\left(\dfrac{R_1 R_2}{R_1+R_2}\right)}$

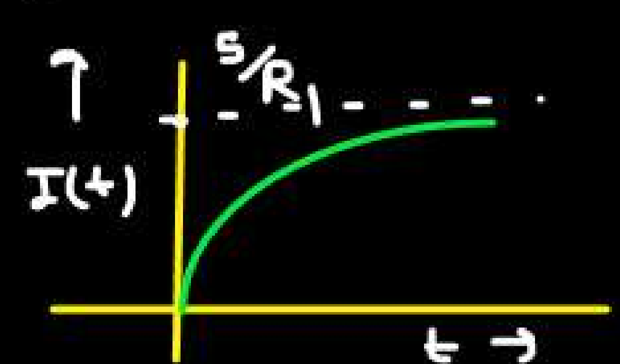
→ initially; inductor → o.c.

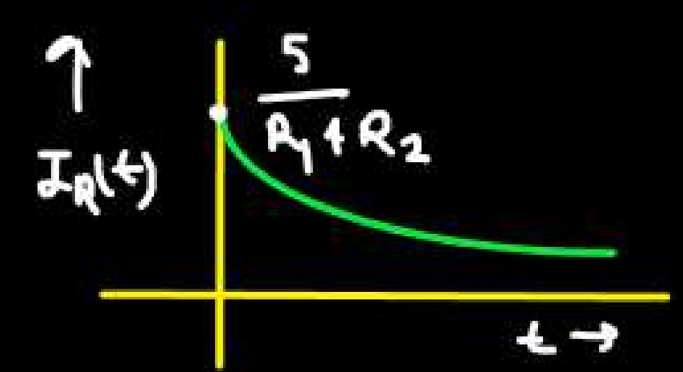
$V_L(0^+) = \dfrac{5R_2}{R_1+R_2}$; $I_L(0^+) = 0$ Amp ; $I_R(0^+) = \dfrac{5}{R_1+R_2}$ Amp.

@ steady state; inductor → s.c.

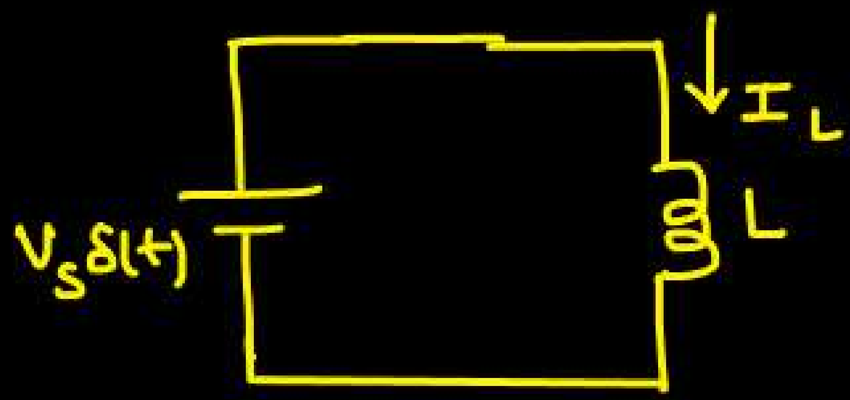
$V_L(\infty) = 0V$, $I_L(\infty) = 5/R_1$; $I_R(\infty) = 0$ Amp.







Q. Find I_0.



Here inductor is connected across infinite voltage (impulse voltage)

$\Downarrow$

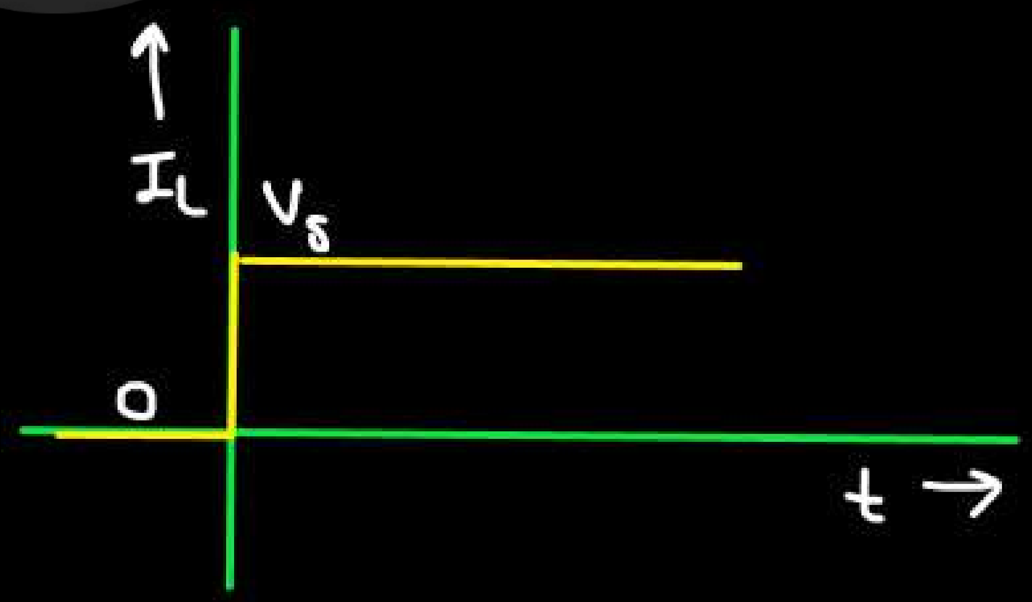
current can change instantaneously

$I_L(0^-) = 0\ \text{Amp} \neq I_L(0^+)$

$$I_L(t) = \frac{1}{L}\int_0^t V(t)\cdot dt$$

$$= \frac{1}{L}\int_0^t V_s\,\delta(t)\cdot dt$$

$$I_L(t) = \frac{V_s}{L}u(t)$$



V_s is the flux Here.

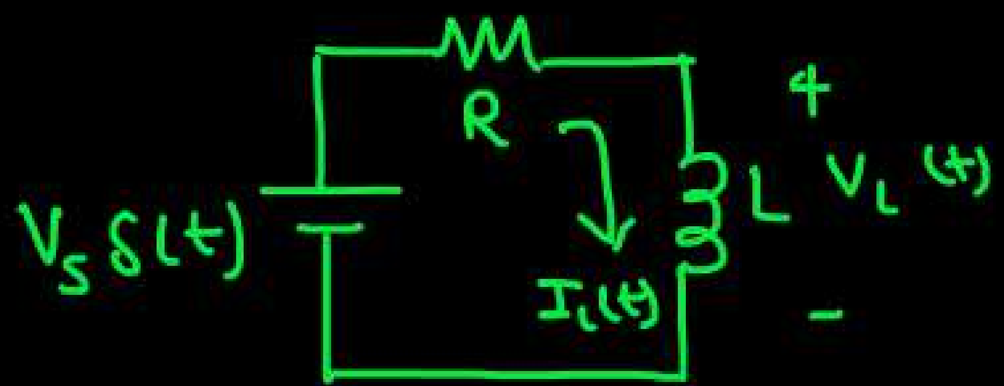
you are giving V_s amount of flux to the induc

$$\phi = LI$$

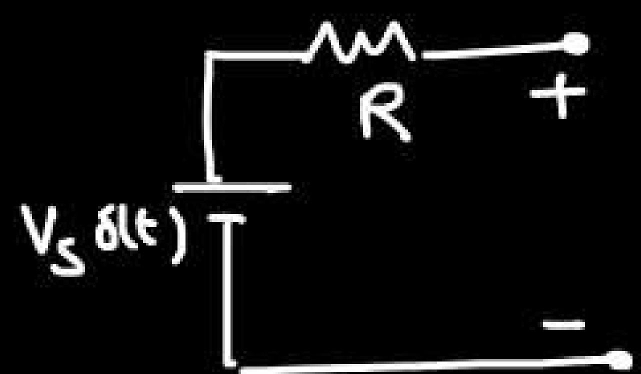
$$V_s = L I_L$$

$$\boxed{I_L = V_s / L}$$

Q. Find $V_L(t)$ and $I_L(t)$



→ @ $t=0$ ⇒ inductor o.c.



$V_L(0) = V_s \delta(t)$

⇓

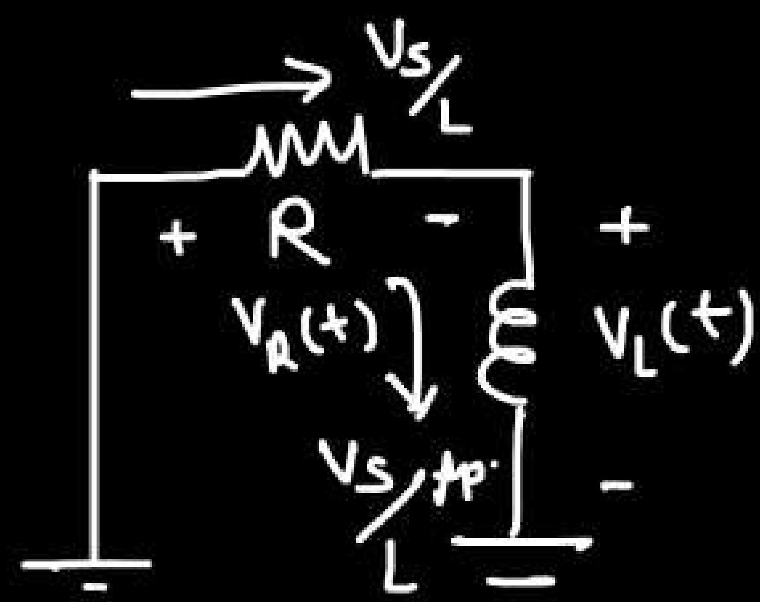
impulsive voltage is coming across inductor.

⇓

sudden jump in current will be there.

@ $t = 0^+$

$V_i = 0$



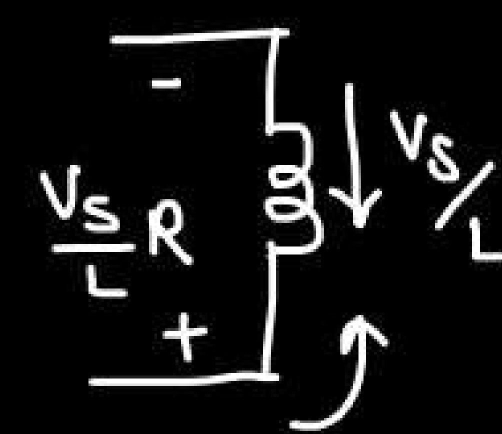
$$I_L(0^+) = \frac{V_s}{L} \text{ Ap}$$

{ previously derived }

$$V_L(0^+) = -\frac{V_s}{L}R \qquad \{ V_R(t) = -V_L(t) \}$$

$\Downarrow$

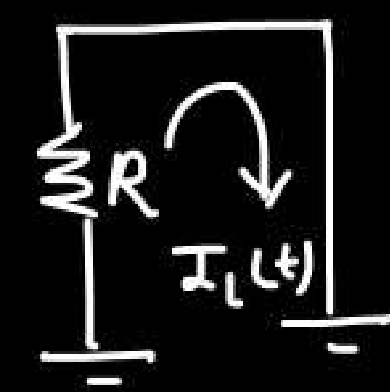
now this negative voltage will oppose the current and reduce it

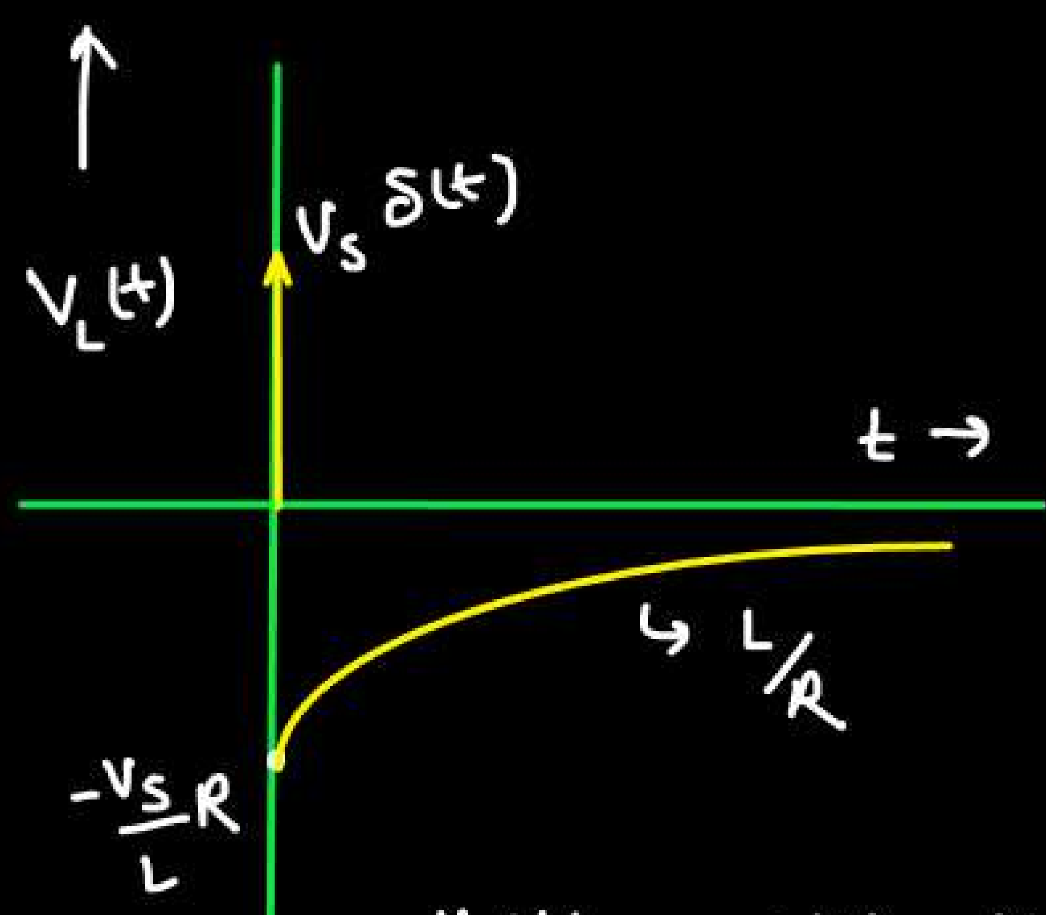


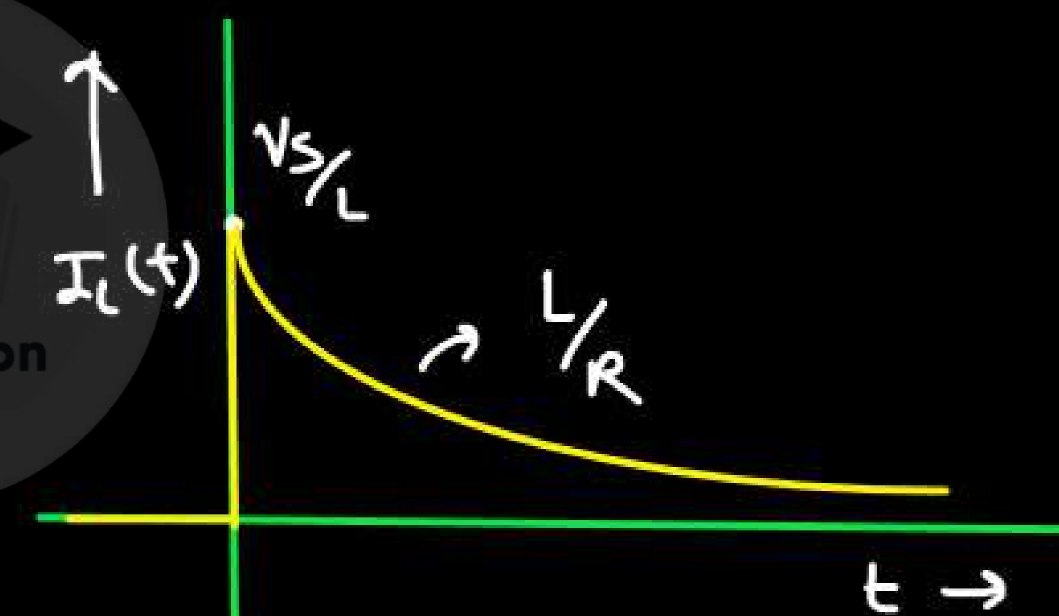
@ steady state $\{t=\infty\}$

$$V_L(\infty) = 0\ V$$

$$I_L(\infty) = 0\ \text{Amp.}$$



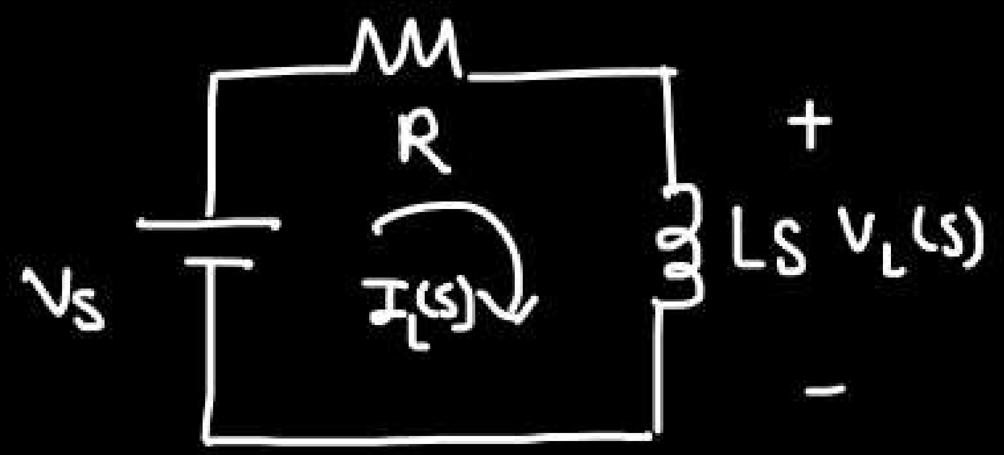




$$I_L(t) = \frac{V_s}{L} e^{-t/\tau}\, u(t)$$

$$V_L(t) = V_s\,\delta(t) - \frac{V_s}{L} R\, e^{-t/\tau}\, u(t)$$

Solving by Laplace:-



$$V_s\delta(t) \xrightarrow[\text{Laplace}]{} V_s$$

$$V_s = I_L(s)\left[R + LS\right]$$

$$I_L(s) = \frac{V_s}{R + LS}$$

$$I_L(s) = \frac{V_s/L}{s + R/L}$$

$$\boxed{i_L(t) = \frac{V_s}{L} e^{-R/L\, t} u(t)}$$

$$V_L(s) = I_L(s) \times LS$$

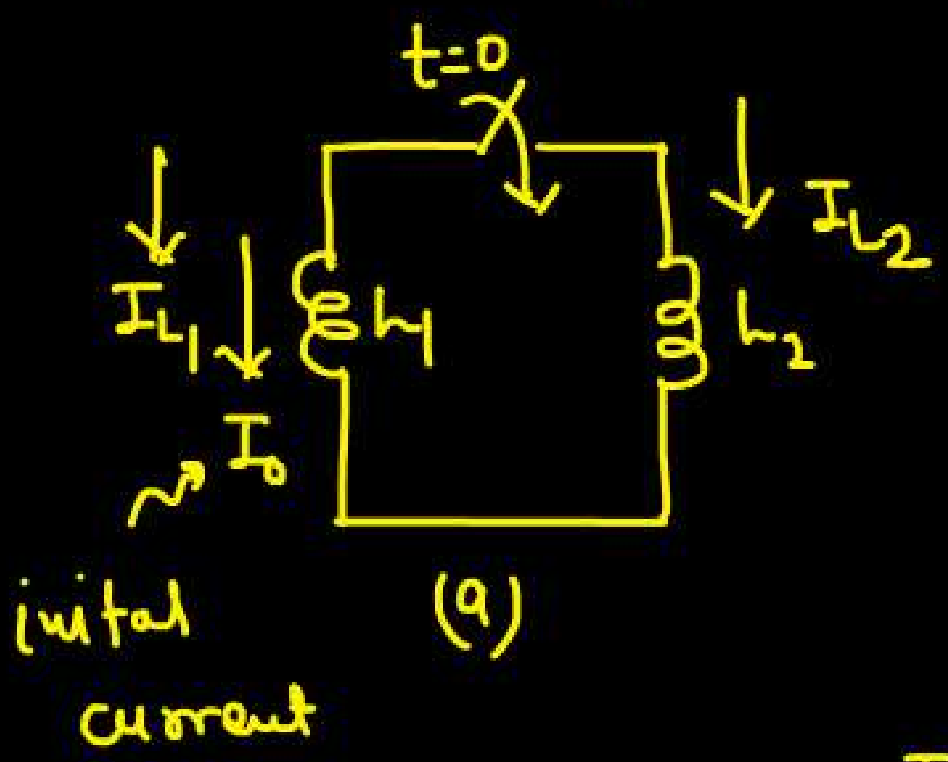
$$= V_s \times \frac{LS}{R + LS}$$

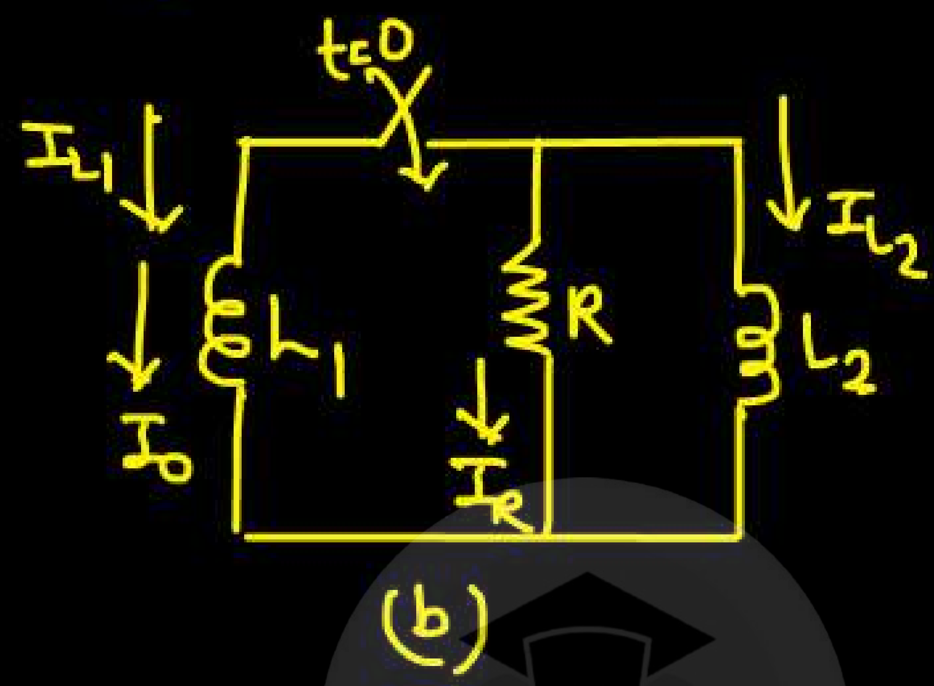
$$= V_s\left[\frac{R + LS - R}{R + LS}\right]$$

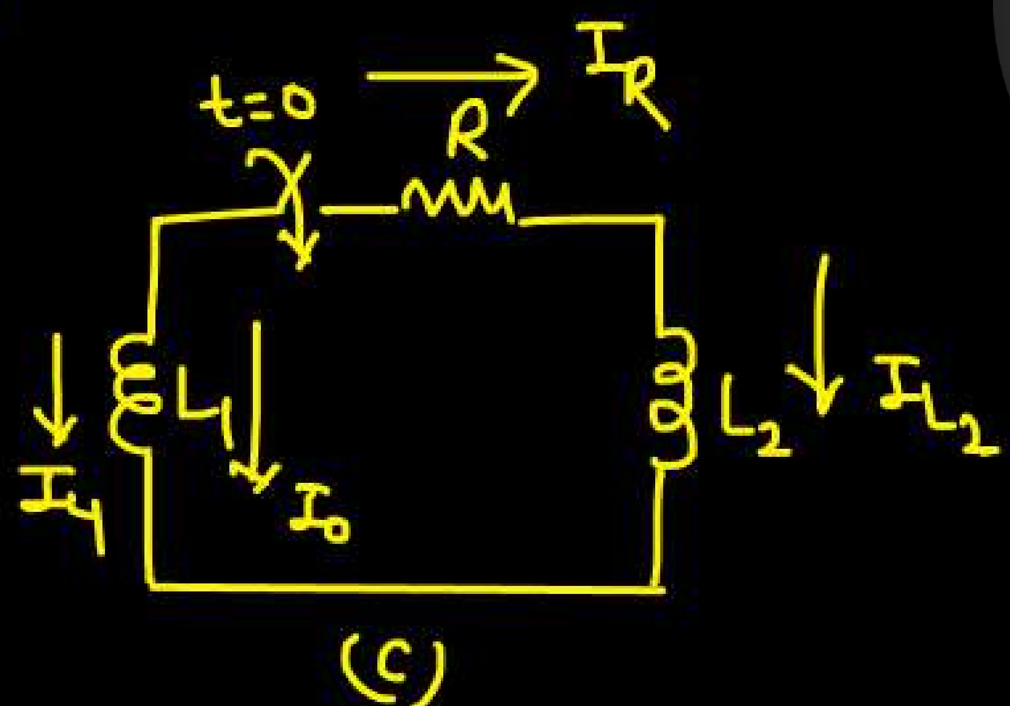
$$= V_s\left[1 - \frac{R/L}{s + R/L}\right] \Rightarrow$$

$$\boxed{V_L(t) = V_s\delta(t) - \frac{V_s R}{L} e^{-R/L\, t} u(t)}$$

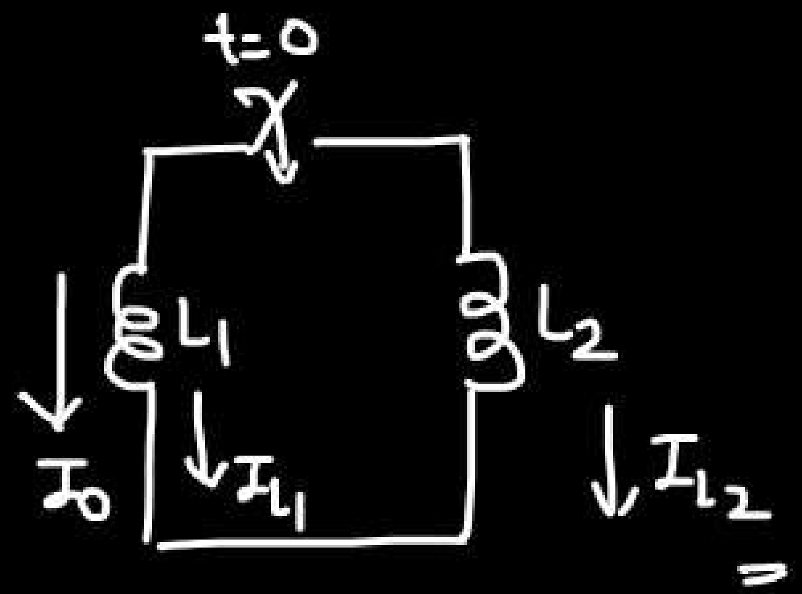
Q. Find I_{L_1}, I_{L_2} and I_R.



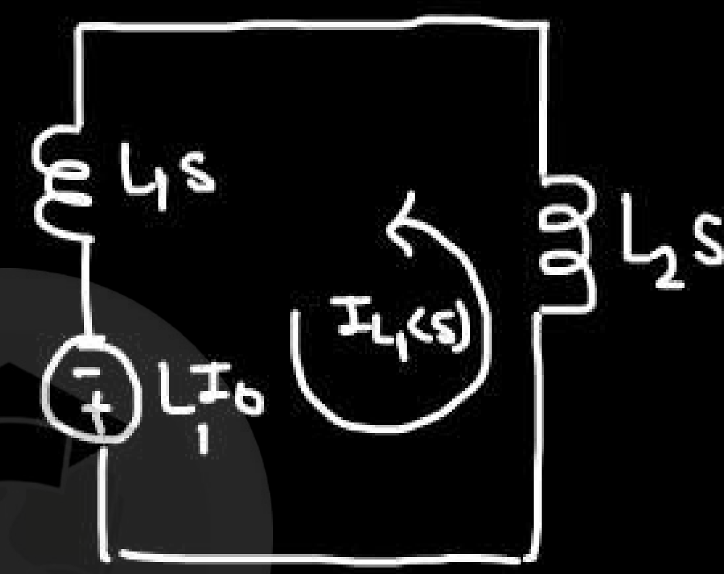




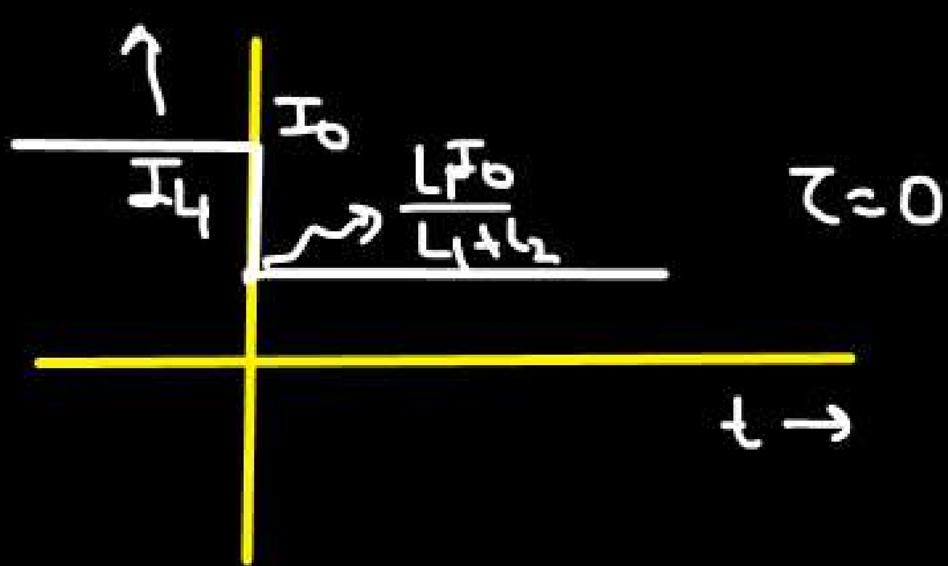
(a)



→ By Laplace Transform :-



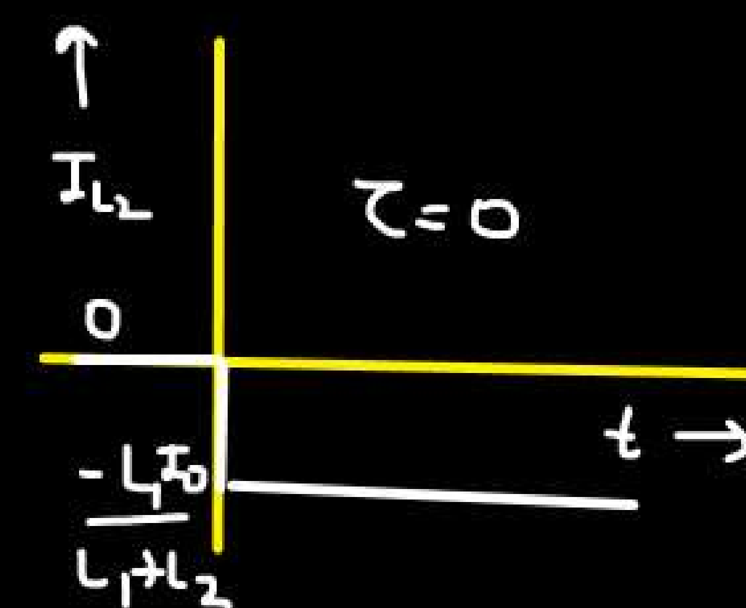
$$i_{L_1}(t) = -i_{L_2}(t)$$



$$L_1 I_0 = I_{L_1}(s)\left[L_1 s + L_2 s\right]$$

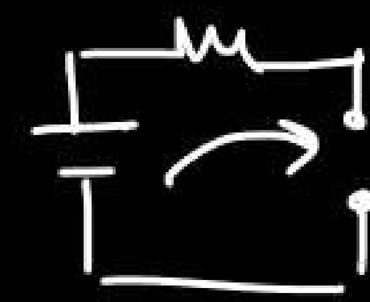
$$I_{L_1}(s) = \frac{L_1 I_0}{(L_1+L_2)s}$$

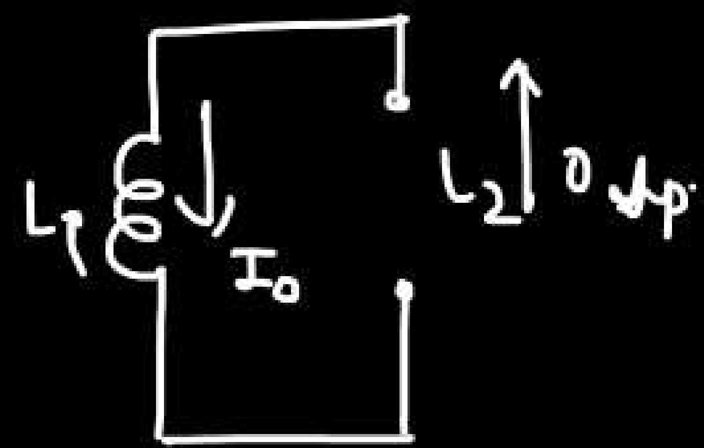
$$\boxed{i_{L_1}(t) = \frac{L_1}{L_1+L_2} I_0 \, u(t)}$$



M-II

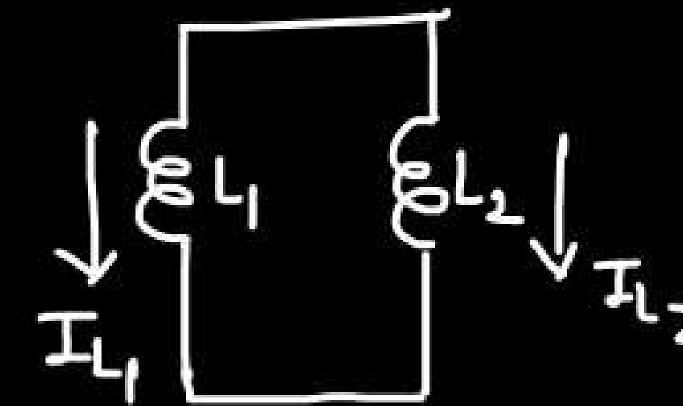
@ $t=0$





→ KCL invalid

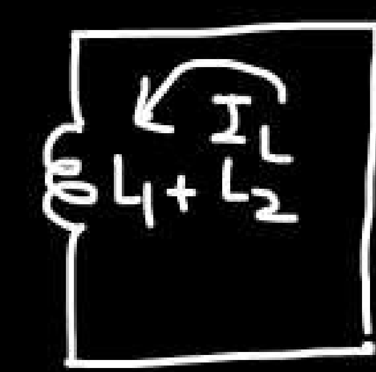
⇒ flux conservation →



$$L_1 I_0 = (L_1 + L_2) I_L$$

$$I_L = \frac{L_1 I_0}{L_1 + L_2}$$

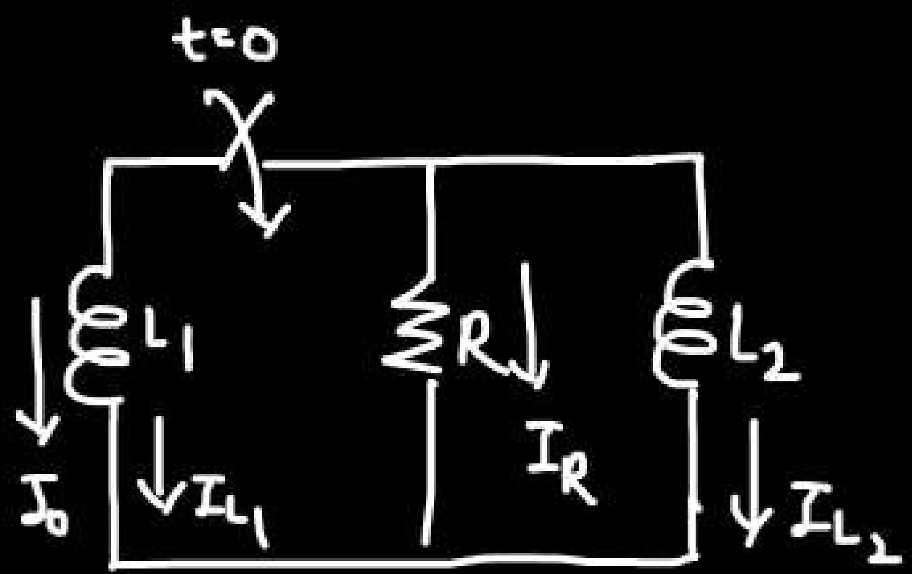
⇓



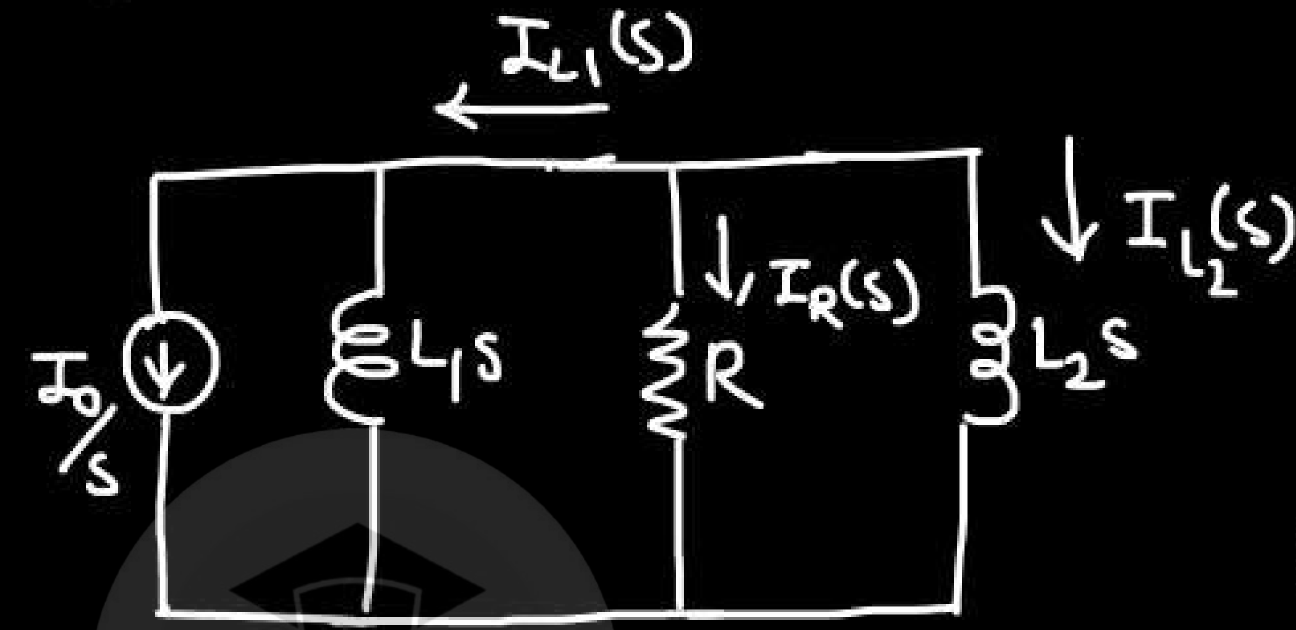
$$I_L = I_{L_1} = -I_{L_2}$$

$$\boxed{\begin{aligned} V_{L_2} &= I \times \infty \\ V_{L_2} &= \infty = V_{L_1} \end{aligned}}$$

$$\boxed{I_{L_1} = \frac{L_1 I_0}{L_1 + L_2}} \qquad \boxed{I_{L_2} = \frac{-L_1 I_0}{L_1 + L_2}}$$



→ By laplace Transform



impedance $\frac{RL_1 s}{R+L_1 s}$

$$I_{L_1}(s) = -\left[I_R(s) + I_{L_2}(s)\right]$$

$$I_{L_2}(s) = \frac{-\frac{RL_1 s}{R+L_1 s}}{\frac{RL_1 s}{R+L_1 s} + L_2 s} \times \frac{I_0}{s} = \frac{-RL_1 s}{RL_1 s + RL_2 s + L_1 L_2 s^2} \times I_0/s$$

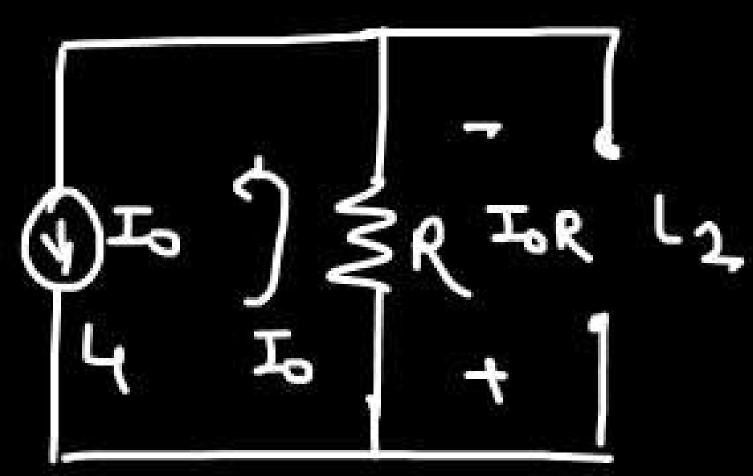
$$= \frac{-RL_1}{L_1 L_2 s + R(L_1+L_2)} \times I_0/s$$

$$i_{L_2}(t) = \frac{L_1 I_0}{L_1+L_2}\left[1 - e^{-t/\tau}\right]u(t) \; ; \; \tau = \frac{L_1 L_2}{R(L_1+L_2)}$$

Solve similarly for $I_R(s)$ and $I_{L_1}(s)$ using current divison.

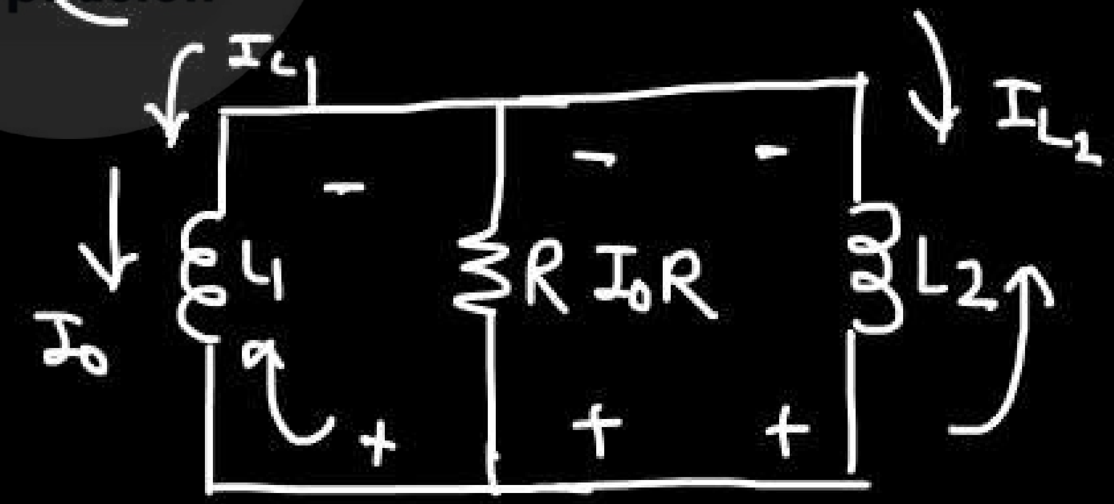
M-II :-

@ t=0



$\Rightarrow$

@ $t=0^+$



I_{L_1} will be reducing from I_0 to some value.
and I_{L_2} will be increasing (but in negative dir^n)

I_{L_1} and I_{L_2} will be constant when the drop across them becomes zero $\Rightarrow$ when there is no current in resistance

↳ I_{L_1} ⓓ and $-I_{L_2}$ ⓤ

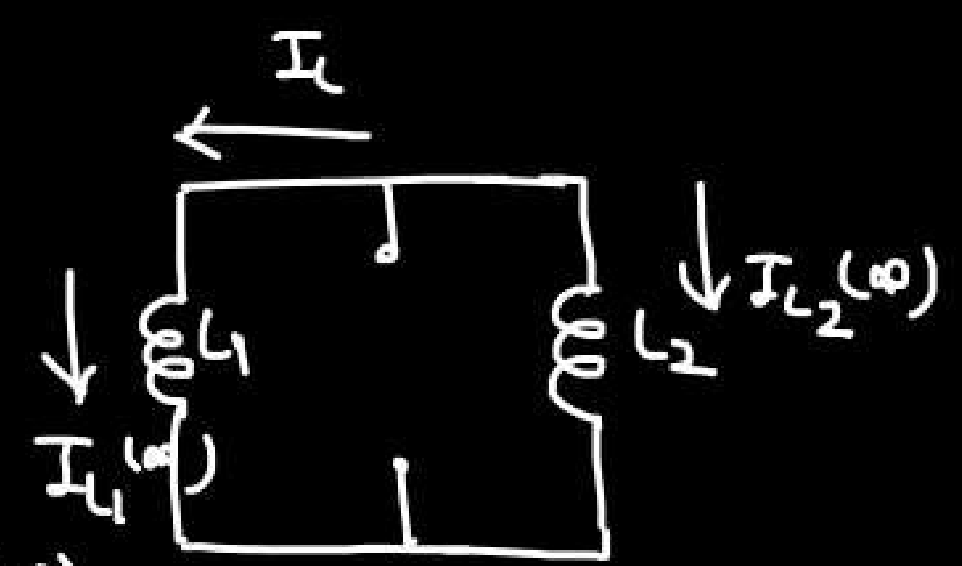
@ steady state $I_{L_1} = -I_{L_2}$ and $I_R = 0$

steady state I_{L_1} and I_{L_2}?

Flux conservation,

$$L I_0 = (L_1 + L_2) I_L$$

$$\boxed{I_L = \frac{L_1 I_0}{L_1 + L_2}}$$



where;
$I_L = I_{L_1}^{(\infty)} = -I_{L_2}^{(\infty)}$

$$I_{L_1}(\infty) = \frac{L_1 I_0}{L_1 + L_2} \qquad I_{L_2}(\infty) = \frac{-L_1 I_0}{L_1 + L_2}$$

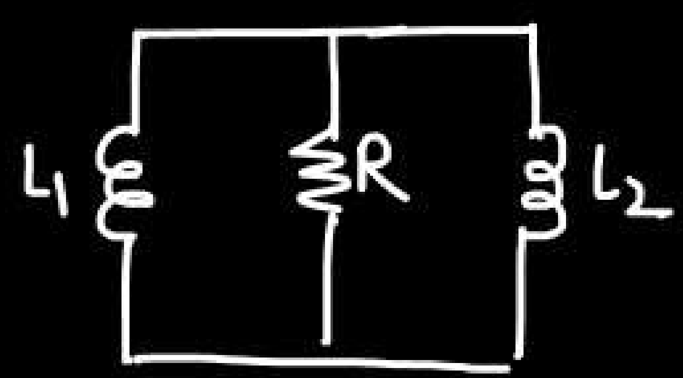
$\Rightarrow$

$$I_R(0^+) = I_0 \qquad I_R(\infty) = 0$$

$$I_{L_1}(0^+) = I_0 \qquad I_{L_1}(\infty) = \frac{L_1 I_0}{L_1 + L_2}$$

$$I_{L_2}(0^+) = 0 \qquad I_{L_2}(\infty) = \frac{-L_1 I_0}{L_1 + L_2}$$

$\underline{\underline{\tau}} \rightarrow$



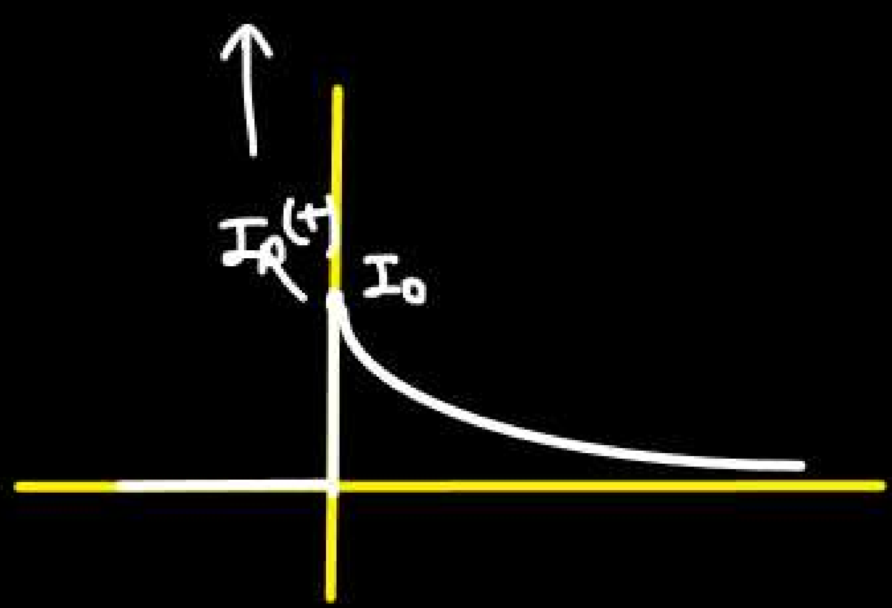
$$L_{eff} = \frac{L_1 L_2}{L_1 + L_2} \qquad \tau = \frac{L_1 L_2}{R(L_1 + L_2)}$$

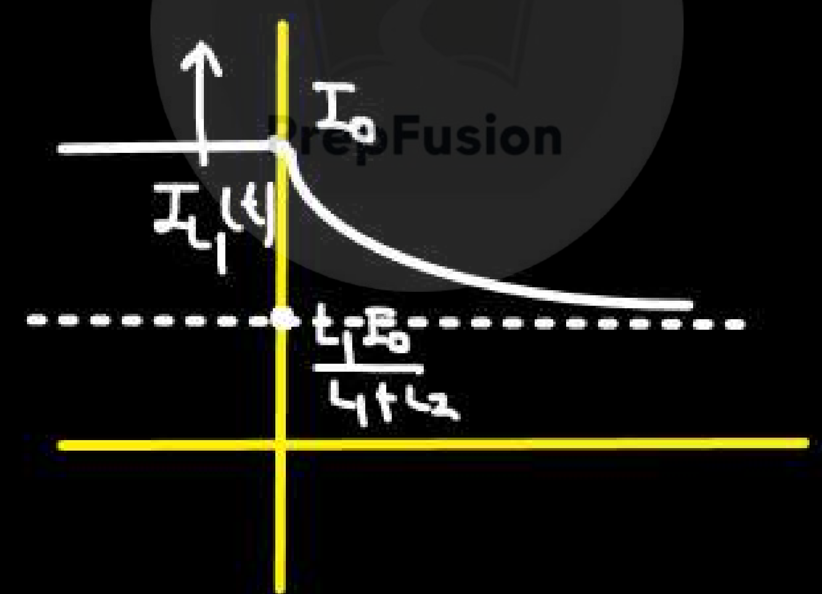
$$R_{eq} = R$$

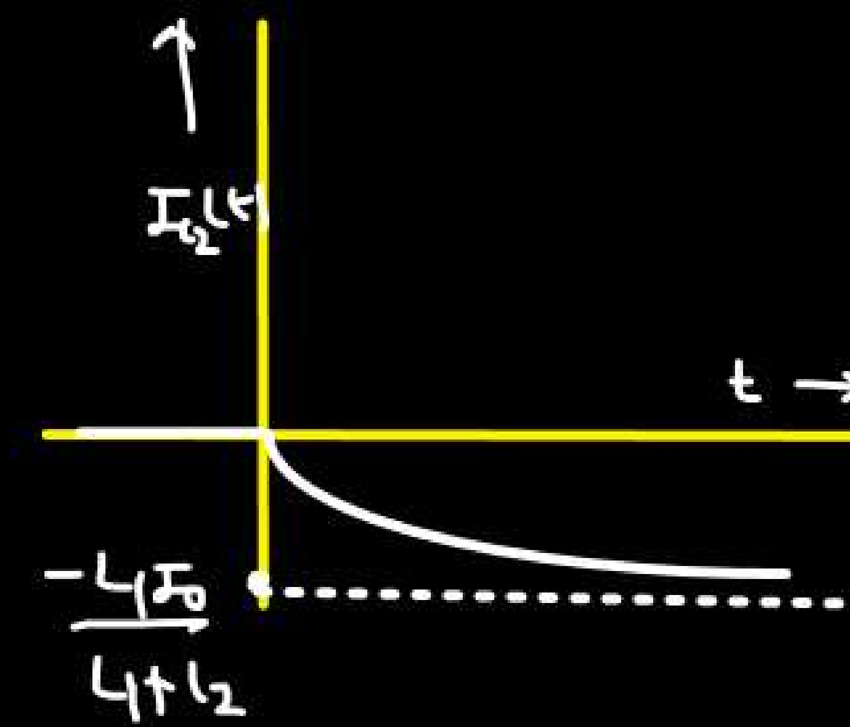
$$I_R(t) = I_0 e^{-t/\tau} u(t)$$

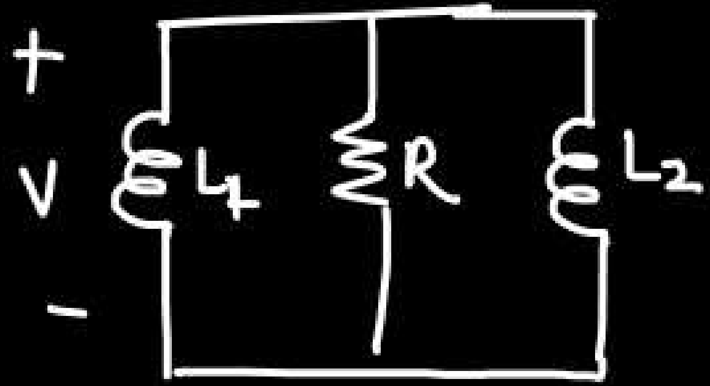
$$I_{L_1}(t) = \frac{L_1 I_0}{L_1+L_2} + \frac{L_2 I_0}{L_1+L_2} e^{-t/\tau} u(t)$$

$$I_{L_2}(t) = -\frac{L_1 I_0}{L_1+L_2}\left[1 - e^{-t/\tau}\right] u(t)$$





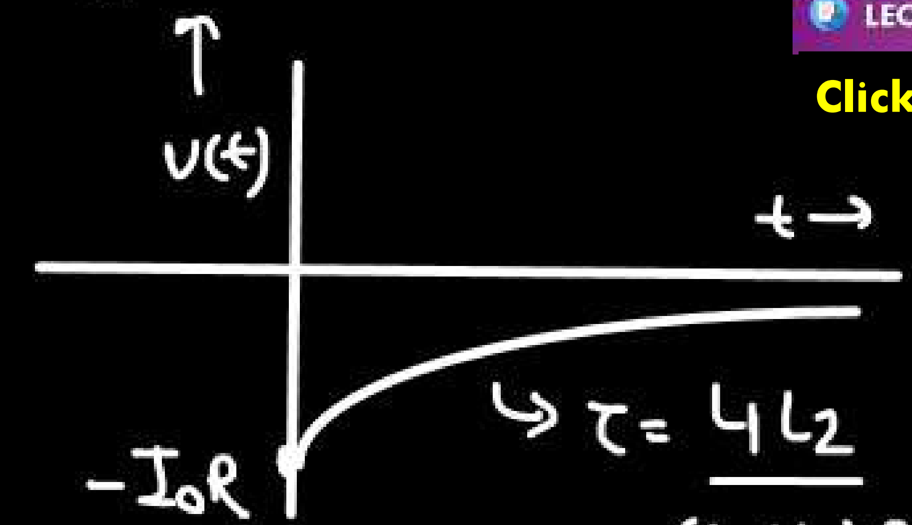




$$V = V_{L_1}(t) = V_{L_2}(t) = V_R(t)$$

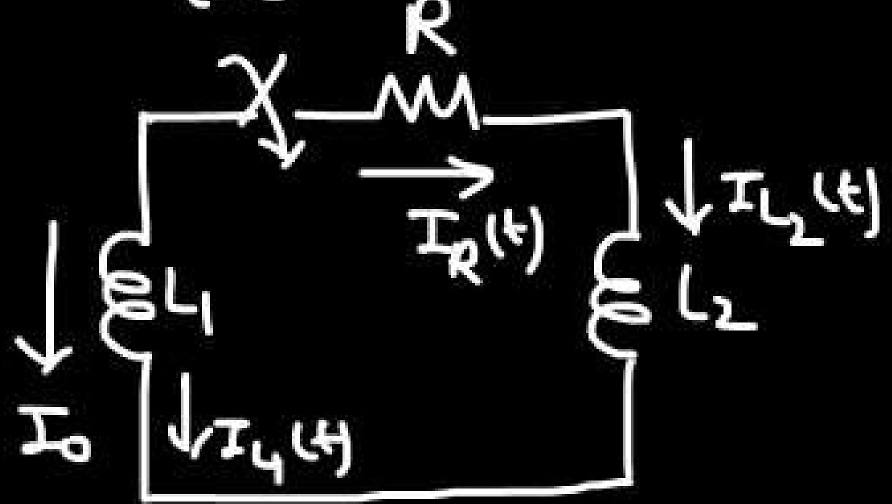
$$v(0^+) = -I_0 R$$

$$v(\infty) = 0$$

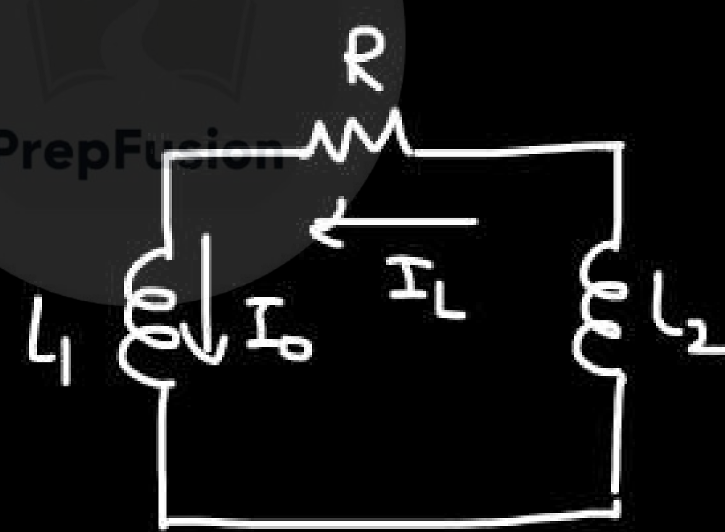


$$\hookrightarrow \tau = \frac{L_1 L_2}{(L_1+L_2)R}$$

(c)



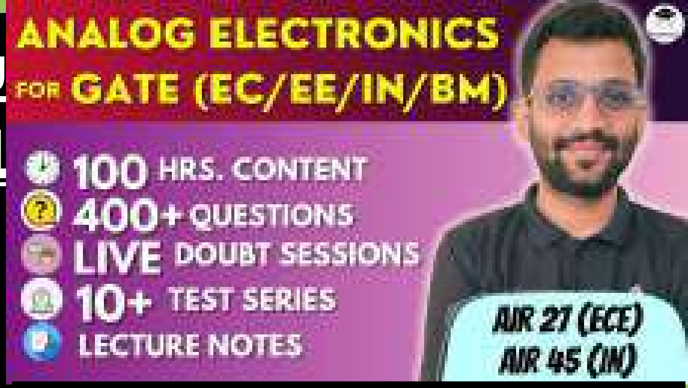
@t=0 ⟶



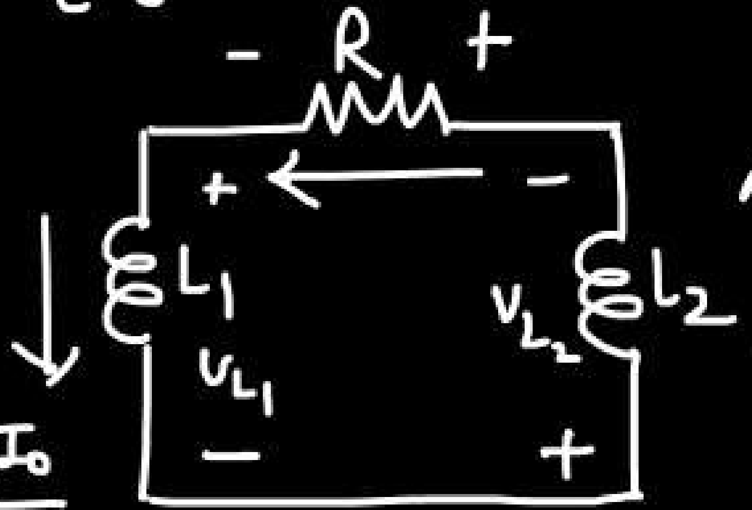
$$L_1 I_0 = (L_1 + L_2) I_L$$

$$\boxed{I_L = \frac{L_1 I_0}{L_1 + L_2}}$$

$$I_L = I_{L_1}(0^+) = -I_{L_2}(0^+)$$



at $t=0^+$

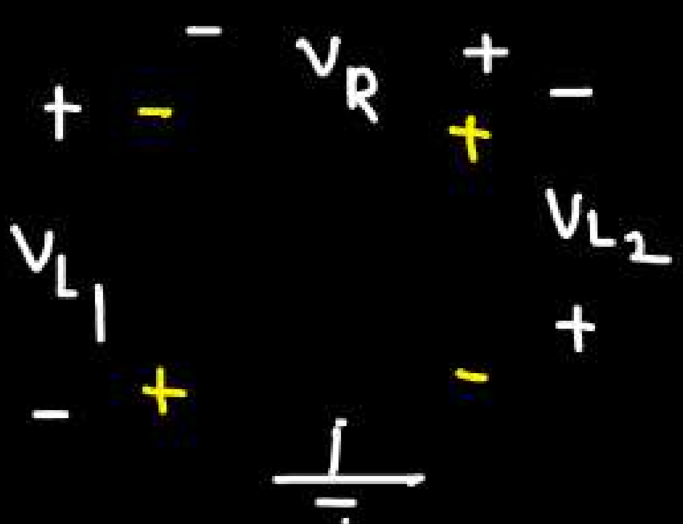


$$\frac{L_1 I_0}{L_1+L_2} = I'$$

$$I' = \frac{L_1 I_0}{L_1+L_2}$$

$$\boxed{\tau = \frac{L_1+L_2}{R}}$$

$\Rightarrow$

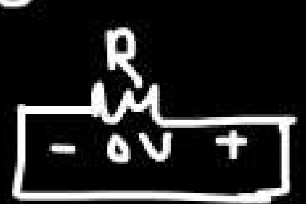


$$V_{L_1} = -[V_R + V_{L_2}]$$

$$V_{L_2} = V_R + V_{L_2}$$

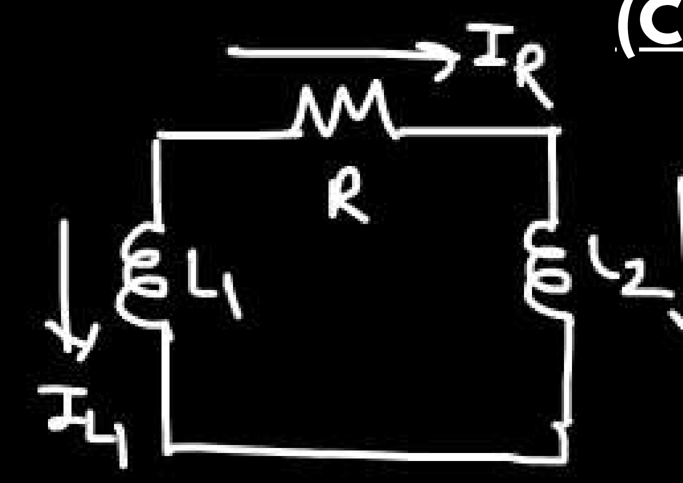
Because of the opposite voltage drop, the current in both L_1 and L_2 will be decreasing and goes to zero @ steady state

@ s.s. $V_{L_2}(\infty) = V_{L_1}(\infty) = 0\,V$ or



$\Rightarrow I_{L_1}(\infty) = I_{L_2}(\infty) = I_R(\infty) = 0\,Amp$

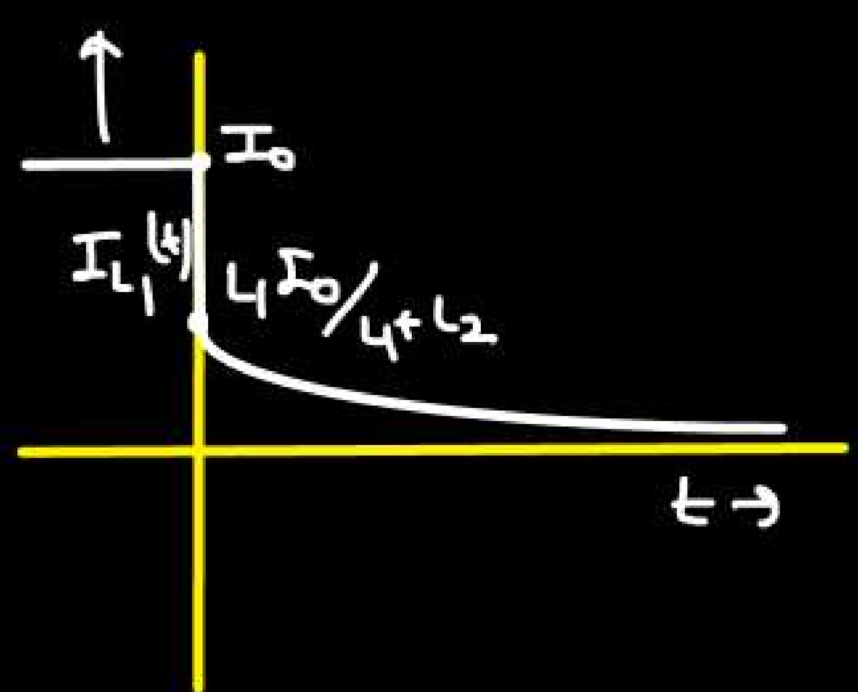
$$I_{L_1}(0^+) = \frac{L_1 I_0}{L_1+L_2} \qquad I_{L_1}(\infty) = 0 \text{ Amp.}$$

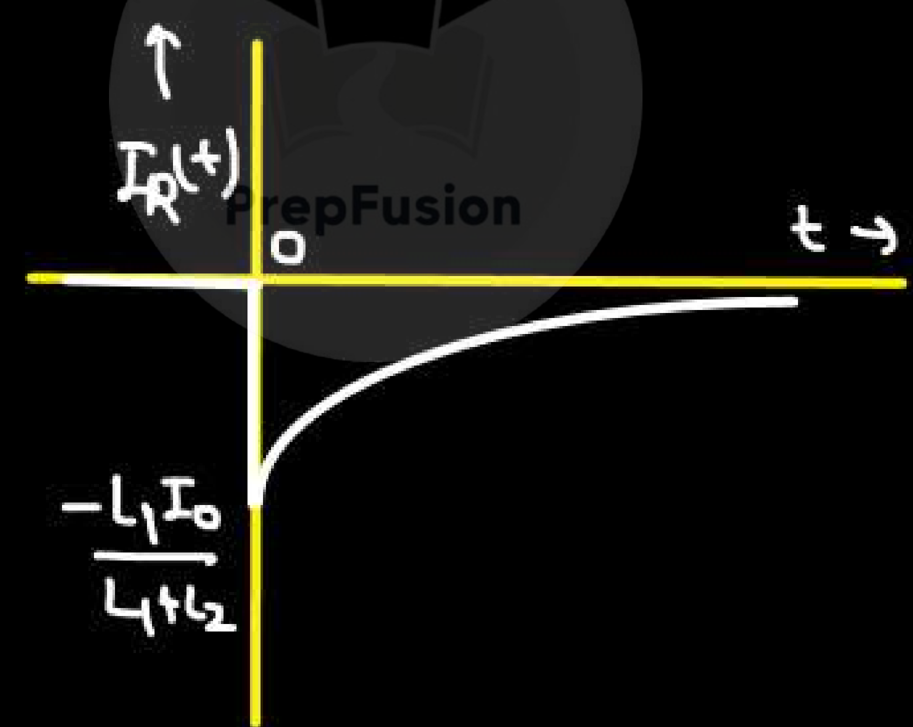


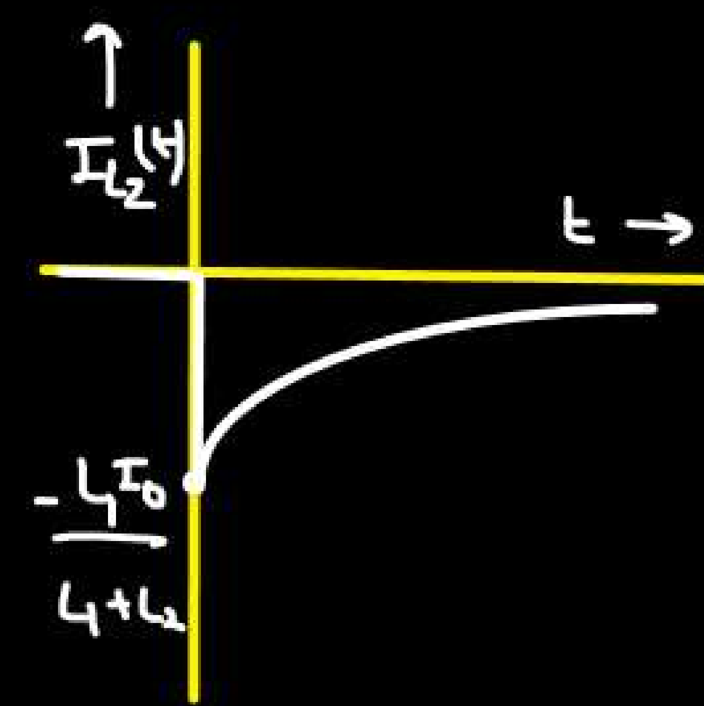
$$I_R(0^+) = \frac{-L_1 I_0}{L_1+L_2} \qquad I_R(\infty) = 0 \text{ Amp.}$$

$$I_{L_2}(0^+) = \frac{-L_1 I_0}{L_1+L_2} \qquad I_{L_2}(\infty) = 0 \text{ Amp.}$$

$$I_{L_1} = -I_R = -I_{L_2}$$

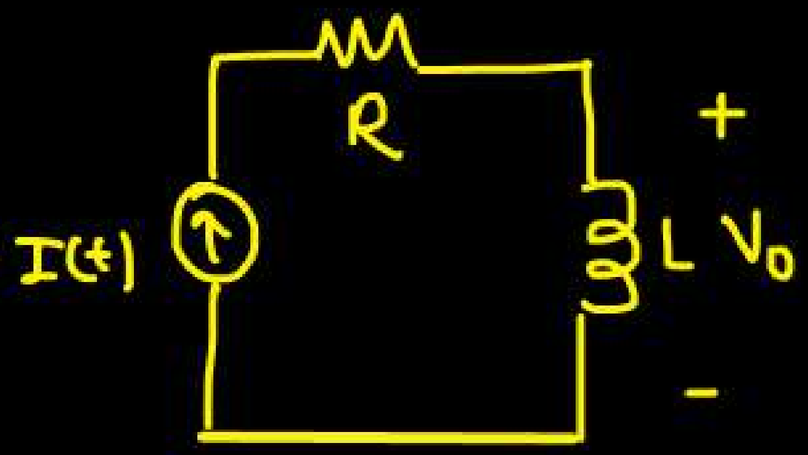






$$I_{L_1}(t) = I_0 u(-t) + \frac{L_1 I_0}{L_1+L_2} e^{-t/\tau} u(t) \; ; \quad I_{L_2} = \frac{-L_1 I_0}{L_1+L_2} e^{-t/\tau} u(t) \; ; \quad I_R(t) = \frac{-L_1 I_0}{L_1+L_2} e^{-t/\tau} u(t)$$

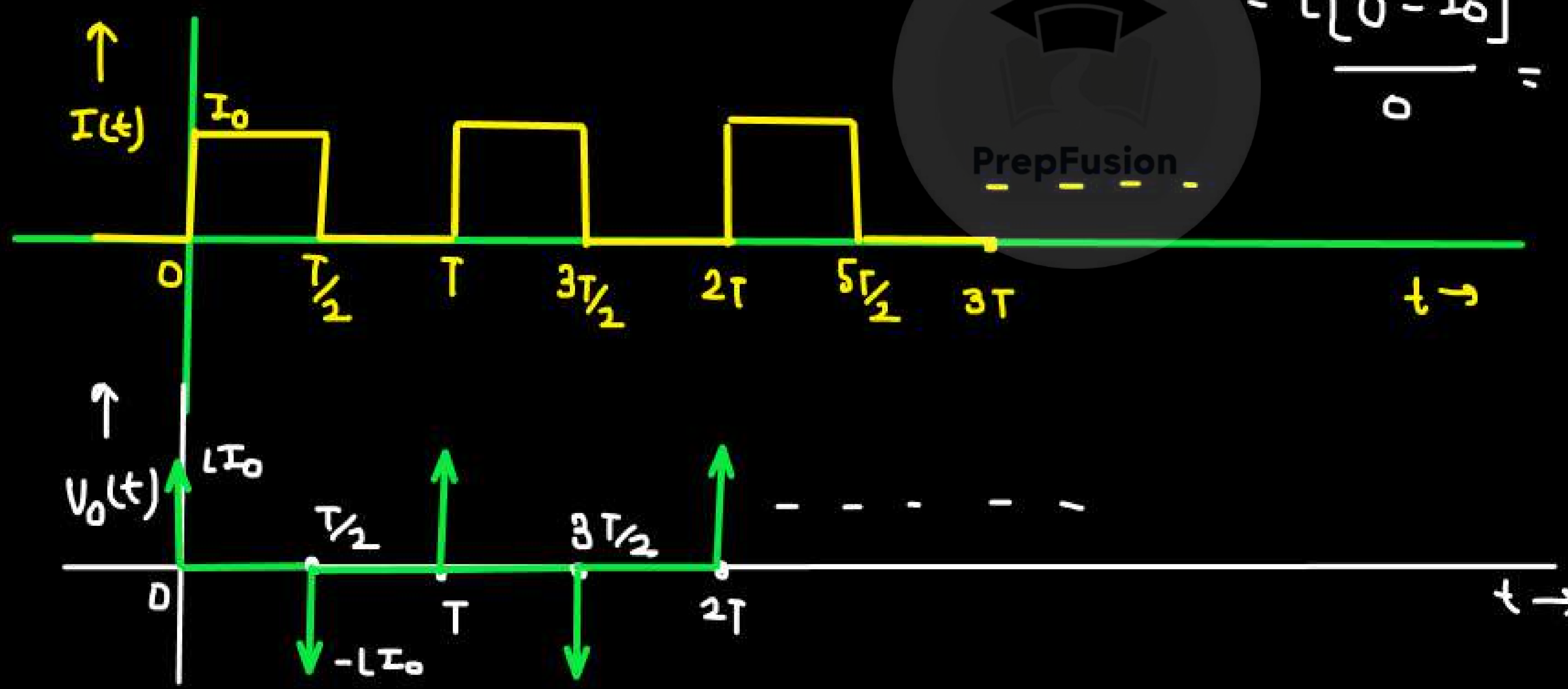
Q. Draw V_0 waveform.



$$V_0(t) = L\frac{dI(t)}{dt}$$

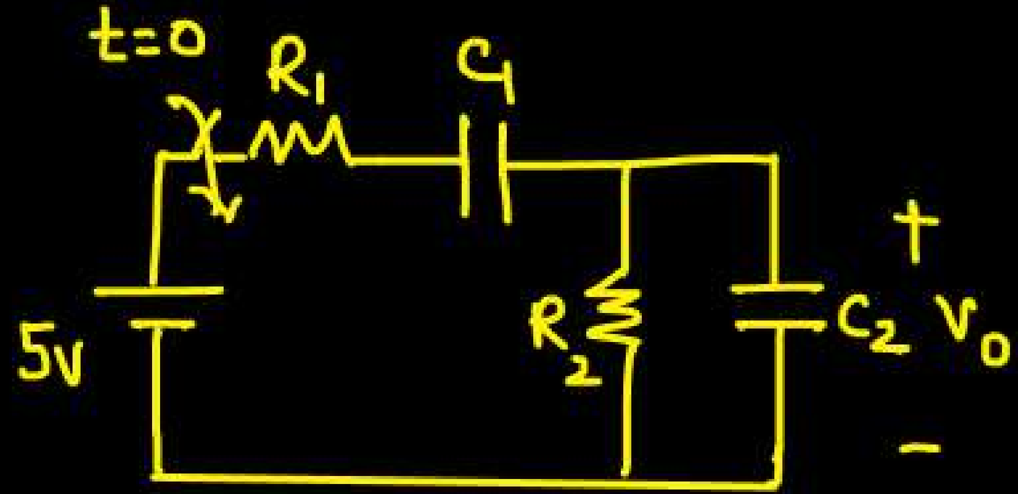
$$= L\frac{[I_0 - 0]}{0} = LI_0\,\delta(t) \quad \{t=0\}$$

$$= L\frac{[0 - I_0]}{0} = -LI_0\,\delta\left(t-\frac{T}{2}\right) \quad \left\{t=\frac{T}{2}\right\}$$

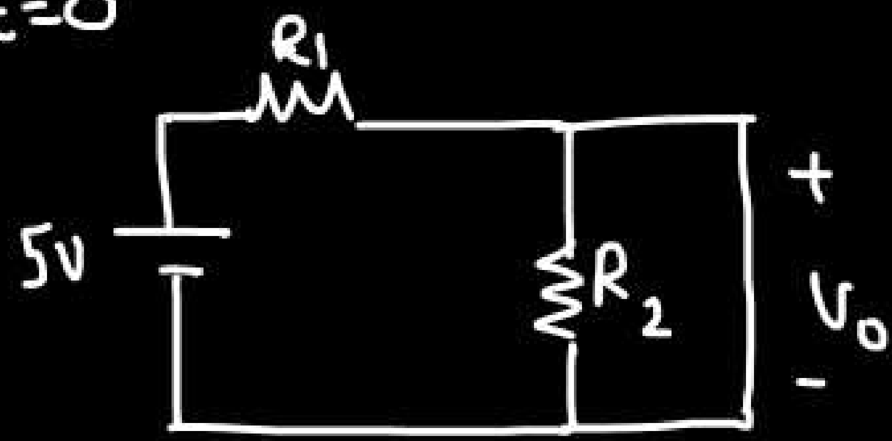


$$V_0(t) = \begin{cases} L I_0 \, \delta(t - nT) \\ -L I_0 \, \delta\left[t - \frac{(2n+1)T}{2}\right] \end{cases} ; \; n = 0, 1, 2 \ldots$$

Q. Draw the graph for V_0.

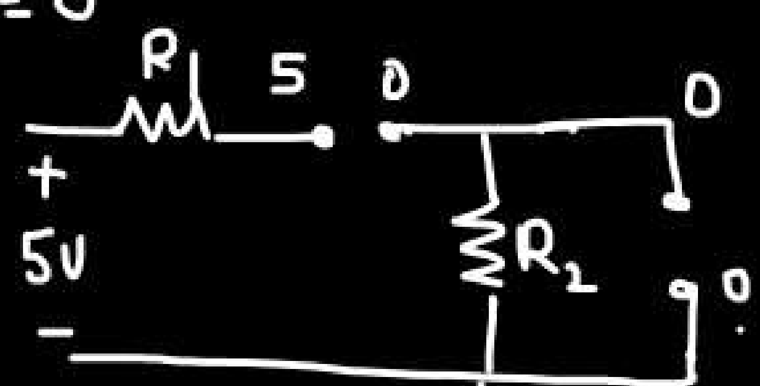


→ @ t=0



$V_0(0^+) = 0V$ ✓

@ t=0



$V_0(\infty) = 0V$ ✓

not a first order ckt

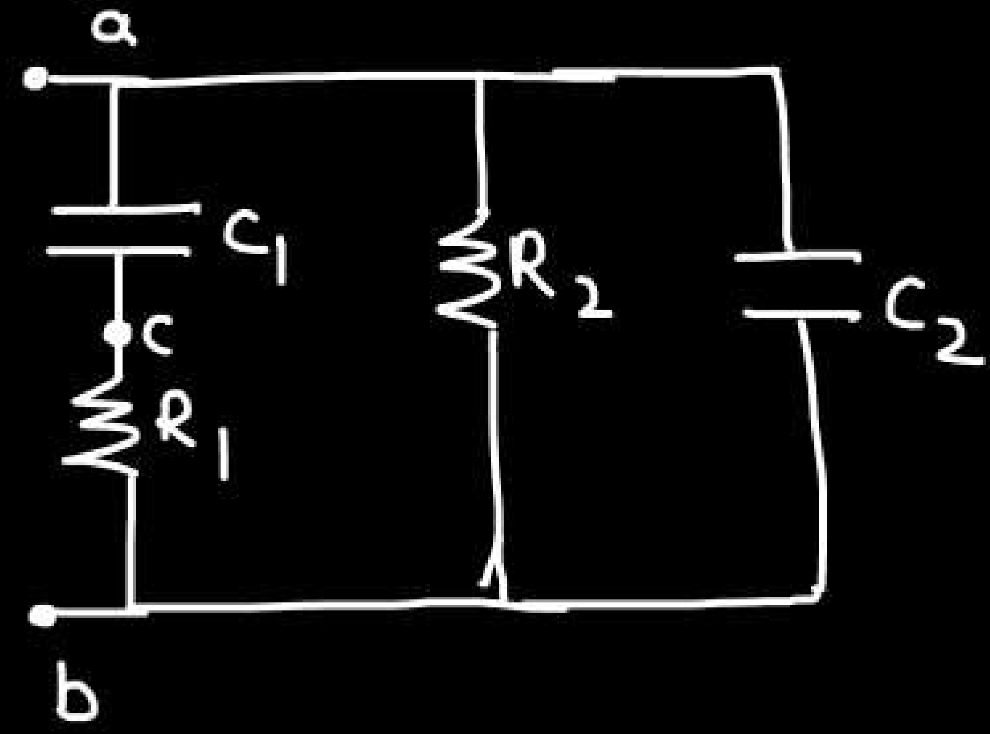
⇓

you can't apply

$v(\infty) + [v(0) - v(\infty)]e^{-t/\tau}$ ✗

{Applicable for first order ckt}

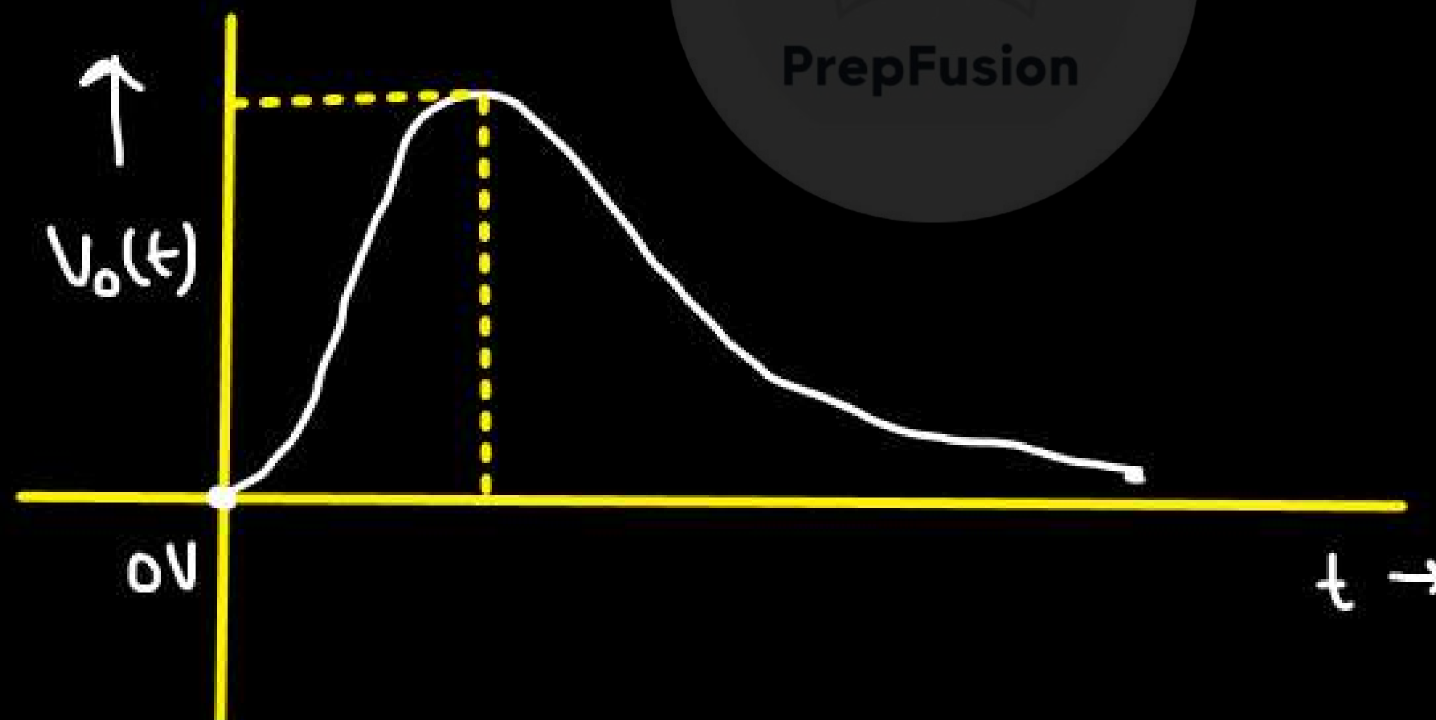
Order ?



→ Two effective storing element

⇓

This is second order ckt



initial and Final cond^n doesn't depend on the order of the ckt

$$\left\{ \begin{array}{l} V_0(0^+) = 0V \\ V_0(\infty) = 0V \end{array} \checkmark \right\}$$

* Transfer function:-

in Laplace domain →

$$T.F. = \left.\frac{O/P}{I/P}\right|_{\text{with no initial cond}^n}$$

* Poles and Zeros:-

Transfer f^n $T(s) = \dfrac{N(s)}{D(s)}$

when $N(S)=0 \Rightarrow S = S_{z_1}, S_{z_2} \dots \rightarrow$ Zeros

when $D(s) = 0 \Rightarrow S = S_{p_1}, S_{p_2} \dots \rightarrow$ poles

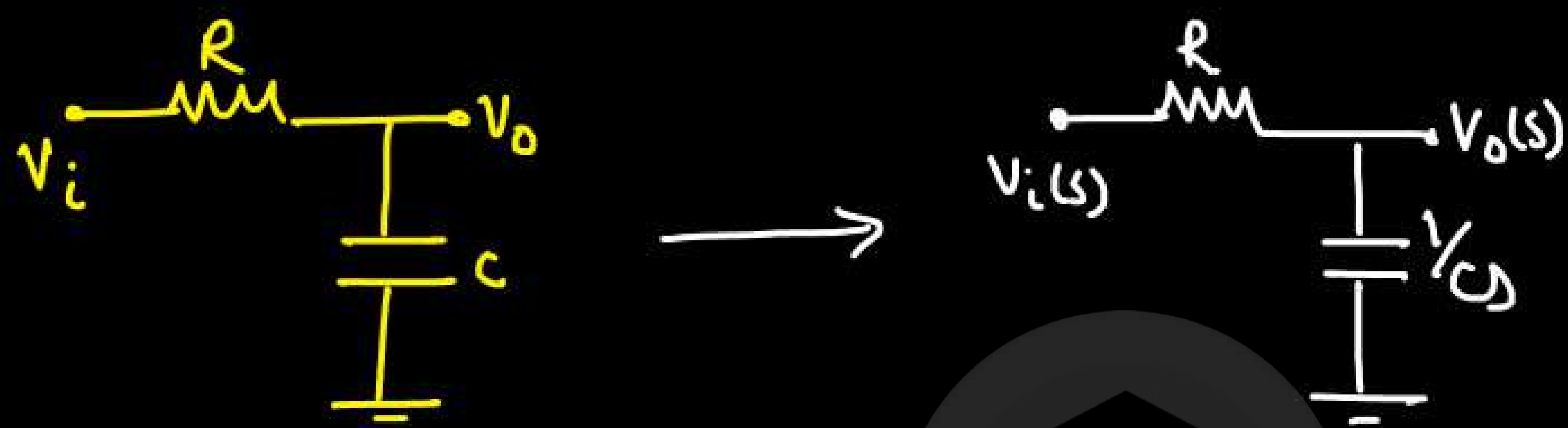
Eg. → $T(S) = \dfrac{(S+3)(s+2)}{(S+5)(s+1)}$

Zeros → $-3, -2$

Poles → $-5, -1$

Q. Find T.F. for the given ckt and then find poles ar

(1)



$$\frac{V_o(s)}{V_i(s)} = \frac{1/Cs}{1/Cs + R} = \frac{1}{RCs + 1}$$

$$\boxed{T(s) = \frac{V_o(s)}{V_i(s)} = \frac{1}{RCs+1}}$$

N.B. → For a T.F., no. of zeros and no. of poles are always equal.

In this example, there is a poles at $-1/RC$ and a zero at $s = \infty$.

Zeros → no zero / zero at $s=\infty$ → no zero

Poles → $s_p = -1/RC$ → 1 pole

N.B. → * Order of the ckt is defined by the no. of Poles / by the degree of $T(s)$. $\left\{ \because T(s) = \frac{N(s)}{D(s)} \right\}$

⇒ order of the ckt has nothing to do with the no. of zeros.

* For a first order ckt;

Time constant = negative reciprocal of the pole

$$\boxed{\tau = -1/S_p}$$

Eg → For a 1^{st} order ckt, the pole is at $-1/RC$.

→ Time constant $= \frac{-1}{-1/RC} = RC$

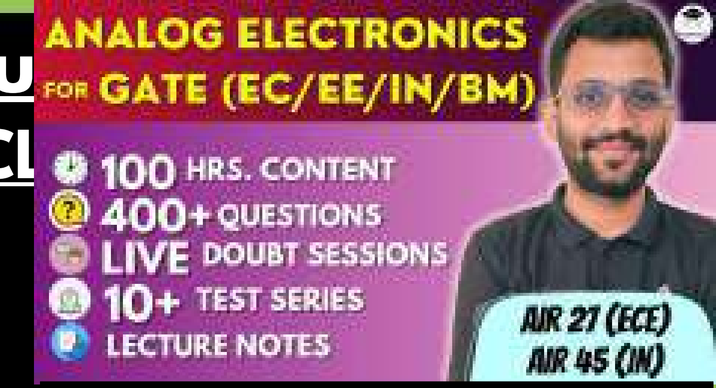
Eg. → Find the order of the ckt whose Transfer f^n is given such as- / Also tell the time const.

(a) $\dfrac{V_o(s)}{V_i(s)} = \dfrac{1}{sRC+1} \rightarrow 1^{st}$ order ; $\omega_p = -1/RC$; $\tau = RC$

(b) $\dfrac{V_o(s)}{V_i(s)} = \dfrac{Ls}{Ls+R} \rightarrow 1^{st}$ order ; $\omega_p = -R/L$; $\tau = L/R$
$\omega_z = 0$

(c) $\dfrac{I_o(s)}{V_i(s)} = \dfrac{2}{s(s+5)} \rightarrow 2^{nd}$ order ; $\omega_{p_1} = 0$, $\omega_{p_2} = -5$;

(d) $\dfrac{Y(s)}{X(s)} = \dfrac{s^2+2s+3}{s^2+5s+13} \rightarrow 2^{nd}$ order ; $\omega_{p_1}, \omega_{p_2}$ ✓ ;
$\omega_{z_1}, \omega_{z_2}$

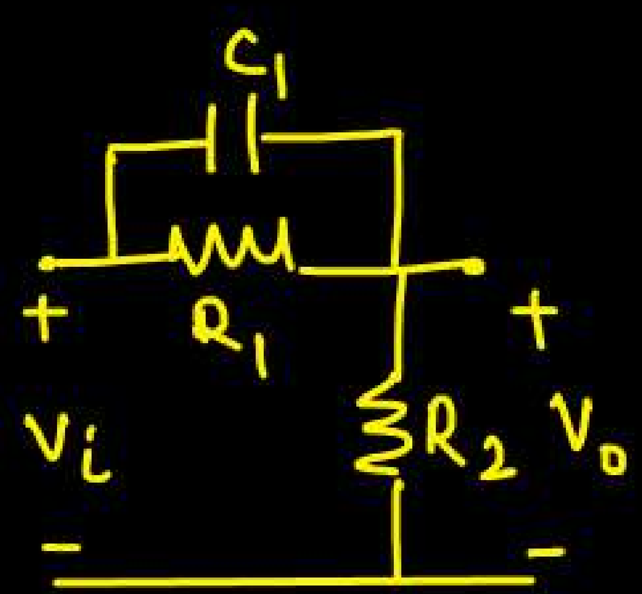


Q. Write down the transfer f^n for the given ckt.

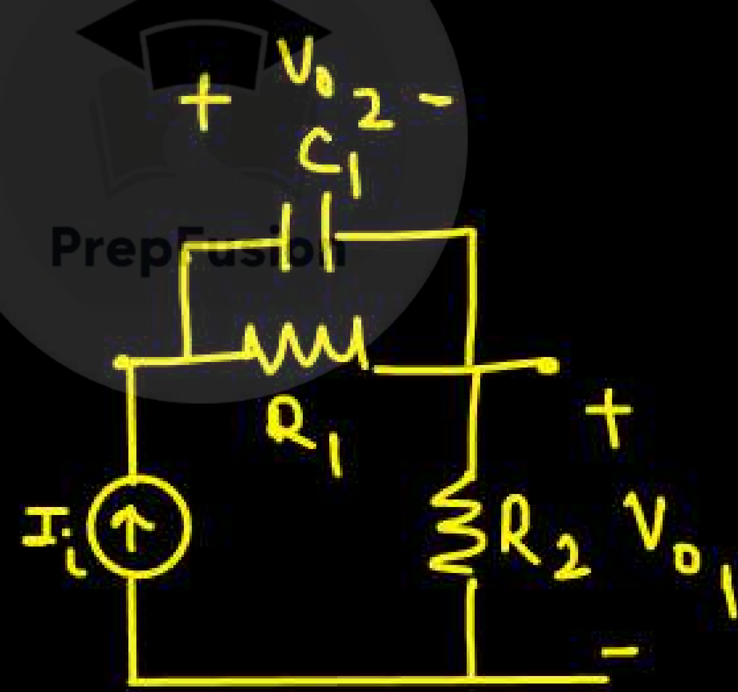
↳ Tell the location of poles and zeros.

↳ Tell the time constant.

↳ Define the order of the ckt.

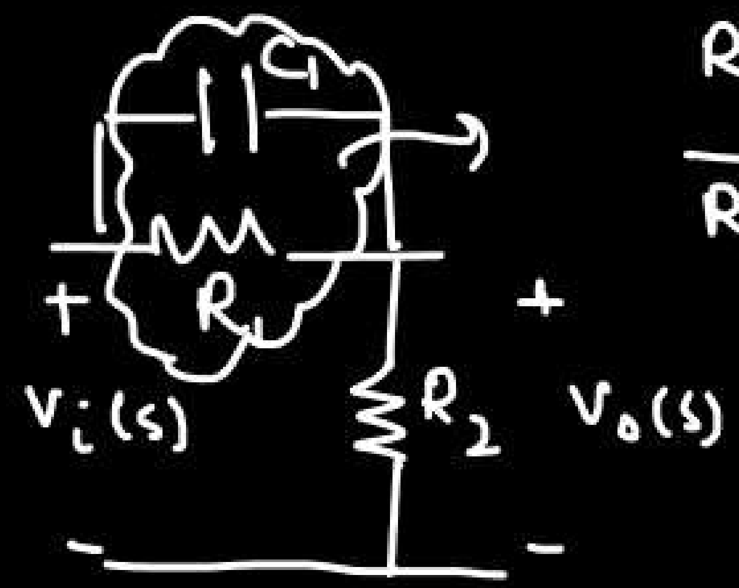


(a)



(b)

(a)



$$\frac{R_1/C_1 s}{R_1 + 1/C_1 s} = \frac{R_1}{R_1 C_1 s + 1}$$

$$\frac{V_o(s)}{V_i(s)} = \frac{R_2}{R_2 + \frac{R_1}{R_1 C_1 s + 1}}$$

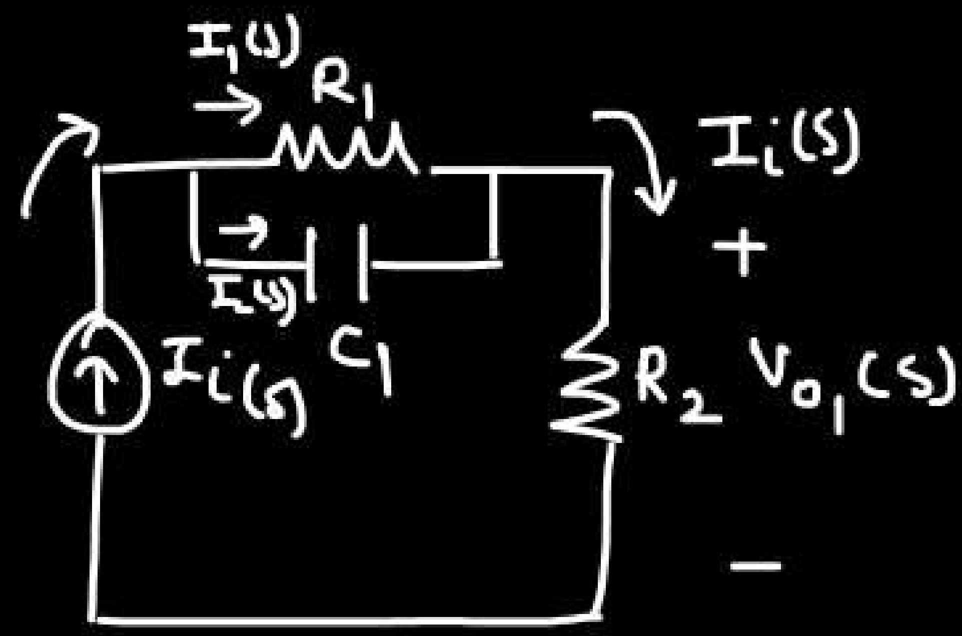
$$\boxed{\frac{V_o(s)}{V_i(s)} = \frac{R_2(R_1 C_1 s + 1)}{R_1 R_2 C_1 s + (R_1 + R_2)}} \rightarrow \text{Transfer } f^n$$

$$\boxed{\omega_z = -1/R_1 C_1 \qquad \omega_p = -\frac{(R_1 + R_2)}{R_1 R_2 \cdot C_1}}$$

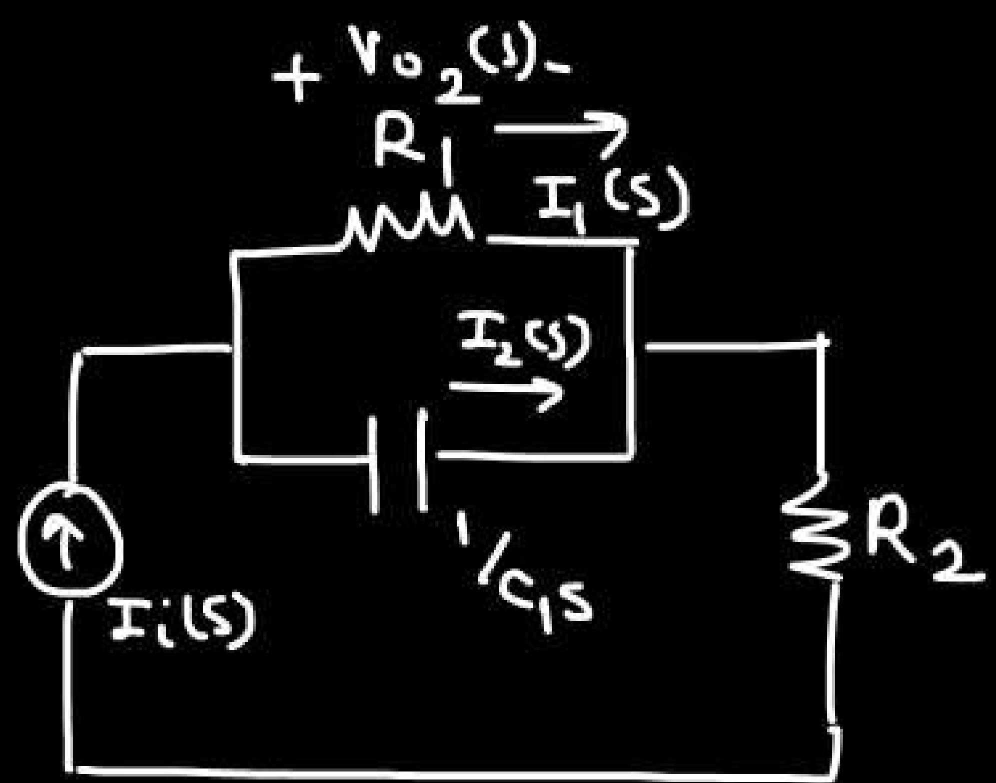
only one pole ⇓ 1st order

$$\boxed{\tau = \frac{-1}{\omega p} \qquad \tau = \left(\frac{R_1 R_2}{R_1 + R_2}\right) C}$$

(b)



(I)



(II)

$$I_i(s) = I_1(s) + I_2(s)$$

$$V_{o_1}(s) = I_i(s) \times R$$

$$\boxed{\frac{V_{o_1}(s)}{I_i(s)} = R} \rightarrow \text{Transfer } f^n$$

$\Downarrow$

no poles, no zero

$\Downarrow$

zero order

$$V_{o_2}(S) = I_1(S) R_1 = I_2(s) \times \frac{1}{C_1 S}$$

$$V_o(S) = I_i(s) \times \frac{\frac{1}{C_1 S}}{\frac{1}{C_1 S} + R_1} \times R_1 = \frac{I_i(s) R_1}{R_1 C_1 s + 1}$$

$$\boxed{\frac{V_o(s)}{I_i(s)} = \frac{R_1}{R_1C_1s+1}}$$

$$\omega_p = \frac{-1}{R_1C_1} \quad ; \quad \tau = R_1C_1$$

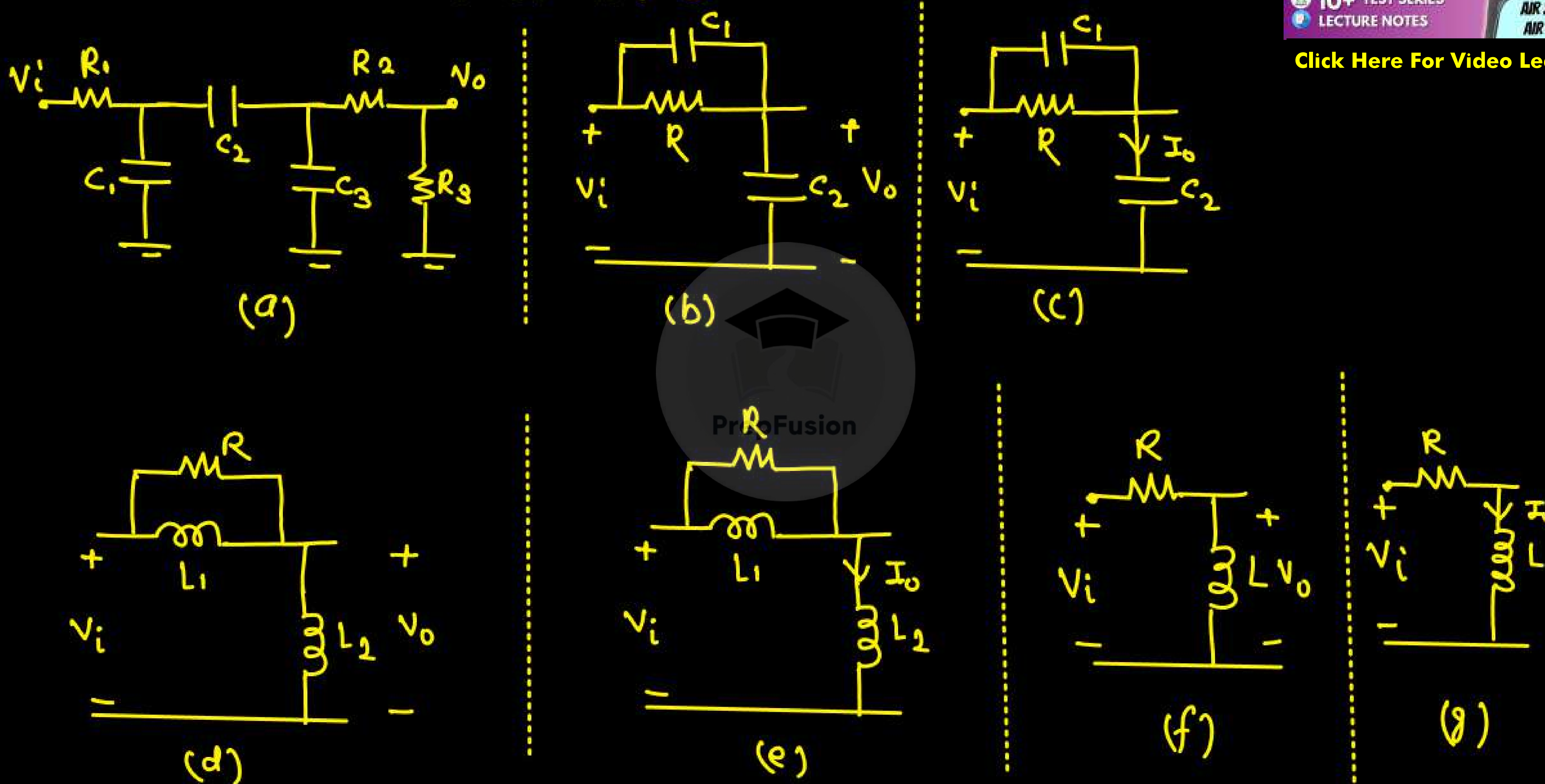
Order = 1st order

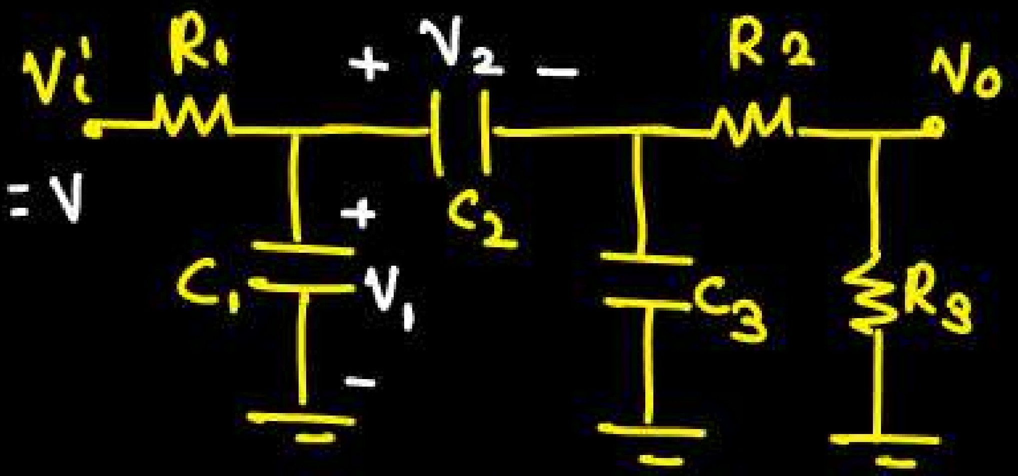
<u>N.B.</u> → The order of a ckt is defined w.r.t a particular o/p

For (I) $\frac{V_{o_1}(s)}{I_i(s)}$ → zero order

For (II) $\frac{V_{o_2}(s)}{I_i(s)}$ → 1st order

Q. Find the order of the ckt.





(a)

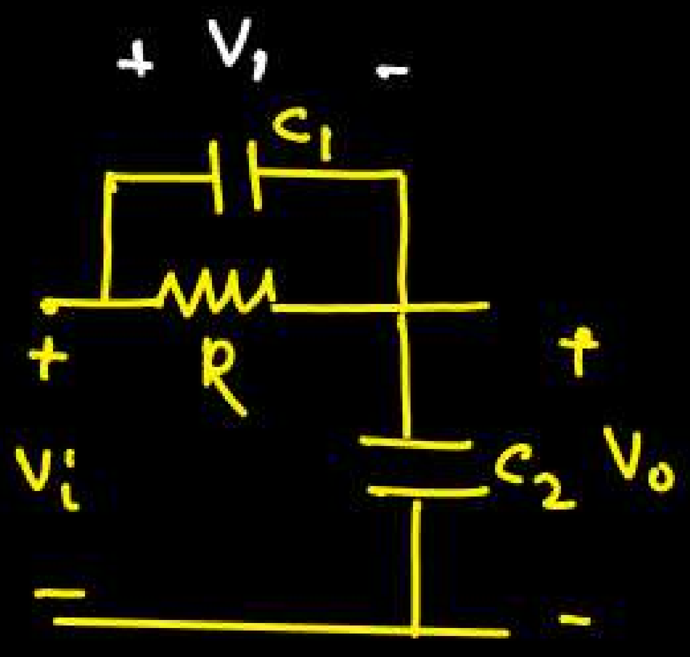
$\rightarrow$ $V_{c_1} = V_1$

$V_{c_2} = V_2$ $\Big\}$ $\rightarrow$ independent voltage $\Rightarrow$ Effective two storing elements

$\Downarrow$

2nd order ckt

$V_{c_3} = V_1 - V_2 \rightarrow$ dependent voltage



(b)

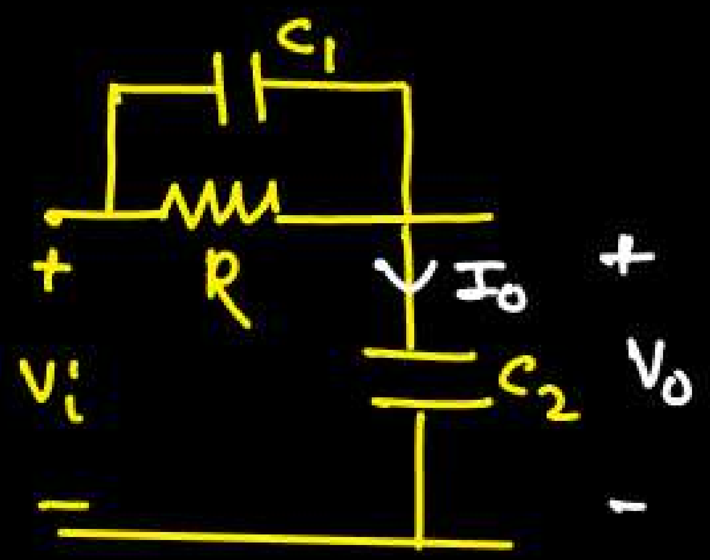
$V_{C_1} = V_1 \leftarrow$ independent

$V_{C_2} = V_i - V_1 \leftarrow$ dependent

$\Downarrow$

Only one storing element

↳ First order ckt



(b)

For V_0, it was first order ckt

$$V_0(s) = \frac{A(s\tau_1+1)}{(sP_1+1)} V_i(s)$$

$$I_0(s) = CsV_i(s)$$

↳ in case of cap., the current adds up a zero at $\omega_z = 0$, not a pole

⇓

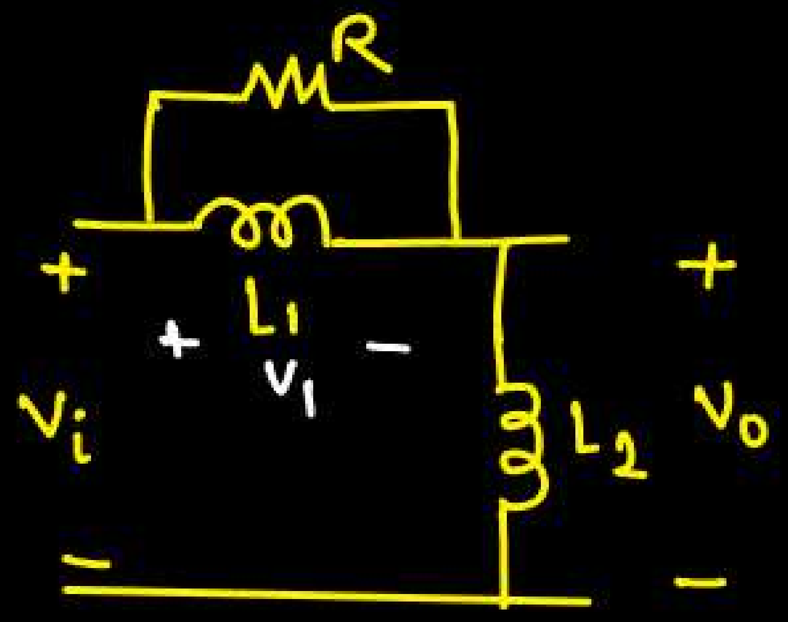
The order remain the same as voltage o/p

$$\frac{I_0(s)}{V_i(s)} = \frac{AC_2(s\tau_1+1)}{(sP_1+1)}$$

$I_0(s)$ C $V_0(s)$

$$V_0(s) = \frac{A(s\tau_1+1)}{\underbrace{s(sP_1+1)}_{\text{2nd order}}} V_i(s)$$

$$\underbrace{I_0(s)}_{\text{1st order}} = \frac{C\cancel{s}A(s\tau_1+1)}{\cancel{s}(sP_1+1)} V_i(s)$$

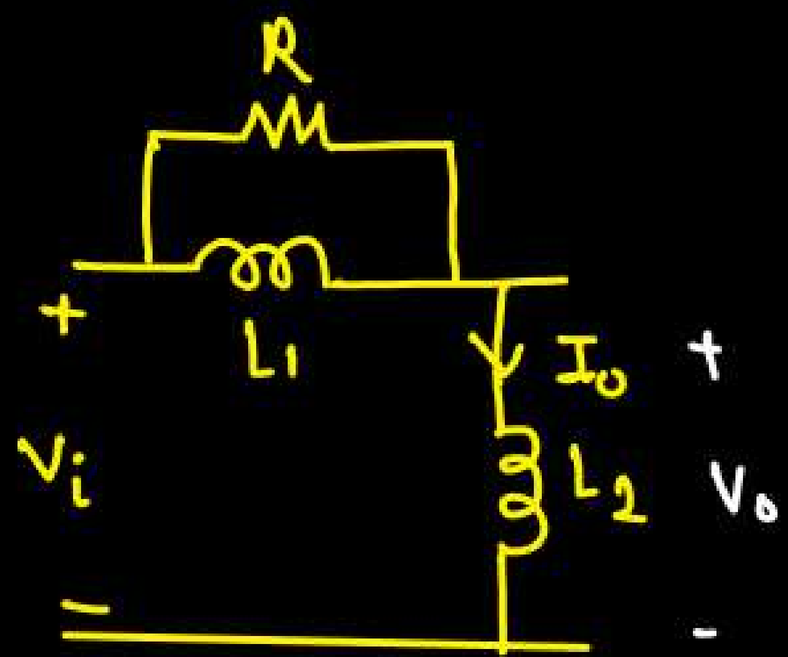


d)

$$\underbrace{\begin{aligned} V_{L_1} &= V_1 \leftarrow \text{independent} \\ V_{L_2} &= V_i - V_1 \leftarrow \text{dependent} \end{aligned}}_{th}$$

only one effective storing element

$\Rightarrow$ 1st order



(e)

$\Downarrow$

2nd order

$$\frac{V_o(s)}{V_i(s)} = \frac{A(sZ_1+1)}{(sP_1+1)}$$

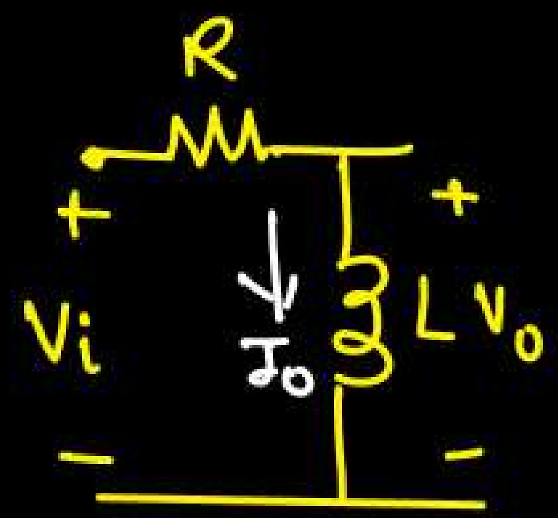
$$V_o(s) = \frac{A(sZ_1+1)}{(sP_1+1)} V_i(s)$$

$$I_o(s) = \frac{1}{Ls} V_o(s)$$

$\Downarrow$

current adds up a pole @ $\omega = 0$

$$I_o(s) = \frac{A(sZ_1+1)}{Ls(sP_1+1)} \rightsquigarrow 2^{nd} \text{ order}$$



(f) (g)

$$\frac{V_o(s)}{V_i(s)} = \frac{Ls}{R+Ls} \Rightarrow \text{zero @ } \omega = 0$$

$\rightarrow$ 1^{st} order

$$V_o(s) = \frac{Ls}{R+Ls} V_i(s)$$

$$I_o(s) = \underbrace{\frac{1}{Ls}} \times \underbrace{V_o(s)}_{\hookrightarrow 1^{st} \text{ order ckt}}$$

↓

adding up another pole @ $\omega = 0$

↓

2^{nd} order } ✗

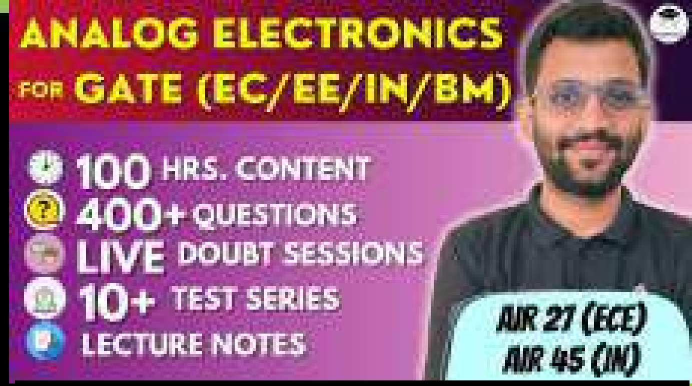
$\rightarrow$ $V_o(s)$ is having a zero at $\omega = 0 \Rightarrow$ so, there is pole - zero cancellation

$$I_o(s) = \frac{1}{Ls} V_o(s)$$

$$= \frac{1}{Ls} \times \frac{Ls}{R+Ls} V_i(s)$$

$$I_o(s) = \frac{1}{R+Ls} V_i(s)$$

↳ 1st order


ANALOG ELECTRONICS
FOR GATE (EC/EE/IN/BM)
100 HRS. CONTENT
400+ QUESTIONS
LIVE DOUBT SESSIONS
10+ TEST SERIES
LECTURE NOTES
AIR 27 (ECE)
AIR 45 (IN)

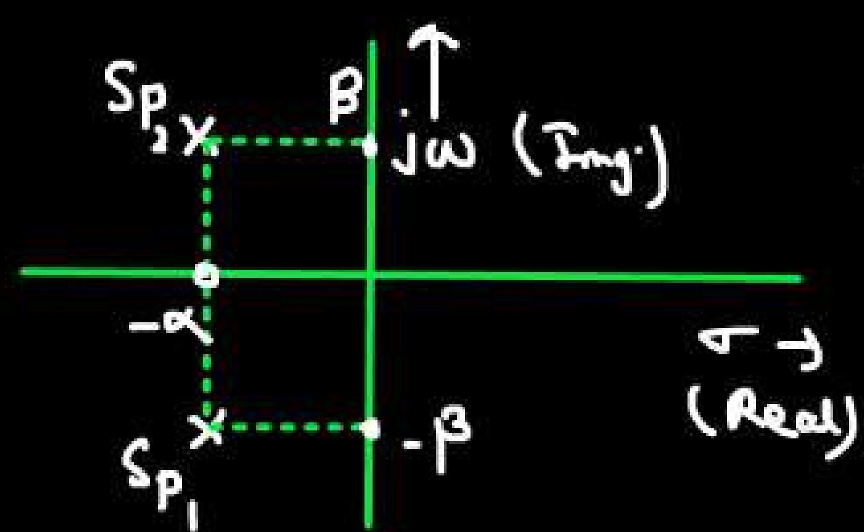
Analysis of 2^{nd} order ckts:-

- → Two effective storing element.
- → Order of differential eqn is two
- → no. of poles = 2

**[N.B. → For a stable s/s, poles will always be in the Left Half of s-plane]

★ nature of poles of a second order s/s:-

(a) Both roots are complex and conjugate:-



$$S_P = -\alpha \pm j\beta$$

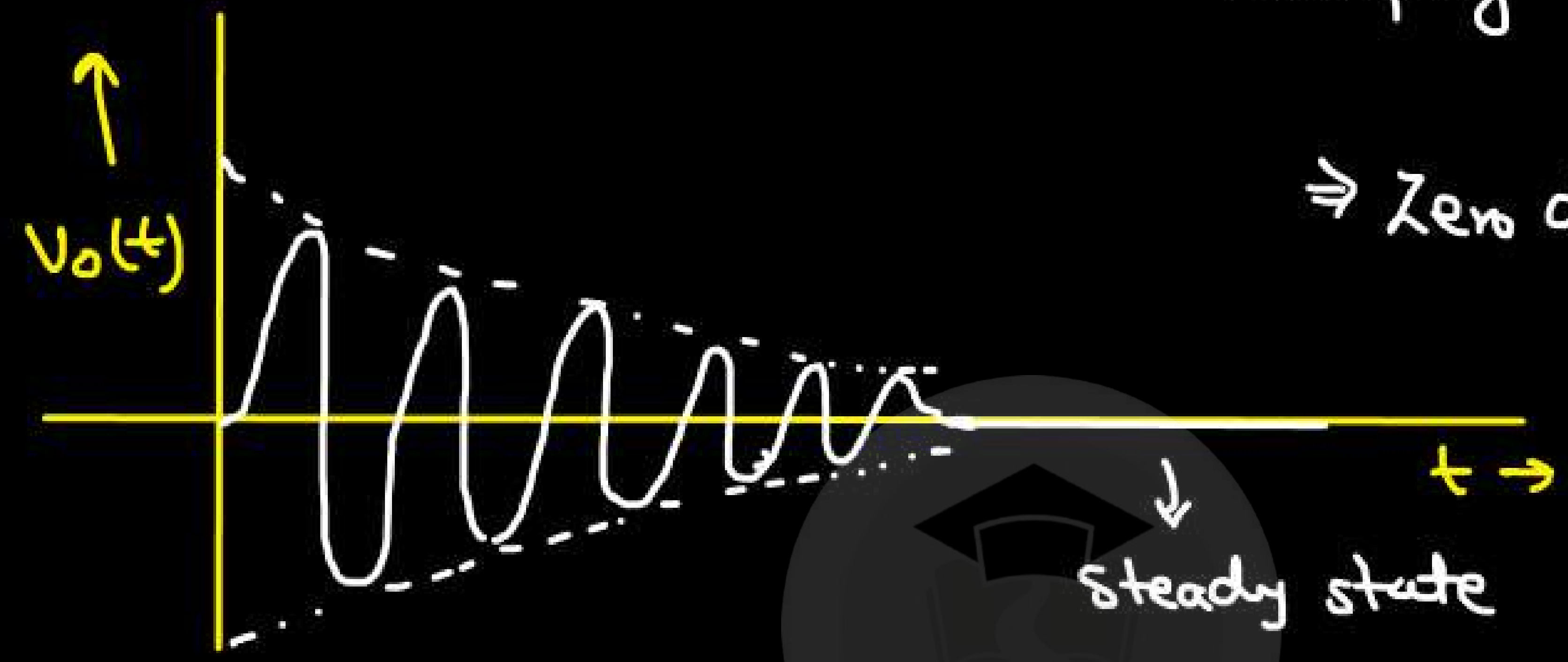
$$\Rightarrow S_{P_1} = -\alpha - j\beta \quad \checkmark \quad \Rightarrow \text{Underdamped s/s}$$

$$S_{P_2} = -\alpha + j\beta \quad \checkmark$$

considering both initial and final values to be zero.

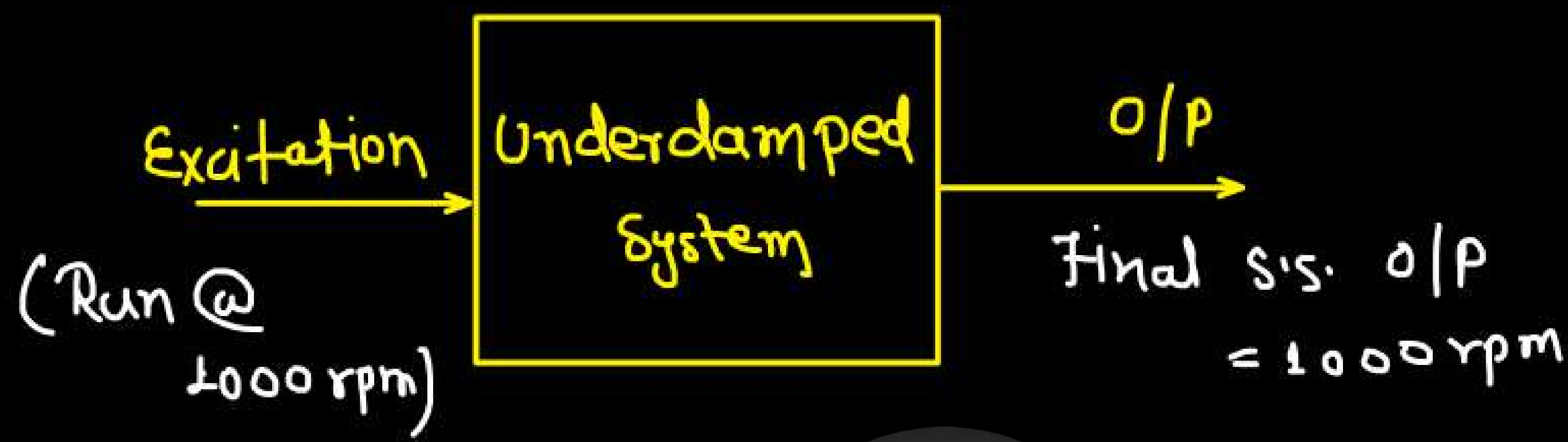
damping $\propto \dfrac{1}{\text{oscillation}}$

$\Rightarrow$ Zero damping = infinite oscillation



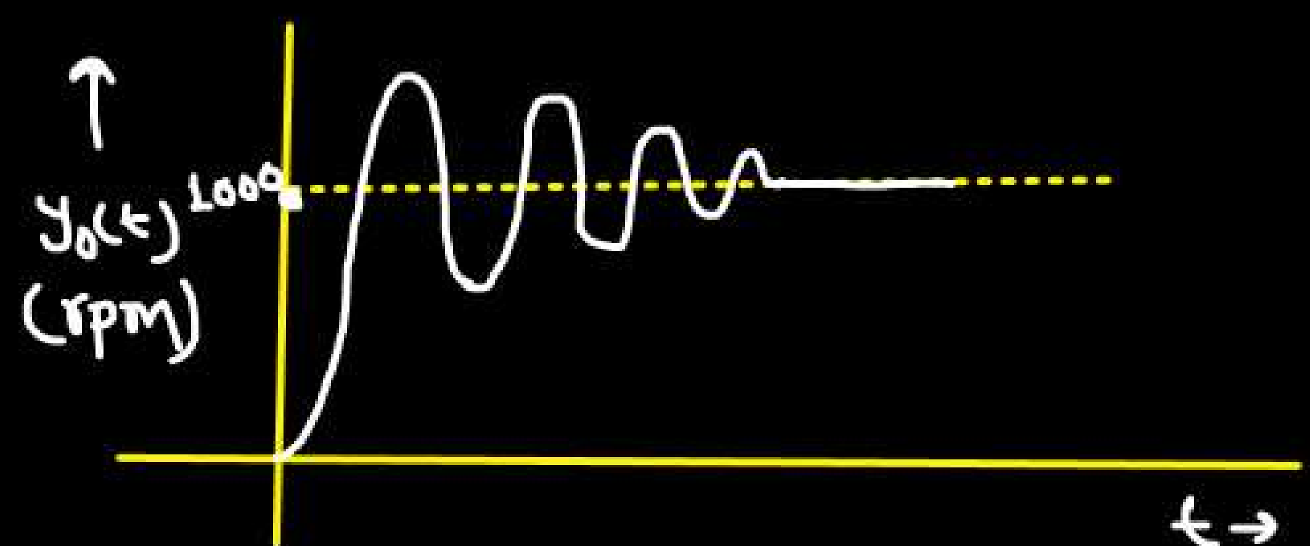
N.B. - in underdamped response, damping is not enough to kill the oscillation but eventually the oscillation will die out.

Eg $\rightarrow$ Let's assume I give an excitation to my motor to run @ 1000rpm. The system is underdamped. How should the response look like?



→ since the s/s is underdamped, the response will oscillate around 1000 rpm and will reach steady state after some time.

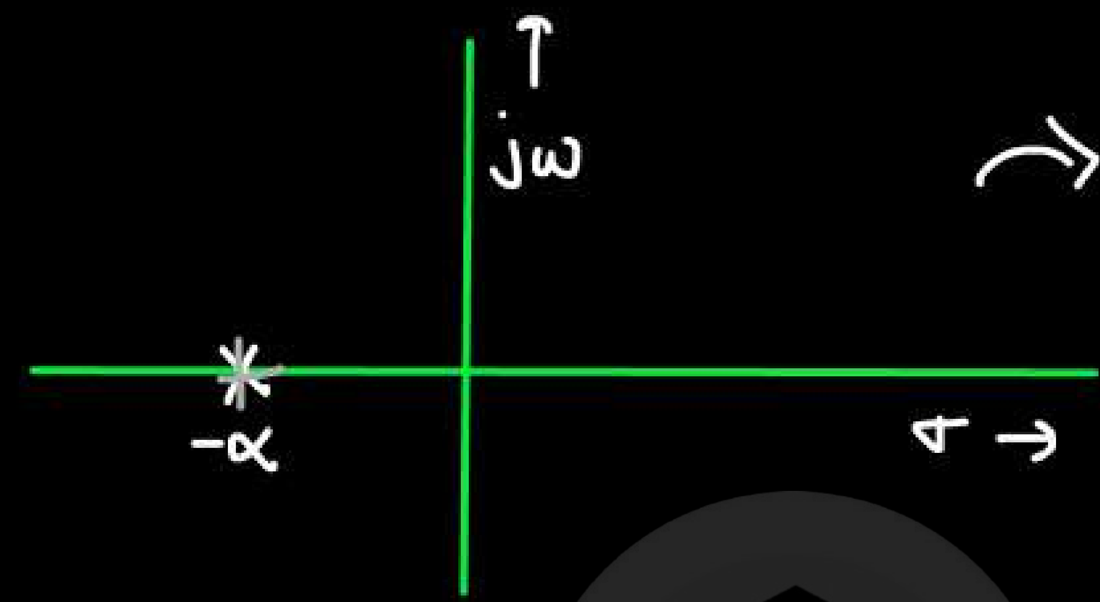
considering initial speed of motor to be zero. ⇒ $y_0(0^+) = 0$



(b) Both real but same roots:-

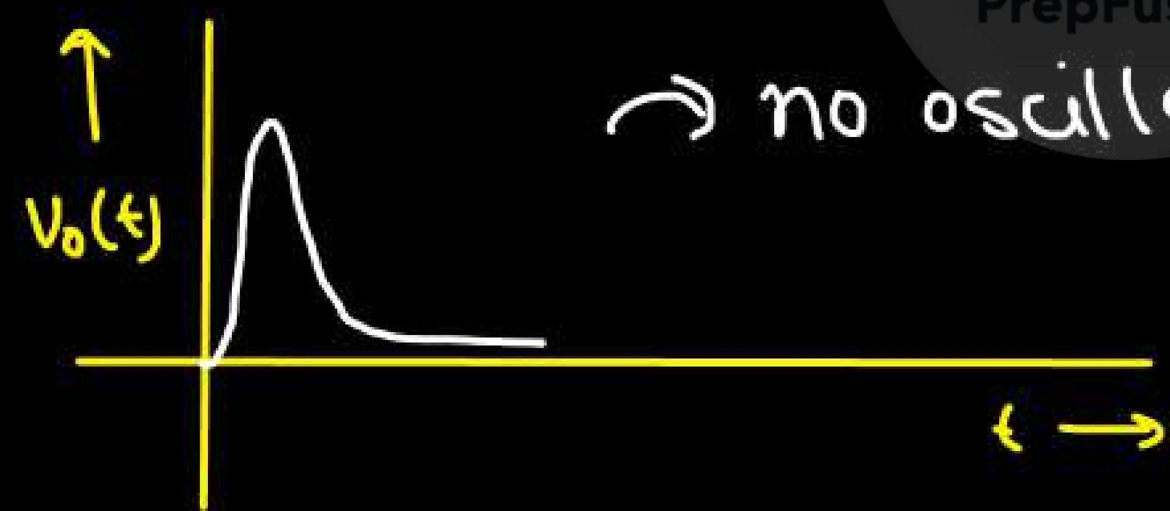
$S_{p_1} = -\alpha$

$S_{p_2} = -\alpha$



→ critically damp

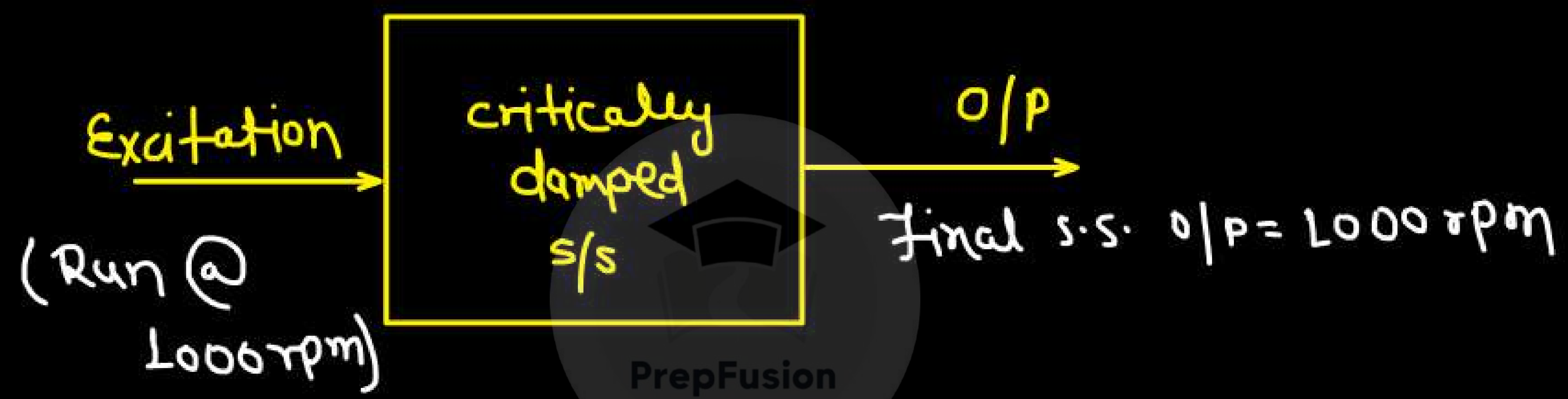
Considering both initial and final value to be zero.



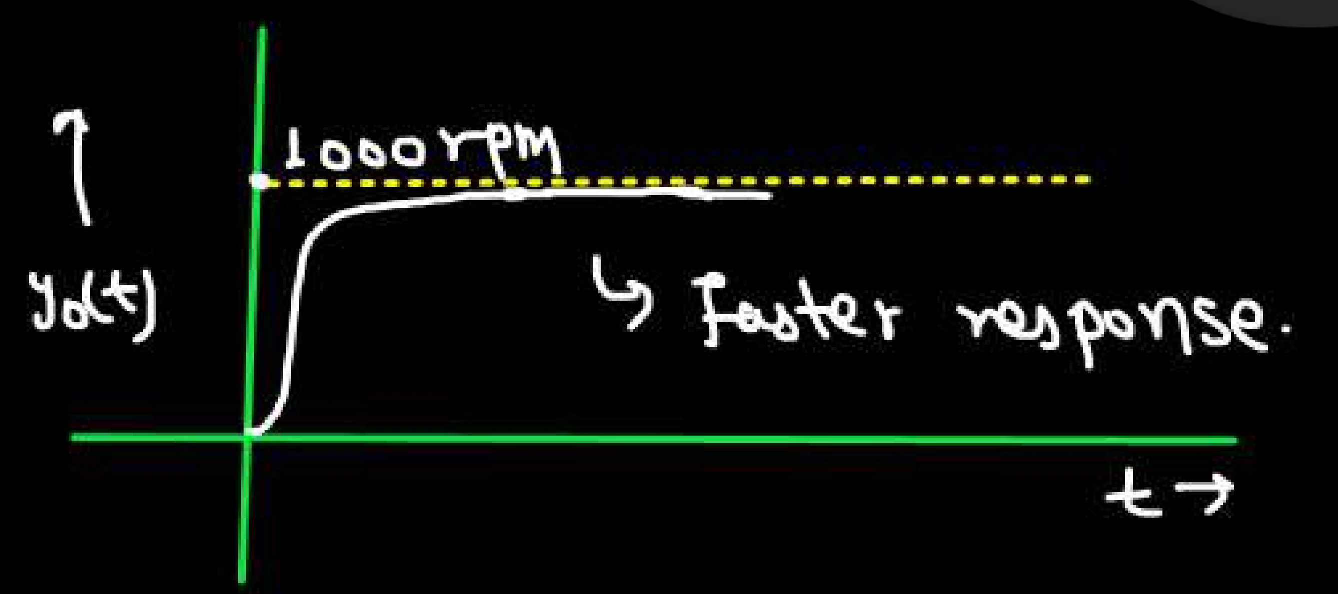
→ no oscillation

N.B.- in critically damped s/s, there are no oscillation and the response is faster.

Eg → Let's assume I give an excitation to my motor to run @ 1000 rpm and the system is critical damped. Then How should the response look like?



→

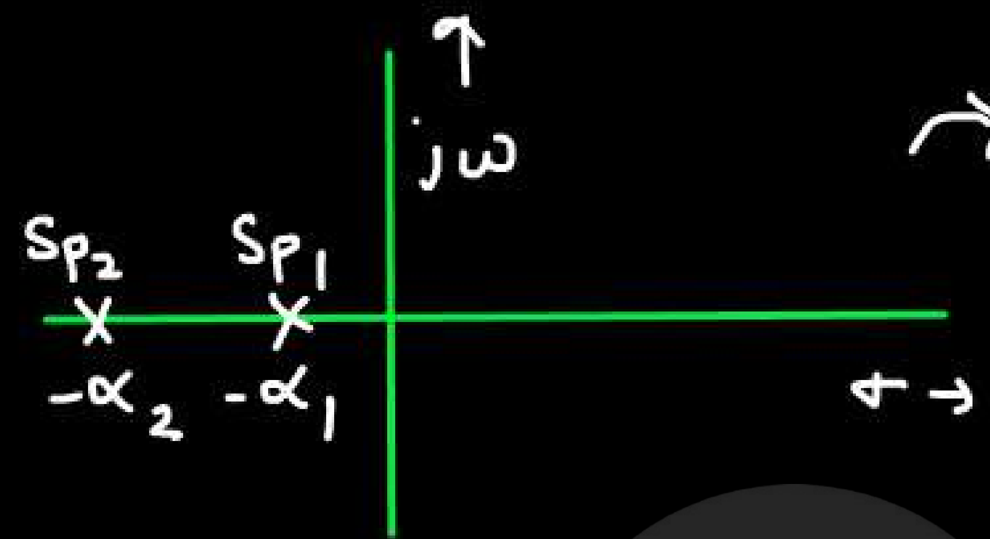


initial speed of motor = 0 rpm

(c) Both roots are real but different.

$S_{p_1} = -\alpha_1$

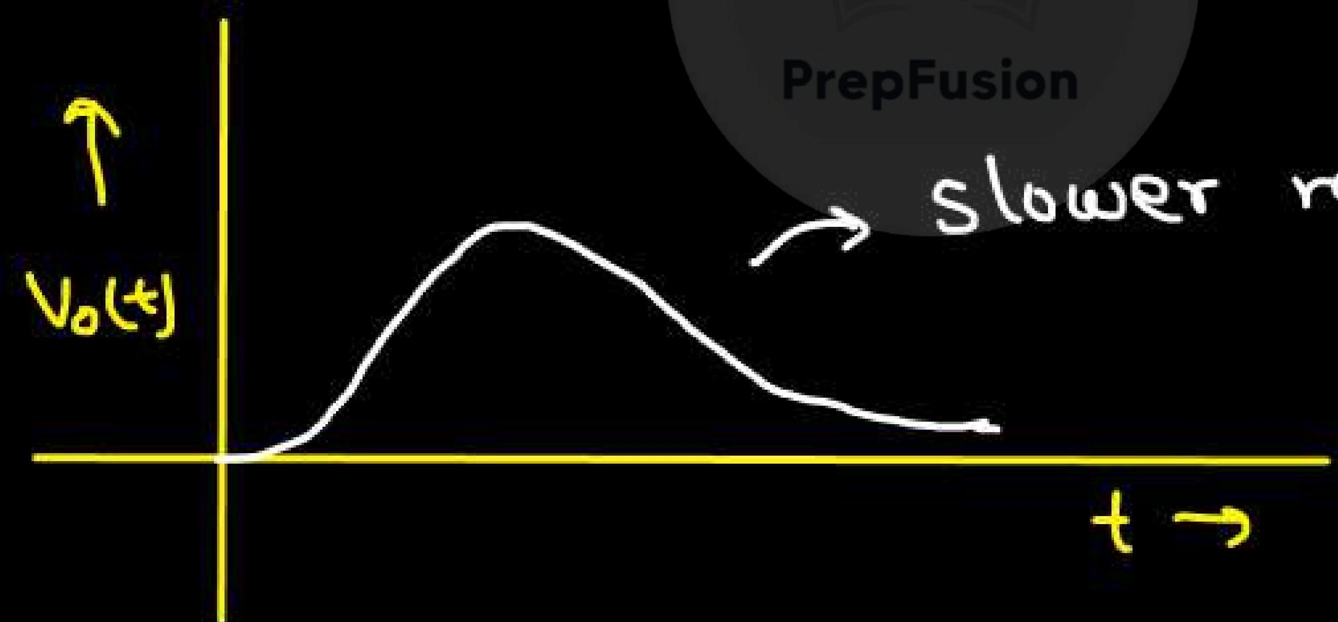
$S_{p_2} = -\alpha_2$



→ over damped s/s

(Very High damping)

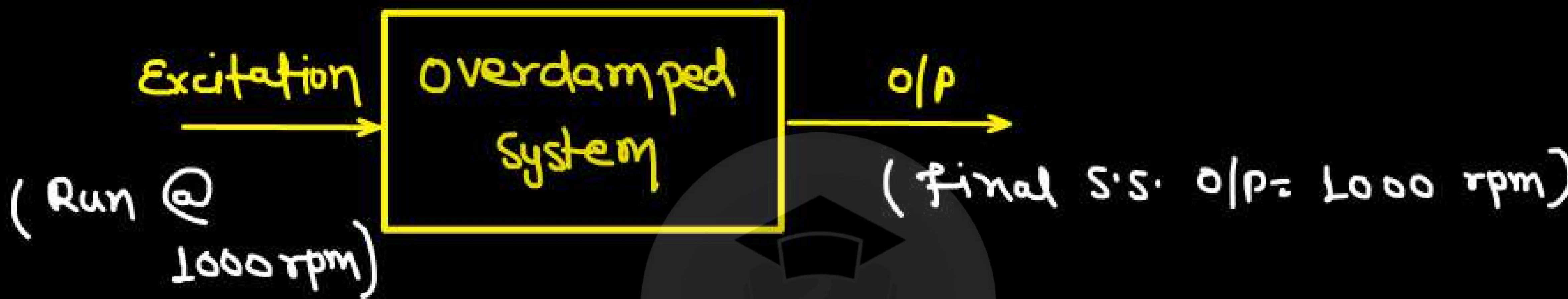
Considering both initial and Final value to be zero.



→ slower response

N.B.- Here there are absolutely no oscillation but the response is slower.

Eg. → Let's assume I given an excitation to my motor to run @ 1000 rpm and the system is over-damped. Then How should the o/p look like?



initial speed = 0 rpm

Speed of response:-

Critical damped > Under damped > Over dampe

$\Downarrow$

→ Fastest

→ no oscillation

→ very tough to design

$\Downarrow$

→ Faster than overdamped

→ oscillation ✓

$\Downarrow$

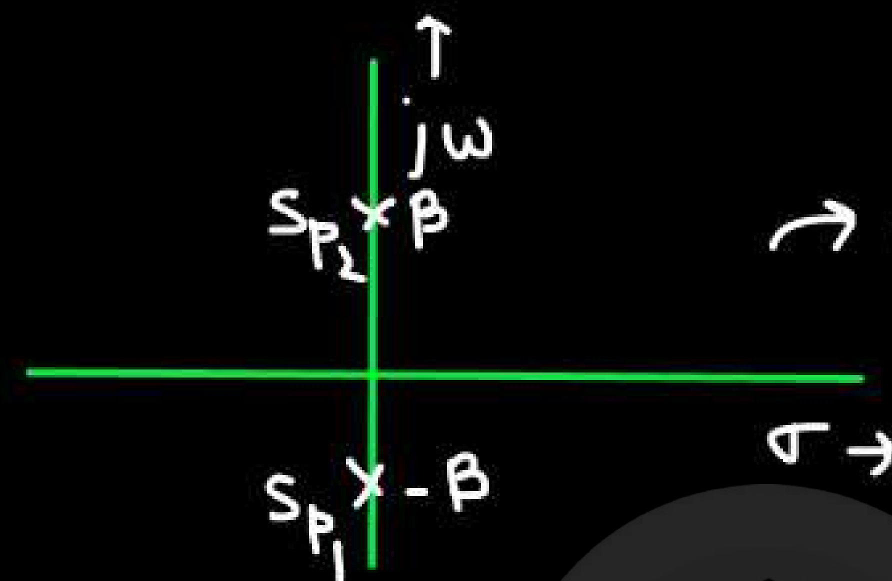
→ Slowest

→ no oscillation

(d) Both roots completely imaginary and conjugate :-

$S_{p_1} = -j\beta$

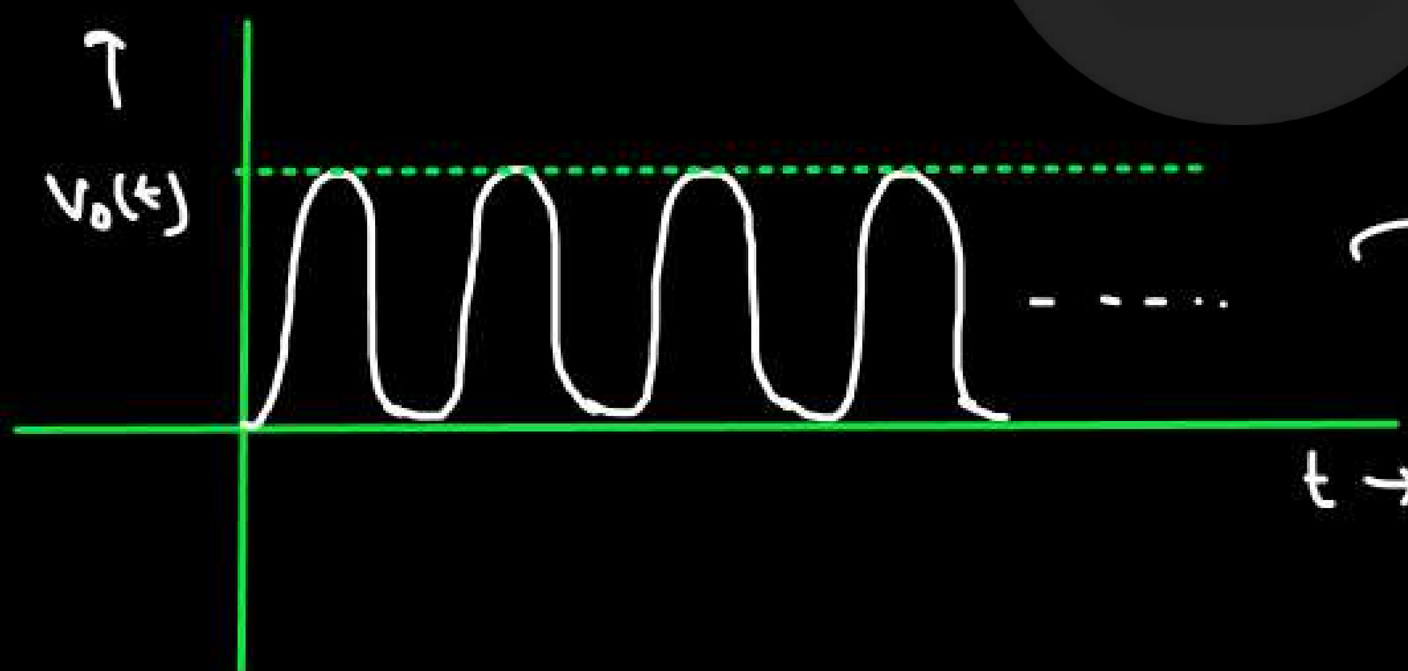
$S_{p_2} = j\beta$



→ Undamped

(no damping = infinite oscillation)

considering initial value to be zero.



→ always oscillation

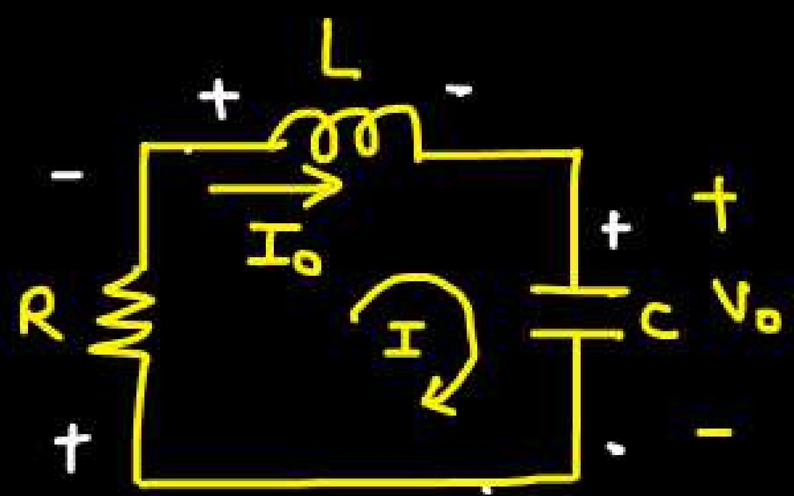
(LC oscillators)

✯ Source free series RLC ckt:-

Let's assume;

inductor is having initial current of I_0.

capacitor is having initial voltage of V_0.



Let's write the expression for current

Apply KVL

$$I(t)R + L\frac{dI(t)}{dt} + V_0 + \frac{1}{C}\int I(t)\cdot dt = 0$$

$$R\frac{dI(t)}{dt} + L\frac{d^2 I(t)}{dt} + \frac{I(t)}{C} = 0$$

$$\frac{d^2 I(t)}{dt} + \frac{R}{L}\frac{dI(t)}{dt} + \frac{1}{LC}I(t) = 0$$

$$\underbrace{\left[D^2 + \frac{R}{L}D + \frac{1}{LC}\right]}_{f(D)} I(t) = 0$$

$$\Rightarrow D^2 + \frac{R}{L}D + \frac{1}{LC} = 0$$

$$D = \frac{-\frac{R}{L} \pm \sqrt{\left(\frac{R}{L}\right)^2 - \frac{4}{LC}}}{2} = \frac{-R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 - \left(\frac{1}{\sqrt{LC}}\right)^2} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$$

$$\alpha = R/2L \; ; \; \omega_0 = \frac{1}{\sqrt{LC}}$$

* Remember

$$\boxed{\text{Roots} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2} \qquad \alpha = \frac{R}{2L} \; ; \; \omega_0 = \frac{1}{\sqrt{LC}}}$$

$$\left[\begin{aligned} s_{p_1} &= -\alpha + \sqrt{\alpha^2 - \omega_0^2} \\ s_{p_2} &= -\alpha - \sqrt{\alpha^2 - \omega_0^2} \end{aligned}\right]$$

Case-1 →

Underdamped system:- [poles must be complex conjugate]

$(\alpha < \omega_0)$

$$\text{Roots} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2} \qquad \{\omega_0 > \alpha\}$$

$$= -\alpha \pm j\sqrt{\omega_0^2 - \alpha^2}$$

$$\text{Roots} = -\alpha \pm j\omega_d \quad ; \quad \omega_d = \sqrt{\omega_0^2 - \alpha^2}$$

For a differential eqn, your roots are $-\alpha - j\omega_d$ and $-\alpha + j\omega_d$.

Soln of differential eqn $y(t) = e^{-\alpha t}\left[c_1 \cos\omega_d t + c_2 \sin\omega_d t\right]$

So, for a underdamped response.

① $\alpha < \omega_0$

$$\frac{R}{2L} < \frac{1}{\sqrt{LC}}$$

② $Y(t) = e^{-\alpha t}\left[C_1 \cos\omega_d t + C_2 \sin\omega_d t\right]$

↳ now for $I(t)$

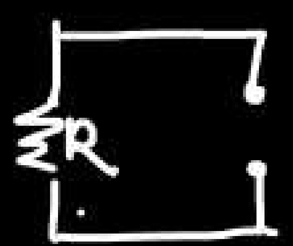
$$I(t) = e^{-\alpha t}\left[C_1 \cos\omega_d t + C_2 \sin\omega_d t\right]$$

in the given ckt ; $I(0^+) = I_0$

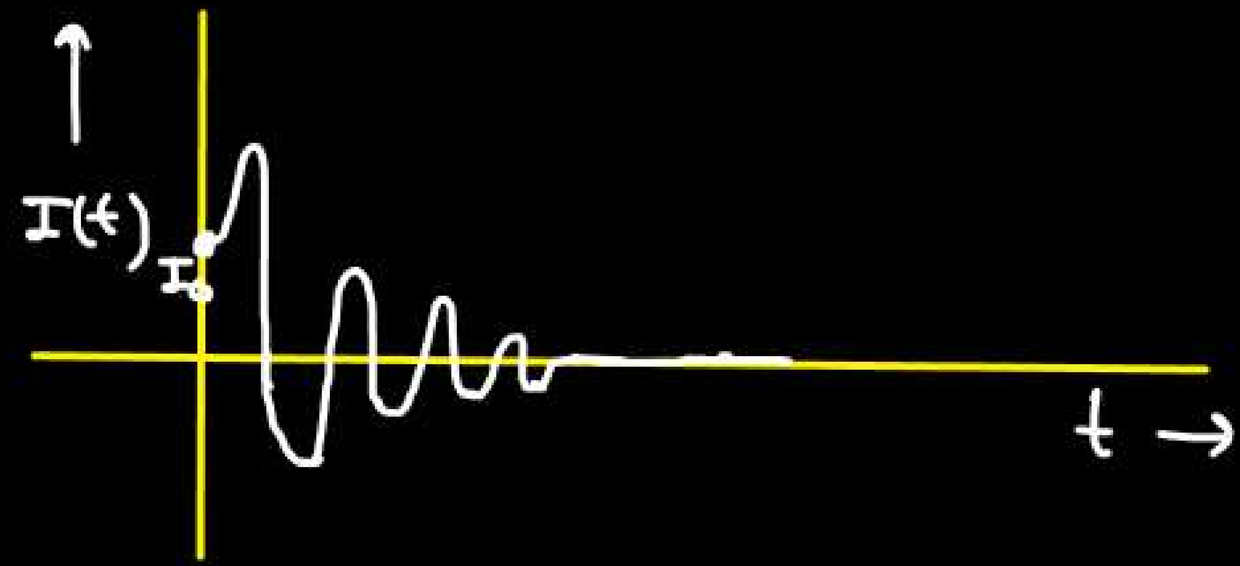
$I(0^+) = C_1 = I_0$ —— ①

⇒ similary, by the other condn you can find the value of C_2 as well.

$I(\infty) = 0$ —— ②



→ ckt @ $t = \infty$



since, all the expression will follow 2^{nd} order eq^n only.

voltage across the capacitor $V_c(t) = e^{-\alpha t}[c_1 \cos w_d t + c_2 \sin w_d t]$

at $t=0^+$ $V_c(0^+) = V_0$

$c_1 = V_0$

you can find c_2 in similar way

$V_c(\infty) = 0$

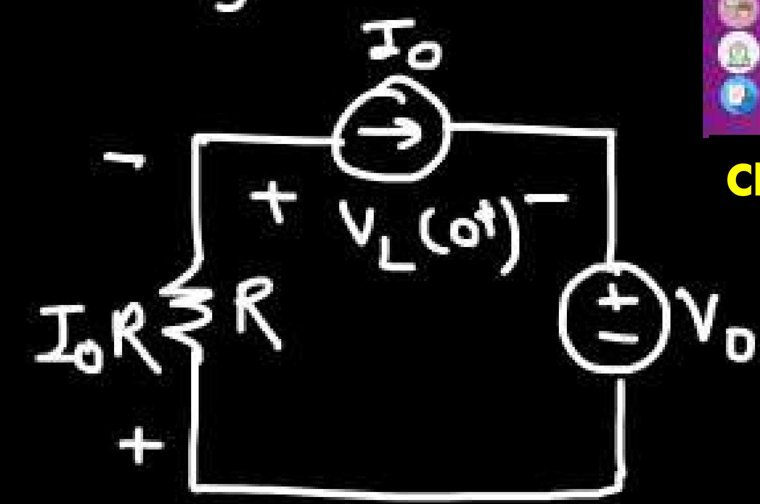
- →

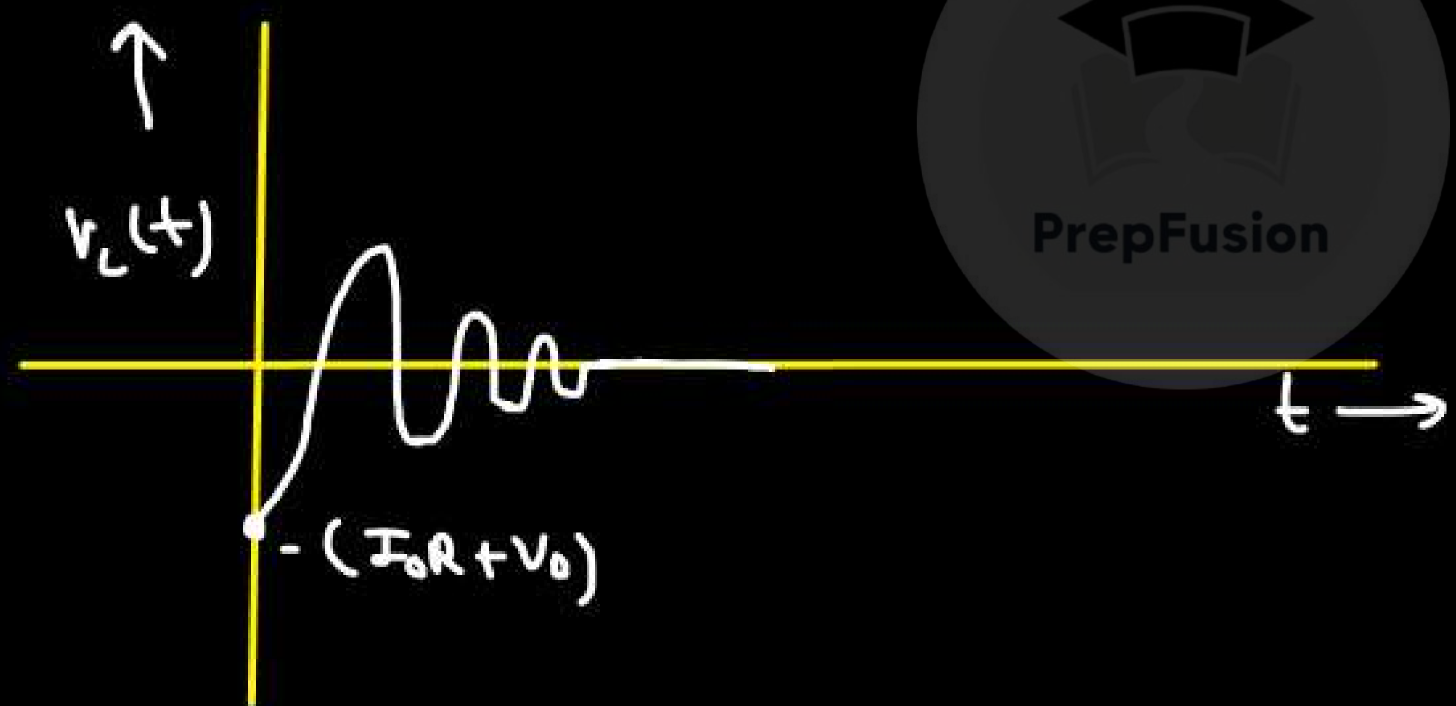
$$\hookrightarrow \quad V_L(t) = e^{-\alpha t}\left[c_1 \cos\omega_d t + c_2 \sin\omega_d t\right]$$

$$@\ t = 0^+ \quad V_L(0^+) = -I_0 R - V_0$$

$$c_1 = -I_0 R - V_0$$

similary you can find c_2.





Case - 2 →

Critically damped [Both roots should equal]

$(\alpha = \omega_0)$

$$\text{roots} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$$

For critically damped ; roots = $-\alpha, -\alpha$

sol^n of differential equation $y(t)$ = $[c_1 + c_2 t]e^{-\alpha t}$

For critical damped response :-

$$\alpha = \omega_0$$

$$\frac{R}{2L} = \frac{1}{\sqrt{LC}}$$

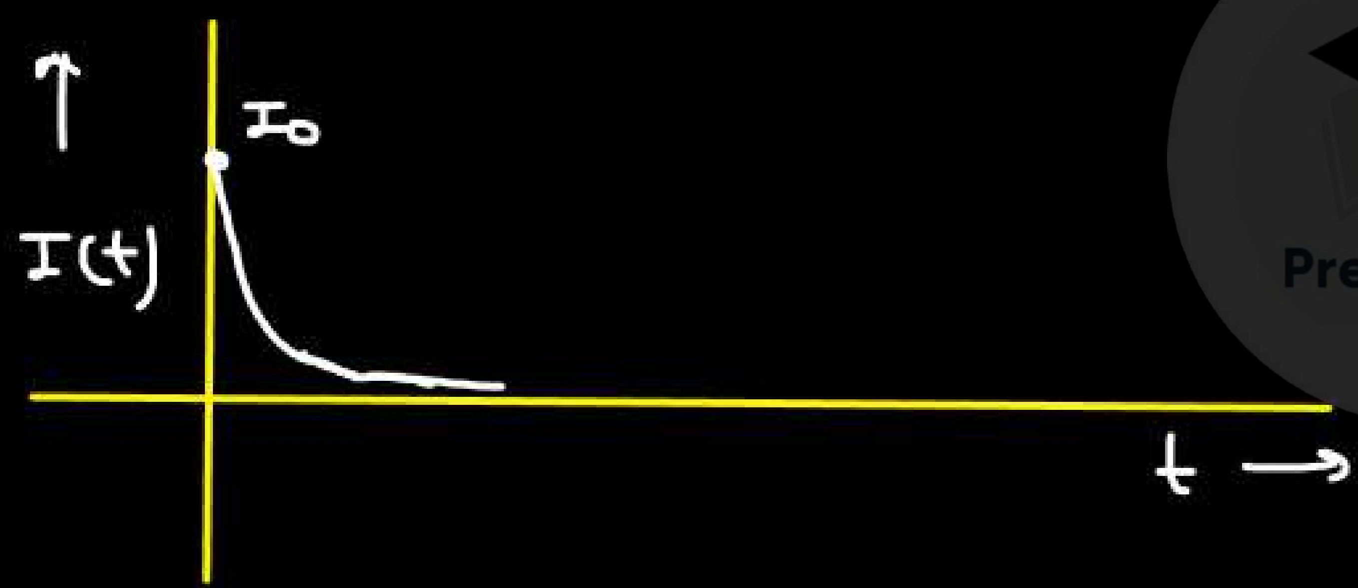
↳ **I(t):-**

$$I(t) = [c_1 + c_2 t] e^{-\alpha t}$$

@ $I(0^+) = I_0 = c_1$

similarly you can find c_2

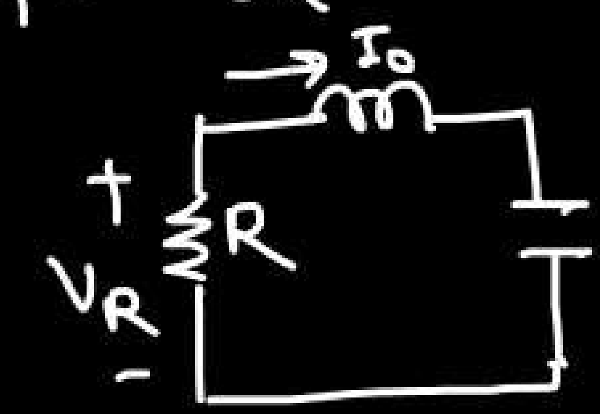
$I(\infty) = 0$

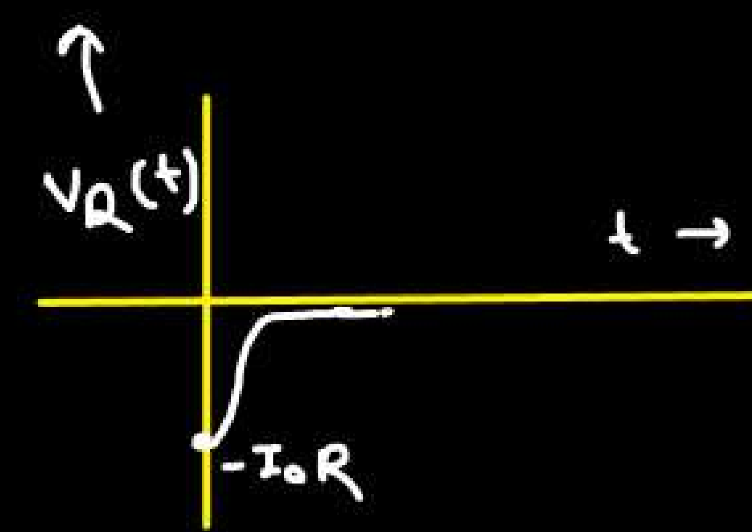


↳ $V_R(t) = [c_1 + c_2 t] e^{-\alpha t}$

$V_R(0^+) = c_1 = -I_0 R$

$V_R(\infty) = 0$





↳ $V_c(t) = [c_1 + c_2 t] e^{-\alpha t}$

$V_c(0^+) = c_1 = V_0$

$V_c(\infty) = 0$

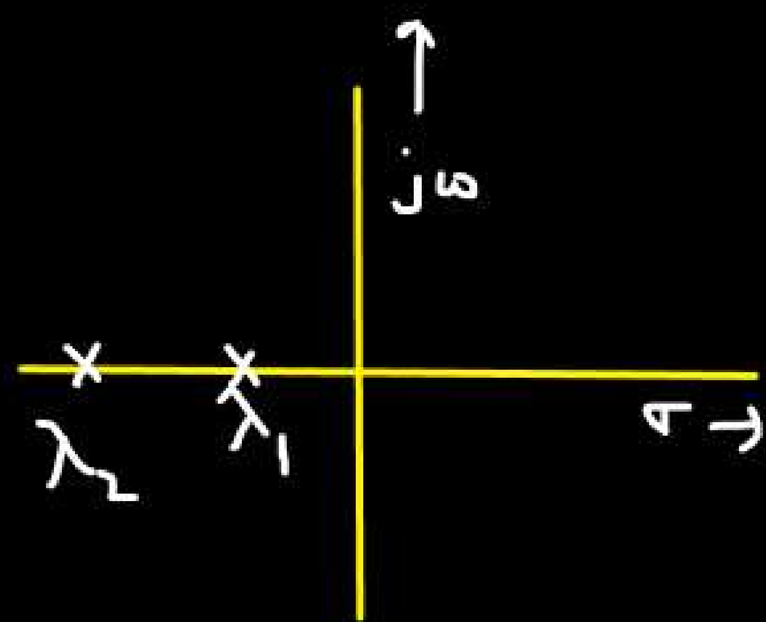
Case 3:-

Overdamped [Both roots will be different]
$(\alpha > \omega_0)$ (Real)

$$\text{roots} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$$

$$S_{p_1} = -\alpha + \sqrt{\alpha^2 - \omega_0^2} = \lambda_1 \text{ (negative)}$$

$$S_{p_2} = -\alpha - \sqrt{\alpha^2 - \omega_0^2} = \lambda_2 \text{ (negative)}$$



Sol^n of differential eq^n $y(t)$ $= c_1 e^{\lambda_1 t} + c_2 e^{\lambda_2 t}$

For overdamped response; $\alpha > \omega_0$

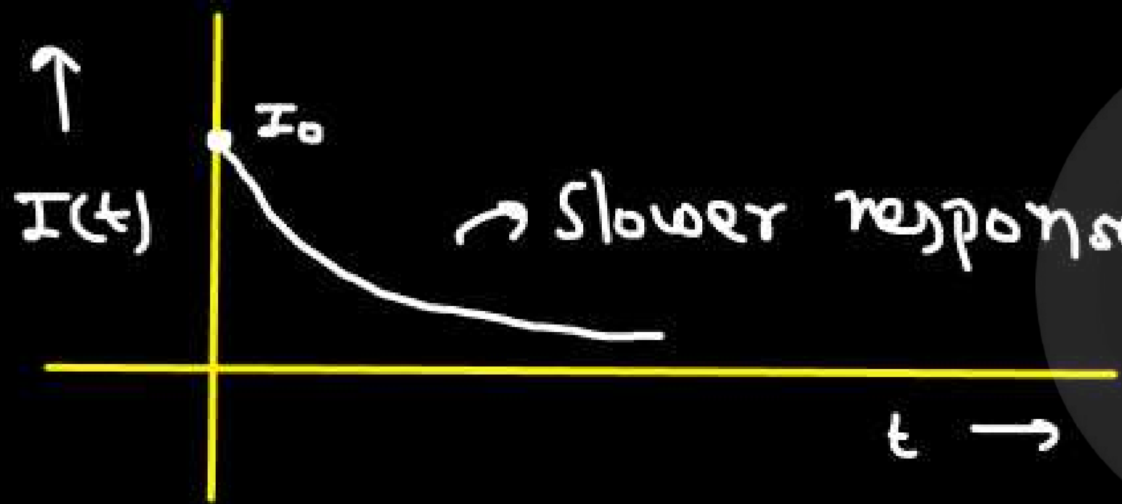
$$\frac{R}{2L} > \frac{1}{\sqrt{LC}}$$

$I(t)$:-

$$I(t) = c_1 e^{\lambda_1 t} + c_2 e^{\lambda_2 t}$$

$$I(0^+) = c_1 + c_2 = I_0$$

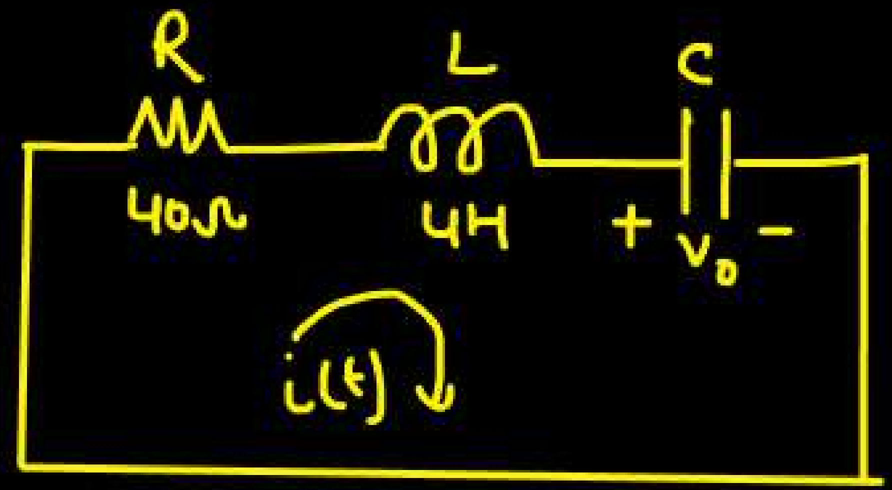
$$I(\infty) = 0$$



→ Slower response.

similarly for all other expressions.

Q. Find the value of capacitor C to have critically damped response.



→ For critically damped

$$\alpha = \omega_0$$

$$\frac{R}{2L} = \frac{1}{\sqrt{LC}}$$

$$\frac{40}{8} = \frac{1}{\sqrt{4C}}$$

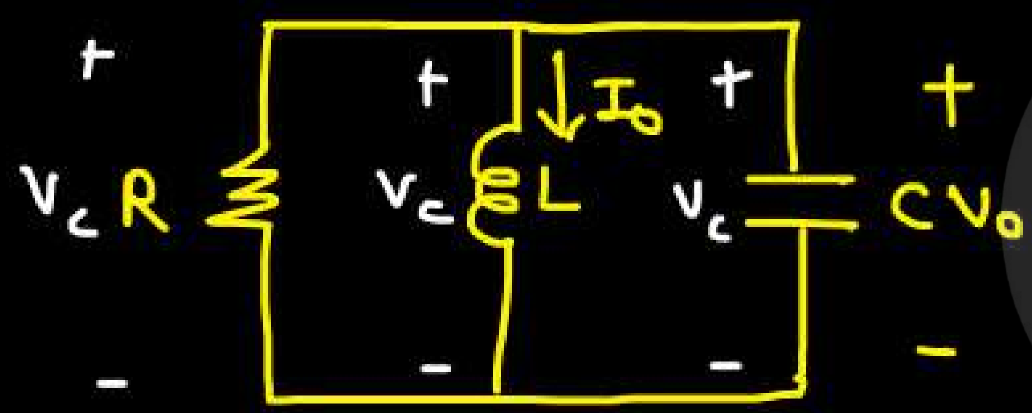
$$\boxed{C = 10\,\text{mF}}$$

★ Source-Free parallel RLC ckt :-

Let's assume,

inductor is having initial current of I_0.

capacitor is having initial voltage of V.



Applying KCL

$$\frac{C\,dV_c}{dt} + I_0 + \frac{1}{L}\int_{-\infty}^{t} V_c\,dt + \frac{V_c}{R} = 0$$

differentiate →

$$\frac{C\,d^2V_c(t)}{dt} + \frac{V_c(t)}{L} + \frac{1}{R}\frac{dV_c(t)}{dt} = 0$$

$$\frac{d^2V_c(t)}{dt} + \frac{1}{RC}\frac{dV_c(t)}{dt} + \frac{V_c(t)}{LC} = 0$$

$$\left[D^2 + \frac{1}{RC}D + \frac{1}{LC}\right]V_c(t) = 0$$

$$f(D)$$

$$D^2 + \frac{1}{RC}D + \frac{1}{LC} = 0$$

$$D = -\frac{1}{2RC} \pm \sqrt{\left(\frac{1}{2RC}\right)^2 - \left(\frac{1}{\sqrt{LC}}\right)^2}$$

$$\text{roots} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$$

$$\boxed{\alpha = \frac{1}{2RC}} \; ; \quad \omega_0 = \frac{1}{\sqrt{LC}}$$

$$\text{Roots} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$$

$$\alpha = \frac{1}{2RC}, \quad \omega_0 = \frac{1}{\sqrt{LC}}$$

* **Underdamped response:-**

$$\alpha < \omega_0 \Rightarrow \frac{1}{2RC} < \frac{1}{\sqrt{LC}}$$

$$y(t) = e^{-\alpha t}\left[c_1 \cos \omega_d t + c_2 \sin \omega_d t\right]$$

* **Critically damped response:-**

$$\alpha = \omega_0 \Rightarrow \frac{1}{2RC} = \frac{1}{\sqrt{LC}}$$

$$y(t) = \left[c_1 + c_2 t\right] e^{-\alpha t}$$

* **Overdamped response:-**

$$\alpha > \omega_0 \Rightarrow \frac{1}{2RC} > \frac{1}{\sqrt{LC}}$$

$$y(t) = c_1 e^{\lambda_1 t} + c_2 e^{\lambda_2 t}$$

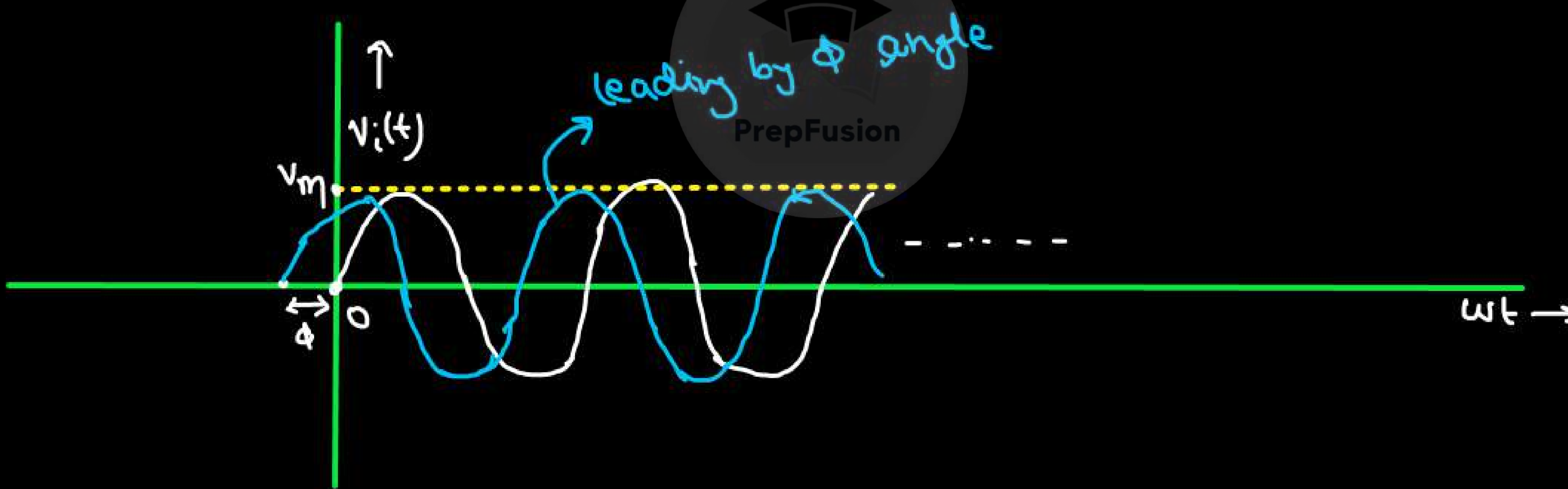
$$\left.\begin{aligned} \lambda_1 &= -\alpha + \sqrt{\alpha^2 - \omega_0^2} \\ \lambda_2 &= -\alpha - \sqrt{\alpha^2 - \omega_0^2} \end{aligned}\right\} \rightarrow \text{negative values}$$

Sinusoidal steady state analysis:-

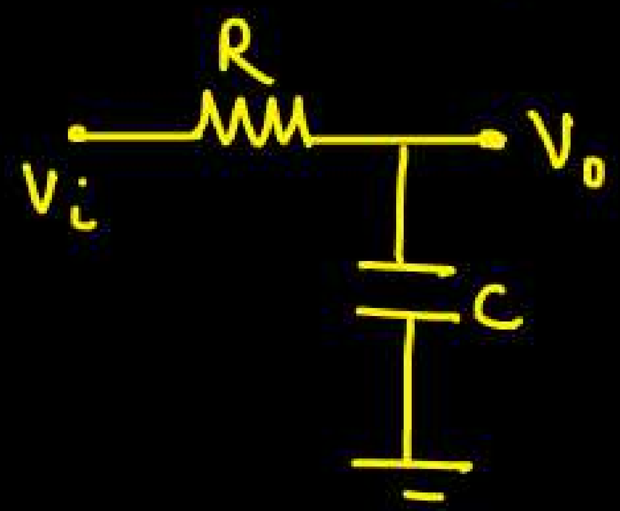
* Draw waveforms:-

(a) $v_i(t) = V_m \sin\omega t$

(b) $v_i(t) = V_m \sin(\omega t + \phi)$



Q. Find $H(j\omega)$.

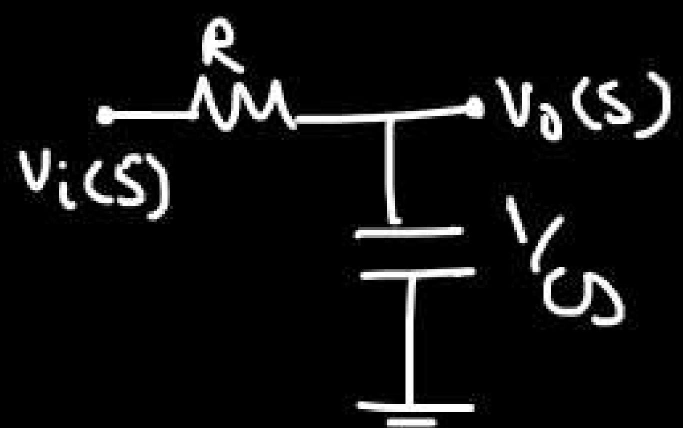


$\Rightarrow$

$\Downarrow$

Impulse response of a system

$\Rightarrow$



$$\frac{V_0(S)}{V_i(S)} = \frac{1}{RCS+1}$$

$$\boxed{H(S) = \frac{1}{1+RCS}}$$

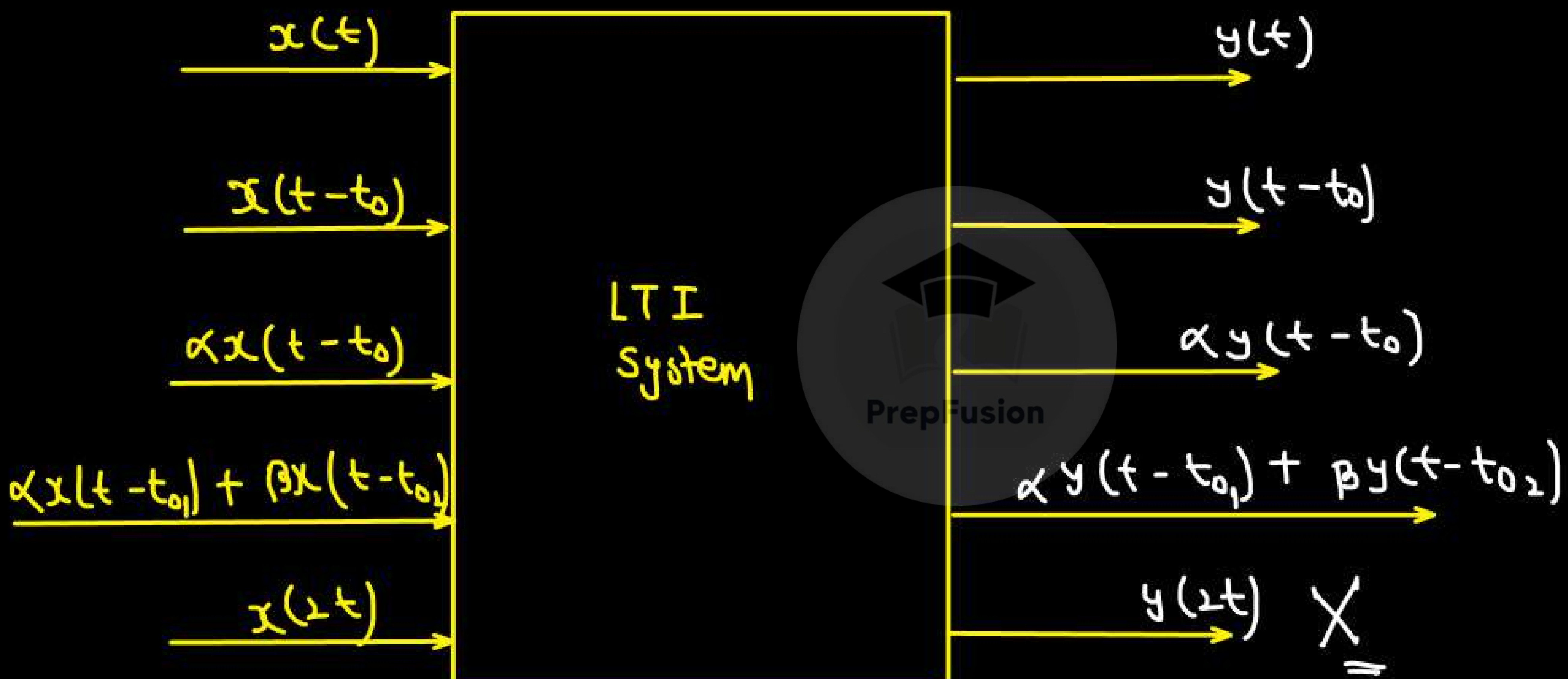
$\Rightarrow$ $s = j\omega$

$$\boxed{H(j\omega) = \frac{1}{j\omega RC+1}}$$

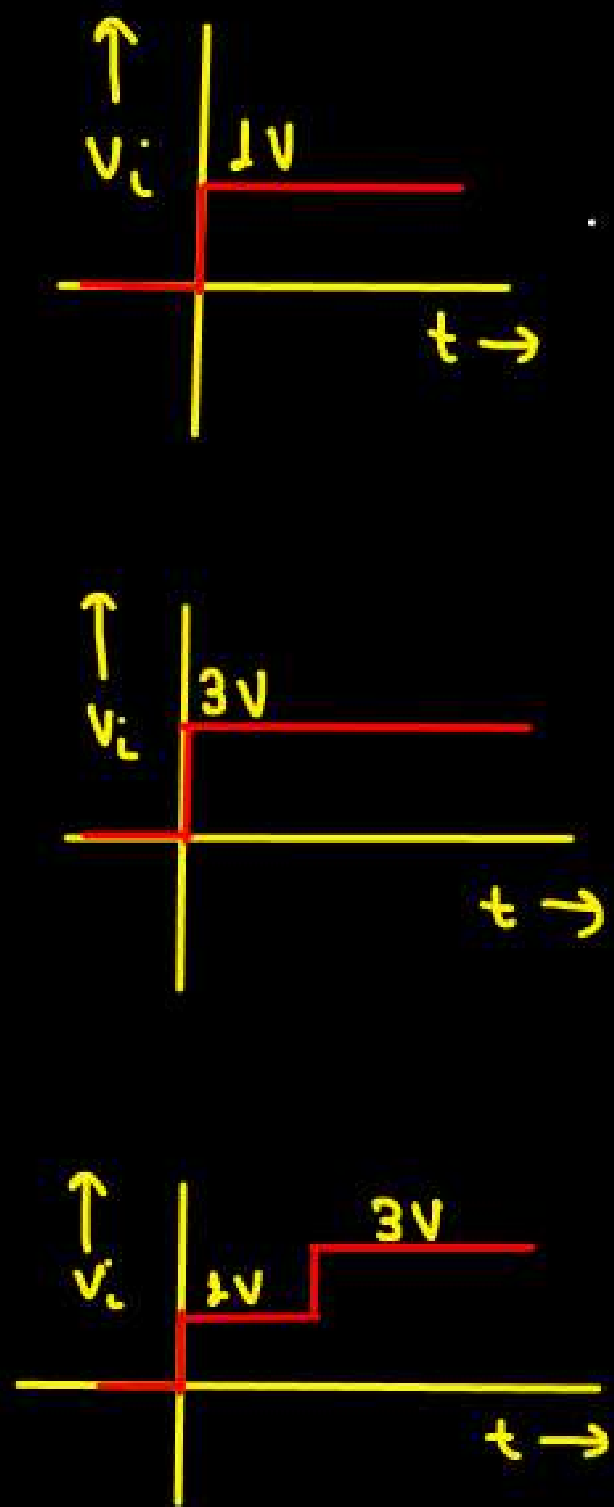
$$|H(j\omega)| = \frac{1}{\sqrt{\omega^2R^2C^2+1}}$$

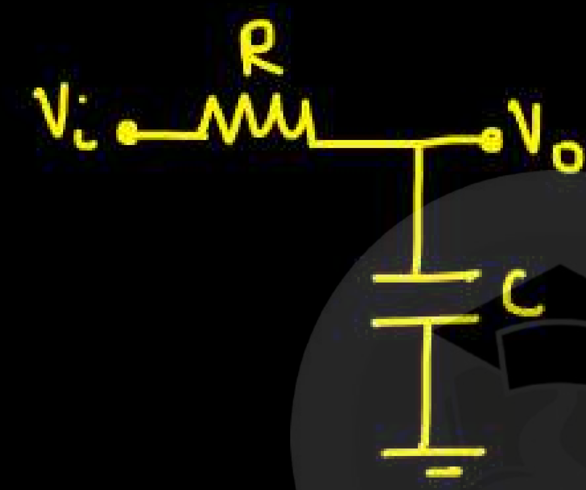
$$\angle H(j\omega) = -\tan^{-1}(\omega RC)$$

For a LTI (Linear Time Invariant) System :-



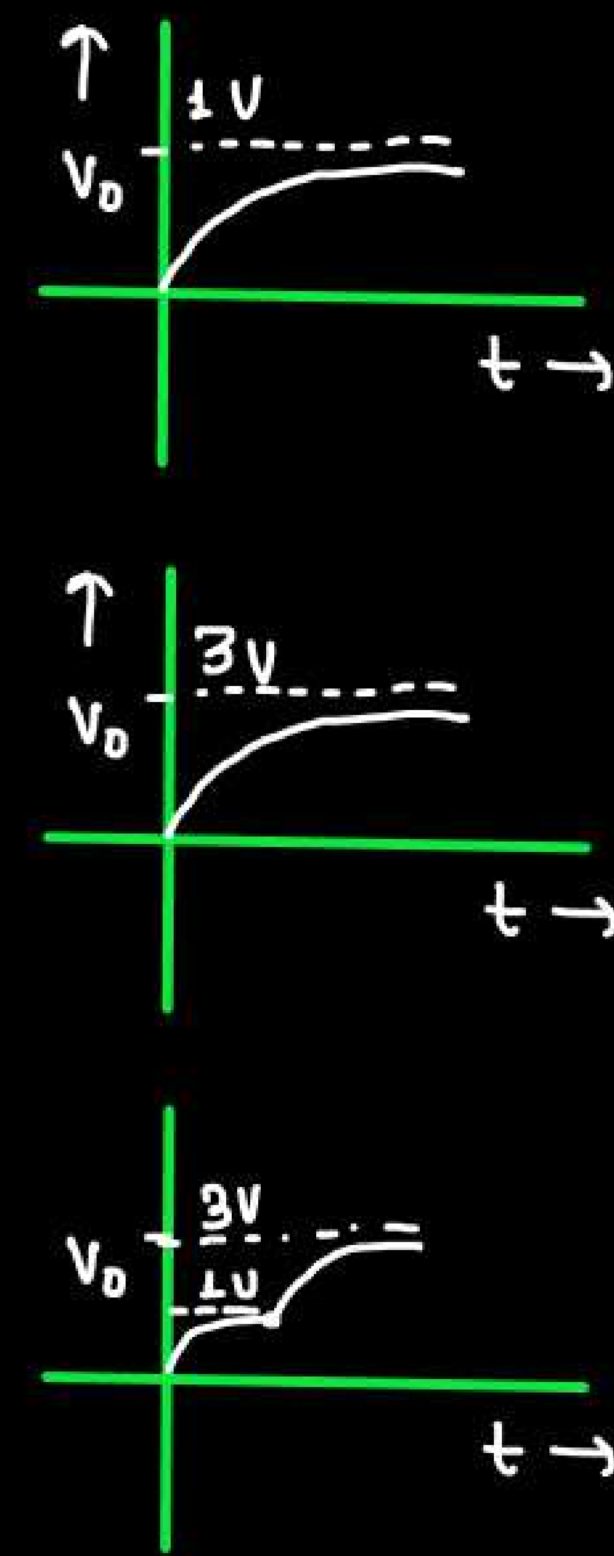
N.B. :- scaling in time domain will not result similarly in the o/p.





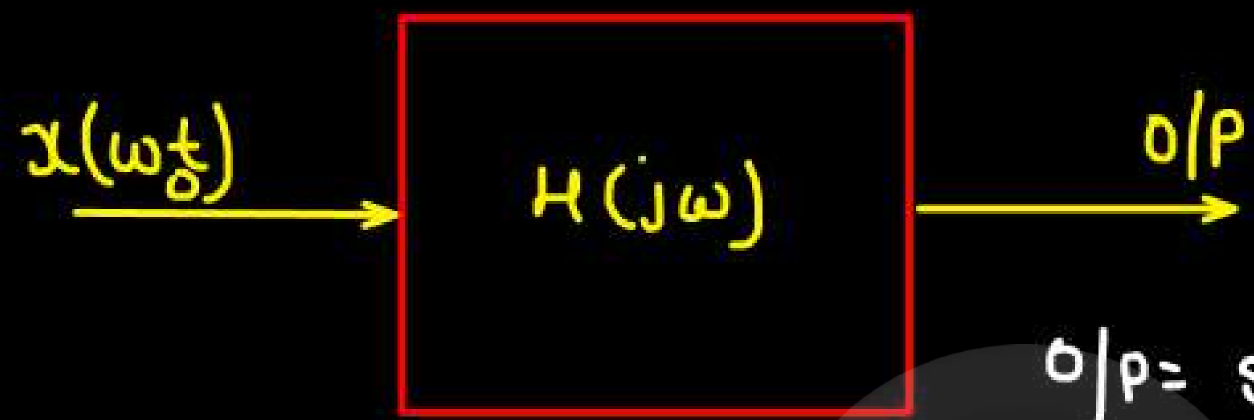
⇓

LTI S|S



Sinusoid steady state response :-

$$x(\omega_0 t) = A\sin(\omega_0 t)$$
$$= B\cos(\omega_0 t)$$
$$= C e^{j\omega_0 t}$$

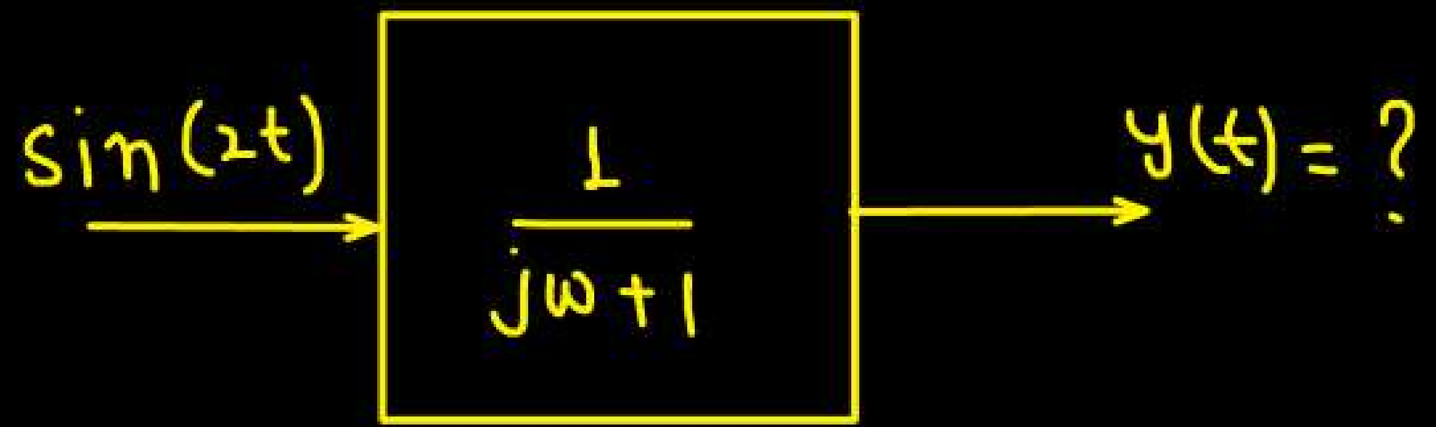


o/p = steady state response + Transient response

Here, I will be only talking about steady state response.

$$(o/p)_{\text{steady o/p}} = |H(j\omega_0)|\, x\left[\omega_0 t + \angle H(j\omega_0)\right]$$

Q.



Find y(t) @ steady state

→

$$H(j\omega) = \frac{1}{j\omega+1}$$

$$|H(j\omega)| = \frac{1}{\sqrt{\omega^2+1}}$$

$$\angle H(j\omega) = -\tan^{-1}(\omega)$$

$$\Rightarrow H(j\omega) = \frac{1}{\sqrt{\omega^2+1}} \angle -\tan^{-1}(\omega)$$

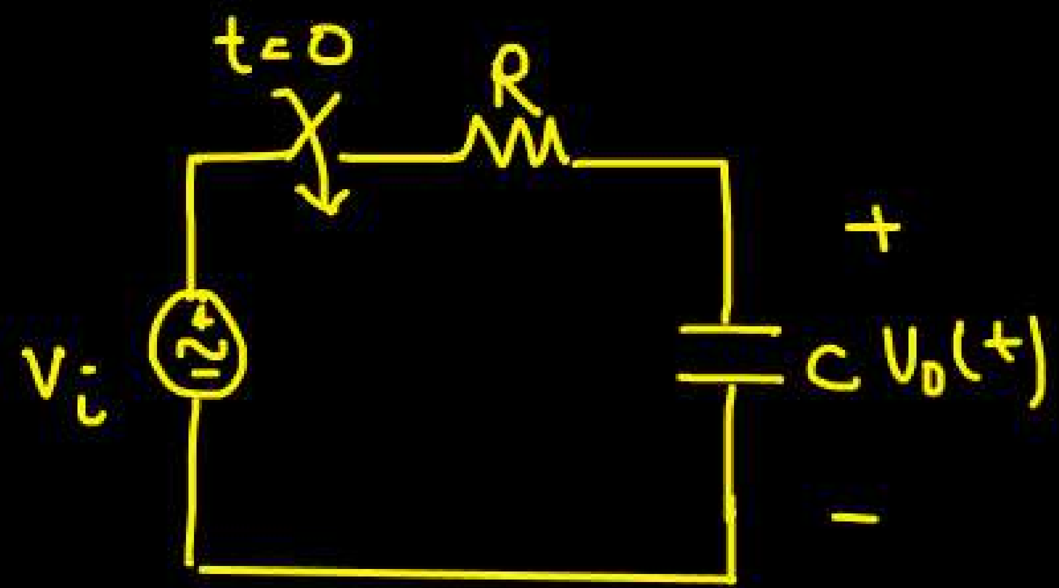
$$i/p = \sin(2t)$$

$$\omega_0 = 2$$

$$H(j2) = \frac{1}{\sqrt{5}} \angle -\tan^{-1}(2)$$

$$\boxed{y(t) = \frac{1}{\sqrt{5}} \sin(2t - \tan^{-1} 2)}$$ ⇒ steady state o/p

Q.



$v_i(t) = 5\sin(t)$; $RC = 1$ se

Find $v_0(t)$.

$\rightarrow$ $V_i(t) = 5\sin(t)$

$$V_0(s) = \frac{1}{1+RCs} V_i(s)$$

$$H(j\omega) = \frac{V_0(j\omega)}{V_i(j\omega)} = \frac{1}{1+j\omega RC} = \frac{1}{1+j\omega}$$

$$V_i(j\omega) \longrightarrow \boxed{\frac{1}{1+j\omega}} \longrightarrow V_0(j\omega)$$

$$\boxed{V_0(j\omega) = \underbrace{\frac{1}{1+j\omega}}_{H(\omega)} V_i(j\omega)} \Rightarrow \text{freq. domain}$$

$v_i(t) = 5\sin t$

Here $\omega_0 = 1$

$$H(\omega) = \frac{1}{1+j}$$

$$\Rightarrow H(\omega) = \frac{1}{\sqrt{2}} \angle -45^\circ$$

$$\boxed{v_0(t) = \frac{5}{\sqrt{2}} \sin(t - 45^\circ)} \quad \times$$

@ $t=0$; cap. will have zero voltage. $\Rightarrow v_0(0^+) = 0V$

now, our $\boxed{V_0(t) = \frac{5}{\sqrt{2}} \sin(t - 45^\circ)}$

@ $t = 0^+$ $\quad V_0(0^+) = \frac{5}{\sqrt{2}} \sin(-45^\circ) = -\frac{5}{2} V$

$$= -2.5V$$

so $V_0(t) = \frac{5}{\sqrt{2}} \sin(t - 45^\circ)$ is not your final o/p but steady state response

$$[V_0(t)]_{s.s.} = \frac{5}{\sqrt{2}} \sin(t - 45^\circ)$$

$$[V_0(t)]_{tr.} = ?$$

from s.s. response, @ $t=0$ you are getting $-2.5V$

But conceptually $V_0(0^+)$ should be zero voltage

$\Downarrow$

So, there has to be some transient response

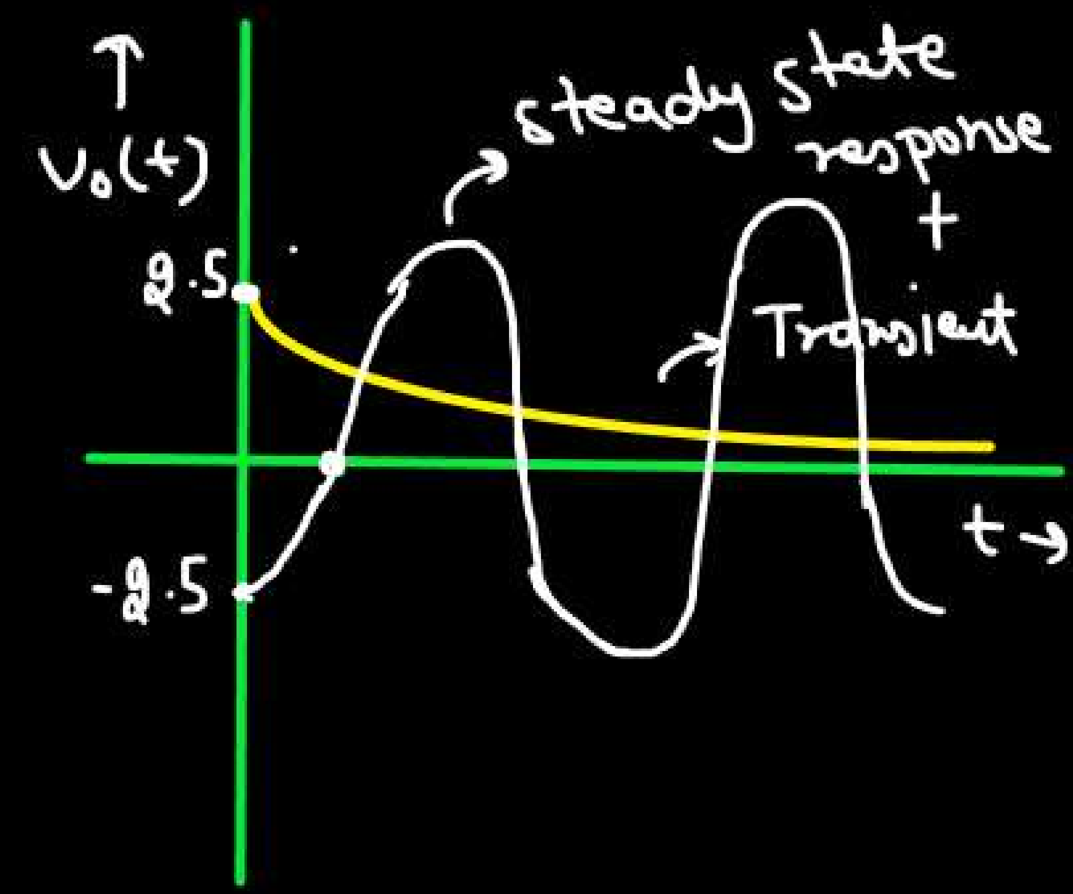
that kills out $-2.5V$

$$[V_0(t)]_{tr} = 2.5e^{-t/\tau} \quad ; \quad \tau = RC = 1\text{sec.}$$

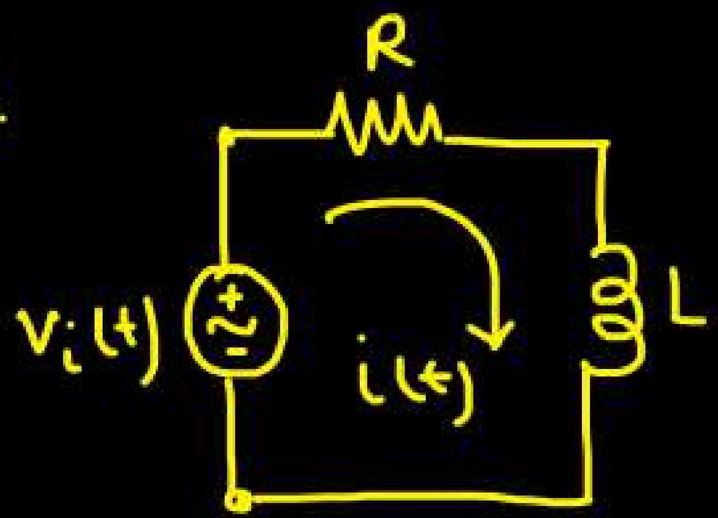
$$\boxed{V_0(t) = \left[\frac{5}{\sqrt{2}}\sin(t-45^\circ) + 2.5e^{-t/\tau}\right]u(t)}$$

$\Downarrow$ S.S o/p

$\Downarrow$ Transient o/p



Q.



$$V_i(t) = [5\sin(t)]\,u(t)$$

$R = 1\,\Omega, \quad L = 1\,H$

Find $I(t)$

$\rightarrow$ $$V_i(s) = (R + Ls)\, I(s)$$

$$\frac{I(s)}{V_i(s)} = H(s) = \frac{1}{R + Ls}$$

$$H(j\omega) = \frac{1}{R + j\omega L}$$

$$V_i(j\omega) \rightarrow \boxed{\frac{1}{R + j\omega L} = \frac{1}{1 + j\omega}} \rightarrow I(j\omega)$$

$$H(j\omega) = \frac{1}{1+j\omega}$$

$$V_i(t) = 5 \sin t$$

$$\omega_0 = 1 \text{ rad/sec.}$$

$$H(j1) = \frac{1}{1+j}$$

$$= \frac{1}{\sqrt{2}} \angle -45^\circ$$

$$\boxed{[I(t)]_{s.s} = \frac{5}{\sqrt{2}} \sin(t - 45^\circ)}$$

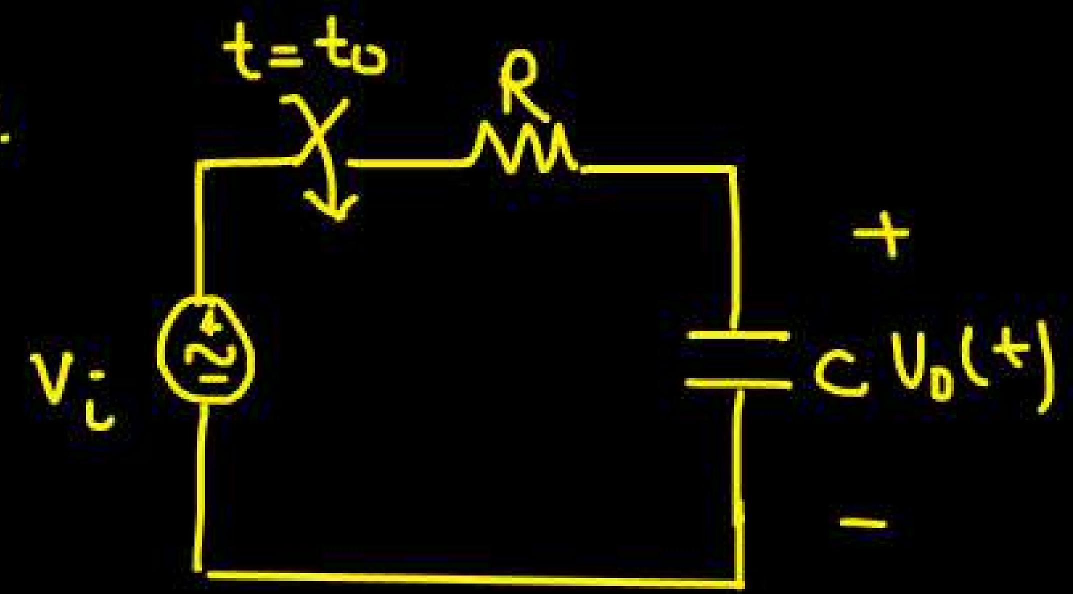
@ $t = 0^+$ $[I(t)]_{s.s.} = -5/2 = -2.5$ Amp.

But conceptualy $I(0^+) = 0$ Amp.

$$[I(t)]_{tr} = 2.5e^{-t/\tau}\,u(t) \qquad \tau = L/R = 1\,\text{sec.}$$

$$\boxed{I(t) = \left[\frac{5}{\sqrt{2}}\sin(t-45^\circ) + 2.5e^{-t/\tau}\right]u(t)}$$

Q.



$v_i(t) = 5\sin(t)$ $\quad RC = 1$ se

Find time t_0 such that $v_0(t)$ doesn't have any transient component.

→

$$V_0(j\omega) = \frac{1}{1 + j\omega RC} V_i(j\omega)$$

$$\omega_0 = 1 \;, \quad RC = 1\,\text{sec.}$$

$$\boxed{v_0(t) = \frac{5}{\sqrt{2}} \sin(t - 45^\circ)\, u(t - t_0)}$$ → Steady state

when you turn on the switch, cap. will want zero voltage across it

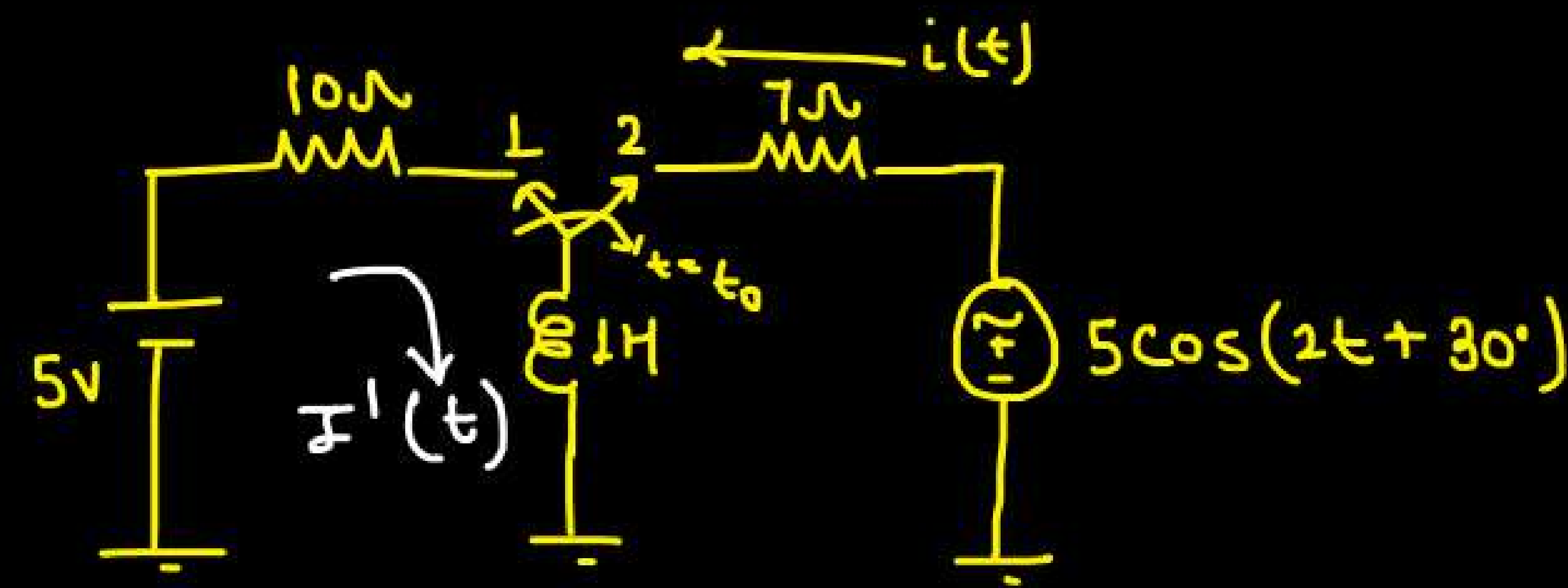
$$V_o(t_0^-) = v_o(t_0^+) = 0\,V$$

$$\frac{5}{\sqrt{2}}\sin(t_0 - 45^\circ) = 0\,V$$

$$t_0 = 45 \times \frac{\pi}{180}$$

$$\boxed{t_0 = 0.78\,\text{sec.}}$$

Q.

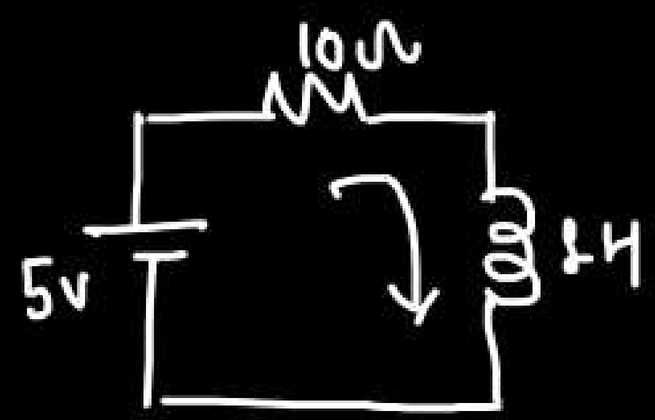


The swith is at position 1 for a long time.

It's moved to position 2 @ $t = t_0$.

Find the value of t_0 such that current $i(t)$ is transient-free.

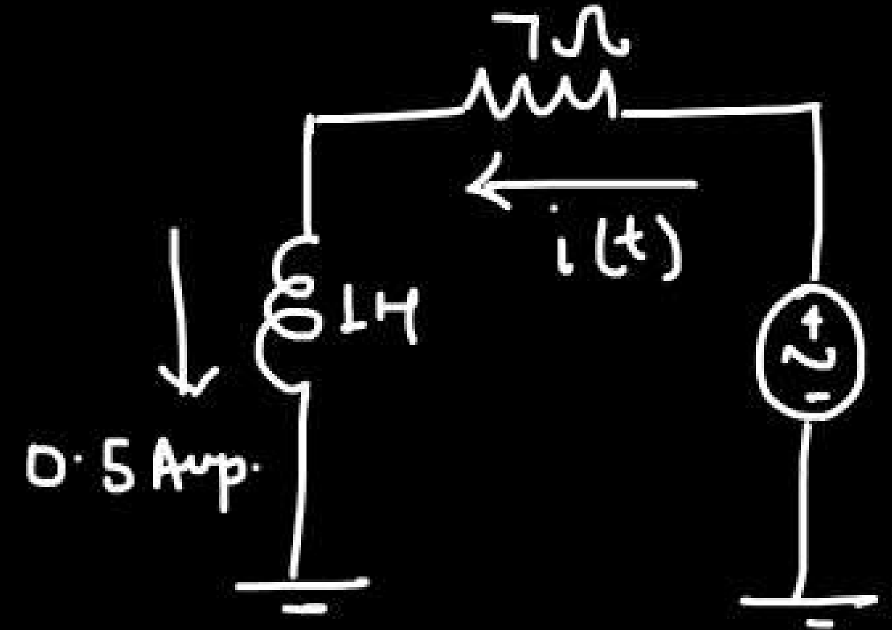
→ for $t < t_0$



Steady state would have been reached.

$$I'(t_0^-) = \frac{5}{10} = 0.5 \text{ Amp}$$

For $t > t_0$



$5\cos(2t + 30^\circ) = v_i(t)$

@ $t = t_0$; this RL ckt sees an input $= 5\cos(2t + 30^\circ)$

$[i(t)]_{S.S.} = ?$

$V_i(j\omega) = I(j\omega)[7 + j\omega]$ $\{L = 1H\}$

$I(j\omega) = \dfrac{V_i(j\omega)}{7 + j\omega}$ $\quad \omega_0 = 2$ rad/sec

$$\boxed{i(t) = \frac{5}{\sqrt{53}}\cos\left[2t + 30^\circ - \tan^{-1}(2/7)\right]}$$

⇒ steady state

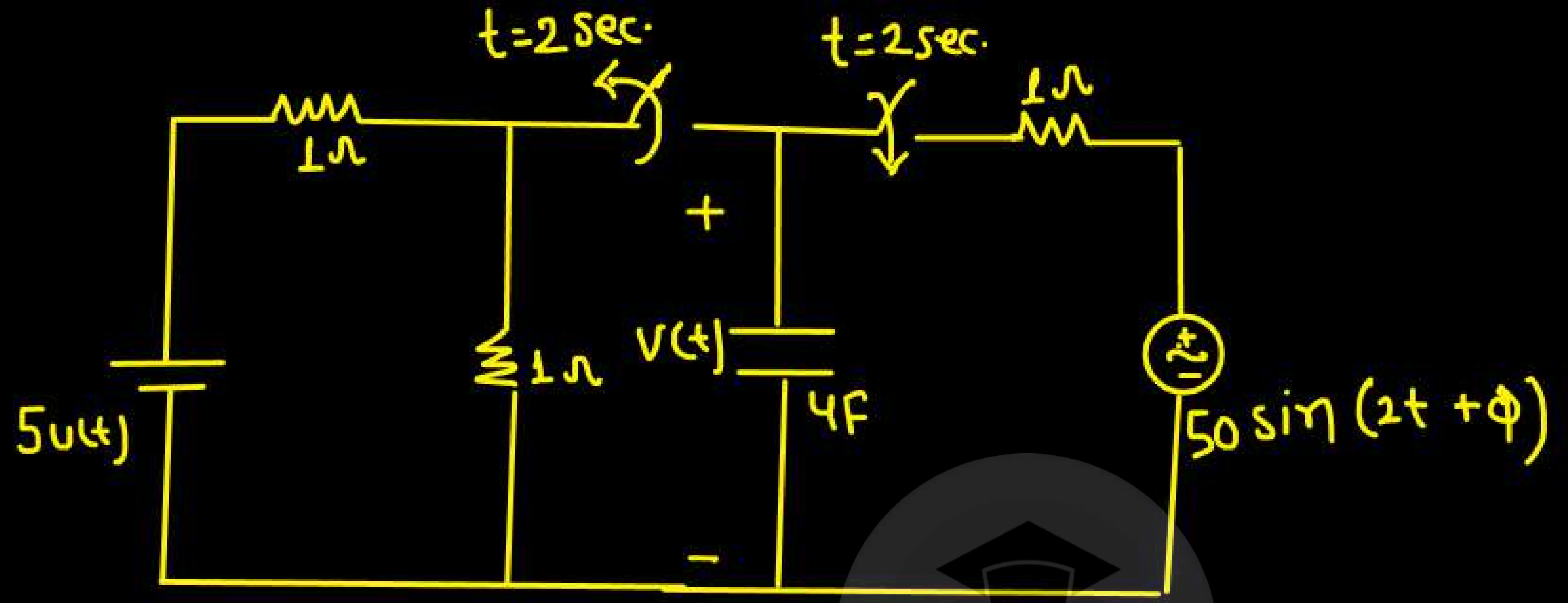
To get a transient free response.

$$I(t_0) = 0.5\,\text{Amp} \qquad \{ I(t_0^-) = 0.5\,\text{Amp} \}$$

$$\frac{5}{\sqrt{53}} \cos\left[2t_0 + \frac{\pi}{6} - \tan^{-1}\left(\frac{2}{7}\right)\right] = 0.5$$

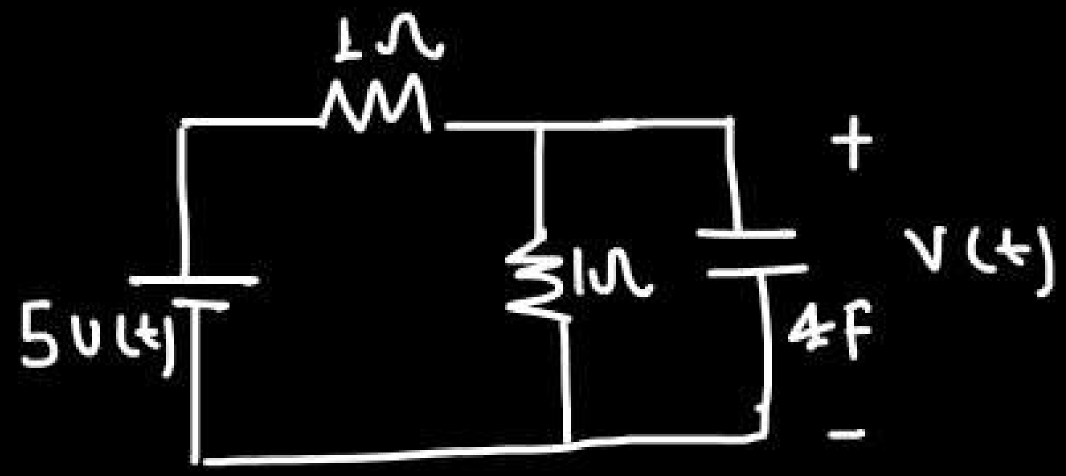
$$\boxed{t_0 = 0.26\ \text{sec.}}$$

Q.



Find the value of Φ such that $v(t)$ has a transient component of maximum amplitude of $0.5\,V$.

→ For $0 \leq t < 2$ sec.



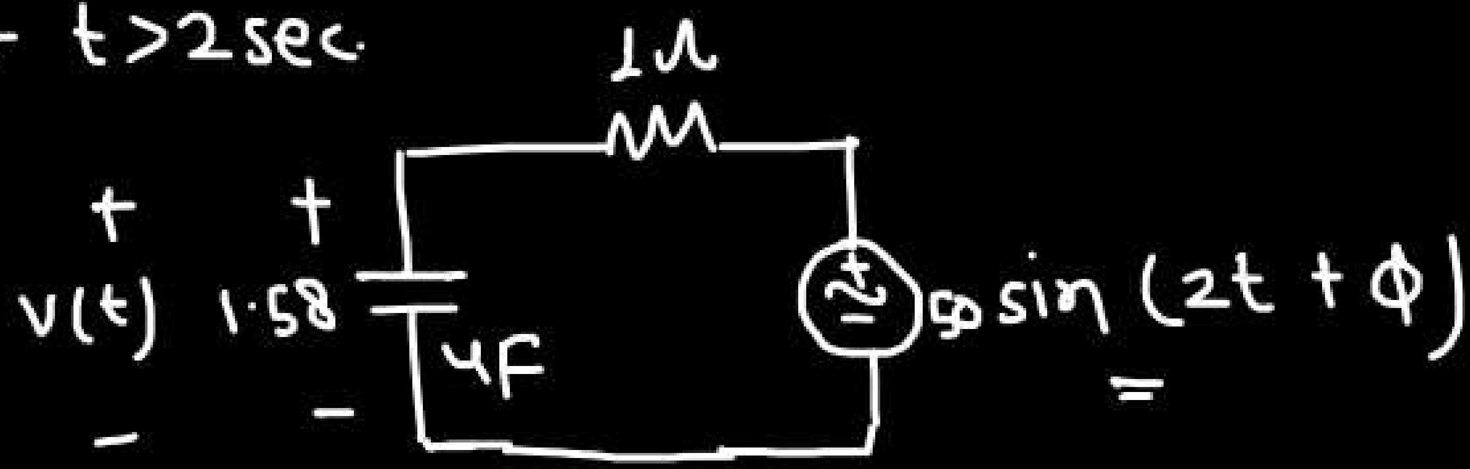
$$v(t) = 2.5\left[1 - e^{-t/\tau}\right]u(t)$$

$$\tau = \frac{1}{2} \times 4 = 2\text{ sec.}$$

$$v(2\text{ sec.}) = 2.5\left[1 - e^{-2/2}\right]$$

$$\boxed{v(2\text{ sec.}) = 1.58\text{ V}}$$

For $t > 2$ sec.



$$v(j\omega) = \frac{v_i(j\omega)}{1 + j\omega RC}$$

$\omega_0 = 2$, $RC = 4$ sec.

$$v(j\omega) = \frac{1}{1+8j} v_i(j\omega)$$

$$\boxed{v(t) = \frac{1}{\sqrt{65}} \times 50\sin\left[2t + \phi - \tan^{-1}(8)\right] u(t-2)}$$ → steady state response

actual o/p required

$$v(t) = \left[\frac{50}{\sqrt{65}} \sin\left[2t + \phi - \tan^{-1}(8)\right] + 0.5 e^{-(t-2)/\tau}\right] u(t-2)$$

@ $t = 2\,\text{sec}$, $V(2\,\text{sec}) = 1.58\,V$

$$\frac{50}{\sqrt{65}} \sin\left[4 + \phi - \tan^{-1}(8)\right] + 0.5 = 1.58$$

$$\frac{50}{\sqrt{65}} \sin\left[4 + \phi - \tan^{-1}(8)\right] = 1.08$$

$$\boxed{\phi = -136.27^\circ}$$

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ANALOG ELECTRONICS

CHAPTER 1 : DIODE CIRCUITS

↳ Basic Semiconductor Physics :-

Material
(Based on conductivity)

Conductor

↳ Allows flow of charge.

Eg → Copper, Brass, Steel, Gold etc.

**** Semiconductor**

↳ Moderately allows flow of charge

⇓

[conductivity can change by adding impurity]

Eg. → Si, Ge, GaAs

Insulator

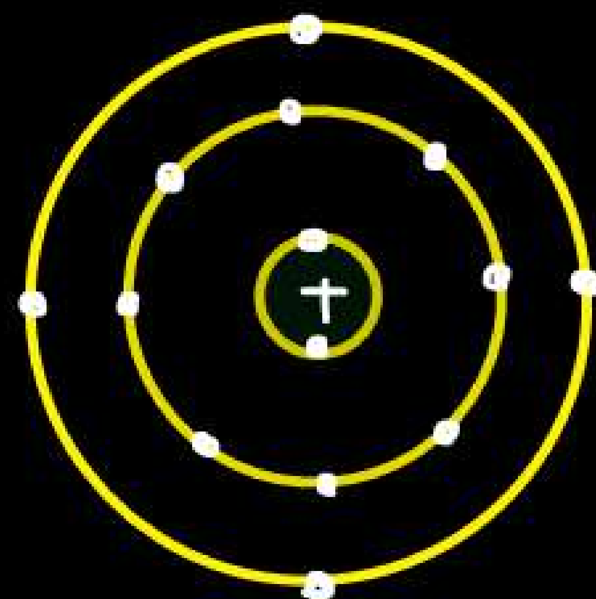
↳ Hardly allows flow of charge

Eg. → Glass, air, wood

Semiconductor :-

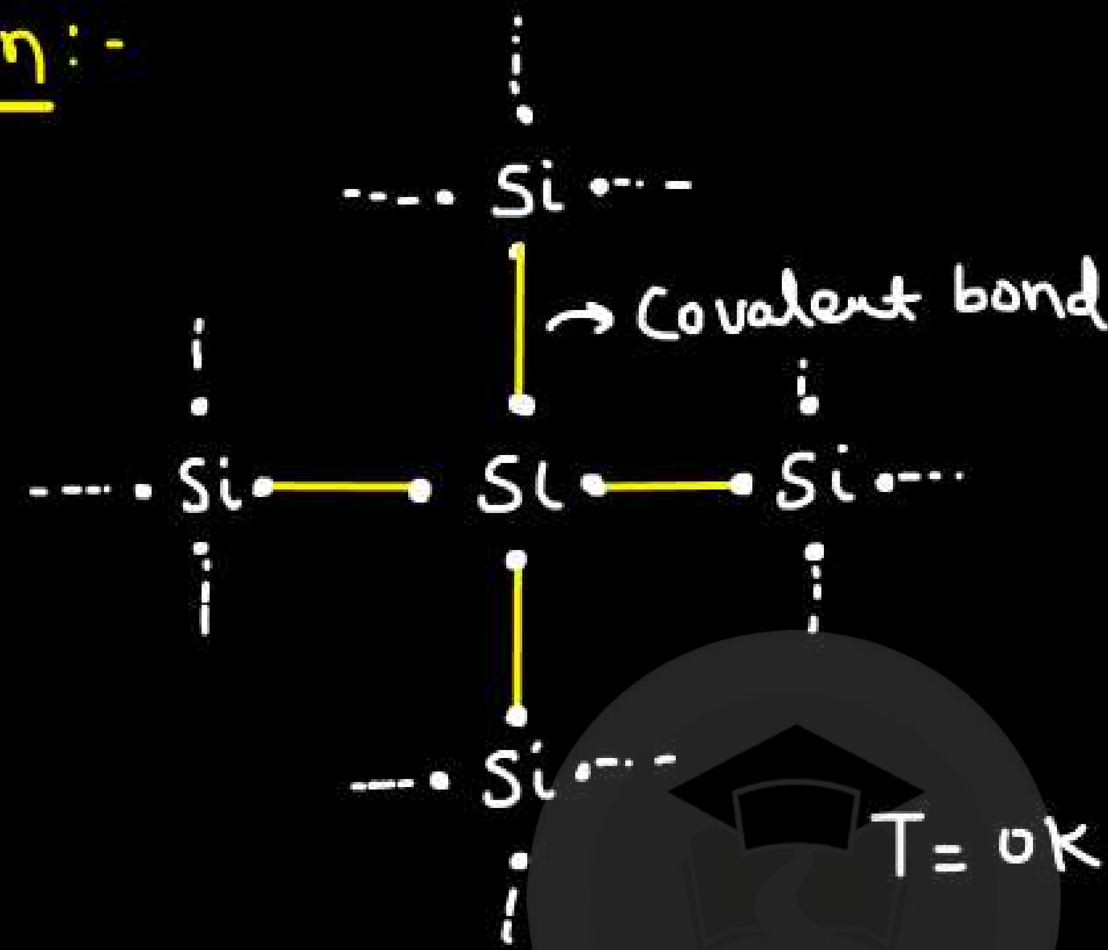
Eg. → $Si \Rightarrow 1s^2 \; 2s^2 \; 2p^6 \; \overbrace{3s^2 \; 3p^2}^{4e^{\ominus}}$

(Electronic configuration)



Outermost orbit has 4 valence electrons.

Crystal of silicon:-



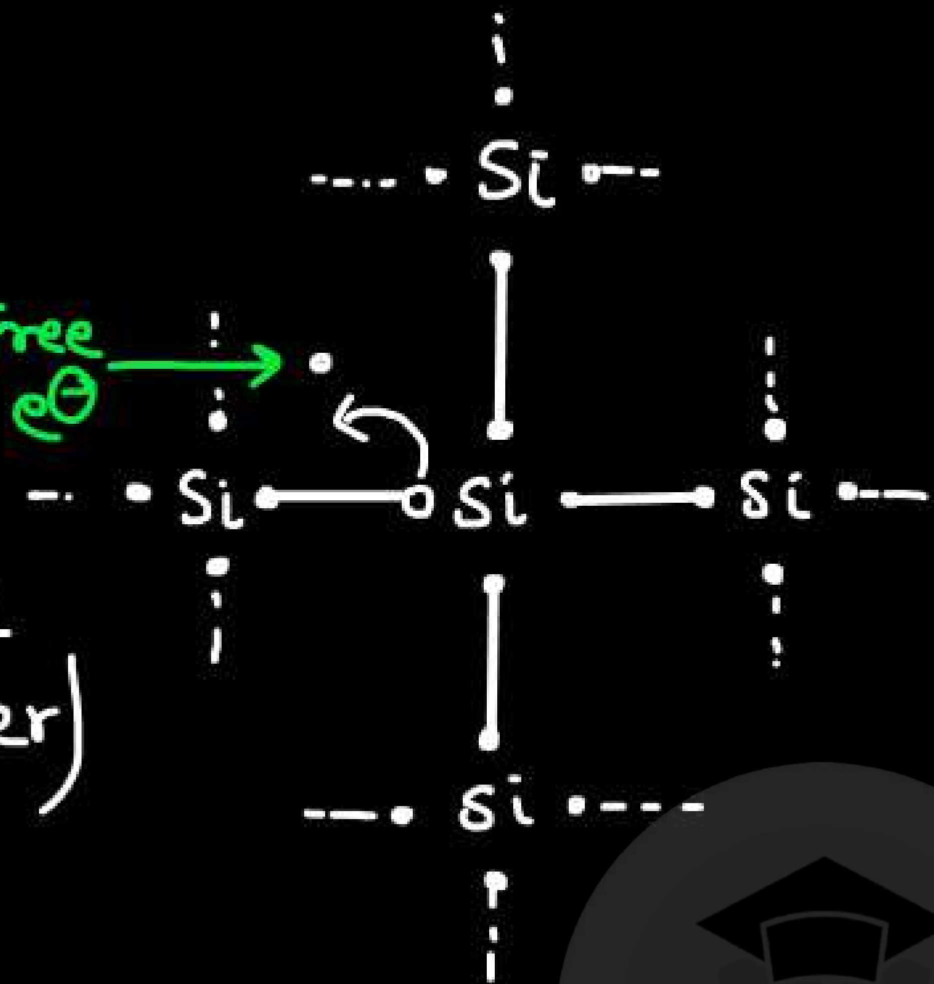
$T = 0K \mid -273^\circ C$

For $T > 0K \Rightarrow$ (@ room's temp.)

Due to thermal energy, some $e^{\ominus}$ gets enough energy to break this covalent bond.

Free $e^{\ominus}$

(Charge carrier)



$\bullet \rightarrow$ electron

$\circ \rightarrow$ Hole

Hole ($\circ$) $\rightarrow$ absense of $e^{\ominus}$

Semiconductors

- **Intrinsic**
  Pure semiconductor
- **Extrinsic**
  (Semiconductor with impurities)
  - p-type
  - n-type

P- type Semiconductors:-

Trivelent atoms are added in the s/c.

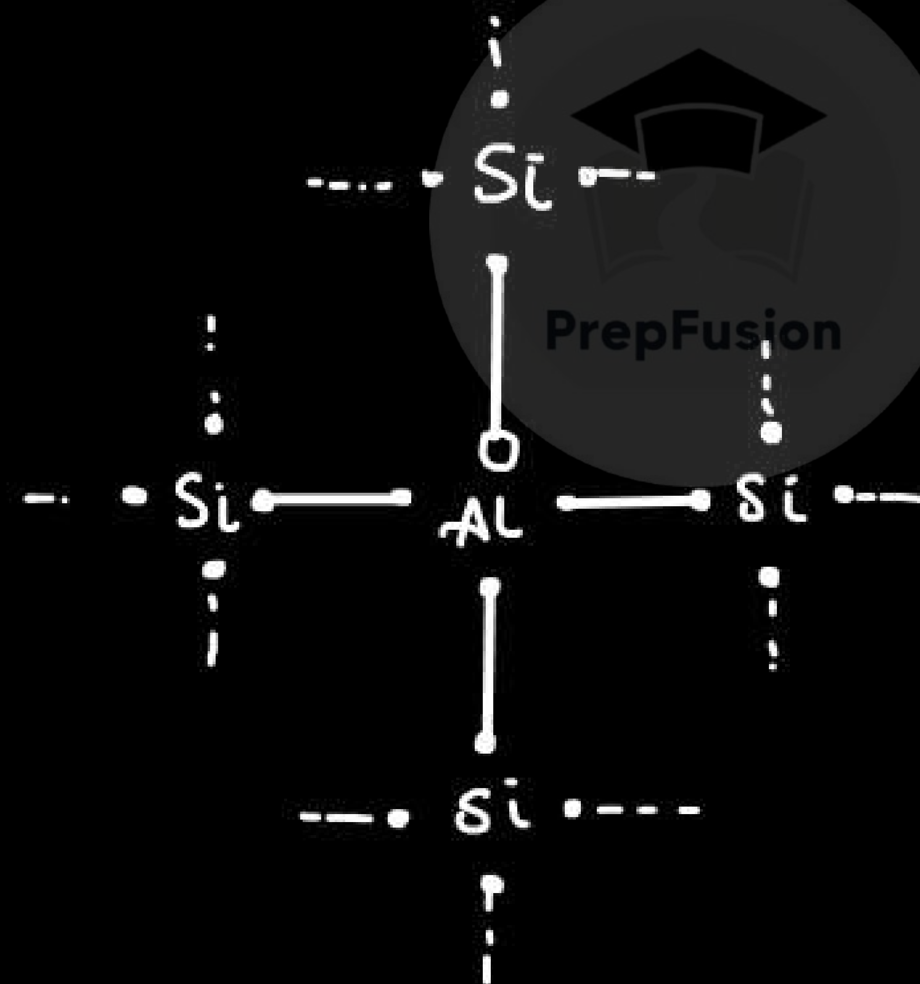
Acceptor atom ⇐ (B, Al, Ga)

→ outermost orbit having 3 free $e^{\ominus}$.

$3e^{\ominus}$ B, $4e^{\ominus}$ C, $5e^{\ominus}$ N

·B·
 ·

 ·
·Al·



doping

[Introducing Impurity]

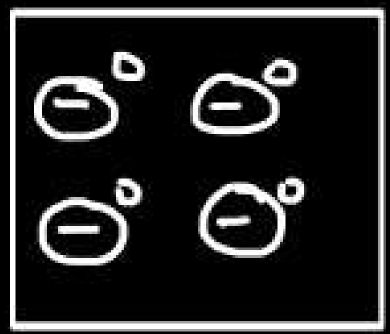
Introduced Hole

Here, "Al" can accept electrons.

→ It will create negative ion.

P-type → $\ominus^{\circ}$

P-type semiconductor:-



⇒ Electrical netural

(Majority charge carrier → Holes)

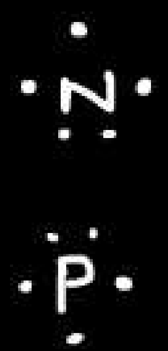
minority charge carrier → electron)

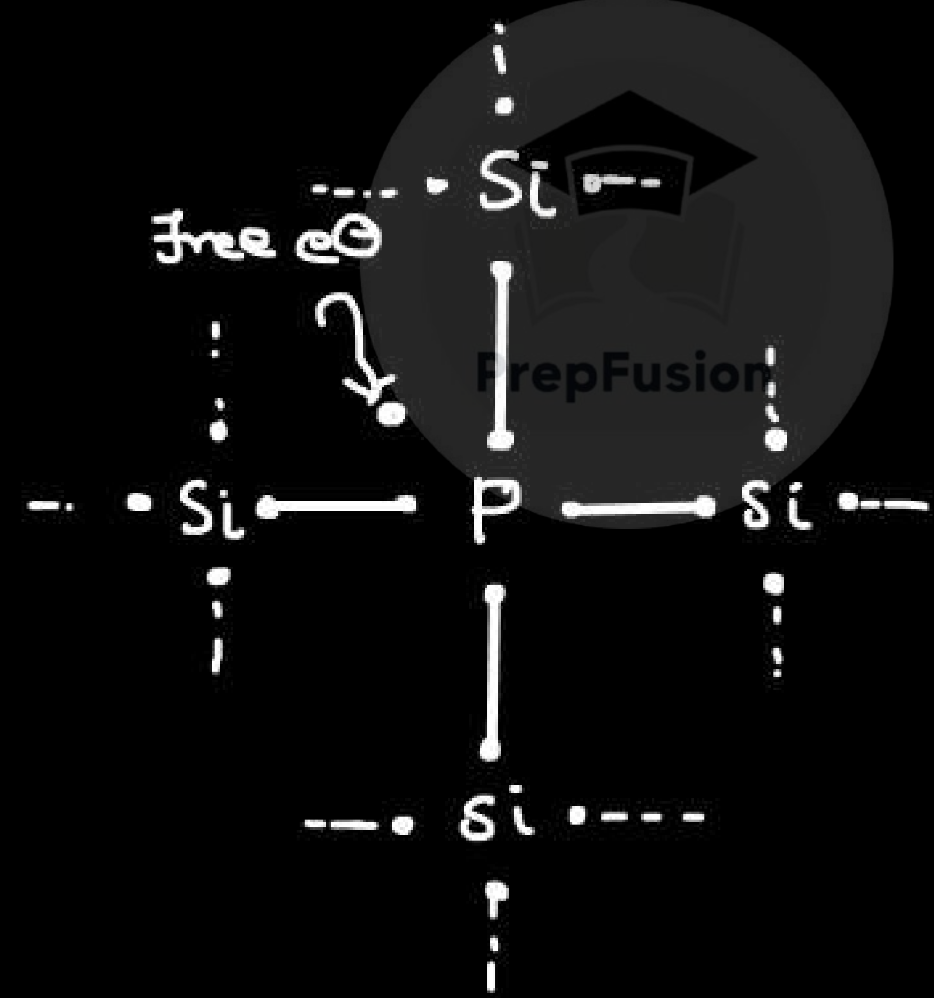
n-type Semiconductor:-

Pentavalent atoms are added in the s/c.

Donor atoms ⇐ (N, P, As) → Nitrogen, Phosphorus, Arsenic

→ outermost orbit have 5 free electrons.





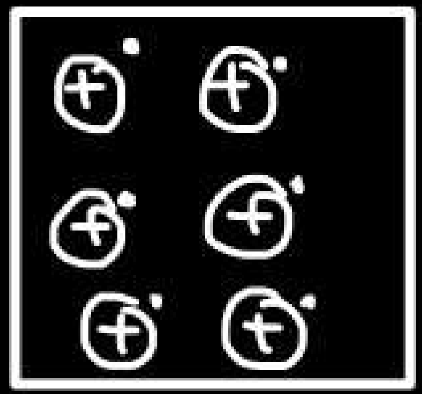
Here, "P" provides electrons.

→ It will create +ve ion

n-type → ⊕•

ions: ⊖° , ⊕• — charge carrier

n-type semiconductor →



⇒ Electrically netural

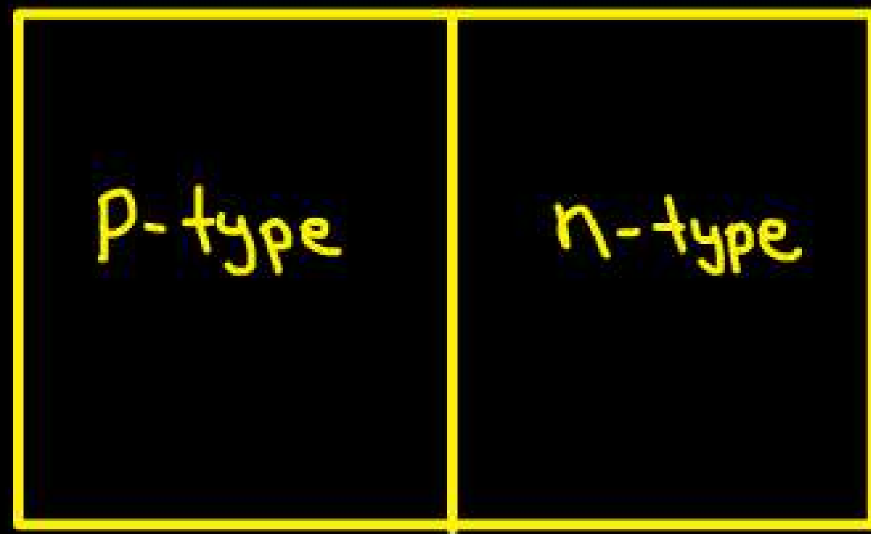
(Majority charge carrier → electrons

Minority charge carrier → Holes)

<u>N.B.</u> → When there is no external force applied across the s/c, it will not generate any current.

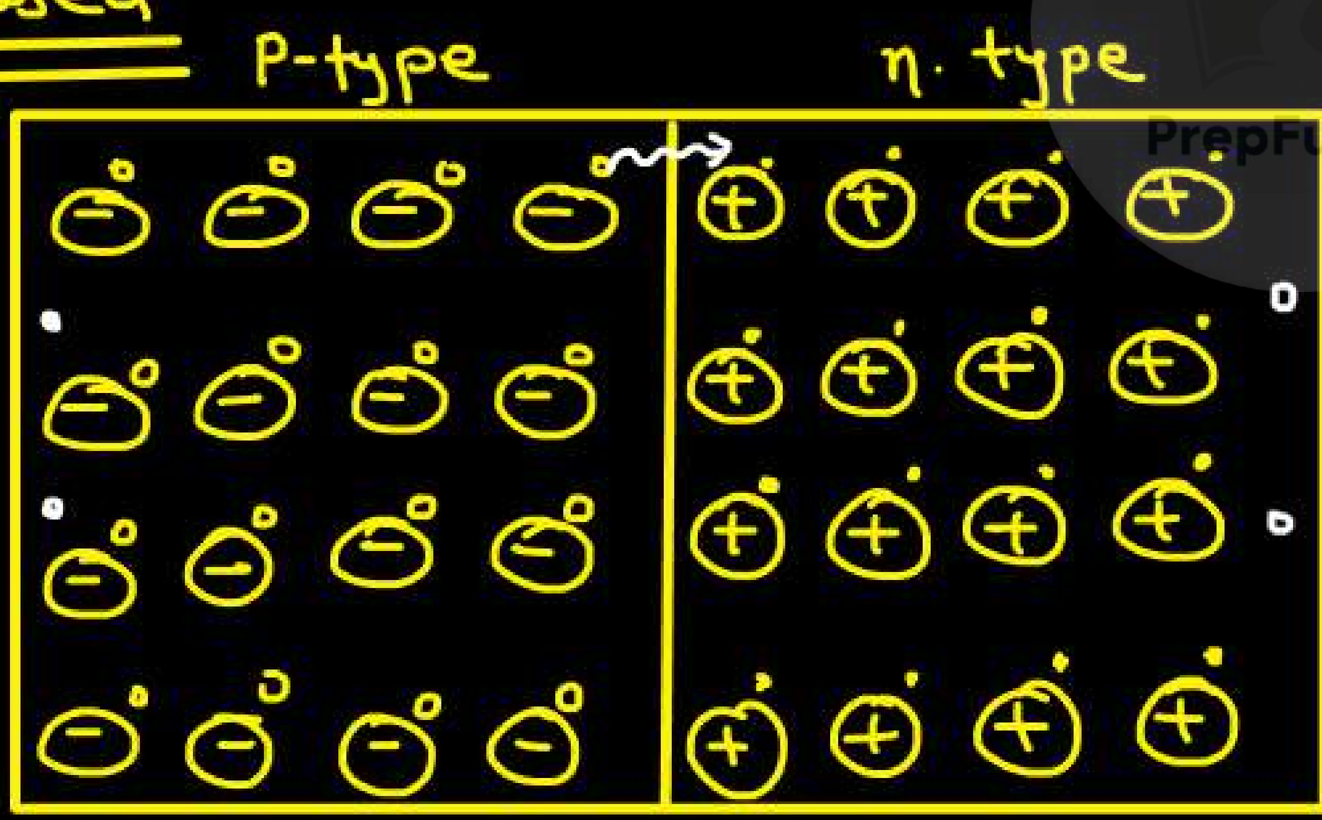
PN - Junction

Formation:-

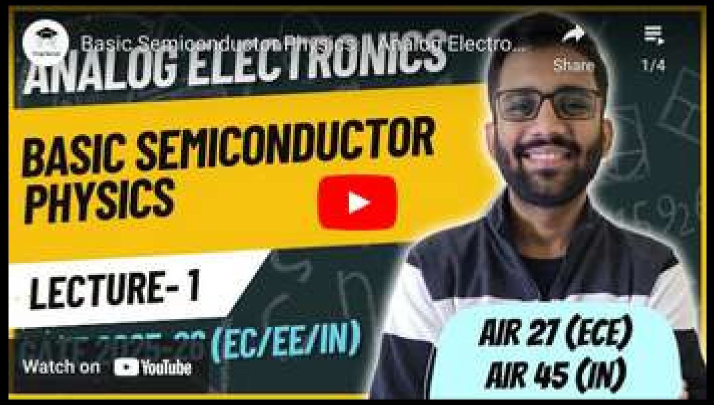


Biasing ⇒ Giving supply

Unbiased



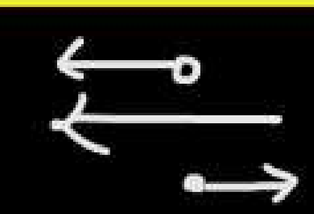
⇒ Due to potential gradient, Holes are diffusing towards electrons and electrons are diffusing toward Holes.



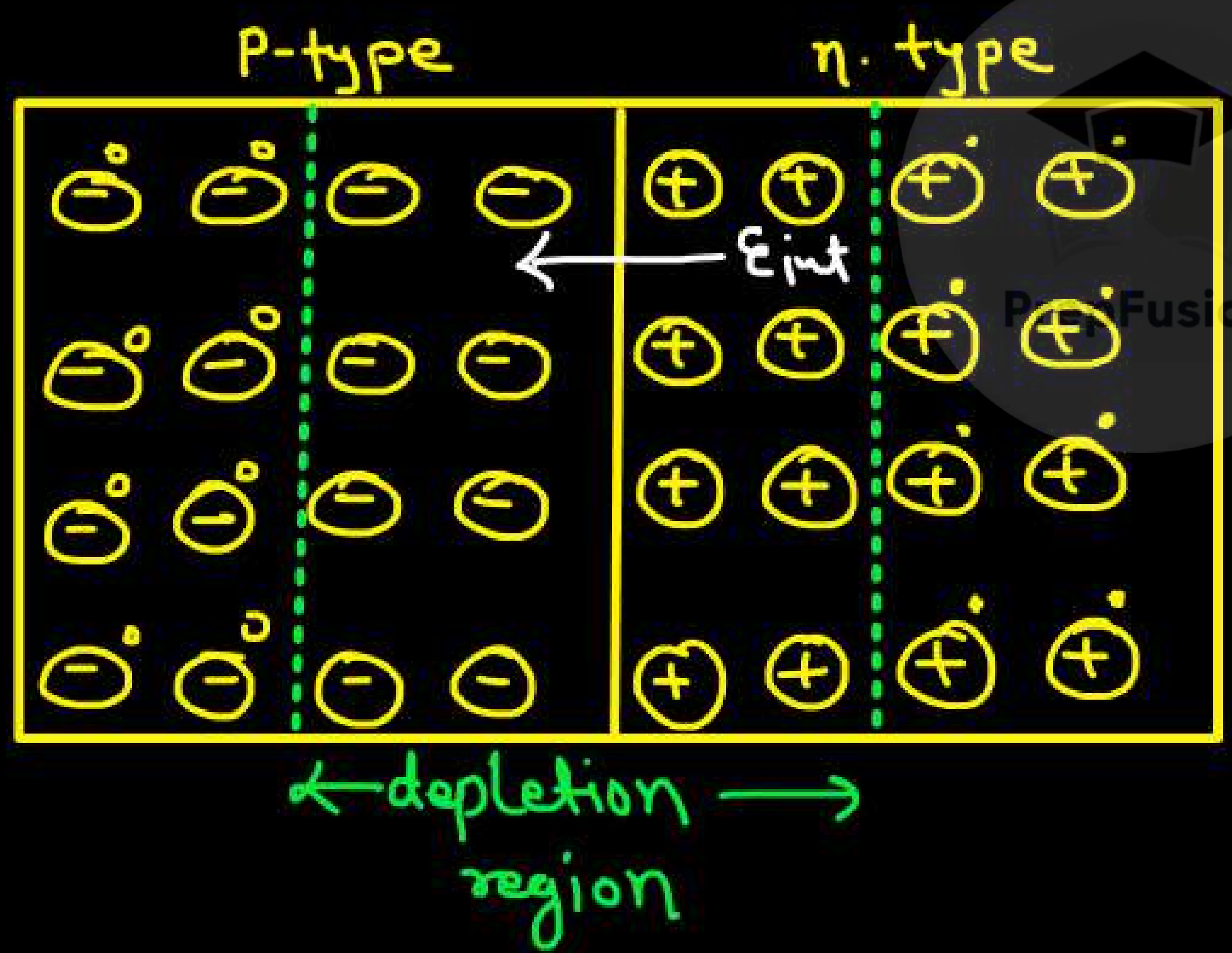
Electrons moves towards p-type region and recombines with the holes.

Holes moves towards n-type region and recombine with the electrons.

⇒ Forms a depletion region



↳ Electrons feel force in the opposite dir^n of Electric field while Holes feel the force in the same dir^n.



⇒ In depletion region, only immobile ions are present, there are no charge carriers.

⇒ these ion generate E_{int} (internal Electric field) from n-type to p-type. this E_{int} keep the equillibrium.

- In a p-n Junction, without an external applied Voltage, an equilibrium condition is reached in which potential difference forms across the junction. This potential difference is called built-in potential (V_{bi}).

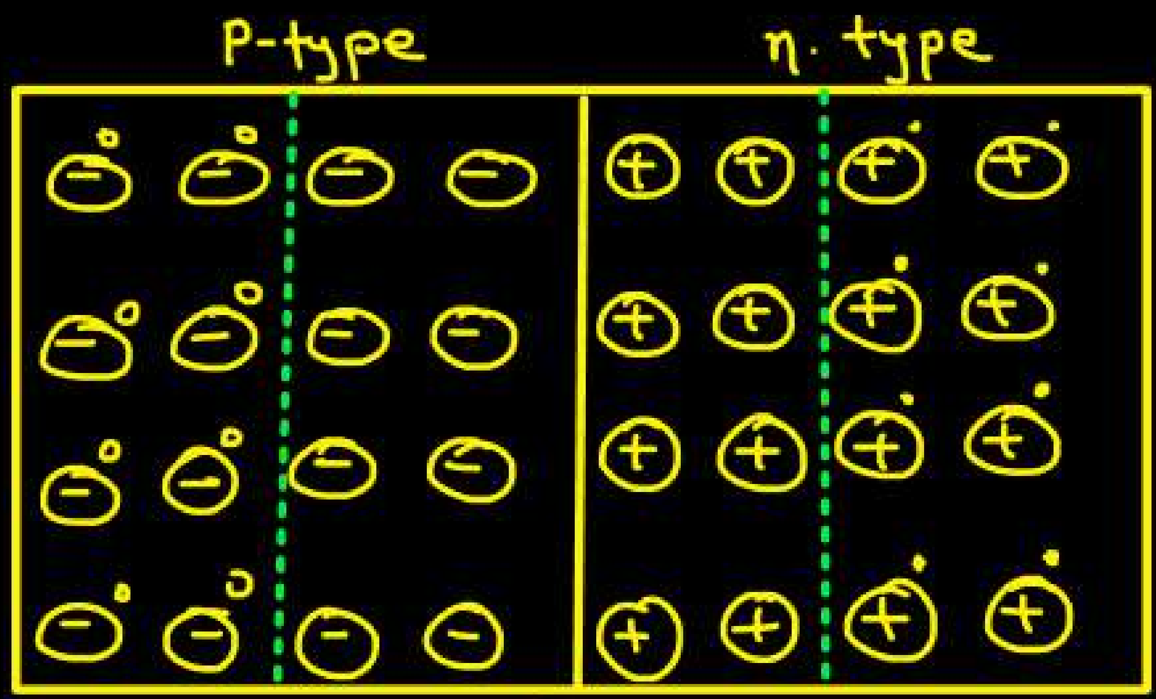
  - $(V_{bi})_{Si} = 0.7V$

    $(V_{bi})_{Ge} = 0.3V$

- So, basically these majority carrier has to cross this barrier potential to generate some current.

  $\Rightarrow$ Unbiased P-N J^n doesn't generate any current.

Unbiased PN- Junction:-

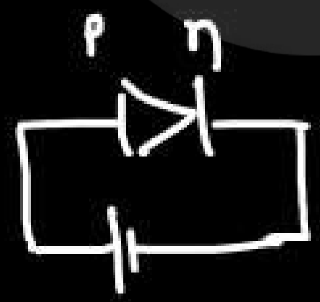


≡

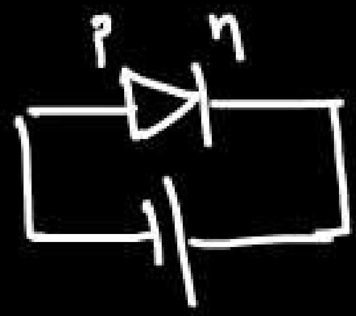
Diode

Biasing P-N Jn:-

→ Forward bias ⇒



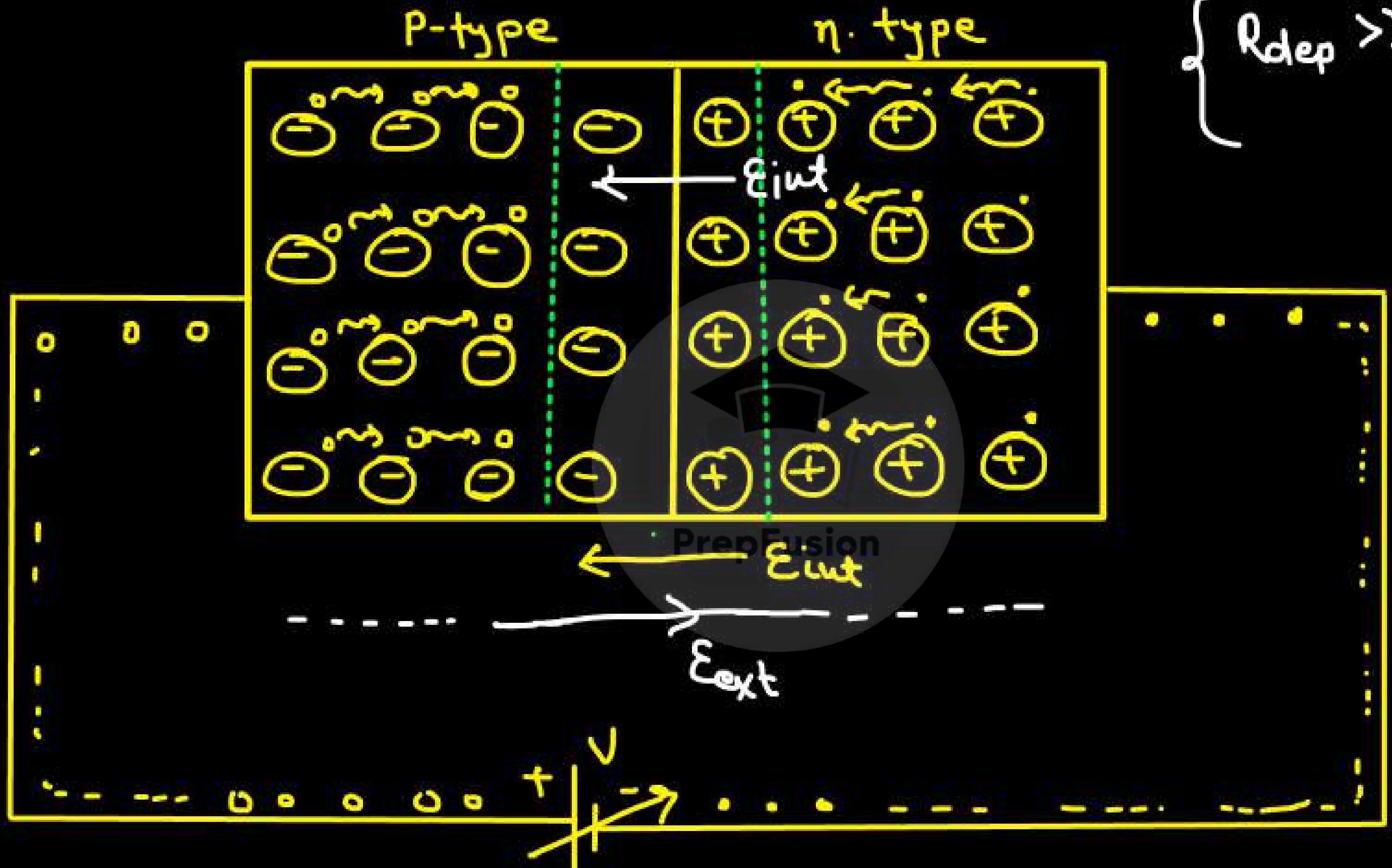
→ Reverse bias ⇒

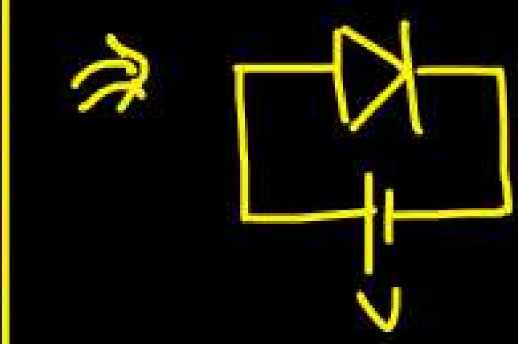


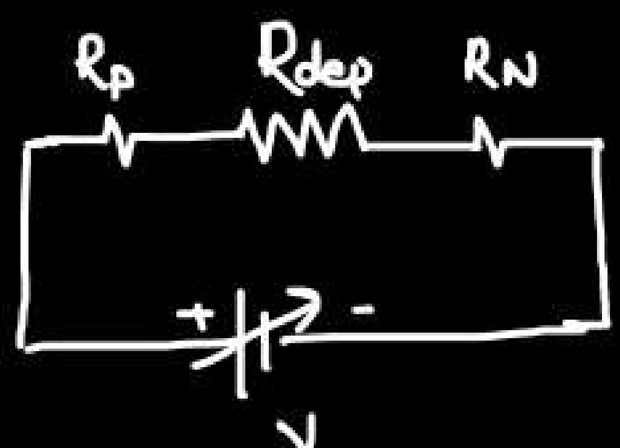
⇒ forward bias P-N J^n :-

⇒ depletion region provides High impedance

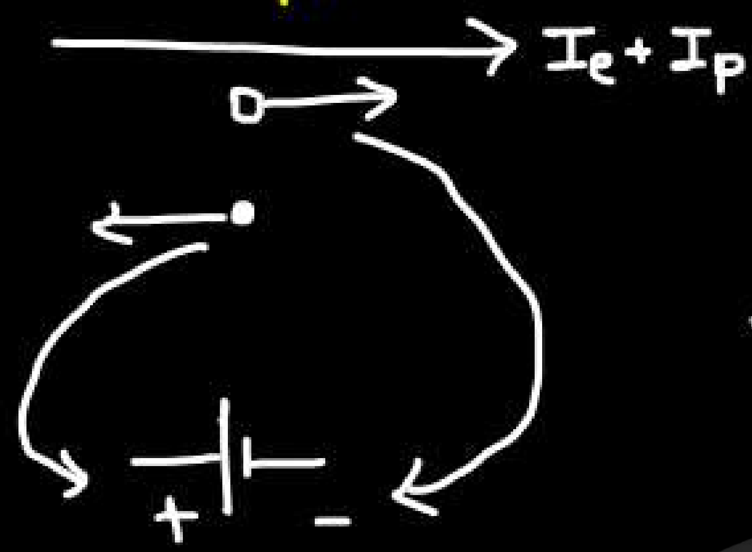
$\{ R_{dep} >> R_P, R_N$







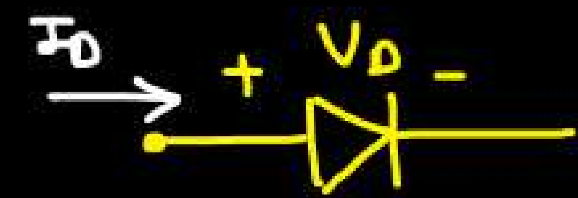
Because of the applied voltage,



The current flows in the same dir^n as the flow of holes and in the opposite dir^n as the flow of $e^\ominus$

Because of the motion of holes and $e^\ominus$ in a certain dir^n, the current will flow from p to n side in forward bias.

When $V > V_{bi} \Rightarrow$ current flows



$$I_D = I_S\left[e^{V_D/\eta V_T} - 1\right]$$

$$\approx I_S e^{V_D/\eta V_T}$$

Here $I_S \rightarrow$ Reverse saturation current

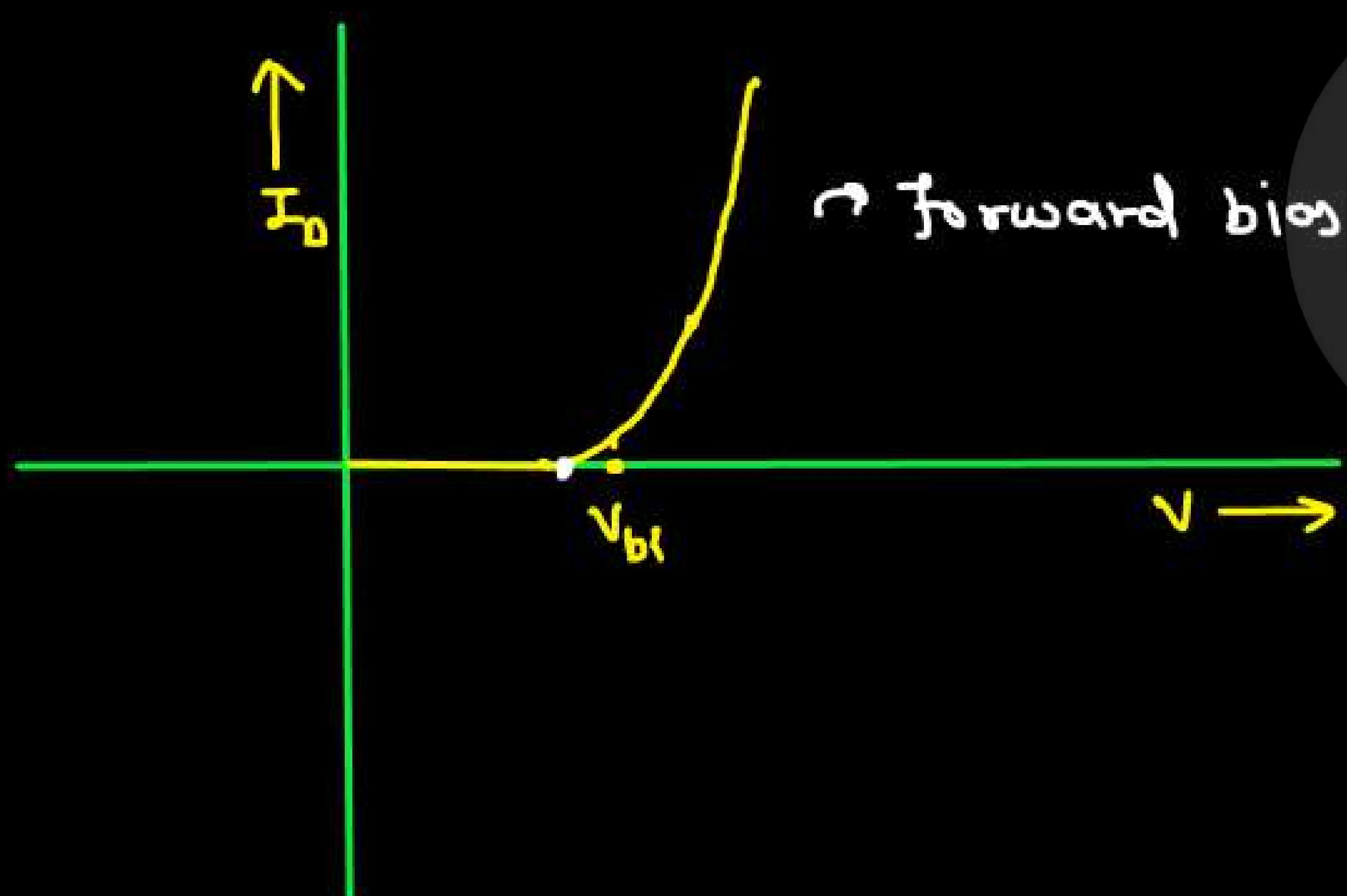
$V_D \rightarrow$ Voltage across diode

$V_T \rightarrow$ Thermal voltage

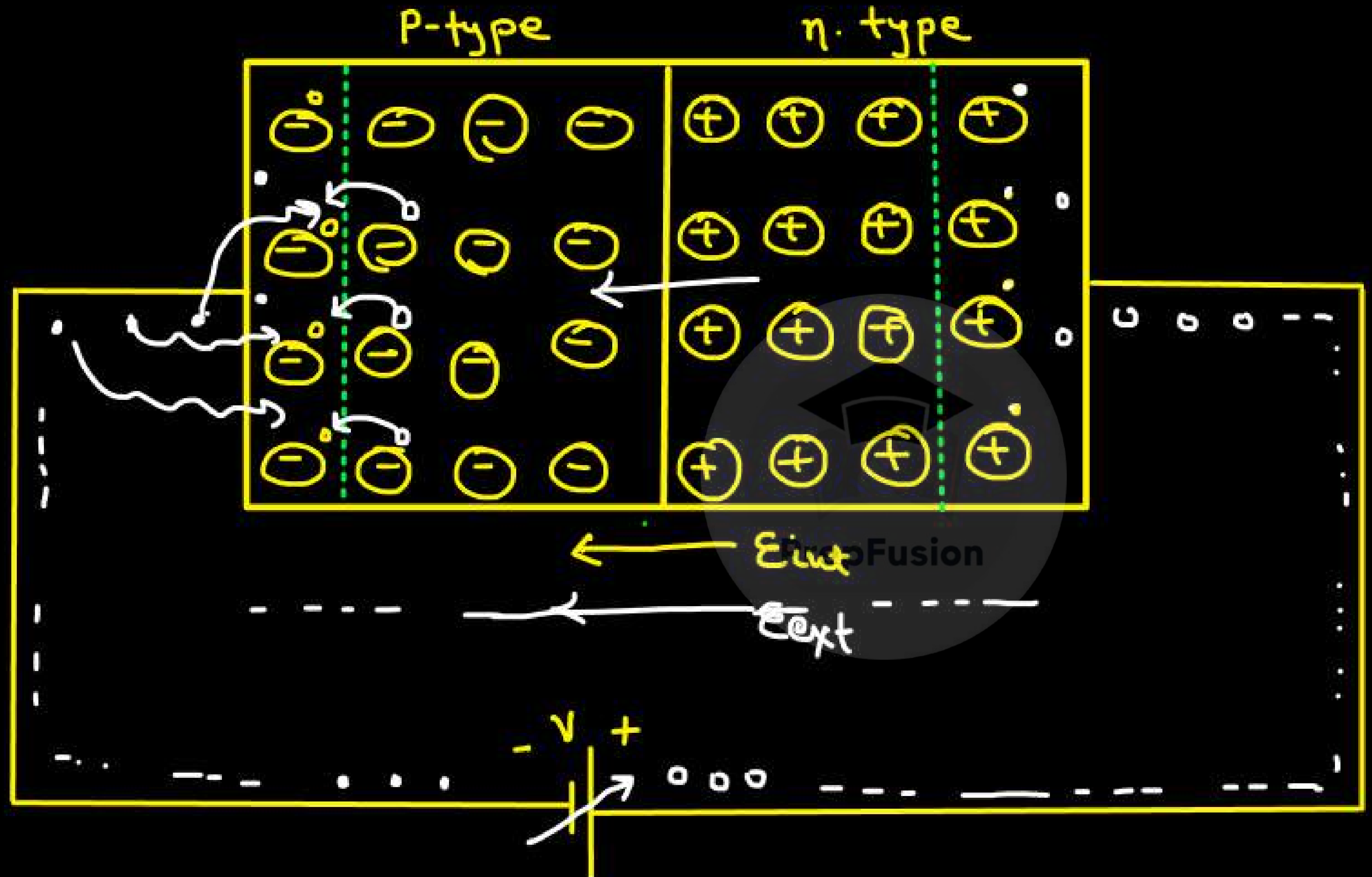
$$\left\{ \begin{array}{l} V_T = 25.9\,mV \text{ @ } T = 300K \\ V_T \propto \dfrac{1}{T(K)} \end{array} \right\}$$

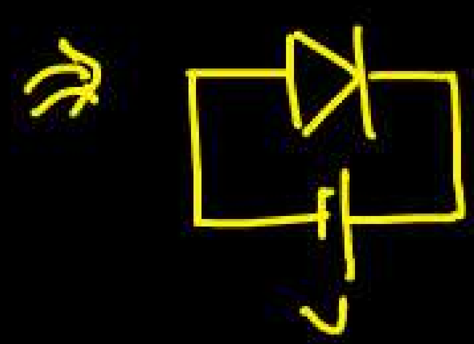
$\eta \rightarrow$ non-ideality co-efficient

$$\left\{ \begin{array}{l} \eta = 1 \rightarrow \text{for Ge} \\ \eta = 2 \rightarrow \text{for Si} \\ \text{take } \eta = 1 \text{ when nothing mentioned} \end{array} \right\}$$

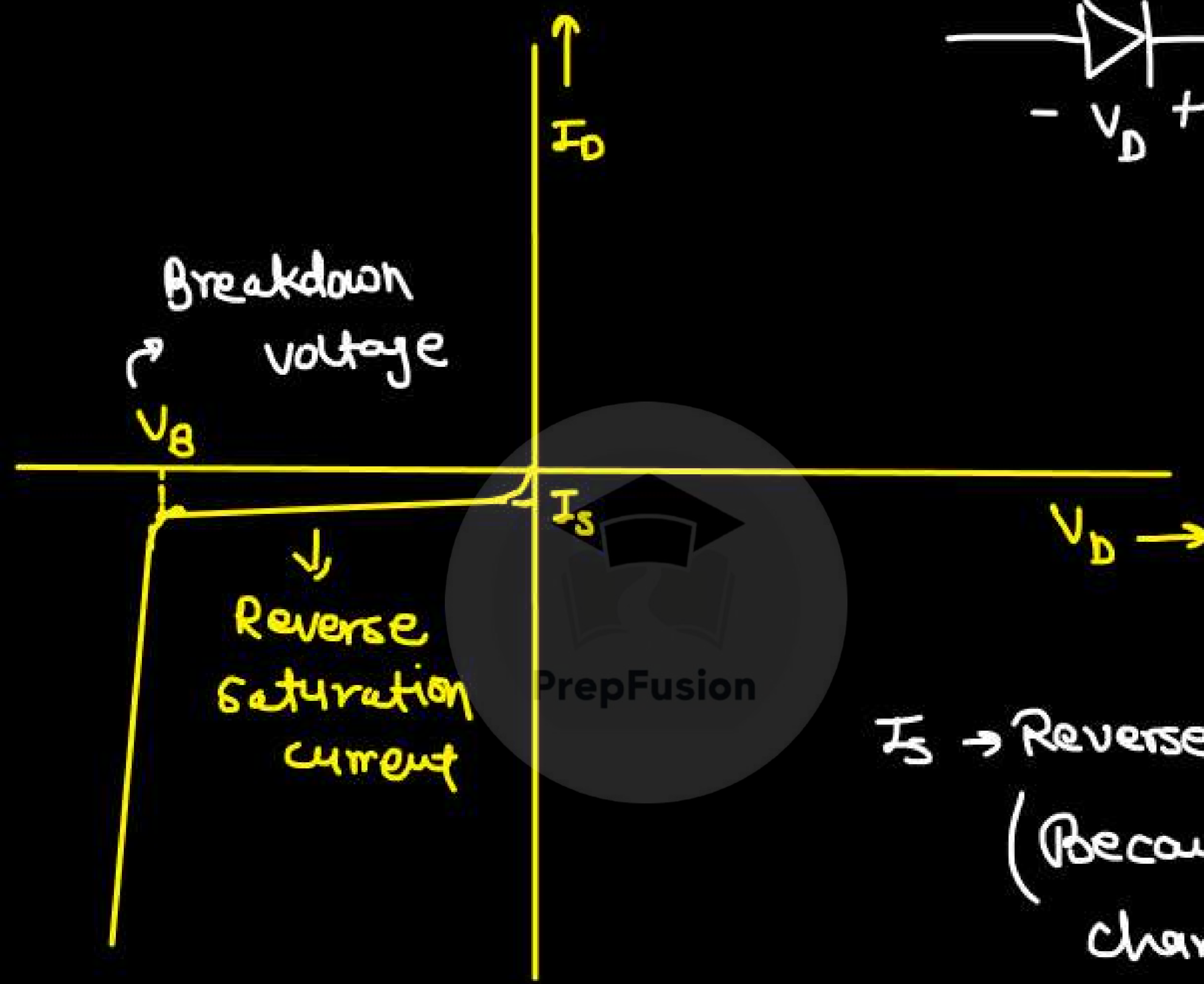


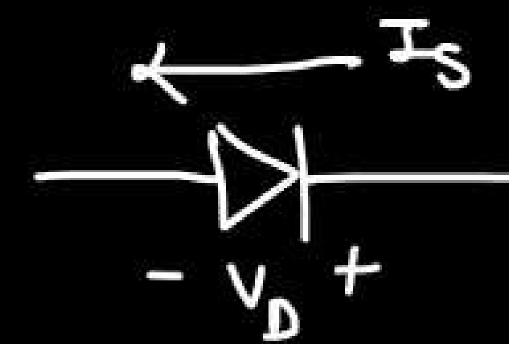
⇒ Reverse bias P-N Junction :-





$\boxed{I_S \propto \text{Temp}}$

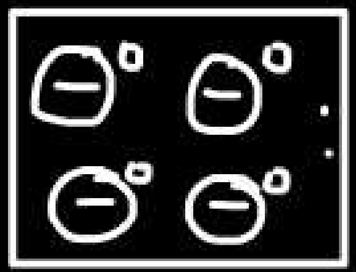




$I_S \rightarrow$ Reverse saturation current (Because of the minority charge carriers)

Summary:-

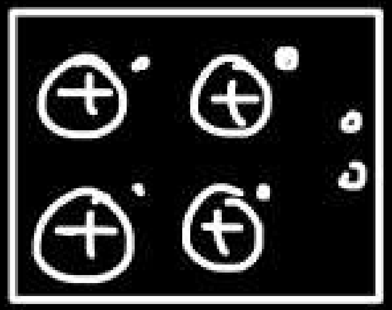
① p-type s/c



majority charge carriers ⇒ Holes

minority charge carriers ⇒ electrons

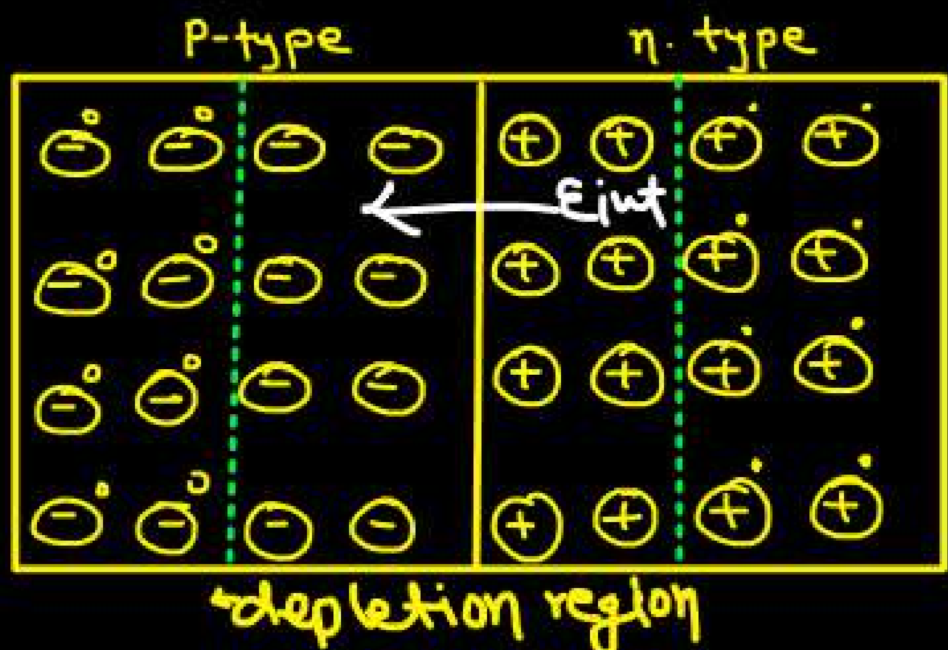
② n-type s/c



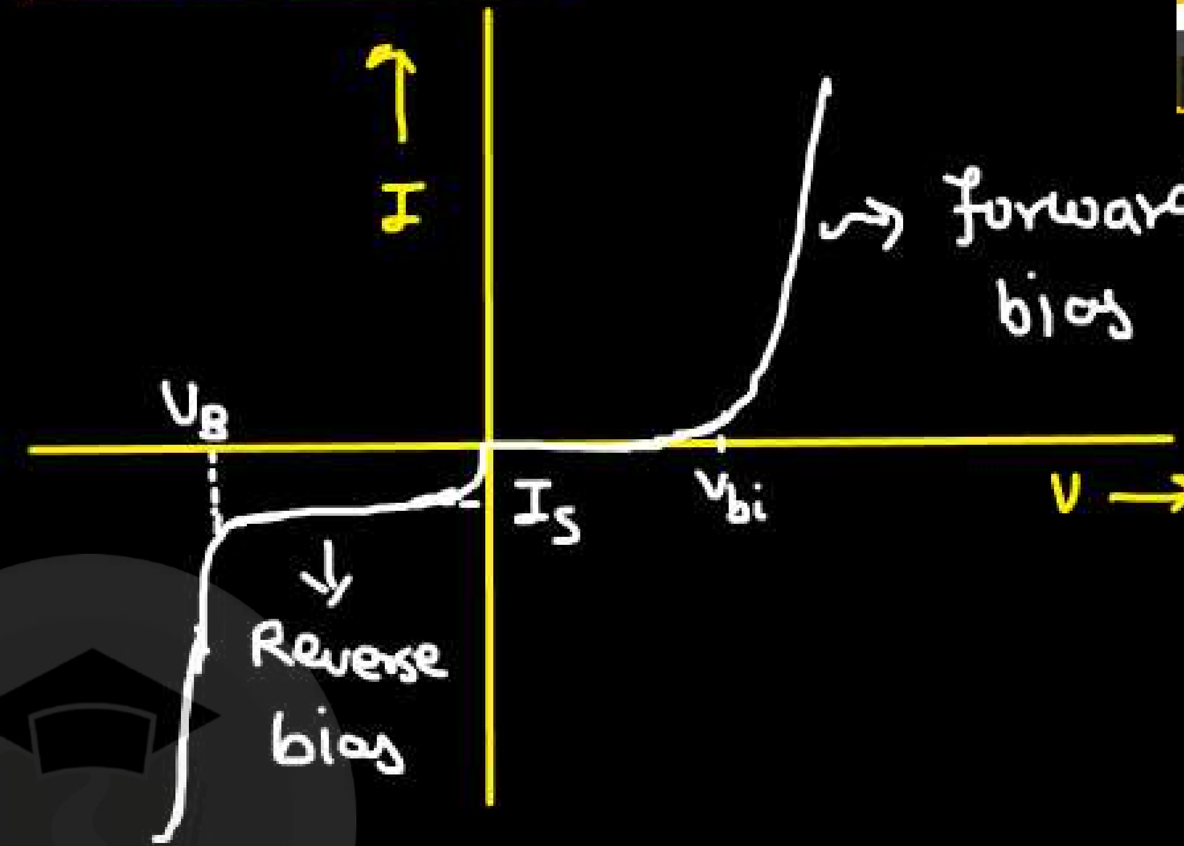
majority charge carrier ⇒ electrons

minority charge carrier ⇒ Holes

↳ Unbiased P-N J^n :-

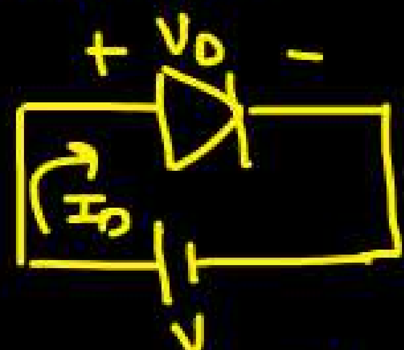


Biased Diode :-



↳ Biased P-N J^n :-

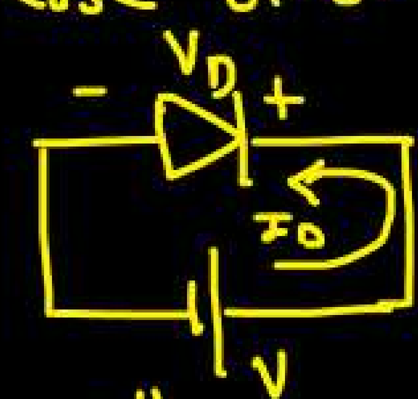
① Forward :-



⇒ Depletion width was reduced

$$I_D \approx I_s e^{V_D/nV_T}$$

② Reverse bias :-



⇓

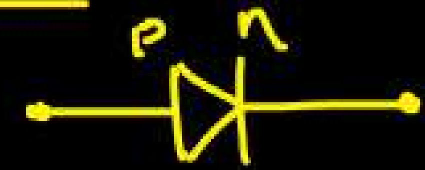
Depletion width was increased

$I_D = I_s$ {Before breakdown}

↓

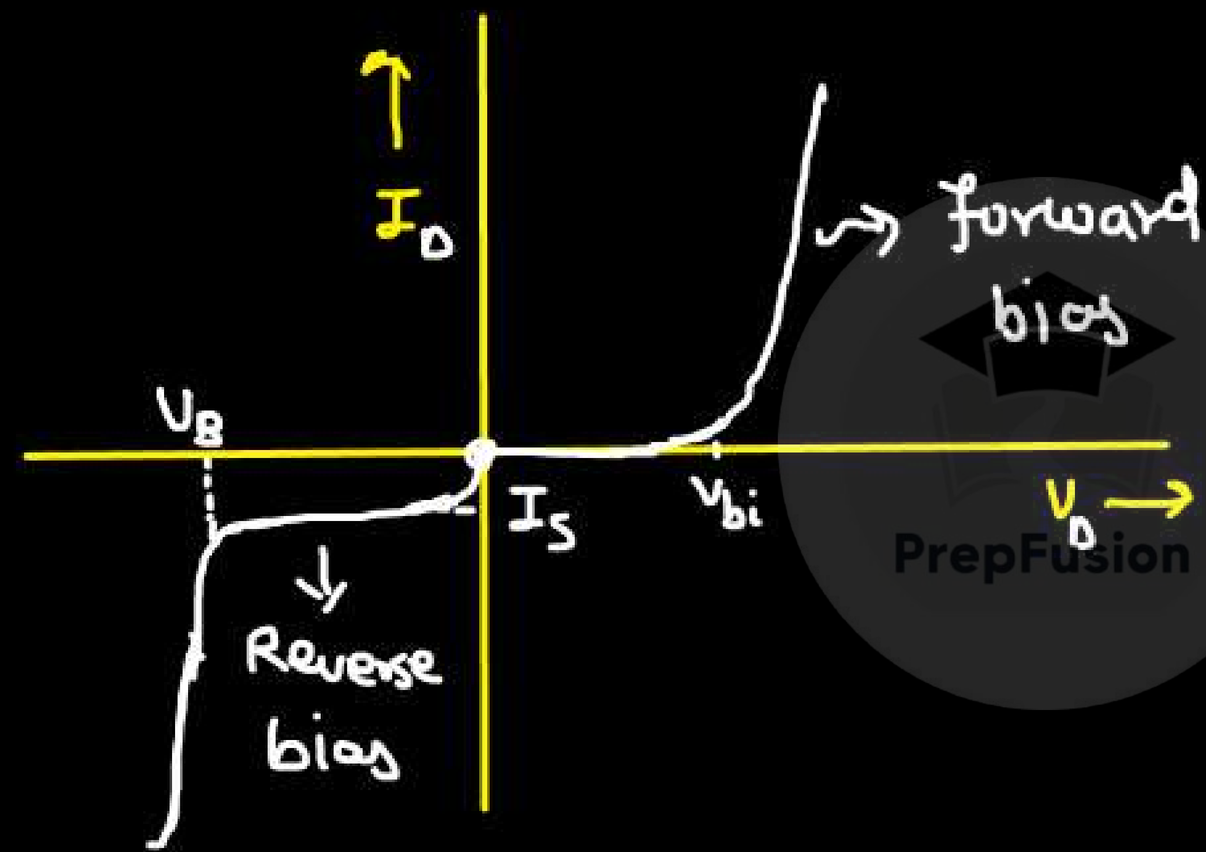
{μA, nA}

Diode as a device:-



$$I_D = I_S e^{V_D/nV_T} \leftarrow \text{forward}$$

$$I_D = I_S \leftarrow \text{reverse}$$



- Non-linear
- Unilateral

↳ Diode Turning ON or off:-

⇒ For diode to turn ON (considering ideal diode)

↳ potential of p > potential of n

↳ (potential of p − potential of n) > 0

p n —▷|—

Q. Tell if the diode is ON or off

① 5V —▷|— 3V ⇒ ON

② 3V —▷|— 5V ⇒ off

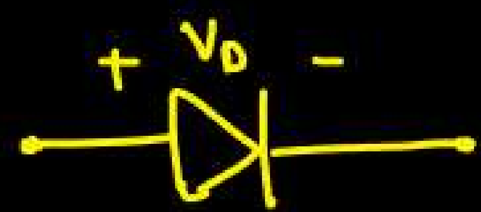
③ 3V —▷|— −2V ⇒ ON

④ −1V —▷|— −3V ⇒ ON

⑤ −2V —▷|— −1V ⇒ off

⇒ Different models of diodes :-

① Ideal diode :-

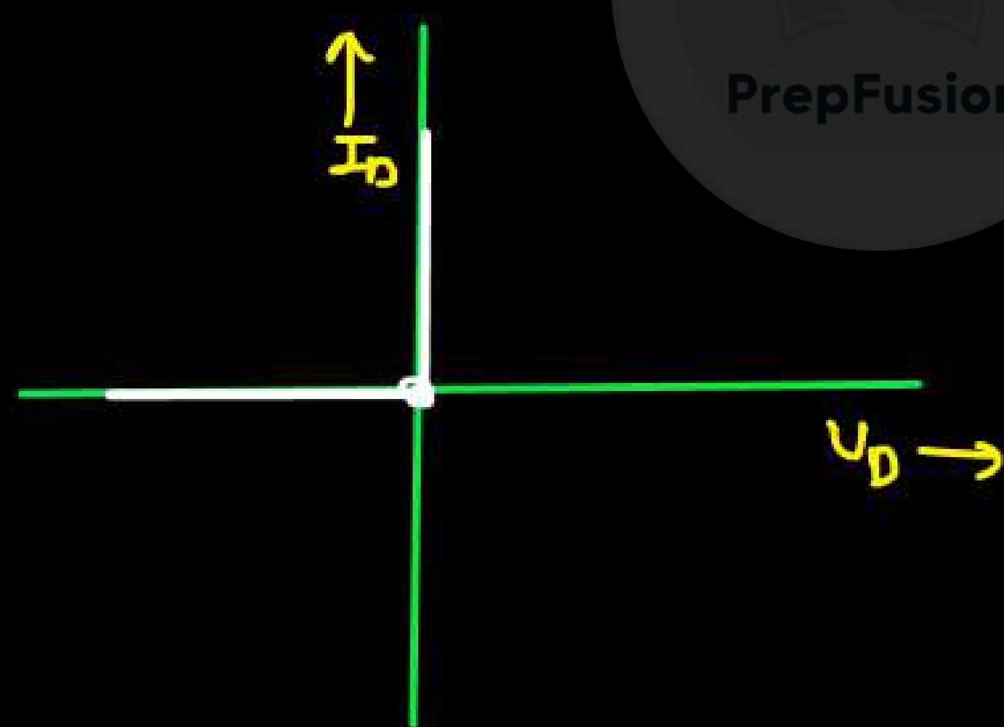


when on $\longrightarrow$

$\Rightarrow \{V_D > 0\}$

when off $\longrightarrow$

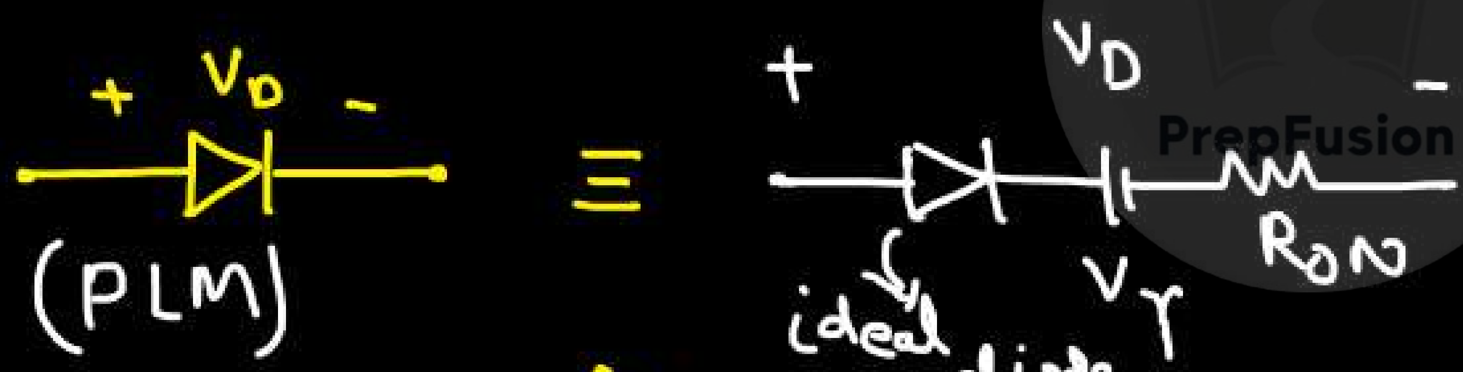
$\Rightarrow \{V_D < 0\}$

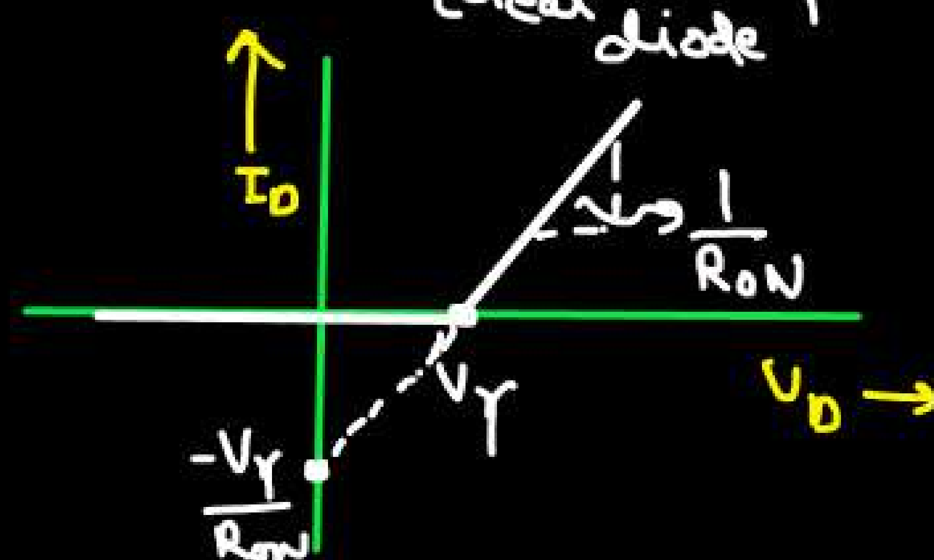


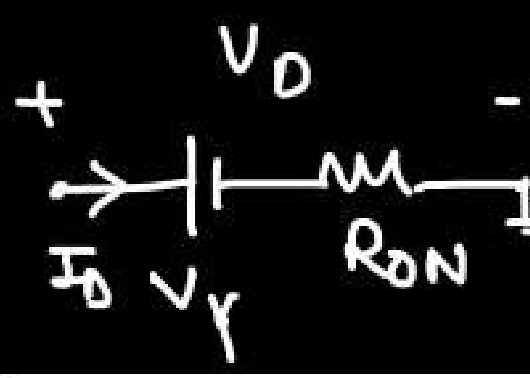
② Piecewise linear Model:-

$\{V_D > V_\gamma\}$

$\{V_D < V_\gamma\}$



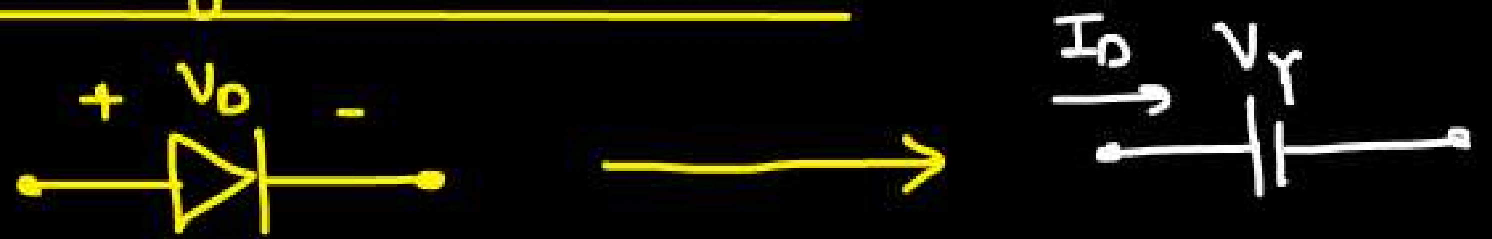




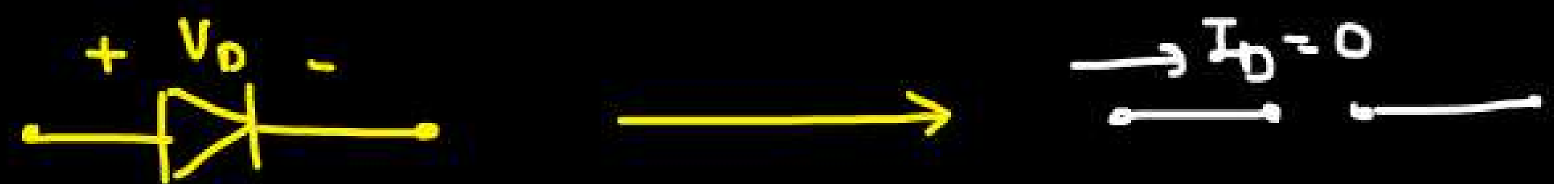
$\Rightarrow V_D = V_\gamma + I_D R_{ON}$

$$\boxed{\frac{V_D - V_\gamma}{R_{ON}} = I_D}$$

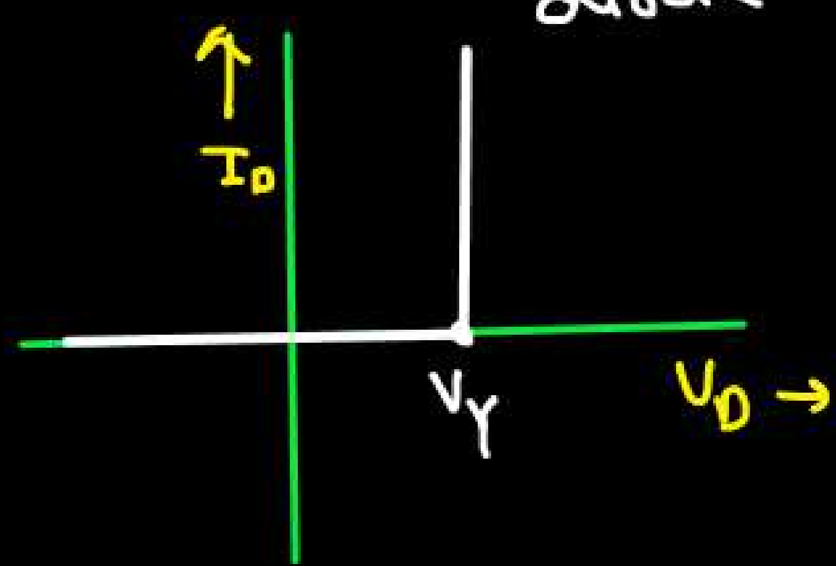
Constant voltage drop model:-



$\{V_D > V_\gamma\}$



$\{V_D < V_\gamma\}$



$$\left\{\begin{array}{l}\text{For Si, } V_\gamma = 0.7V \\ \text{For Ge, } V_\gamma = 0.3V\end{array}\right\}$$

↳ Solving diode ckts:-

- → Short-circuit Test (S.C. Test)
- → Open-circuit Test (O.C. Test)

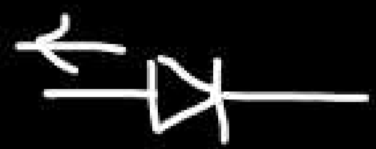
① Short-Circuit Test (S.C. Test):-

(i) Consider diode to be ON.

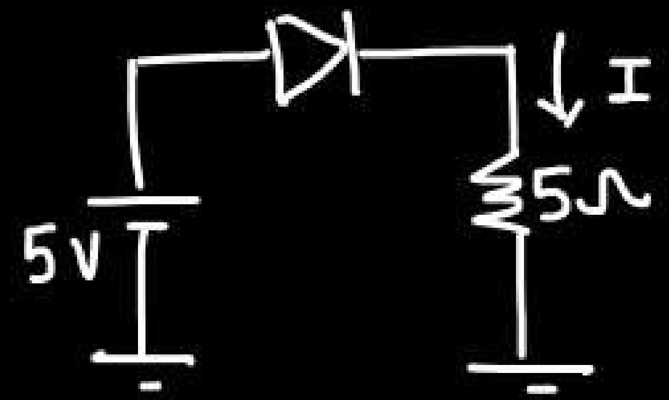
(Short-circuit it or replace with its equivalent model)

(ii) Find current direction in the diode.

if p to n ⇒  ⇒ Assumption correct ⇒ Diode ON

if n to p ⇒  ⇒ Assumption wrong ⇒ Diode off

Q.



Find current I.

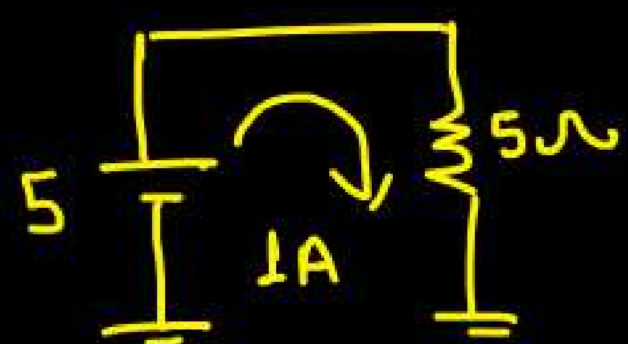
(i) Diode is ideal

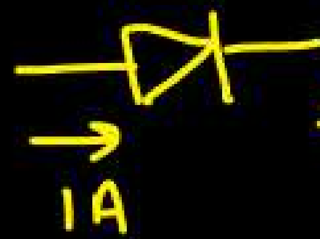
(ii) Diode has $V_\gamma = 1V$ (Cut-in voltage)

(iii) Diode has $V_\gamma = 1V$, $R_{ON} = 3\Omega$

→ (i) Diode is ideal

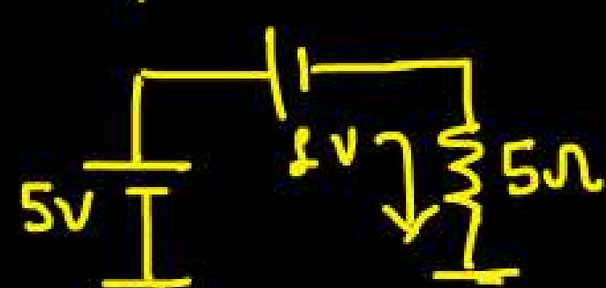
↳ S.C. Test



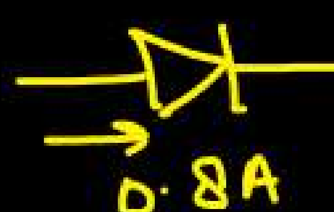


⇒ ON ⇒ $\boxed{I = 1\ \text{Amp}}$ ✓

(ii) $V_\gamma = 1V$

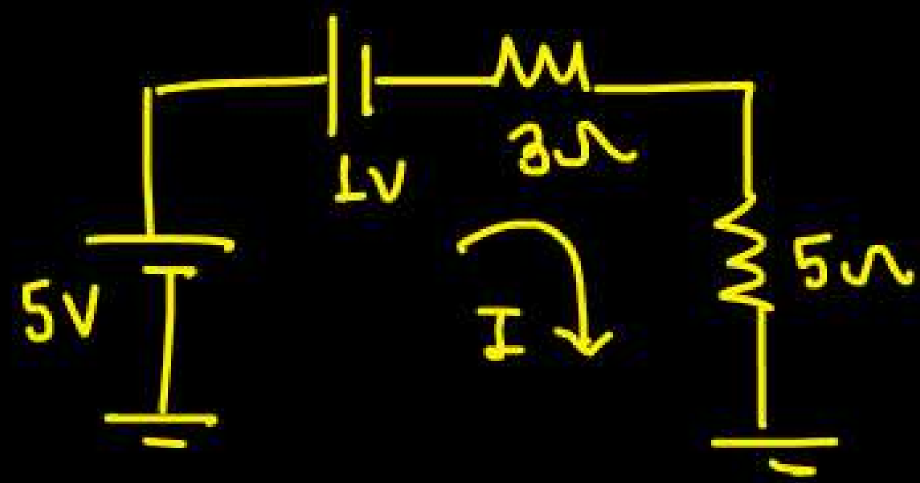


$I = \frac{4}{5} = 0.8A$

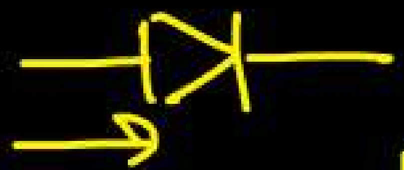


⇒ ON ⇒ $\boxed{I = 0.8\ \text{Amp}}$ ✓

(iii) $V_\gamma = 1V$, $R_{ON} = 3\Omega$



$\Rightarrow I = 0.5\,Amp. \Rightarrow$



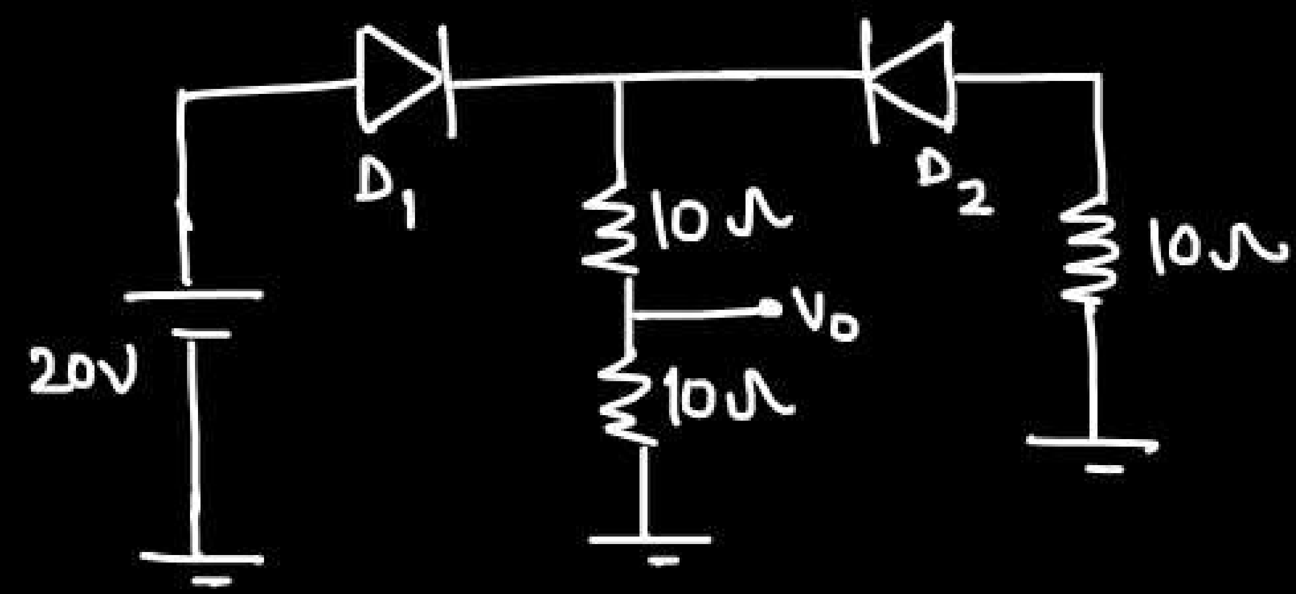
$\Downarrow$

Diode ON

$\Downarrow$

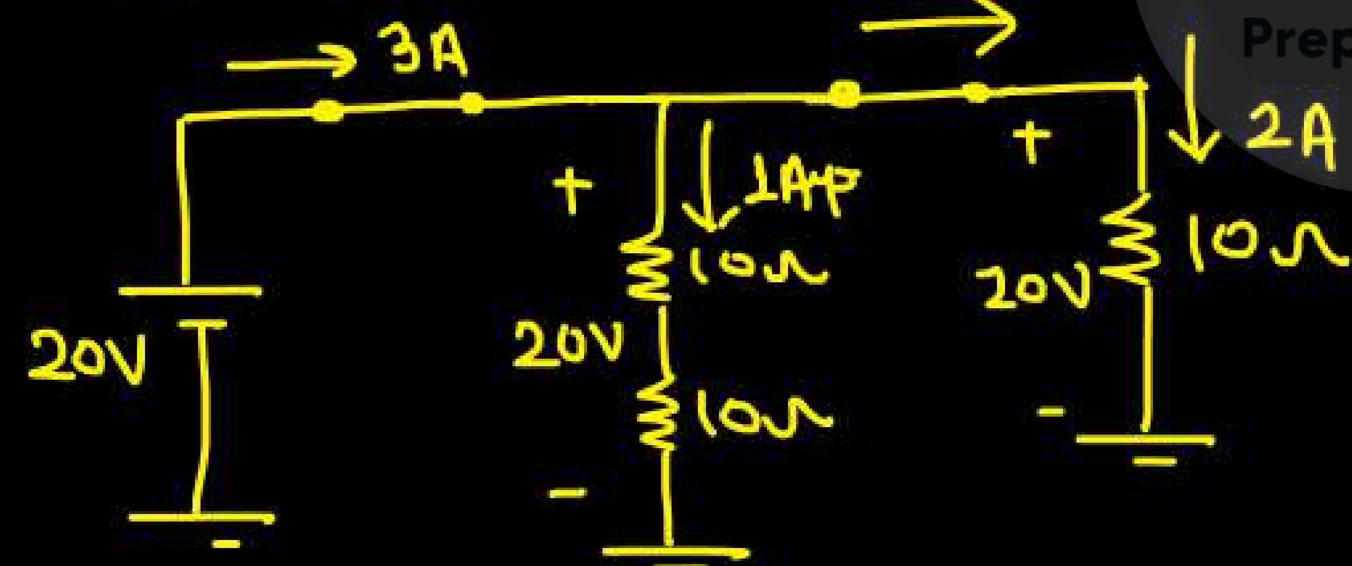
$$\boxed{I = 0.5\,Amp}$$

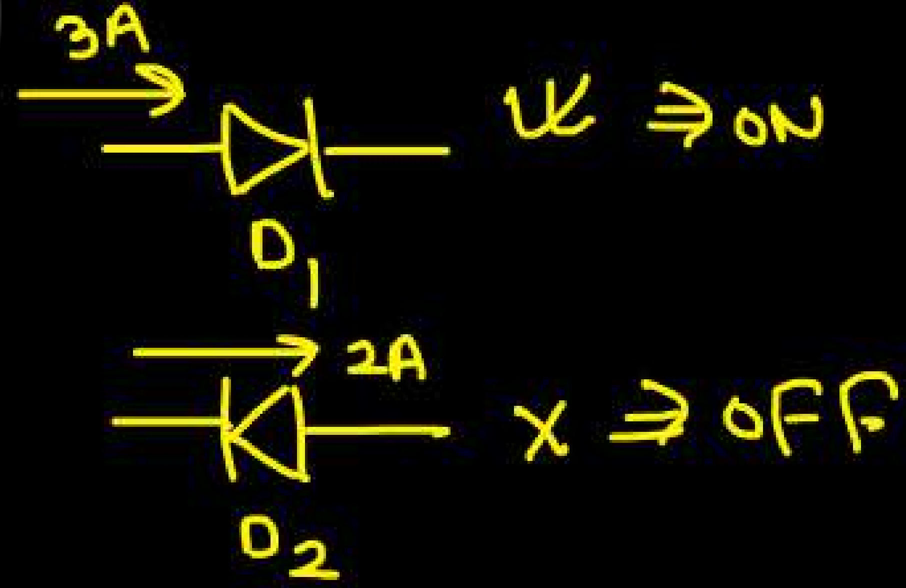
Q.



considering D_1 and D_2 to be ideal. Find V_0.

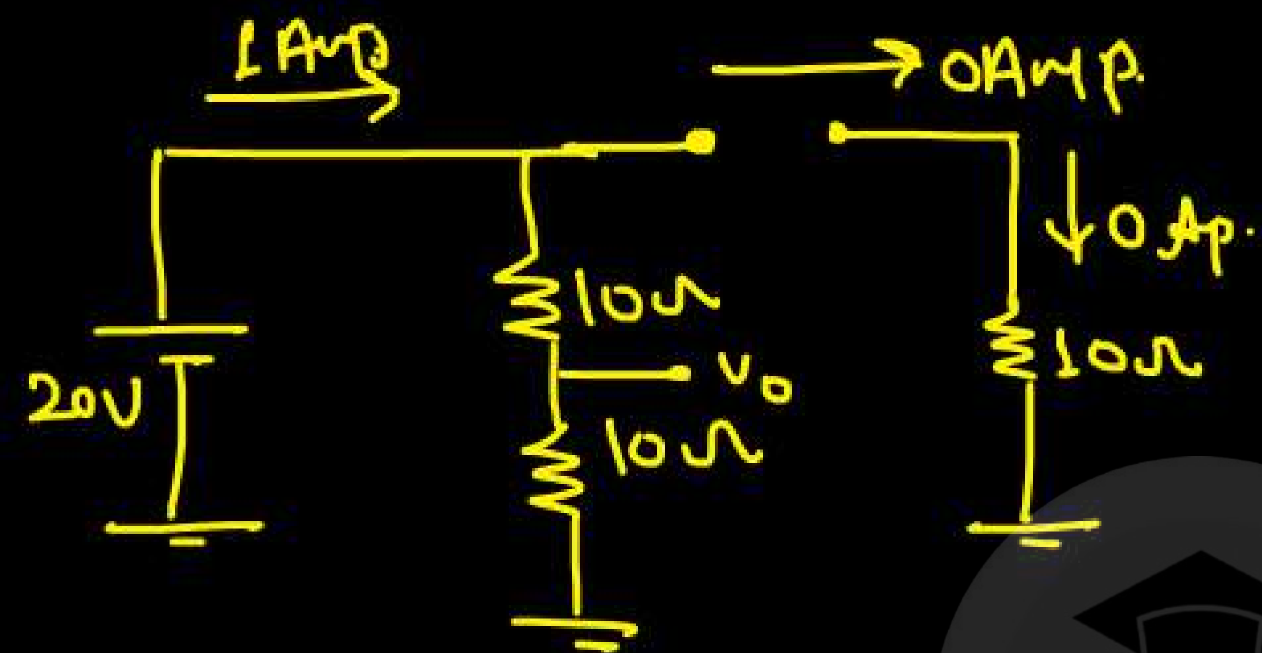
→ Applying S.C. Test





Final ckt: →

$D_1 \to ON$, $D_2 \to OFF$

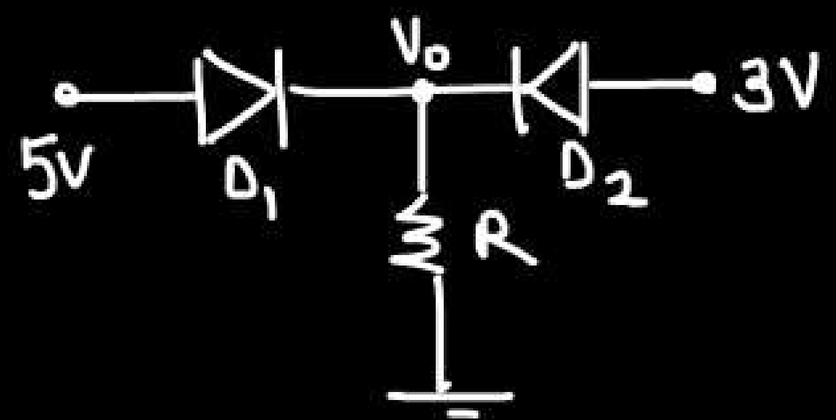


$$\boxed{I_{D_2} = 0 \text{ Ap.}}$$

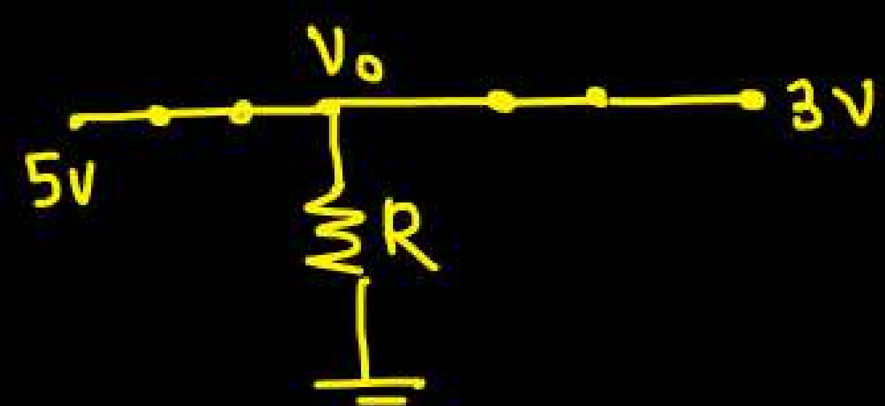
$$\boxed{I_{D_1} = 1 \text{ Ap.}}$$

$$\boxed{V_o = \frac{20 \times 1}{2} = 10V}$$

Q. Apply S.C. Test to find V_0.



→ Applying S.C.



$V_0 = 5V$ or $3V$

⇓

KVL Invalid

⇓

Can't apply S.C. Test

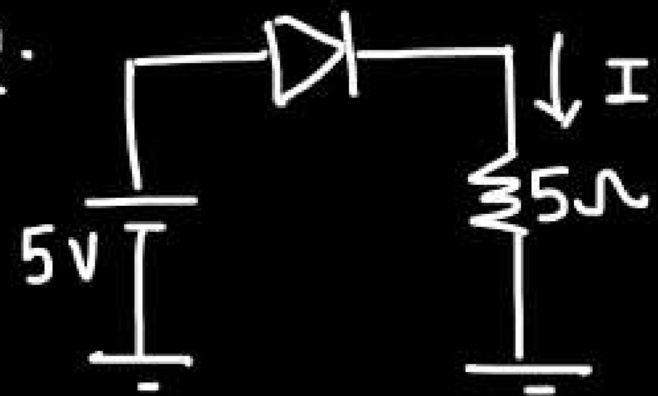
↳ Open circuit Toot:-

① Consider diode to be off.
(open circuit it)

② Find the potential across diode and check if it's ON or off.

N.B.-
In case of multiple diodes; the diode which has the maximum forward voltage drop, consider that to be ON first.
Now compute voltage across rest of the diode and repeat the same process.

Q.



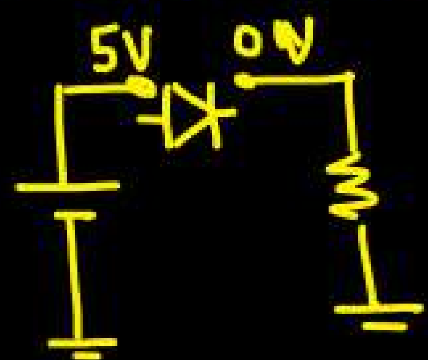
Find current I.

(i) Diode is ideal

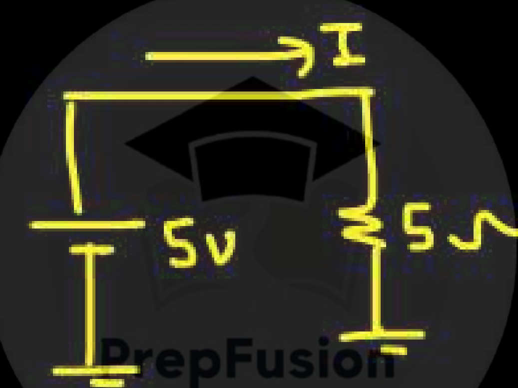
(ii) Diode has $V_\gamma = 1V$

(iii) Diode has $V_\gamma = 1V$, $R_{ON} = 3\Omega$

→ (i) ideal diode

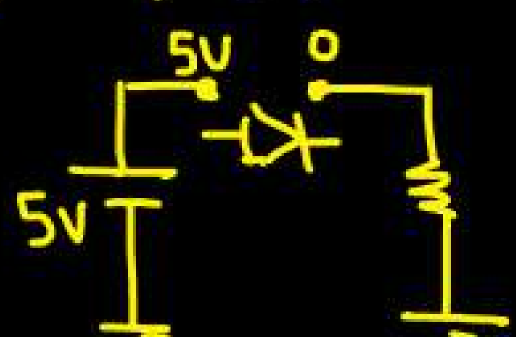


⇒ Diode ON ⇒
(5V > 0V)

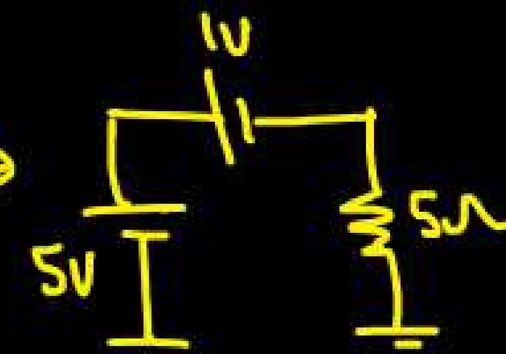


⇒ $\boxed{I = 1\text{ Amp.}}$

(ii) $V_\gamma = 1V$

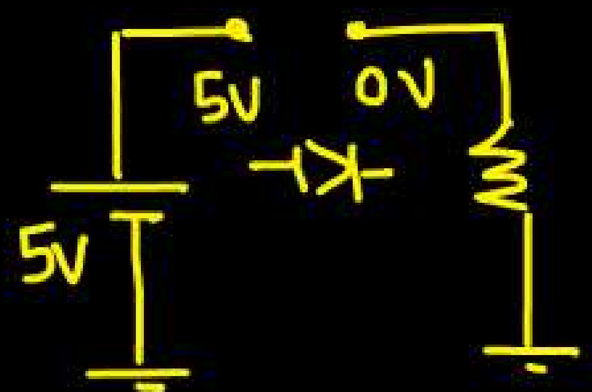


⇒ 5V > 1V ⇒ diode ON ⇒



⇒ $\boxed{I = 0.8\text{ Amp}}$

(iii) $V_\gamma = 1V$, $R_{ON} = 3\Omega$

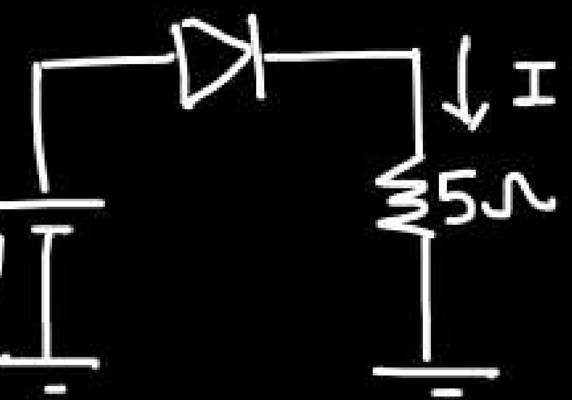


$\Rightarrow 5V > 1V \Rightarrow$ Diode ON

$\Downarrow$

$\Rightarrow \boxed{I = 0.5 \text{ Amp.}}$

Q.

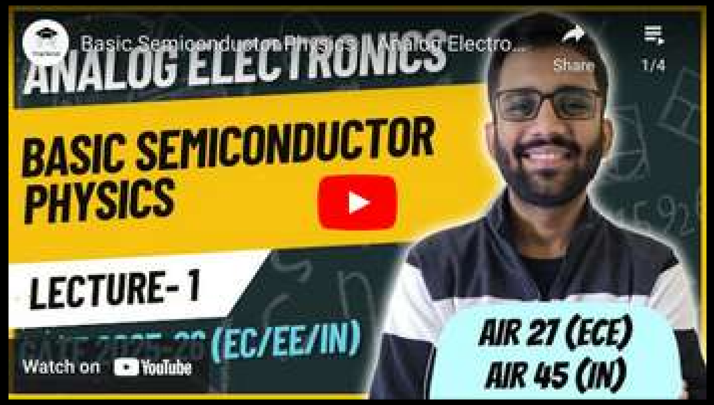


Find current I.

(i) Diode is ideal

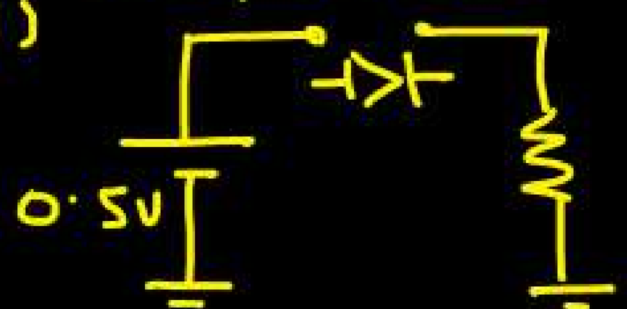
(ii) Diode has $V_\gamma = 1V$

(iii) Diode has $V_\gamma = 1V$, $R_{ON} = 3\Omega$



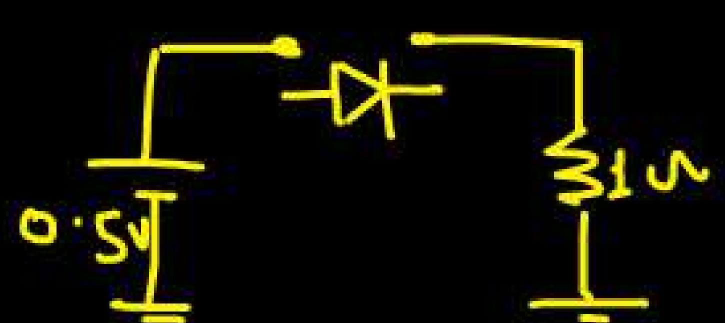
→ open ckt Test:

(i) ideal diode

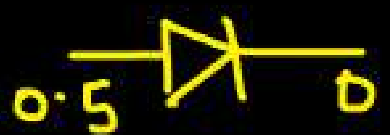


$\Rightarrow 0.5 > 0 \Rightarrow$ diode ON $\Rightarrow I = \frac{0.5}{5} = 0.1$ Amp.

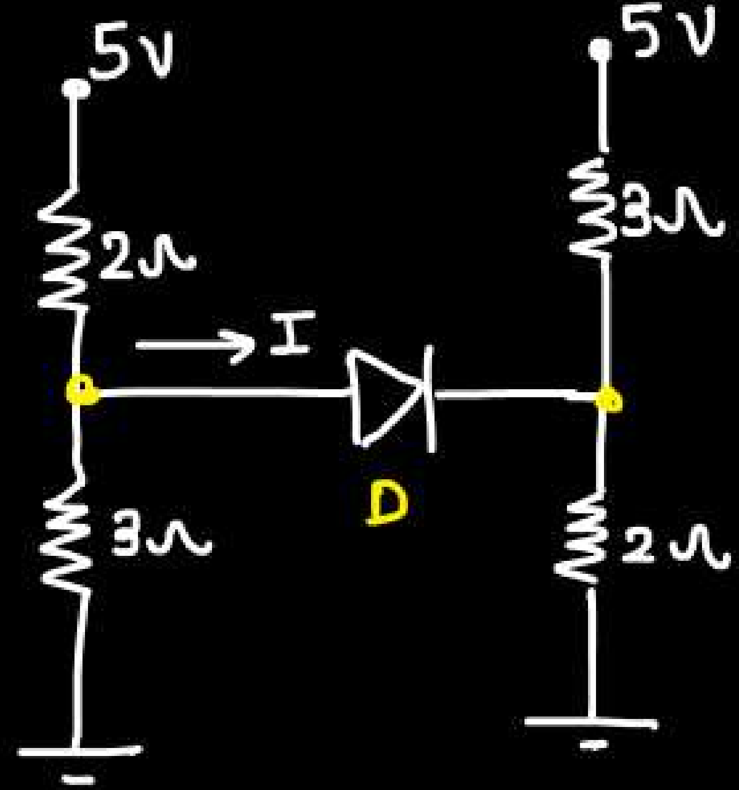
(ii) $V_\gamma = 1V$ (iii) $V_\gamma = 1V$, $R_{ON} = 3\Omega$



$\Rightarrow 0.5 < 1 \Rightarrow$ diode off $\Rightarrow$ $\boxed{I = 0 \text{ Amp}}$

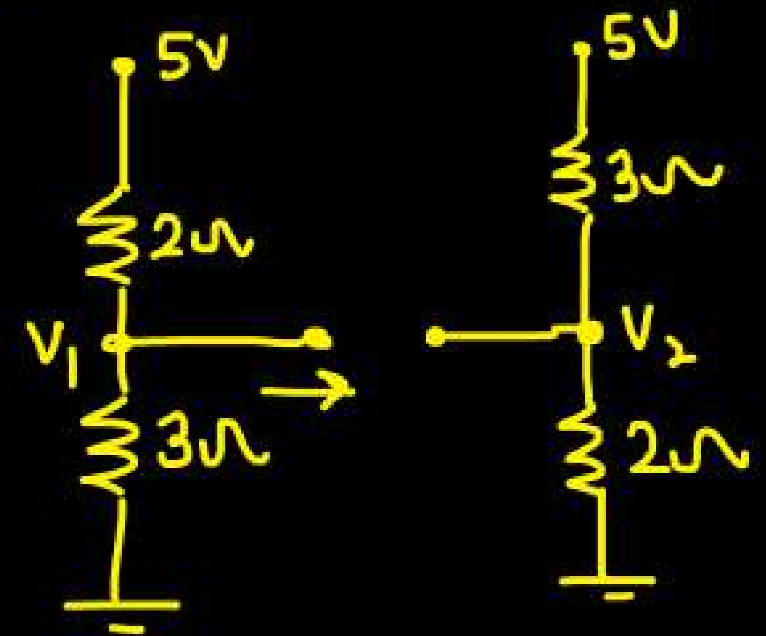


Q.



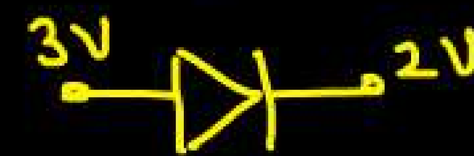
Considering ideal diode. Find current I.

→ open-ckt Test:-



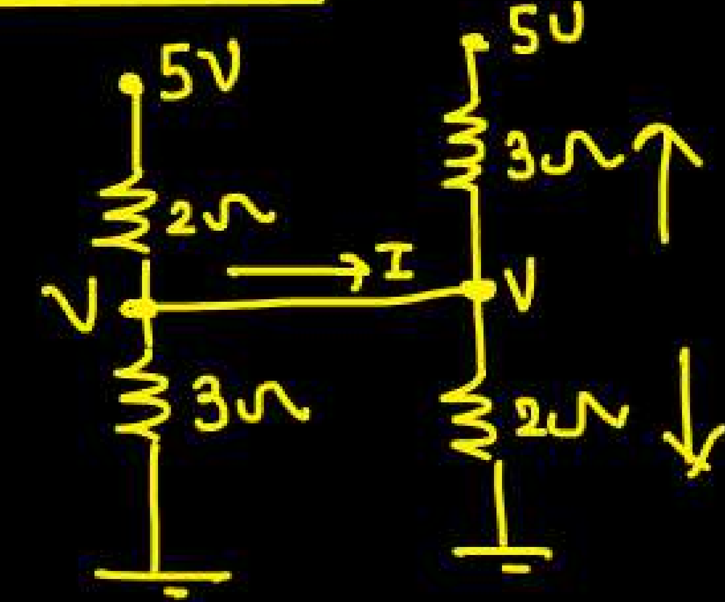
$$V_1 = \frac{5\times 3}{5} = 3V$$

$$V_2 = \frac{5\times 2}{5} = 2V$$



$\Rightarrow$ ON

Final ckt:-



$$\frac{V-5}{2} + \frac{V}{3} + I = 0 \quad \text{— (1)}$$

$$\frac{V-5}{3} + \frac{V}{2} = I \quad \text{— (2)}$$

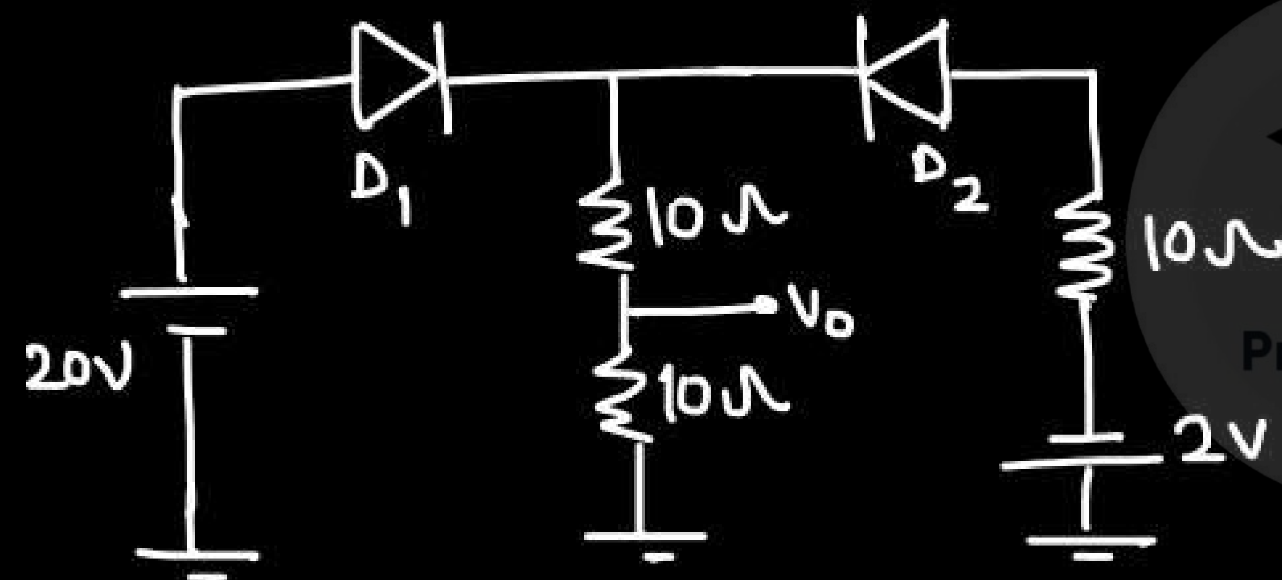
$$\Rightarrow \frac{V-5}{2} + \frac{V}{3} + \frac{V-5}{3} + \frac{V}{2} = 0$$

$$\Rightarrow \boxed{V = 2.5V}$$

$$I = 1.25 - 0.833$$

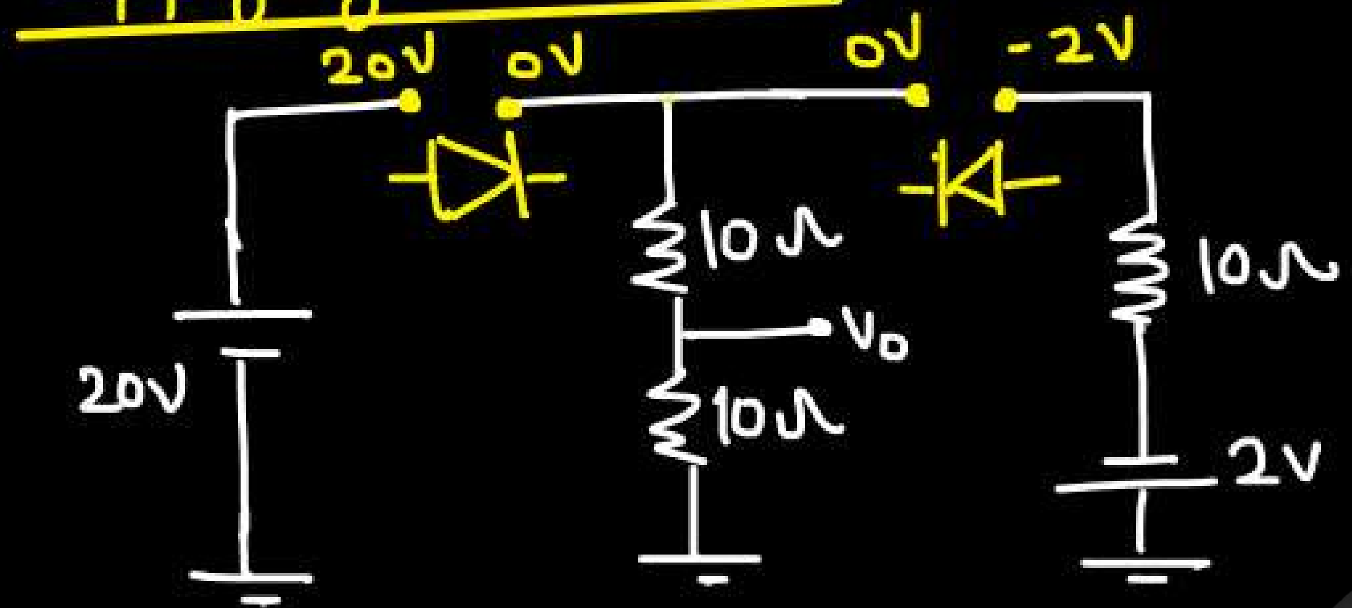
$$\boxed{I = 0.416 \text{ Amp.}}$$

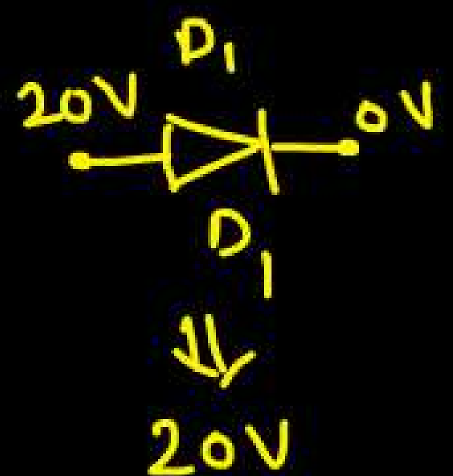
Q.

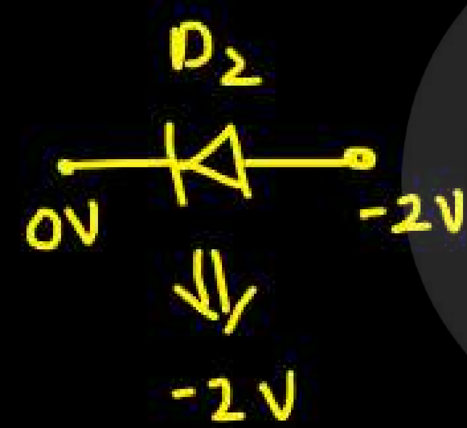


Considering D_1 and D_2 to be ideal. Find V_o.

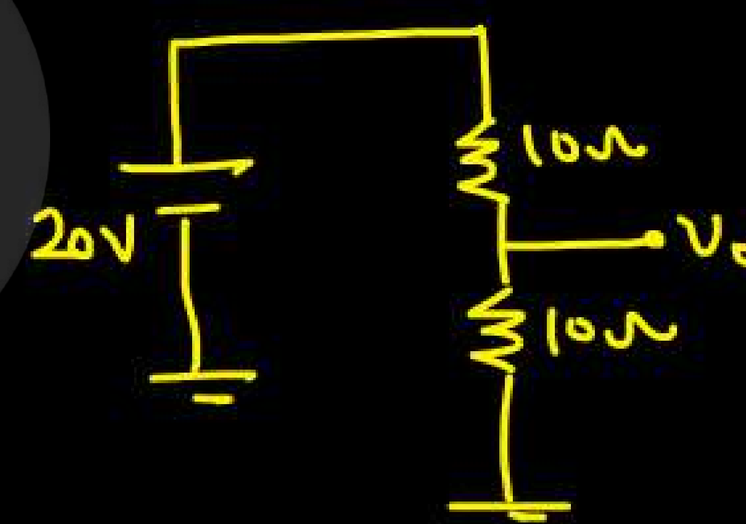
Applying O.C. Test -







$\Rightarrow$

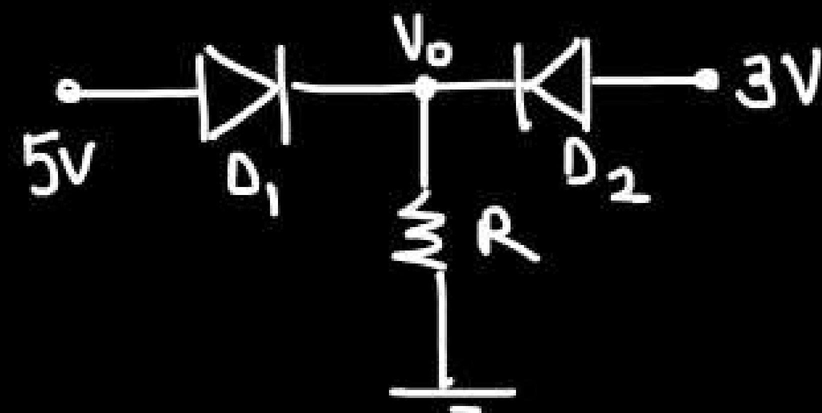


$\Rightarrow \boxed{V_0 = 10V}$

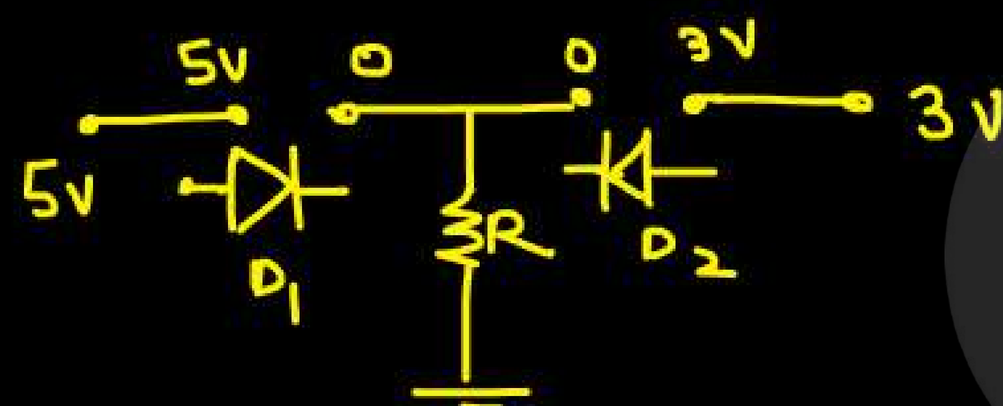
$\Rightarrow D_1 \to ON$

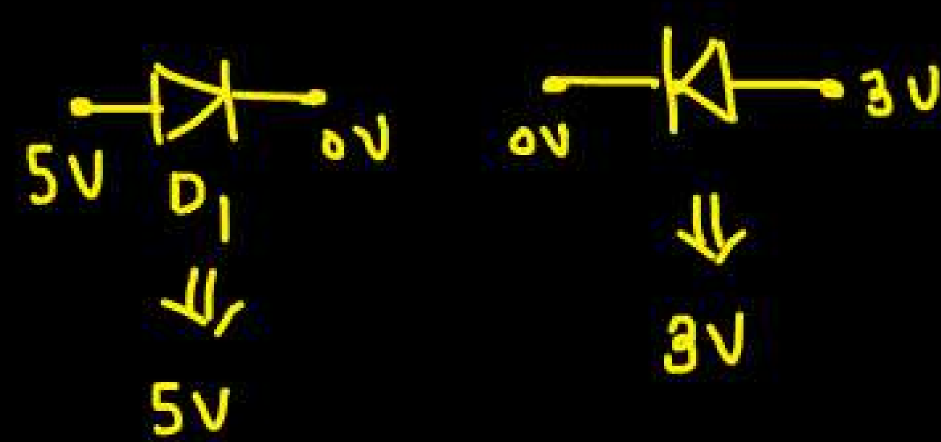
$D_2 \to OFF$

Q. Apply O.C. Test to find V_0.

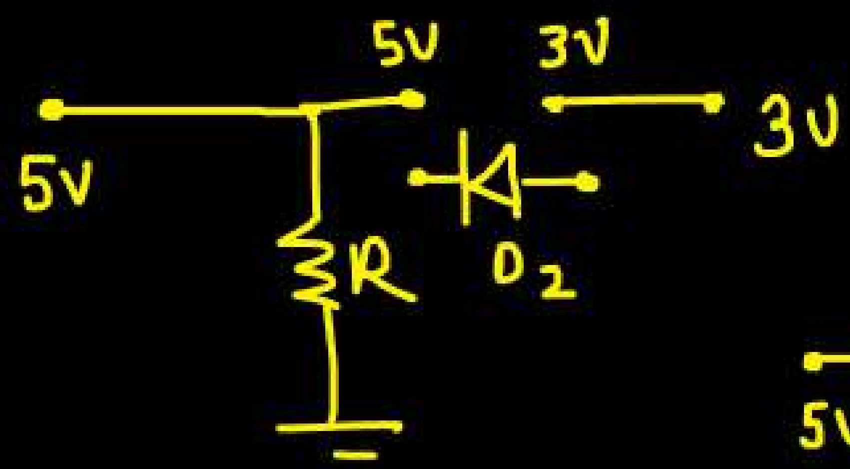


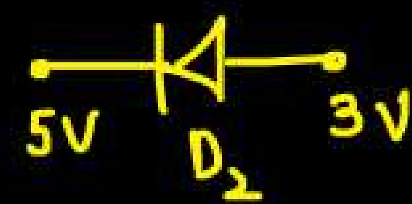
→





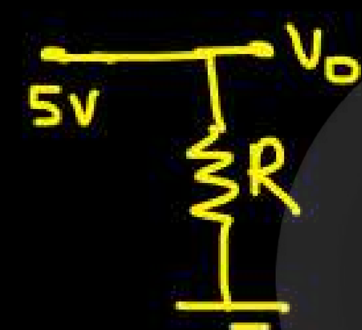
⇒ Both diode <u>can be</u> ON. Since diode D_1 is having more potential in forward dirn (from p to n) ⇒ I will turn ON diode D_1 first





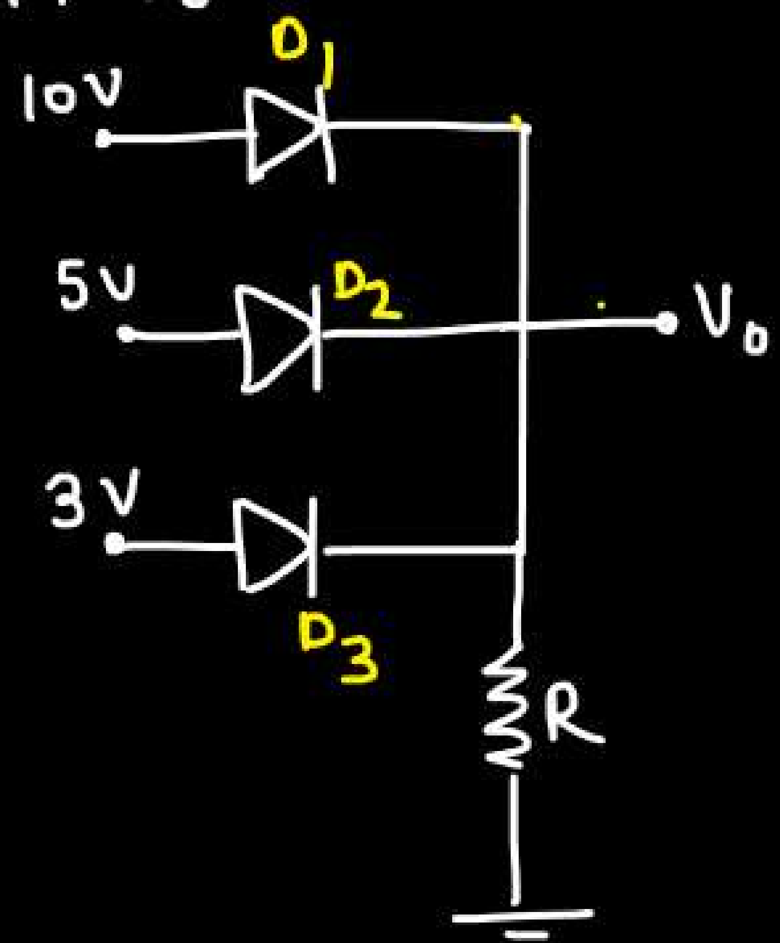
$\Rightarrow$ diode D_2 is off

$\Rightarrow$

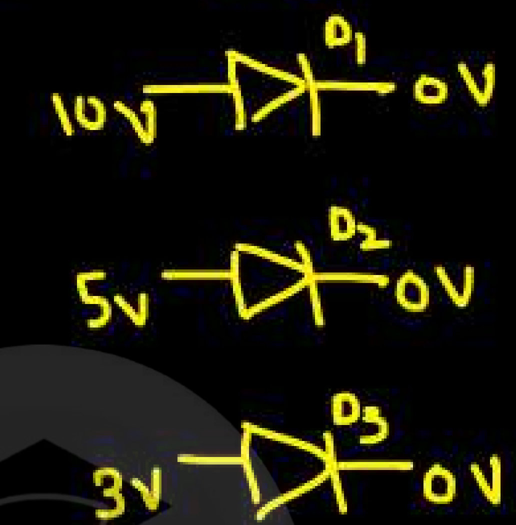


$\Rightarrow$ $\boxed{V_0 = 5V}$

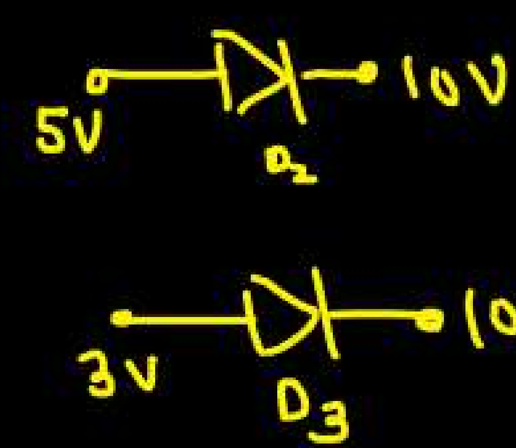
Q. Find V_0.



⇒ O.C. Test



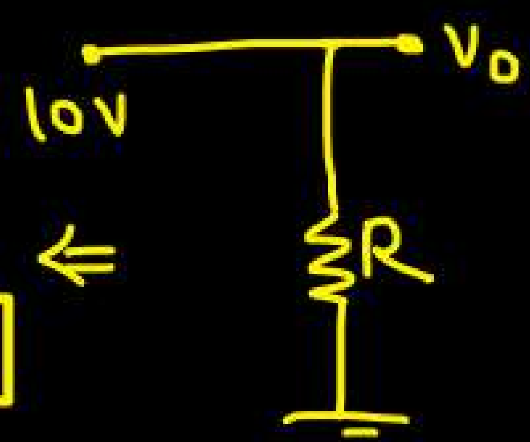
⇒ D_1 will turn ON first



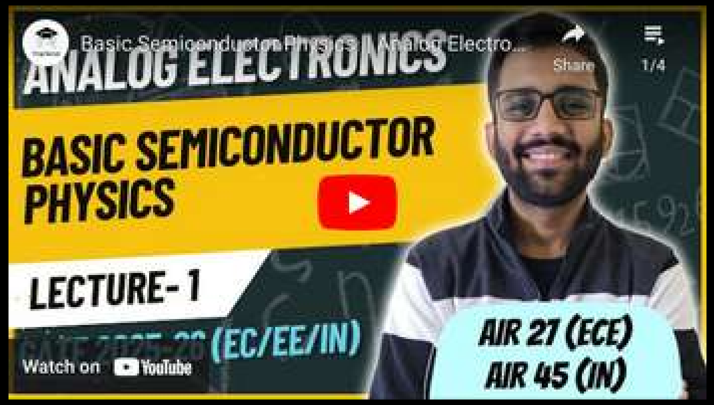
⇒ off

⇒ off

⇐



⇐ $\boxed{V_0 = 10V}$



Operating point:-

Q. Solve the following eq^n.

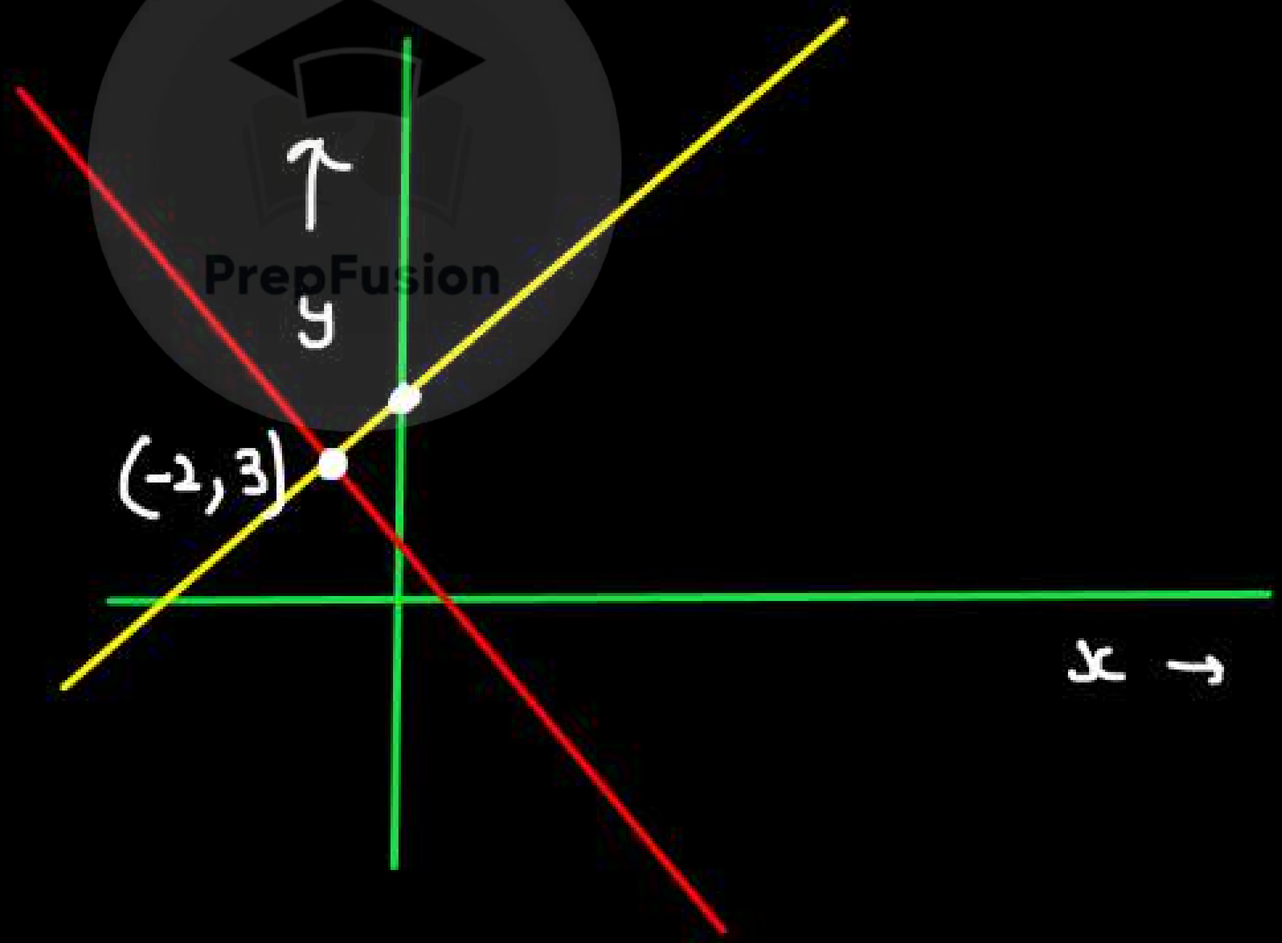
$$y = x + 5$$

$$y = -x + 1$$

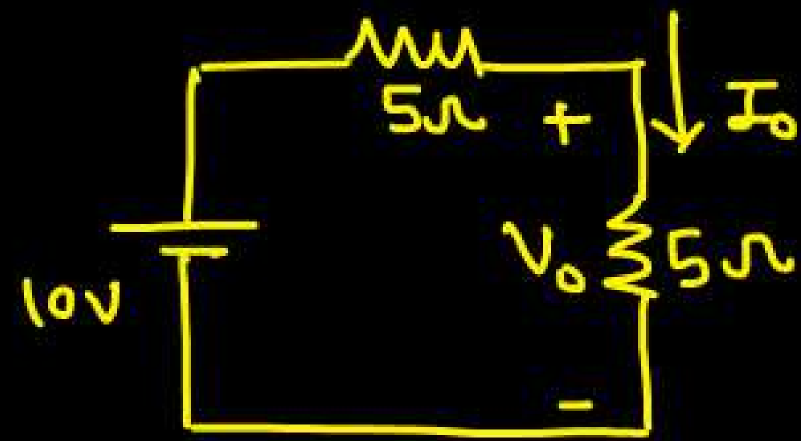
→

$$y = 3$$

$$x = -2$$



Q. Find the operating point V_o and I_o.



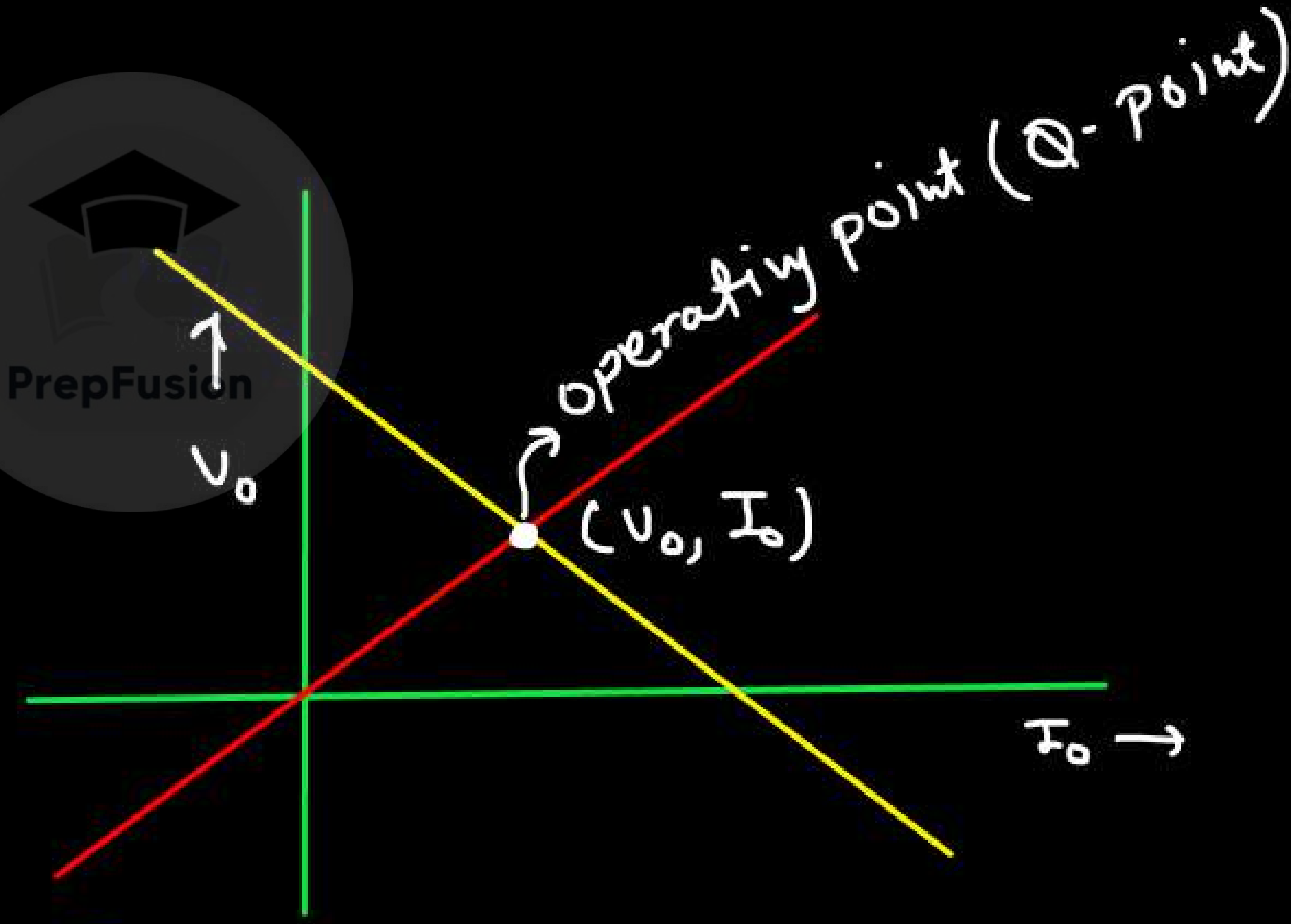
→ $V_o = 5I_o$ — (1)

$10 - V_o = 5I_o$

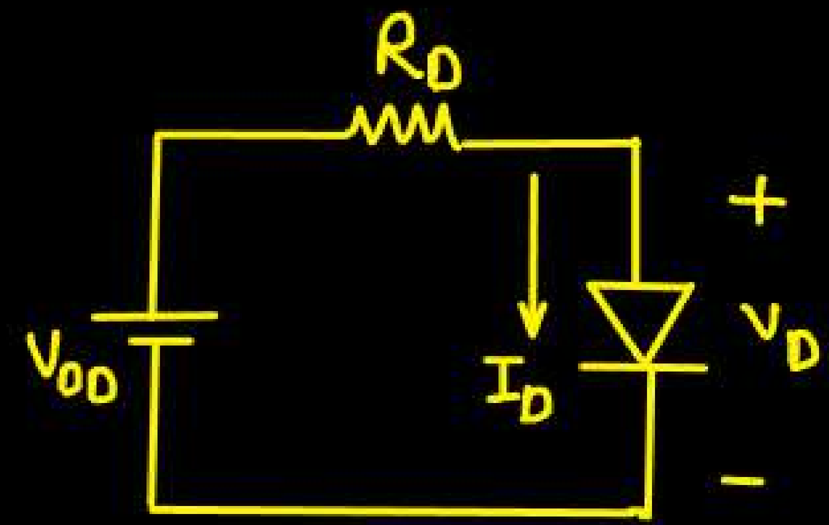
$V_o = -5I_o + 10$ — (2)

⇒ $\boxed{\begin{array}{l} V_o = 5\,V \\ I_o = 1\,\text{Amp.} \end{array}}$

↳ Your ckt is running @ $V_o = 5V$, $I_o = 1\,\text{Amp}$.



⇒ Operating point of a diode :-

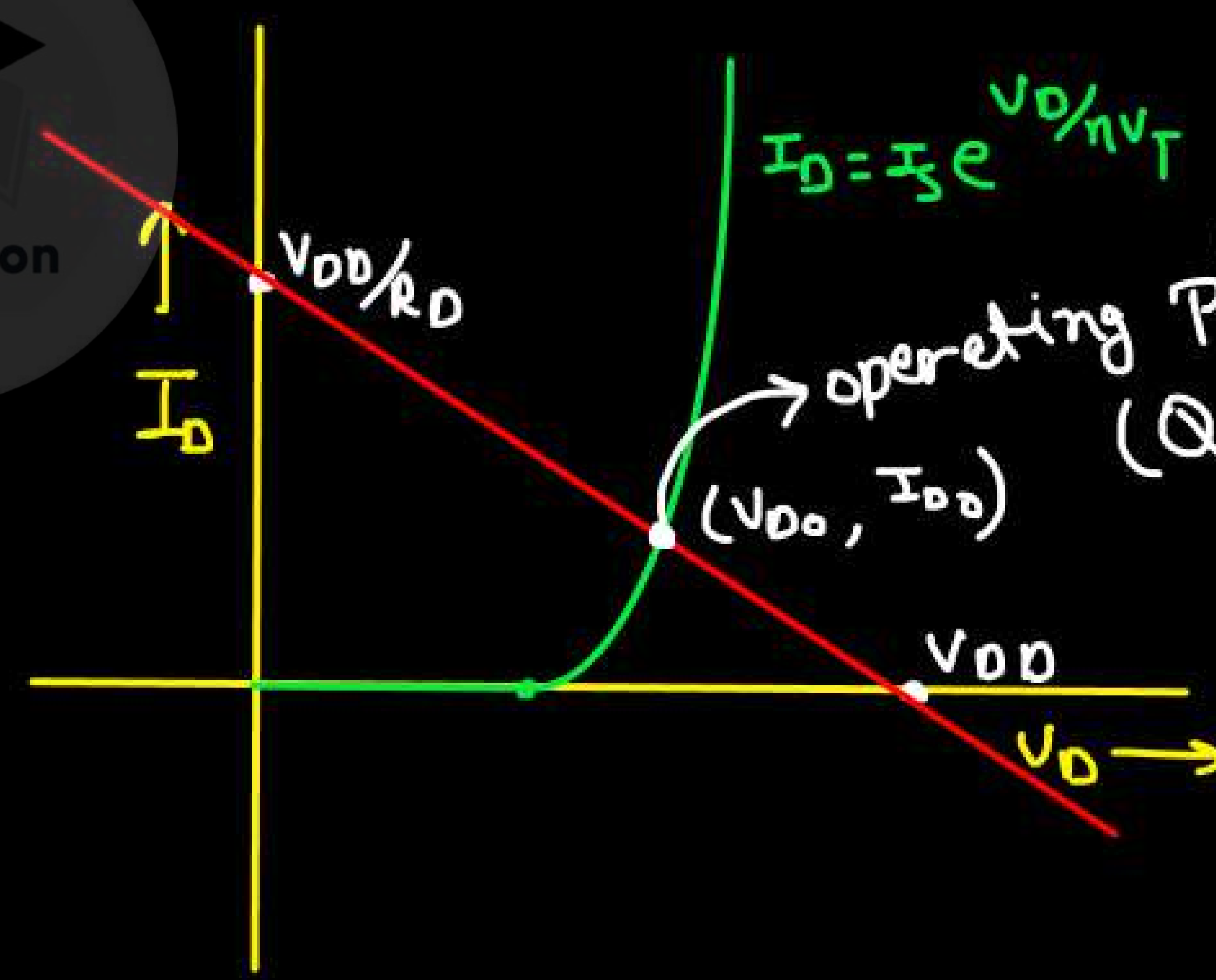


$$I_D = I_S e^{V_D/nV_T} \quad — (1)$$

$$V_{DD} - V_D = I_D R_D$$

$$I_D = \left(-\frac{1}{R_D}\right) V_D + \frac{V_{DD}}{R_D} \quad — (2)$$

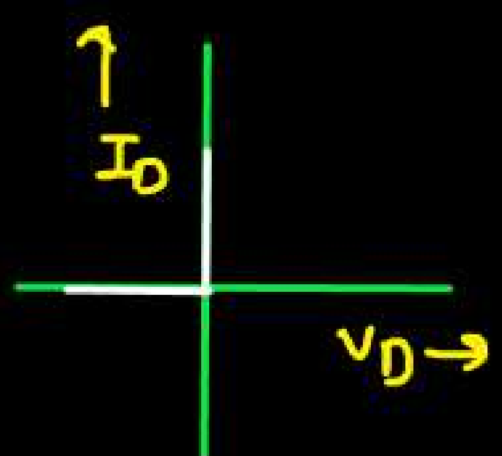
↳ Load line

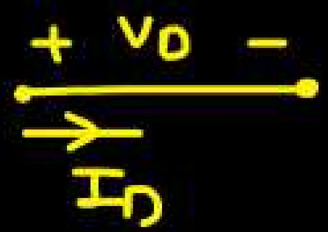


Solving exponential eq^n is a tough task.

To make the calculation easy, we came up with the different models of diode

① Ideal

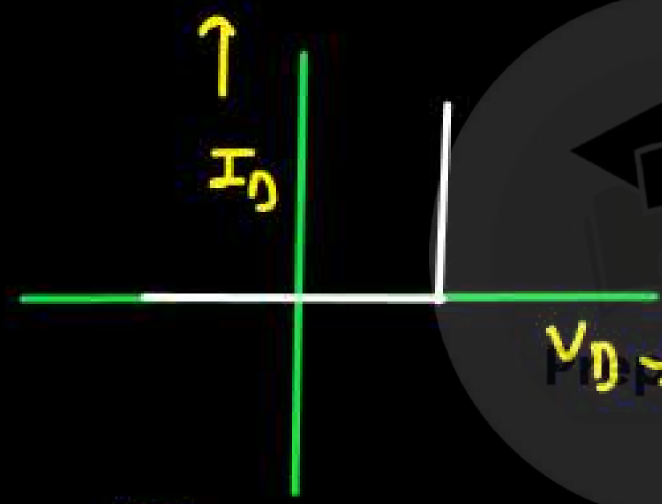


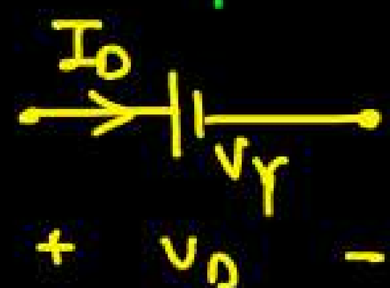


$V_D = 0$

I_D = any value

② Constant voltage drop

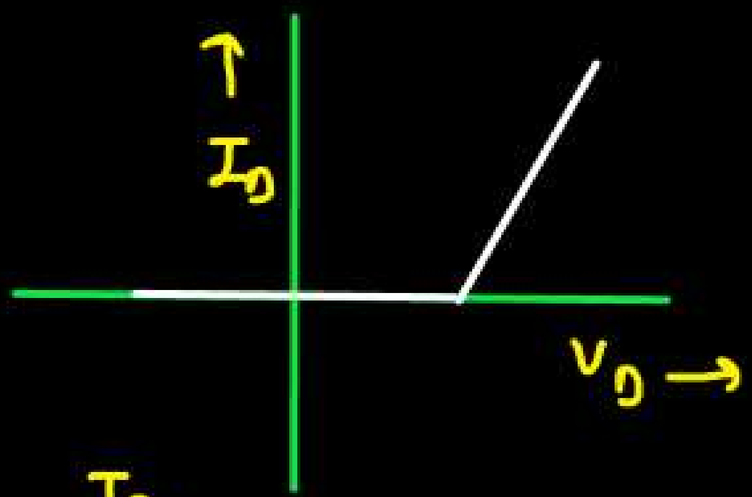


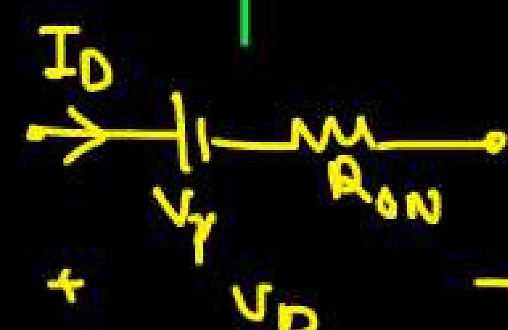


$V_D = V_\gamma$

I_D = any value

③ Piecewise Linear

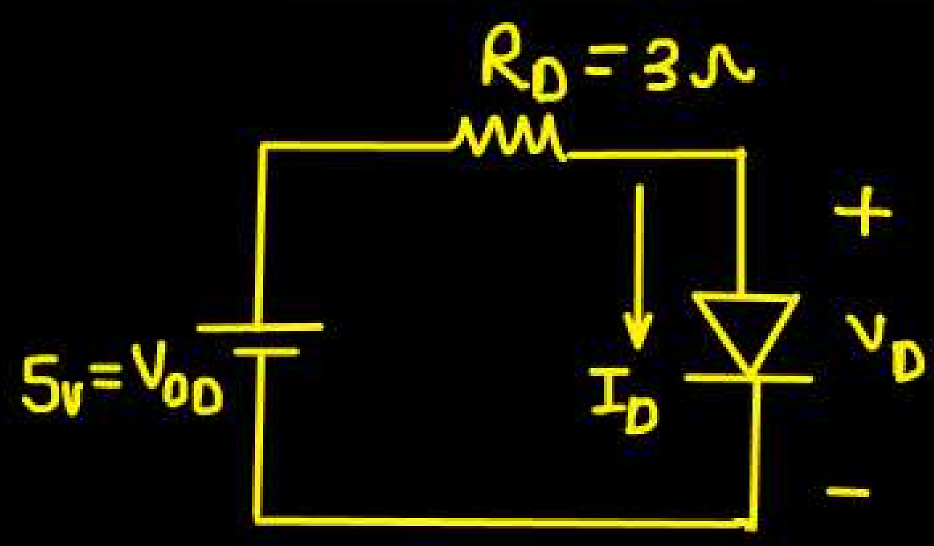




$\Rightarrow V_D = V_\gamma + I_D R_{ON}$

↳ Linear relation

✲ Let's solve this ckt with piecewise linear model:-



Take $V_{DD} = 5V$

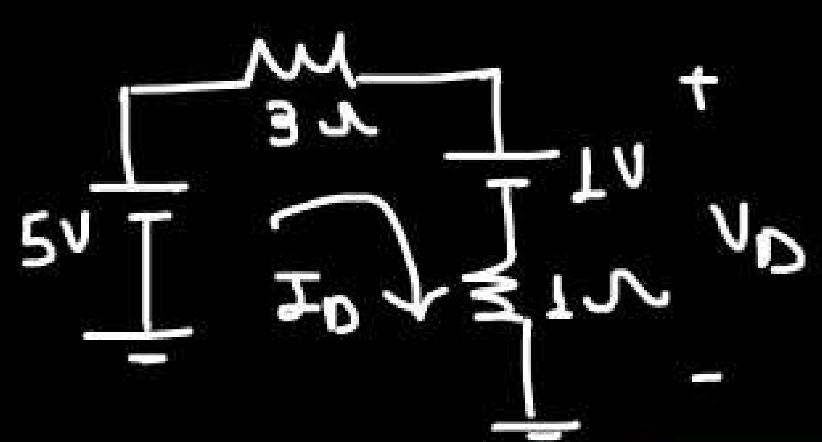
$R_D = 3\Omega$

$V_\gamma = 1V$

$R_{ON} = 1\Omega$

Find V_D and $I_D = ?$

→ solving by ckt



$\boxed{I_D = 1\text{ Amp}}$ $\boxed{V_D = 2V}$

$\Rightarrow V_D = V_\gamma + I_D R_{ON}$

$V_D = 1 + I_D$

$\boxed{I_D = V_D - 1}$ —— 1

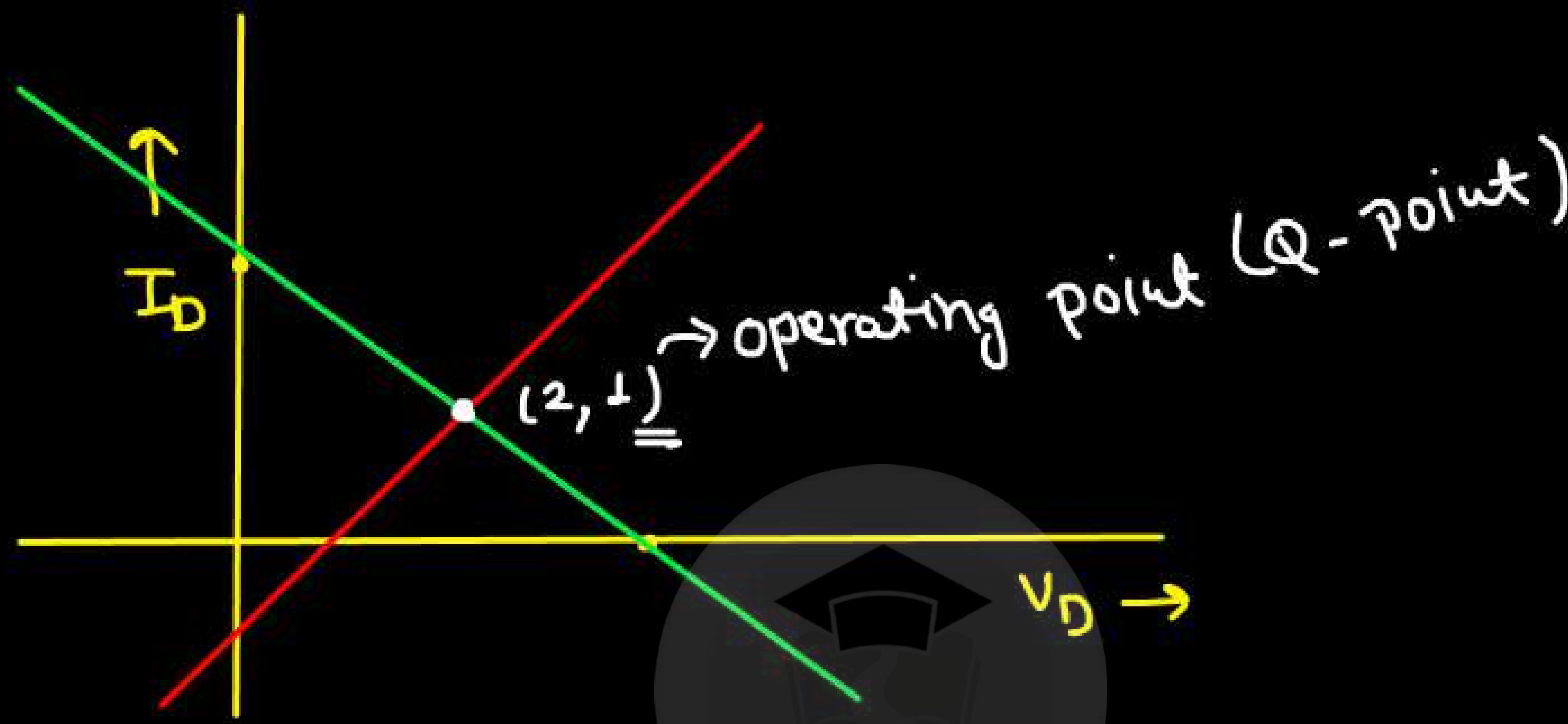
$5 - V_D = 3 I_D$

$\boxed{I_D = -\frac{V_D}{3} + \frac{5}{3}}$ —— 2

$\Rightarrow$ solve these eqn

$\boxed{V_D = 2V}$

$\boxed{I_D = 1A}$



I_D
V_D
(2, 1) → operating point (Q-point)

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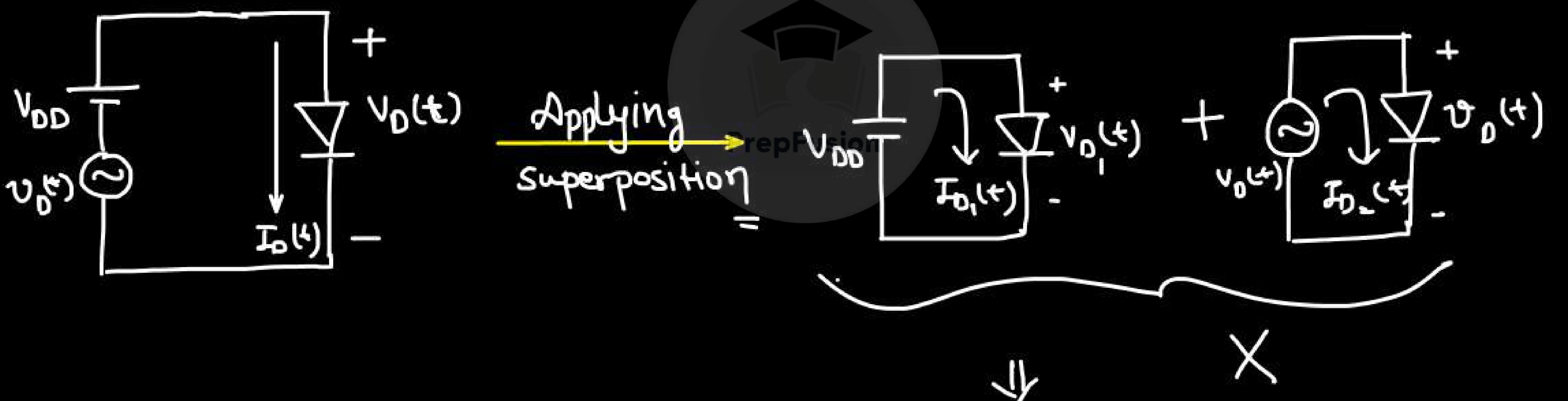
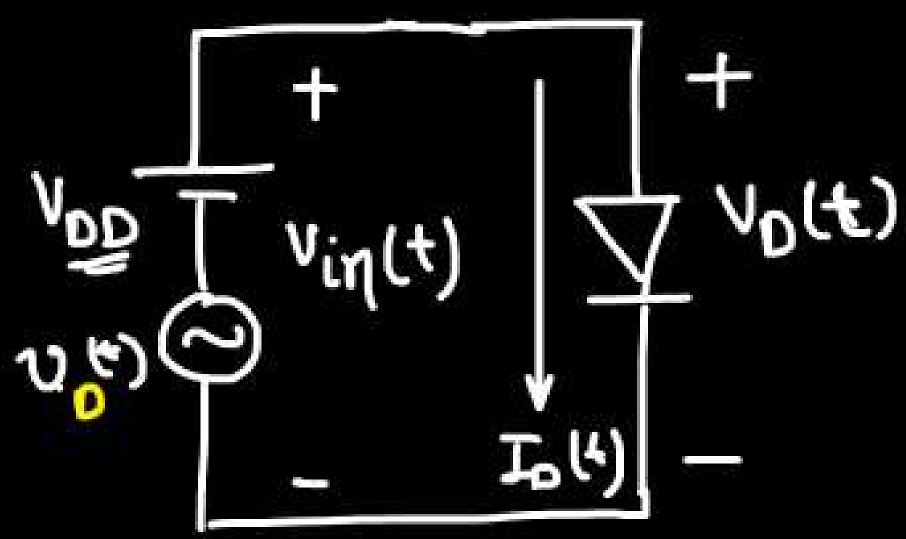
⇒ Small Signal Analysis of Diode:-

↳ **Small Signal**:- Input signal with very small amplitude. (Typically in mV)



⇓

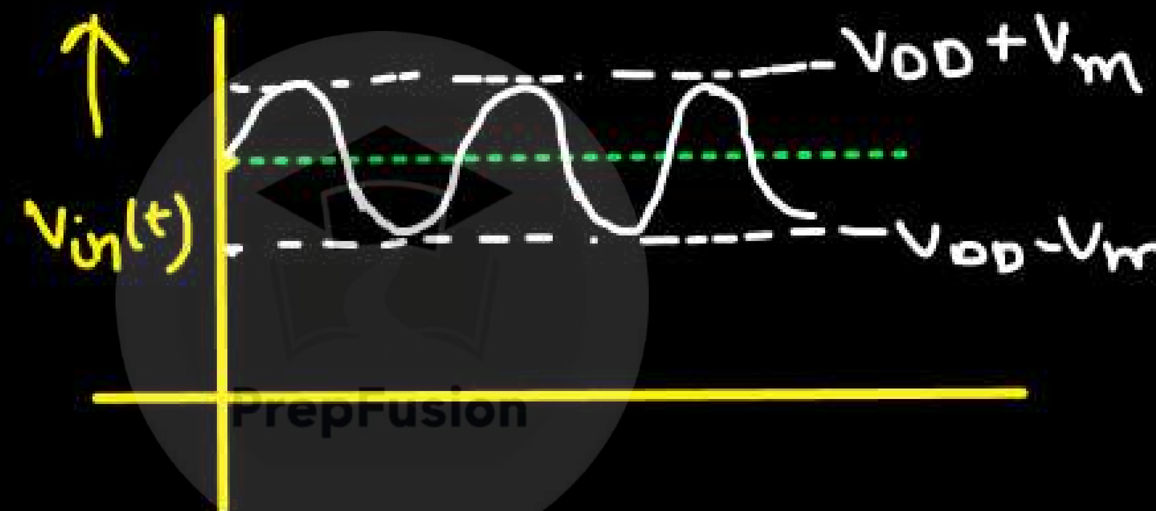
Superposition is only applicable for linear bilateral elements.



⇒ $v_{in}(t) = V_{DD} + v_D(t)$

$\{V_{DD}$ is chosen such that the diode is ON.$\}$

Let $v_D(t) = V_m \sin \omega t$



Now let's find $I_D(t)$:-

$$I_D(t) = I_S e^{V_D(t)/\eta V_T}$$

$$= I_S e^{\frac{V_{DD} + v_D(t)}{\eta V_T}}$$

$$= I_S e^{V_{DD}/\eta V_T} \cdot e^{v_D(t)/\eta V_T}$$

$$= I_S e^{V_{DD}/\eta V_T} \left[1 + \frac{v_D(t)}{\eta V_T}\right] \qquad \left\{ \frac{v_D(t)}{\eta V_T} << 1 \quad \text{Because } v_D(t) \text{ is small} \right\}$$

$$= \underbrace{I_{DC}}_{\Downarrow} \left[1 + \frac{v_D(t)}{\eta V_T}\right] \qquad e^x = 1 + x \text{ ; if } x \text{ is small}$$

dc current of diode

$$I_D(t) = I_{DC} + \frac{I_{DC}}{\eta V_T} \underline{v_D(t)}$$

$$\boxed{I_D(t) = \underbrace{I_{DC}}_{\text{dc current}} + \underbrace{i_a(t)}_{\text{ac current}}}$$

$$\underbrace{i_{ac}(t)}_{\text{small signal ac current}} = \frac{I_{DC}}{\eta V_T} \times \underbrace{v_D(t)}_{\text{small signal ac voltage}}$$

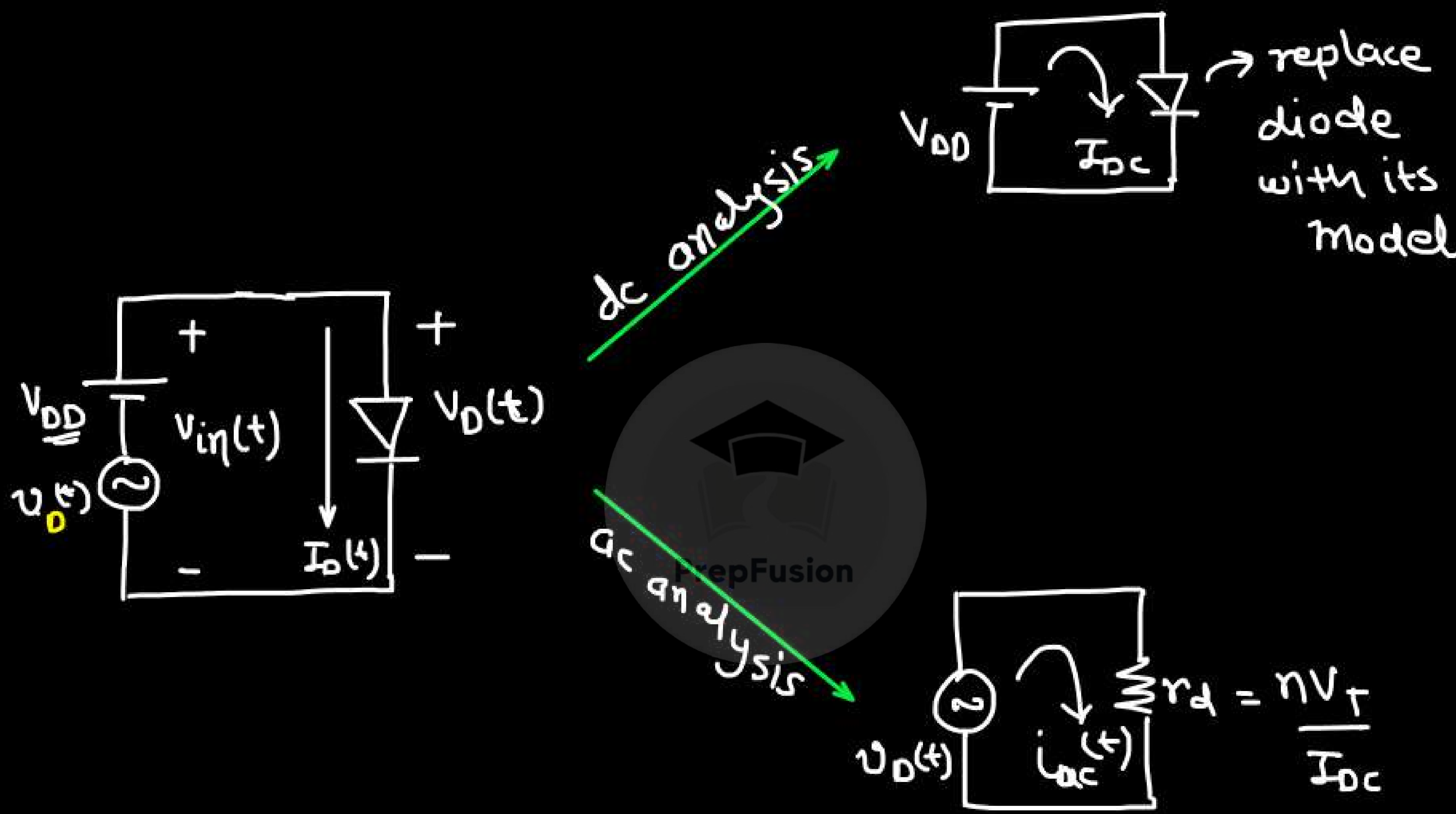
$$\boxed{\frac{v_D(t)}{i_{ac}(t)} = r_d = \text{small signal ac resistance (dynamic resistance)} = \frac{\eta V_T}{I_{DC}}}$$

$$\boxed{r_d = \frac{\eta V_T}{I_{DC}}}$$

⇒ η = non-ideality factor

V_T = Thermal voltage

I_{DC} = DC current of diode



V_{DD}
$v_{in}(t)$
$v_D(t)$
$V_D(t)$
$I_D(t)$
+
−
dc analysis
ac analysis
V_{DD}
I_{DC}
replace diode with its Model
$v_D(t)$
$i_{ac}(t)$
$r_d = \frac{nV_T}{I_{DC}}$
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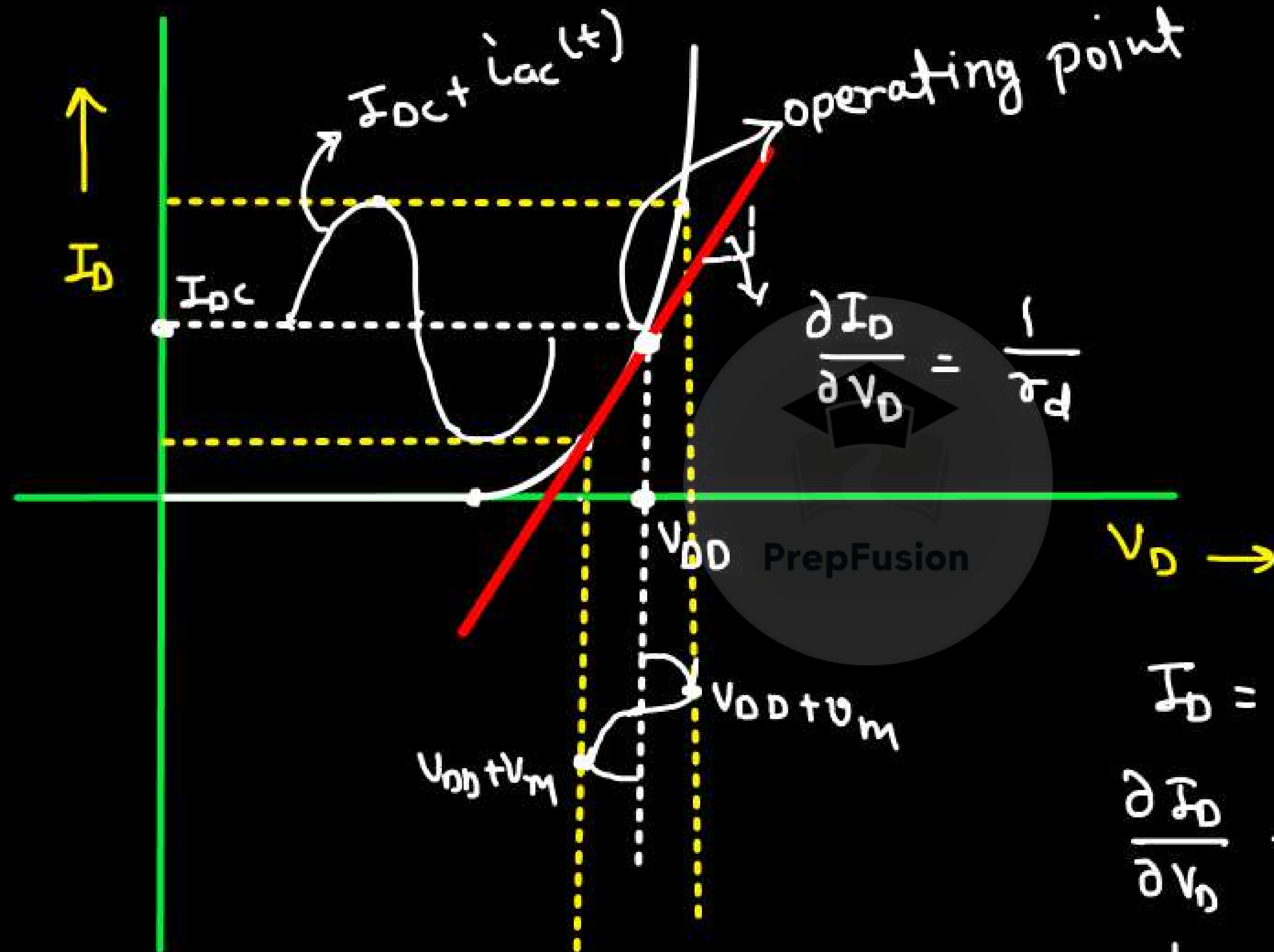
Let's understand this with graphical presentation:-



$$V_{in}(t) = V_{DD} + v_d(t)$$

$$V_D(t) = V_{DD} + v_m \sin \omega t$$

$$\boxed{v_d(t) = r_d\, I_{ac}(t)}$$

$$I_D = I_s e^{V_D/\eta V_T}$$

$$\frac{\partial I_D}{\partial V_D} = \frac{I_s e^{V_D/\eta V_T}}{\eta V_T} = \frac{I_{DC}}{\eta V_T}$$

$$\frac{1}{r_d} = \frac{I_{DC}}{\eta V_T} \Rightarrow \boxed{r_d = \frac{\eta V_T}{I_{DC}}}$$

Conclusion:-

↳ Applied input $v_{in}(t) = \underbrace{V_{DD}}_{\text{Dc signal}} + \underbrace{v_{in}(t)}_{\text{AC signal}}$

Dc Analysis

↳ AC signals nullified

↳ Capacitor o.c.

↳ Diode replaced with its dc equivalent

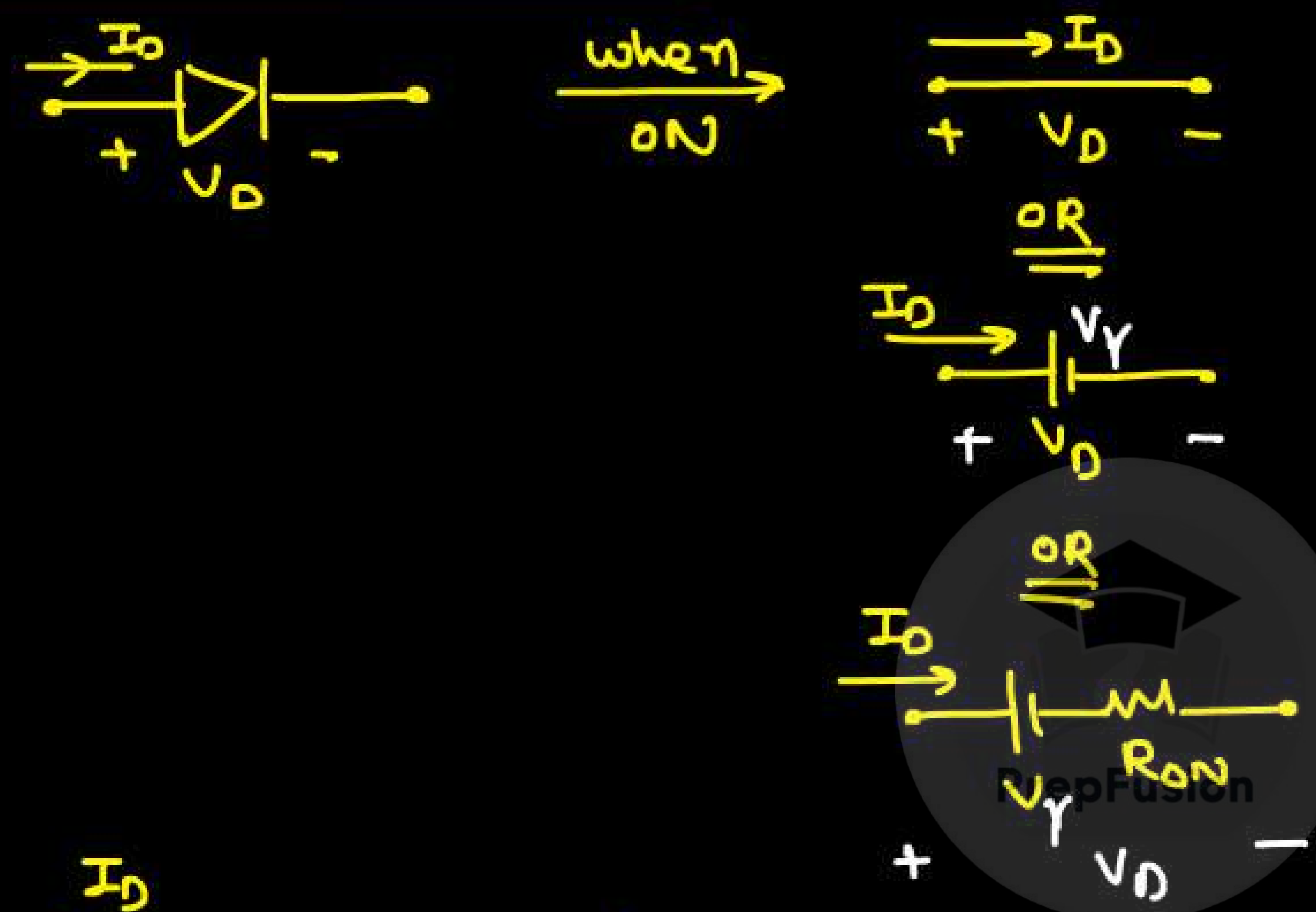
AC Analysis

↳ Dc signals nullified.

↳ Capacitor s.c.

↳ Diode replaced with dynamic resistance (r_d)

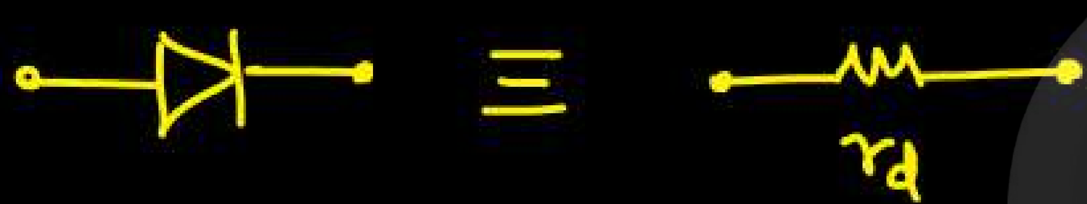
DC Equivalent of diode :-



AC Equivalent of diode :-

Dynamic resistance (r_d) = $\frac{\eta V_T}{I_{DC}}$

↳ when diode is on (in dc analysis):-



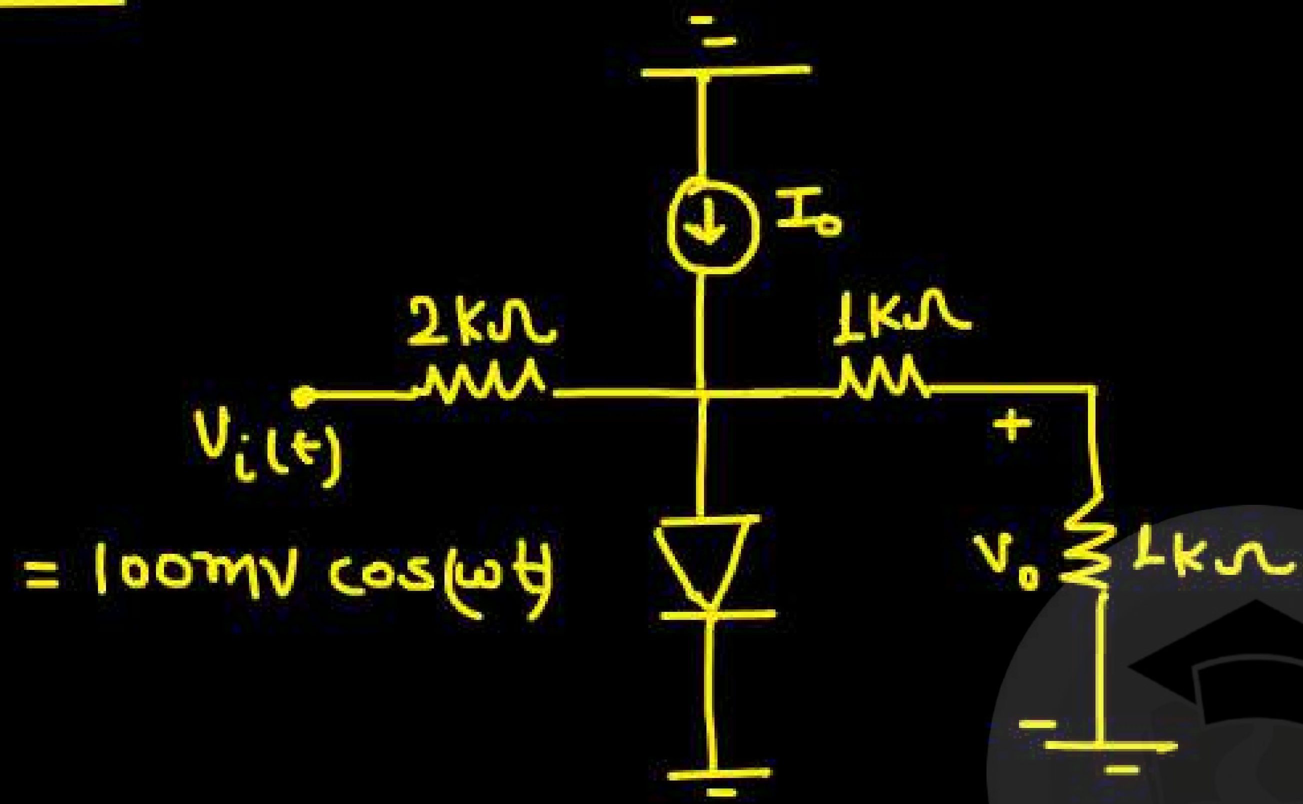
↳ when diode is off (in dc analysis):-

$$r_d = \frac{\eta V_T}{I_{DC}} = \frac{\eta V_T}{0} = \infty$$

$$r_d \in [0, \infty)$$

Question :-

Q. 1



Voltage source → S.C.

Current source → O.C.

determine the amplitude of sinusoid component of v_0 if

(i) $I_0 = 2.7\,mA$

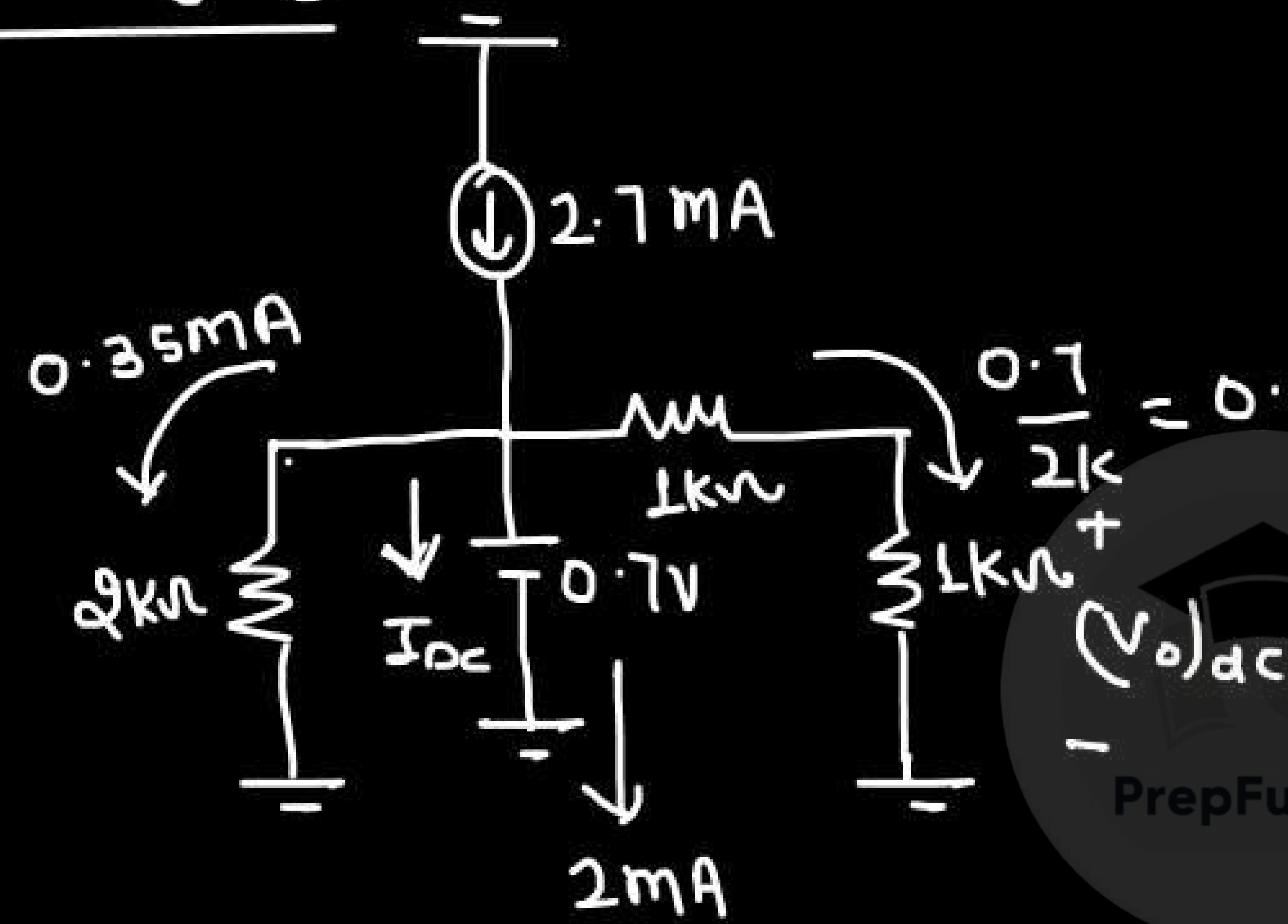
(ii) $I_0 = -2.7\,mA$

cut-in voltage of diode is 0.7 V.

Take $V_T = 25\,mV$

(i) $I_D = 2.7\,mA$

dc analysis:-



Assuming diode to be ON.

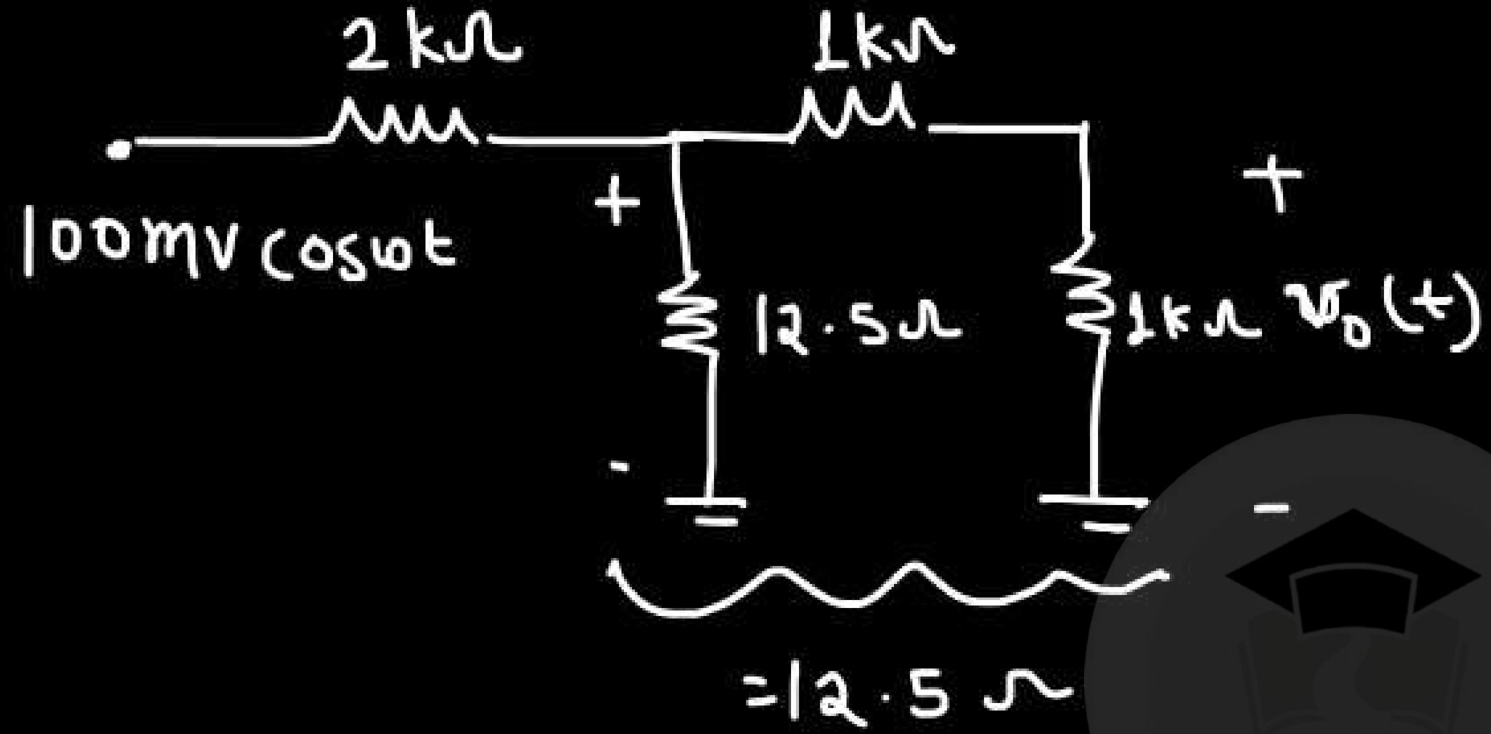
$$\frac{0.7}{2k} = 0.35\,mA$$

$I_{DC} = 2\,mA$

$$\boxed{r_d = \frac{\eta V_T}{I_{DC}} = \frac{25\,mV}{2\,mA} = 12.5\,\Omega}$$

$$\boxed{(V_o)_{dc} = 0.35\,V}$$

ac analysis:-

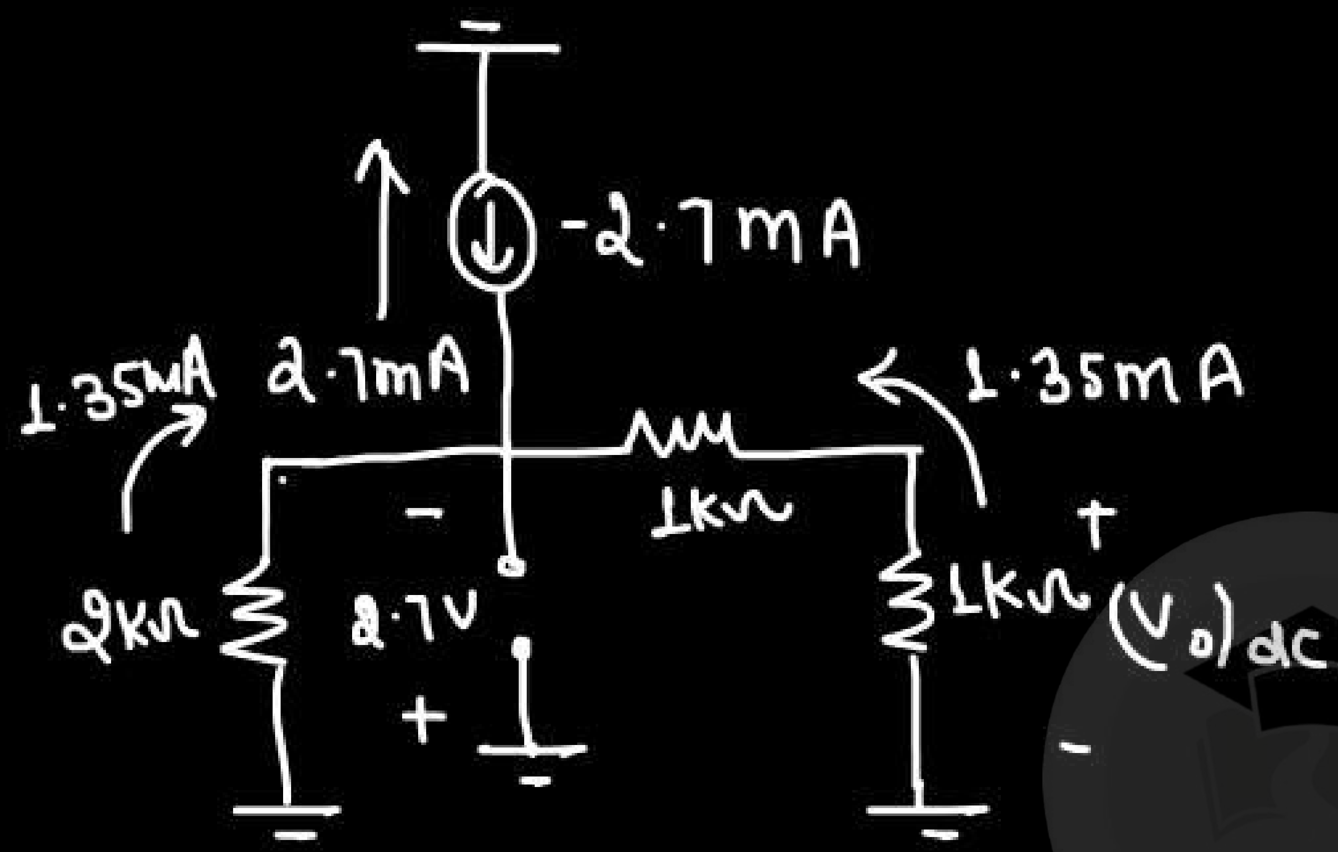


$$v_o(t) = \frac{12.5}{2012.5} \times \frac{1}{2} \times 100\,mV \cos\omega t$$

$$\boxed{v_o(t) = 0.31\,mV \cos\omega t}$$

$$\boxed{V_o = 0.35V + 0.31\,mV \cos\omega t}$$ {dc+ac}

(ii) $I_o = -2.7\,mA$



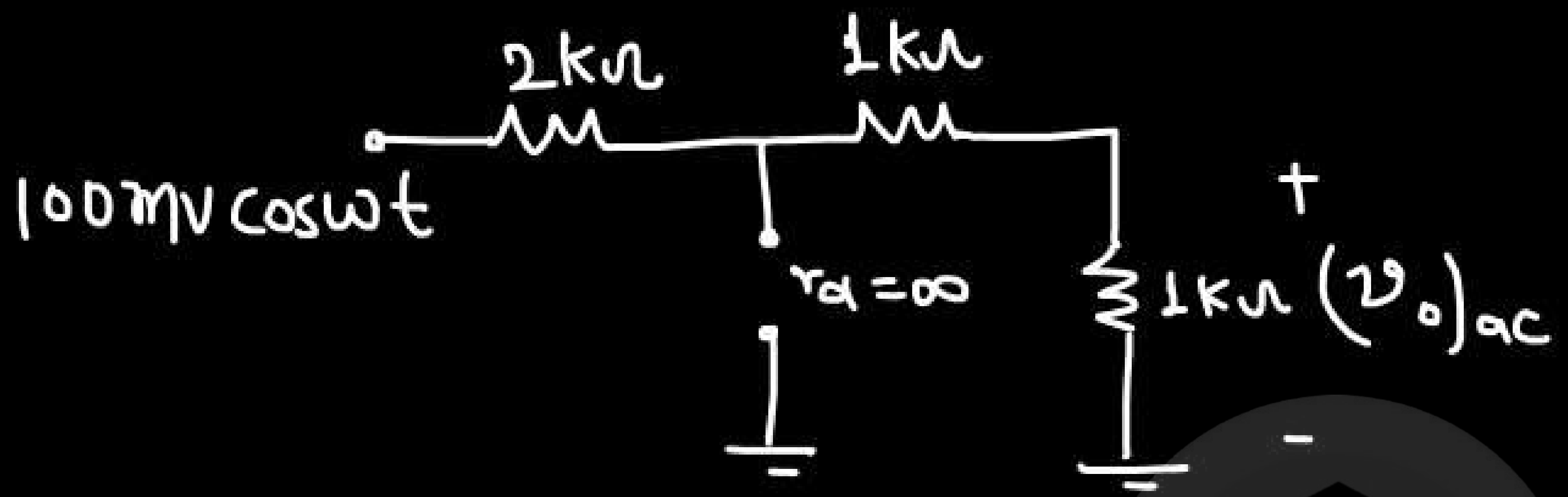
Diode is off

$I_{DC} = 0$ Amp.

$$\boxed{r_d = \frac{\eta V_T}{0} = \infty}$$

$$\boxed{(V_o)_{dc} = -1.35V}$$

ac analysis:-



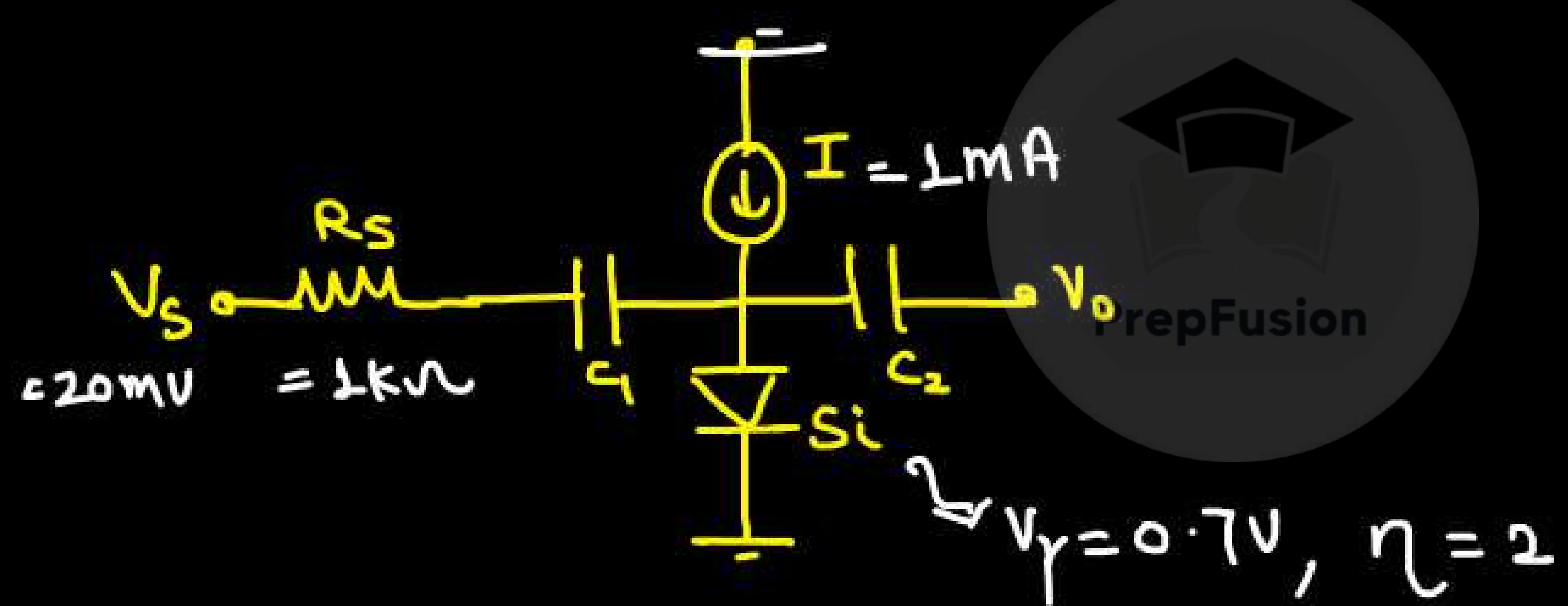
$$(v_o)_{ac} = \frac{1}{4} \times 100\text{mV} \cos\omega t$$

$$\boxed{(v_o)_{ac} = 25\cos\omega t \text{ mV}}$$

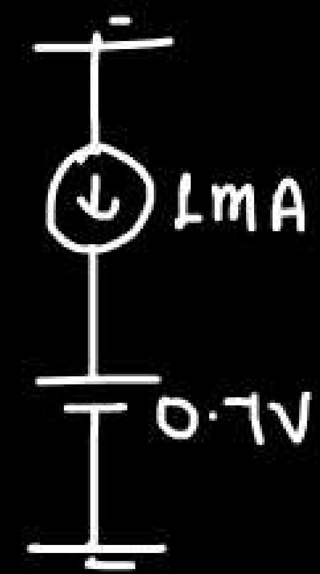
$$\boxed{V_o = -1.35\text{V} + 25\cos(\omega t) \text{ mV}}$$

Q. "I" is the dc current and V_s is the small signal ac voltage. Cap. C_1 and C_2 are very large. Find V_o if $I = 1\,mA$

Take $V_T = 25\,mV$, $V_s = 20\,mV$, $R_s = 1\,k\Omega$



→ dc analysis ⇒ $C \to O.C.$, $V_s \to S.C.$



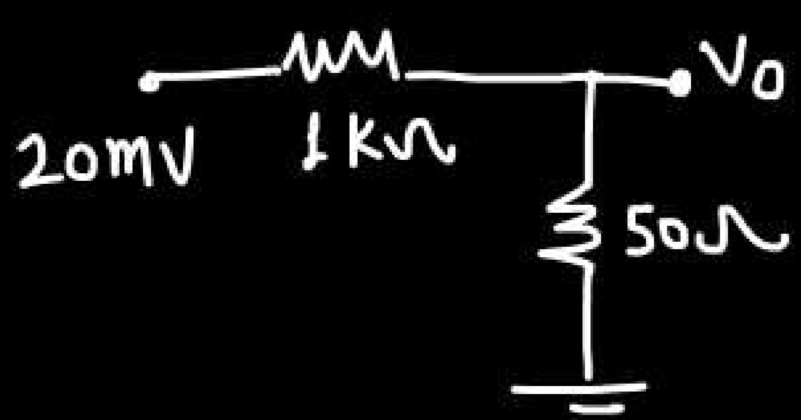
$$I_{DC} = 1\,mA$$

$$r_d = \frac{\eta V_T}{I_{DC}}$$

$$= \frac{2(25)\,mV}{1\,mA} = 50\,\Omega$$

$$\boxed{r_d = 50\,\Omega}$$

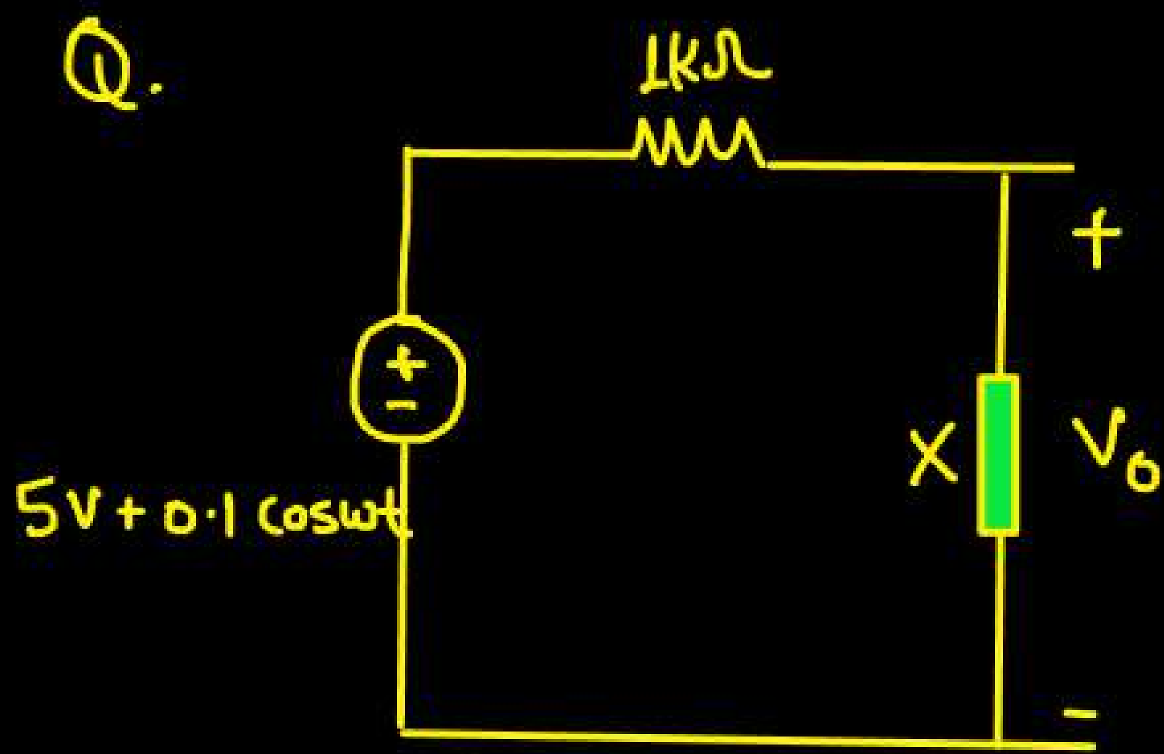
<u>ac analysis</u>:- $C \rightarrow s.c.$, $I_0 \rightarrow o.c.$

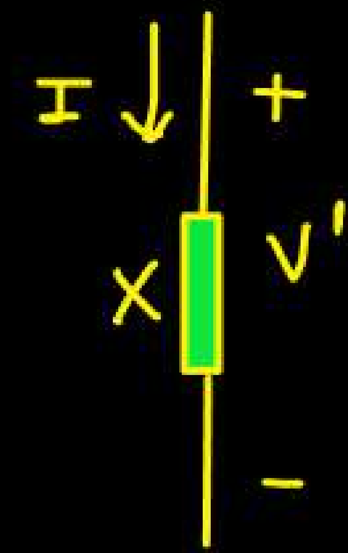


$$V_0 = \frac{50}{1050} \times 20\,mV$$

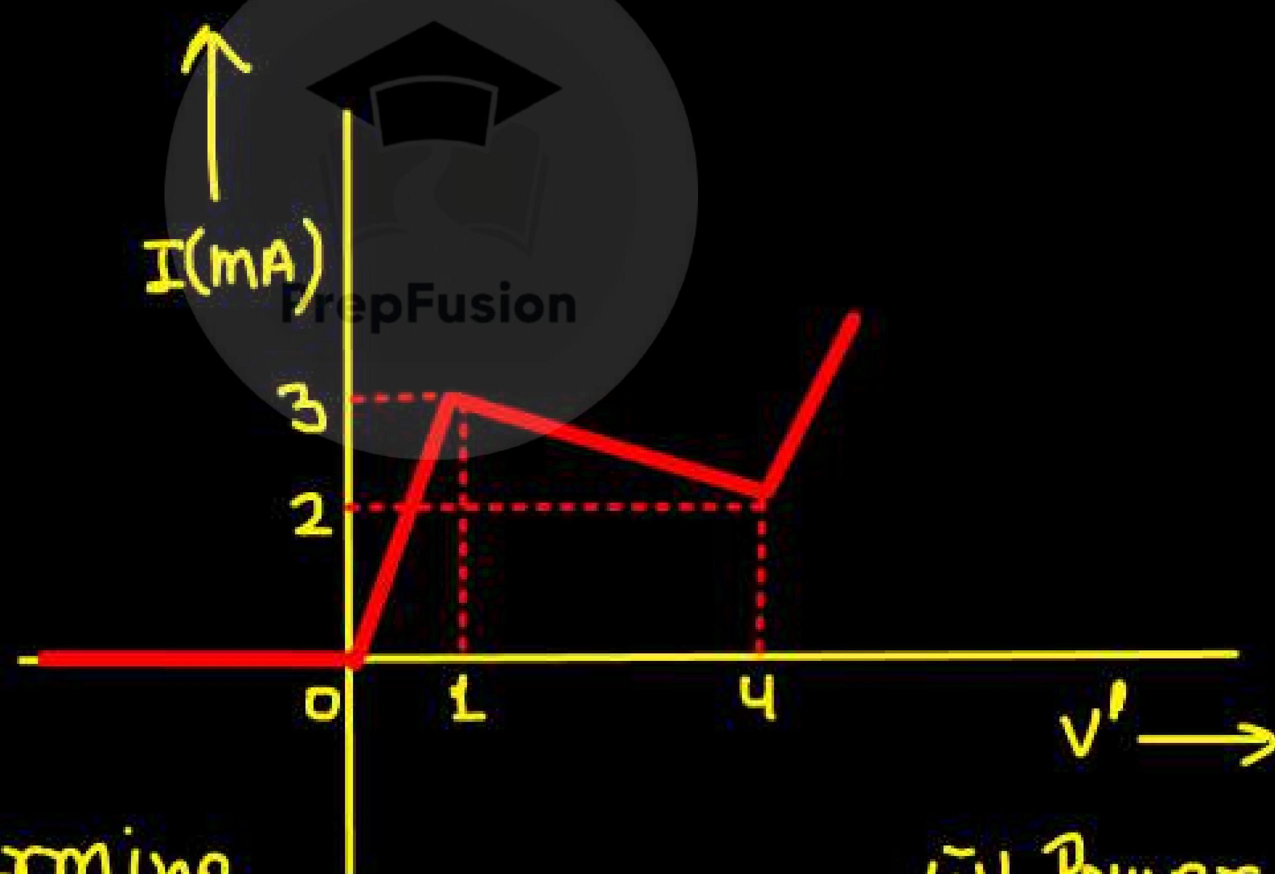
$$\boxed{v_0 = 0.95\,mV = V_0}$$

Q.





In the ckt, there is a non-linear element X is connected. The I-V' characteristic of the element is shown. Determine

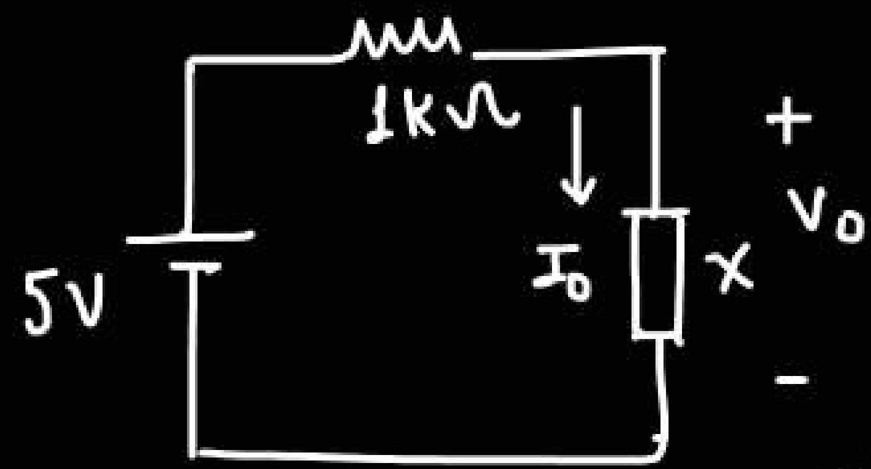


(i) The amplitude of sinusoid component of v_o.

(ii) Power dissipated in the non-linear element @ the operation point.

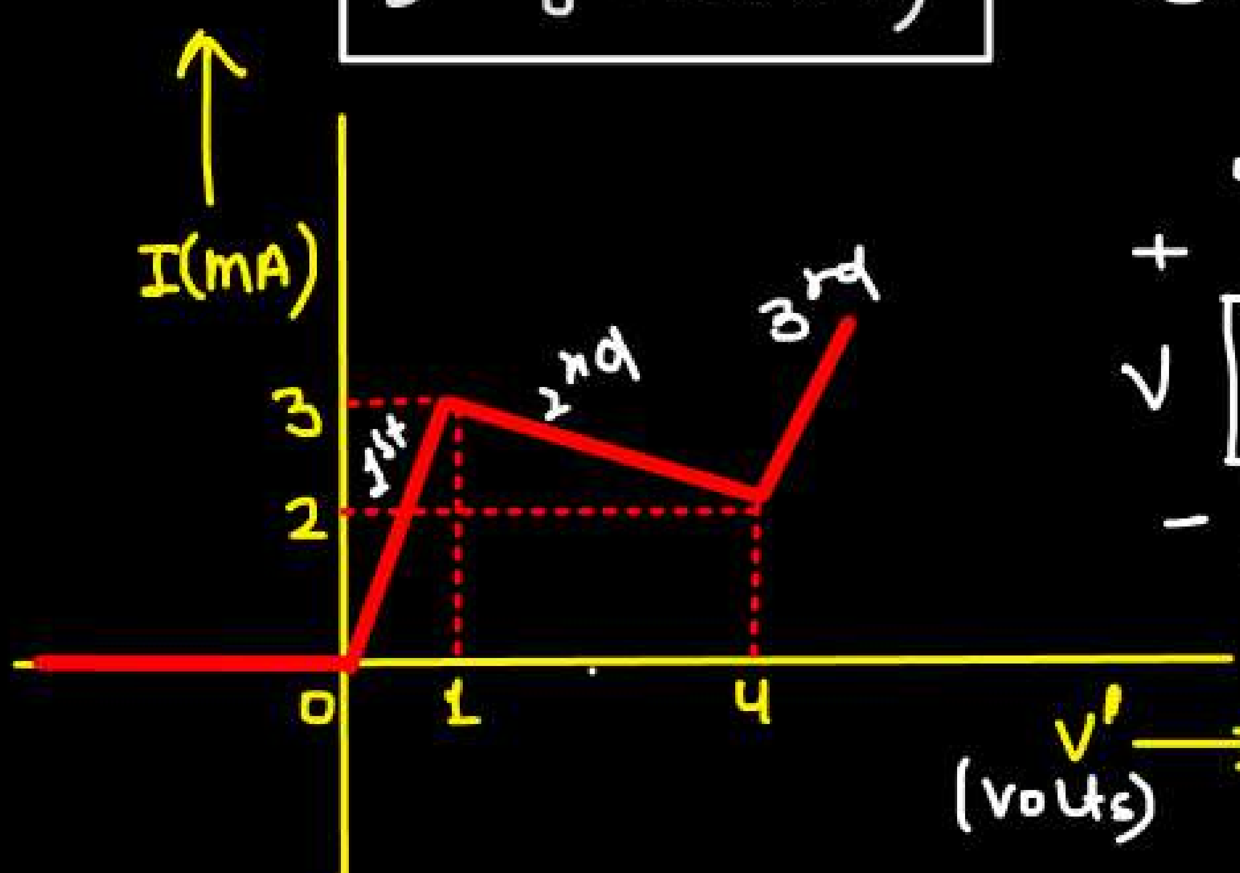
(ii) op^r point →

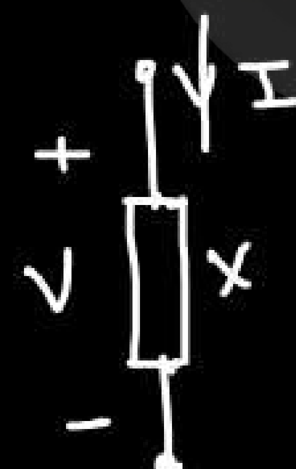
dc analysis



load line

$$\boxed{5 - V_0 = 1k(I_0)} \quad \text{— (1)}$$





region 1st : →

$$I = 3m V' \quad \text{— (2)}$$

region 2nd : →

$$I = -\frac{1m}{3} V' + \frac{10m}{3} \quad \text{— (3)}$$

$\Rightarrow$ Device is either operating in region 1^{st} or 2^{nd} or 3^{rd}.

↳ Assuming device is operating in region 1^{st}

$$5 - V_0 = 1k(I_0) \quad \text{—} \ (1)$$

$$I_0 = 3m\, V_0 \quad \text{—} \ (2)$$

$$5 - V_0 = 3V_0$$

$$\boxed{\begin{aligned} V_0 &= 1.25\,V \\ I_0 &= 3.75\,mA \end{aligned}}$$

→ This point doesn't lie in region 1^{st}

↳ Assuming device is working in region 2^{nd}

$$5 - V_0 = 1k(I_0) \quad \text{—} \ (1) \quad \Rightarrow \quad I_0 = 5m - 1mV_0$$

$$I_0 = -\frac{1m}{3} V_0 + \frac{10m}{3} \quad \text{—} \ (3) \quad \Rightarrow$$

$$5m - 1m V_0 = -\frac{1m}{3} V_0 + \frac{10m}{3}$$

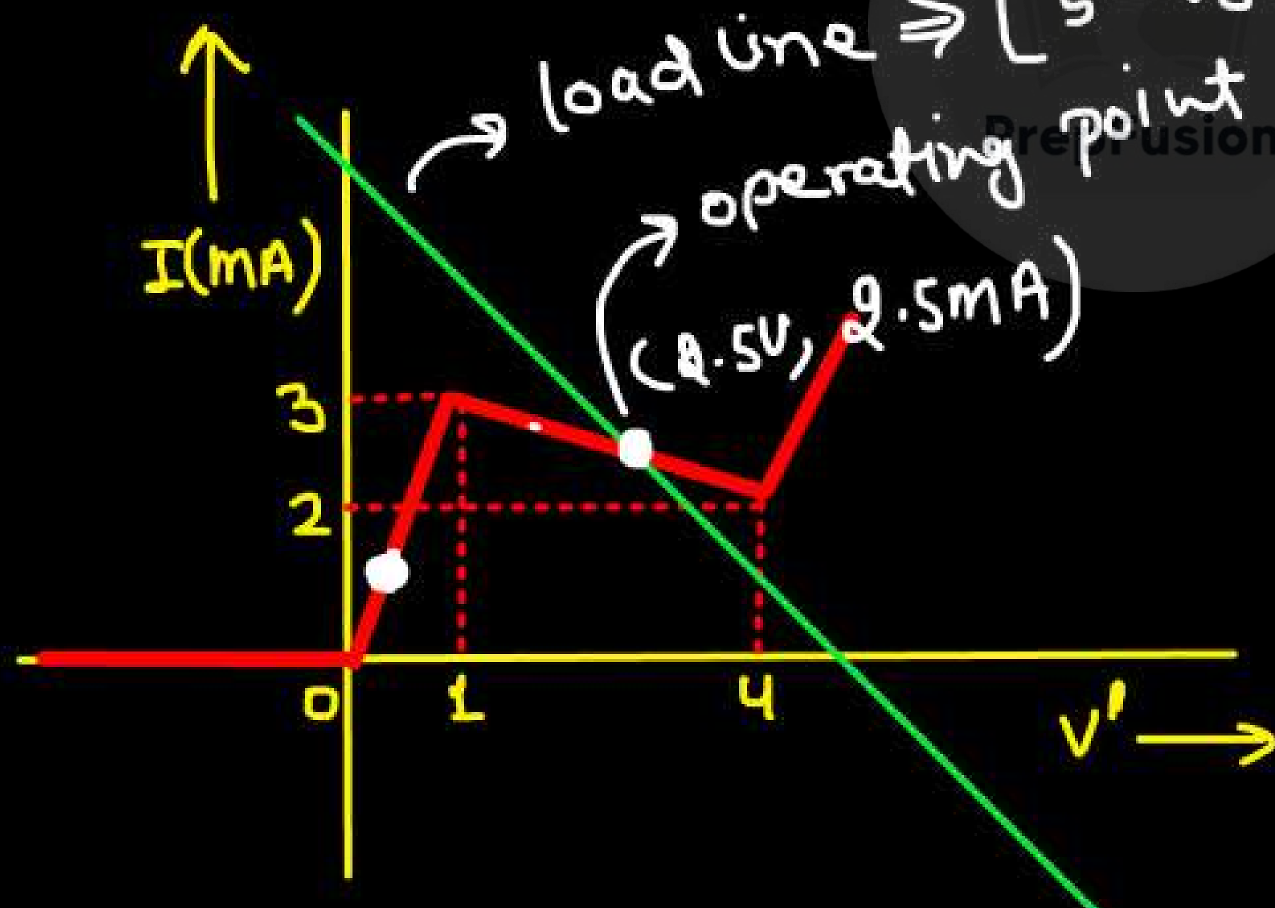
$$\frac{5m}{3} = \frac{2m}{3} V_0$$

$$\boxed{V_0 = 2.5V}$$

$$\boxed{I_0 = 2.5mA}$$

→ This points lies in region 2

load line ⇒ $[5 - V_0 = 1K(I_0)]$



Power dissipated @ operating point

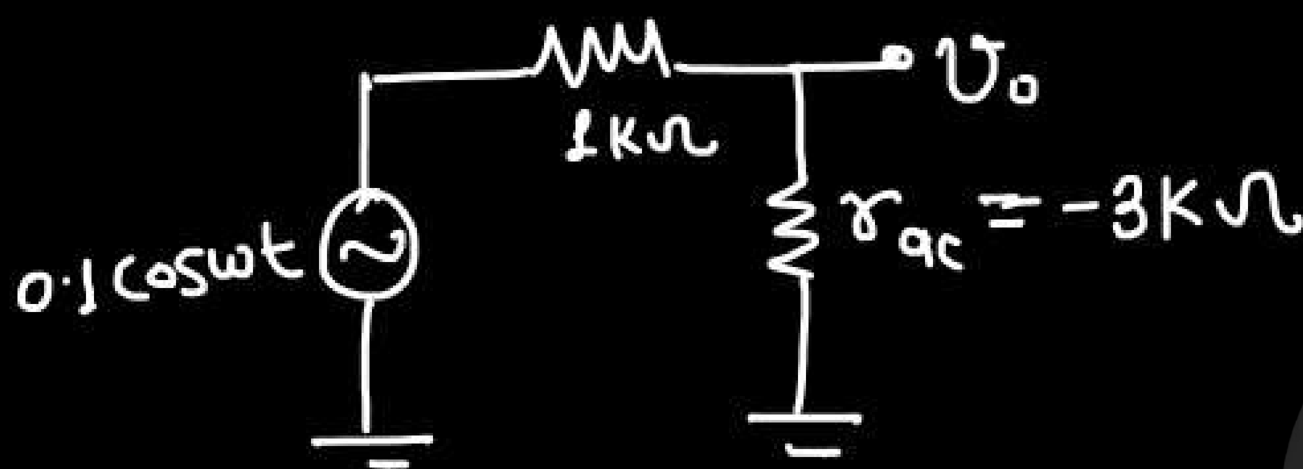
$$P = V_0 I_0$$

$$= 2.5 \times 2.5mA$$

$$\boxed{P = 6.25mW}$$

(ii) $$r_{ac} = \frac{1}{\left(\frac{\partial I}{\partial V}\right)_{@\text{ operating point}}} = \frac{1}{-1m/3} = -3\,K\Omega$$

<u>ac analysis :-</u>

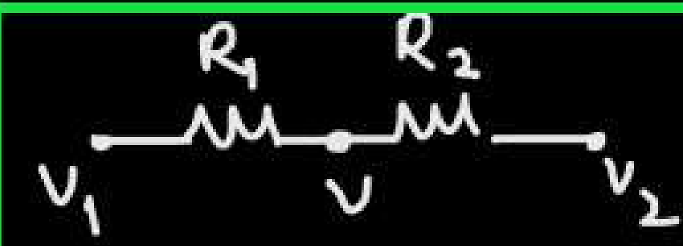


$$v_o = \frac{-3K}{1-3K} \times 0.1\cos\omega t$$

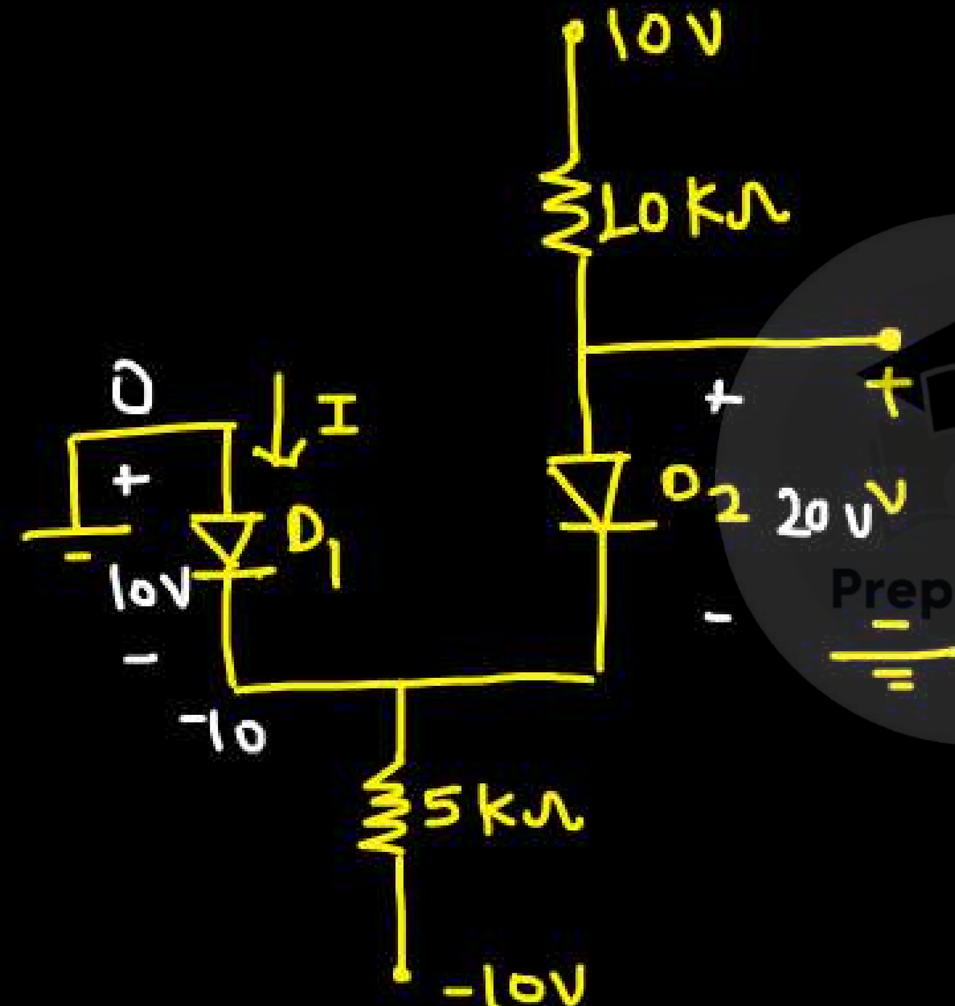
$$\boxed{v_o = 0.15\cos\omega t \text{ mV}}$$

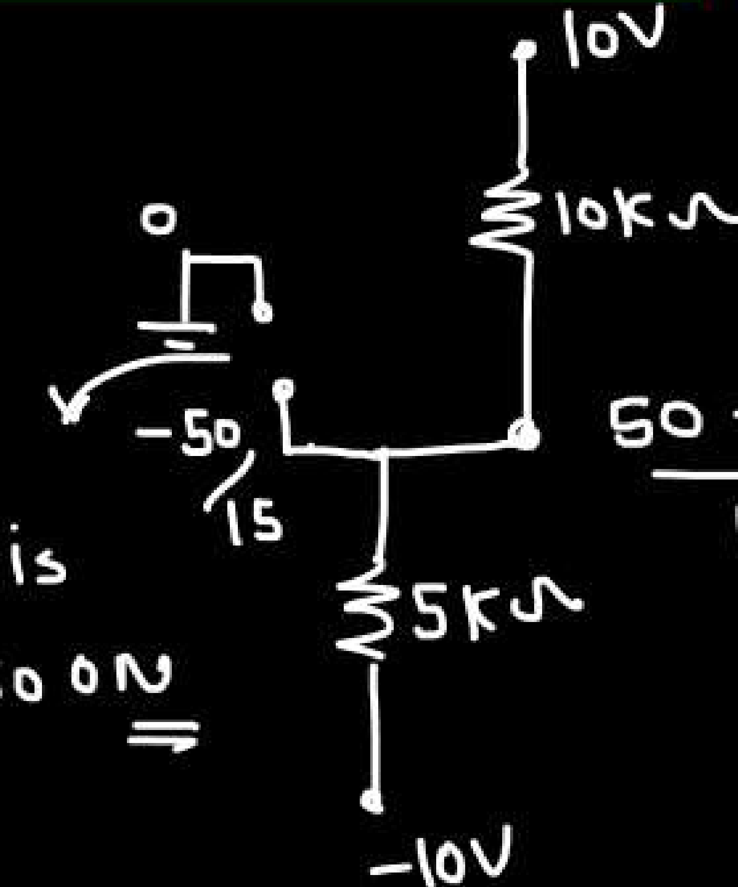
Assignment - 1

Q. Assuming diodes to be ideal. Find I & V.



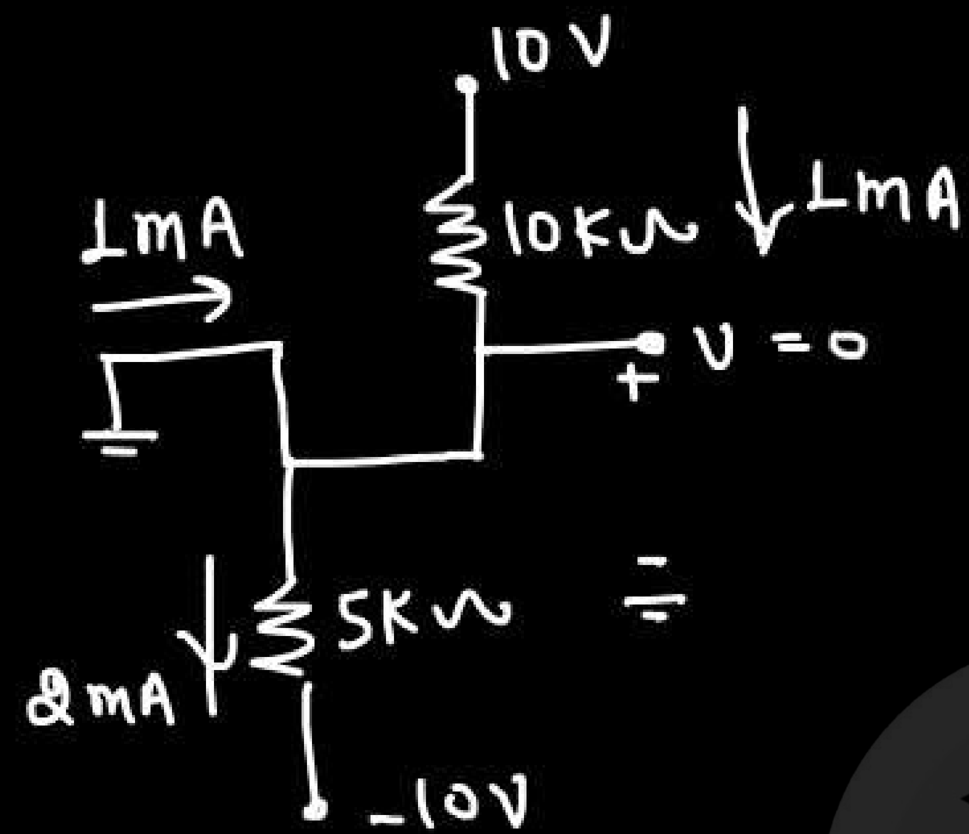
$$V = \frac{V_1 R_2 + V_2 R_1}{R_1 + R_2}$$





D_1 is also ON $\Rightarrow$

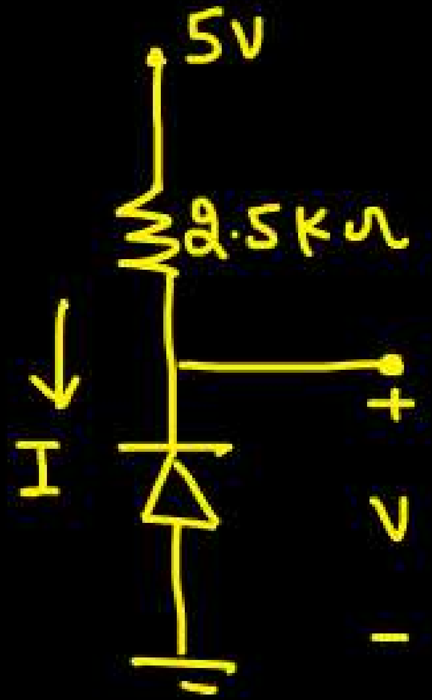
$$\frac{50-100}{15} \approx \frac{-50}{15}$$



$V = 0V$

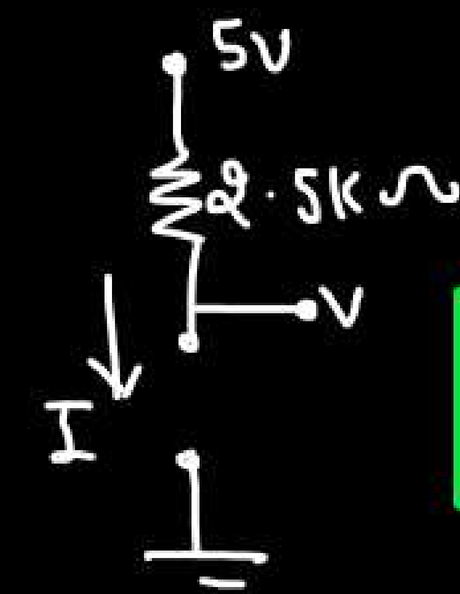
$I = 1mA$

Q. (i)



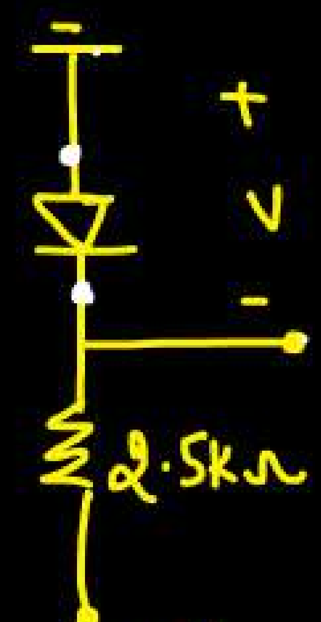
Find V & I.

→ Diode off

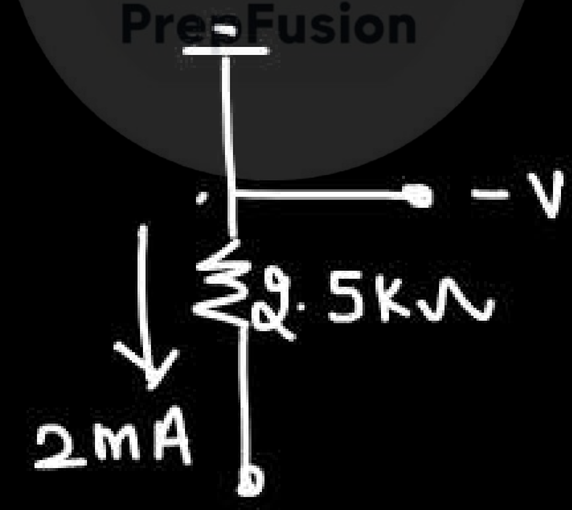


$\boxed{\begin{matrix} I = 0 \\ V = 5V \end{matrix}}$

(ii)



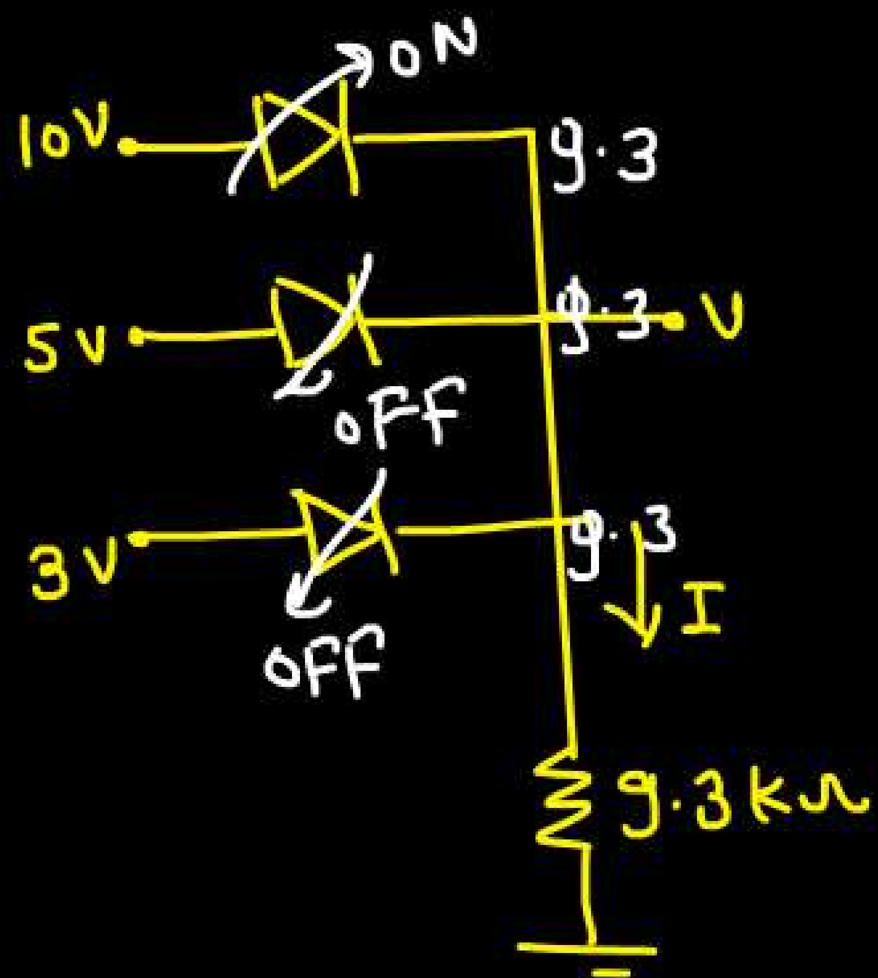
Diode → ON



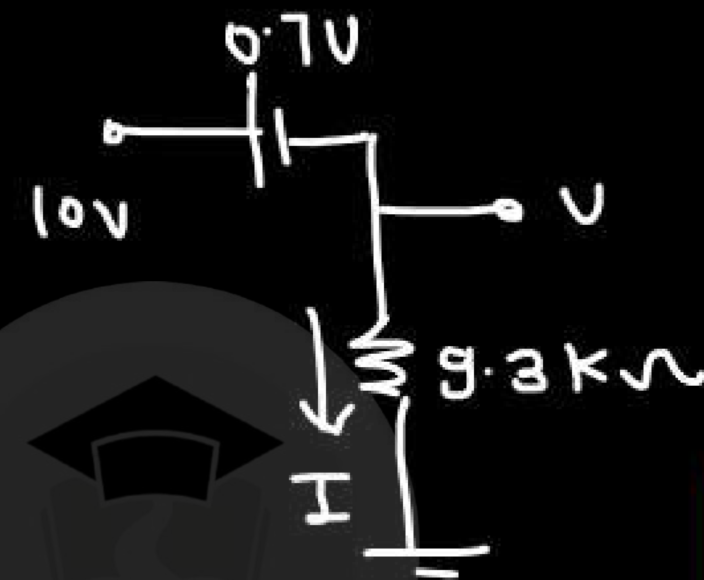
$\boxed{V = 0V}$

Q. $V_\gamma = 0.7V$

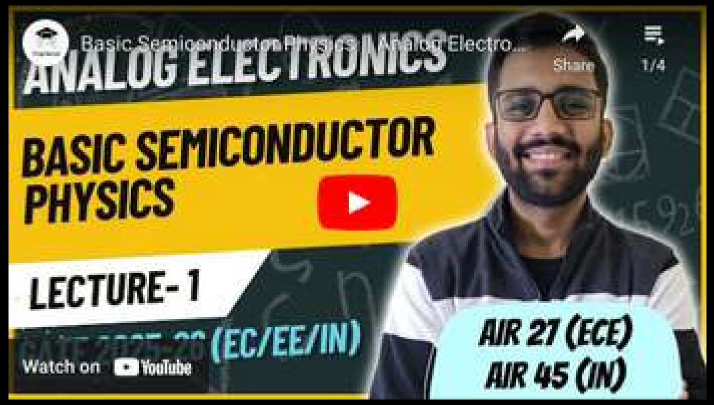
Find v and I



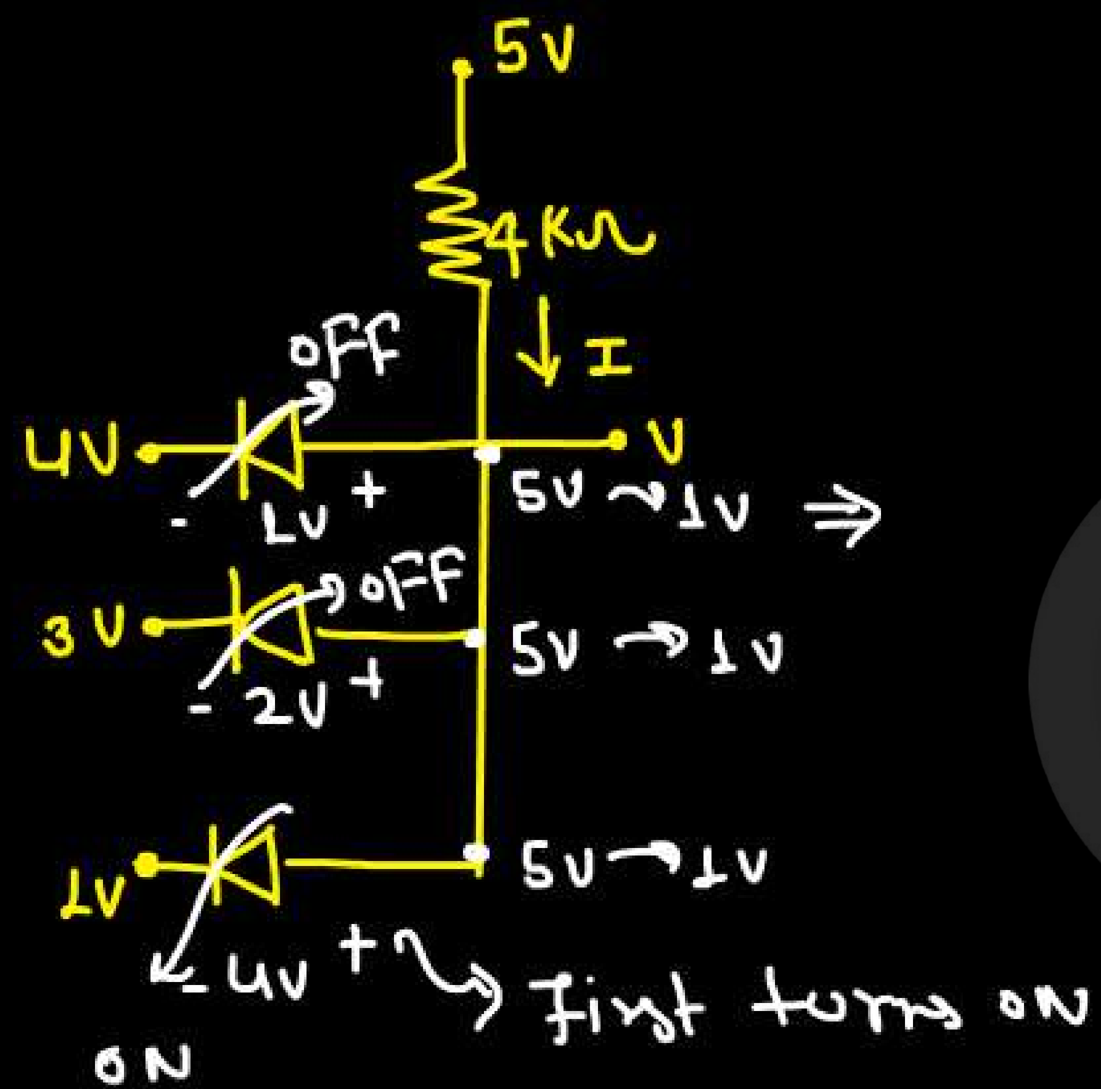
→



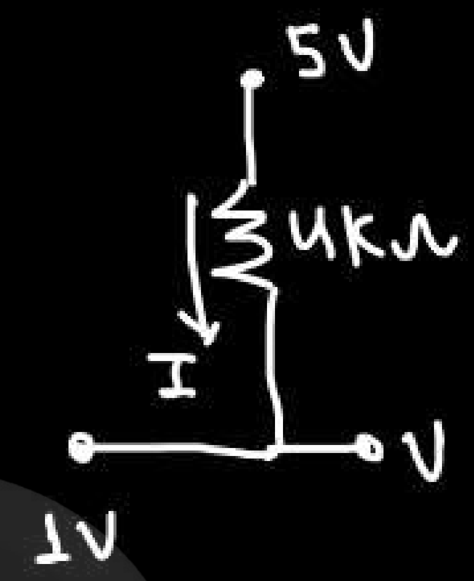
$$\boxed{\begin{aligned} V &= 9.3V \\ I &= 1mA \end{aligned}}$$



Q. Find V and I

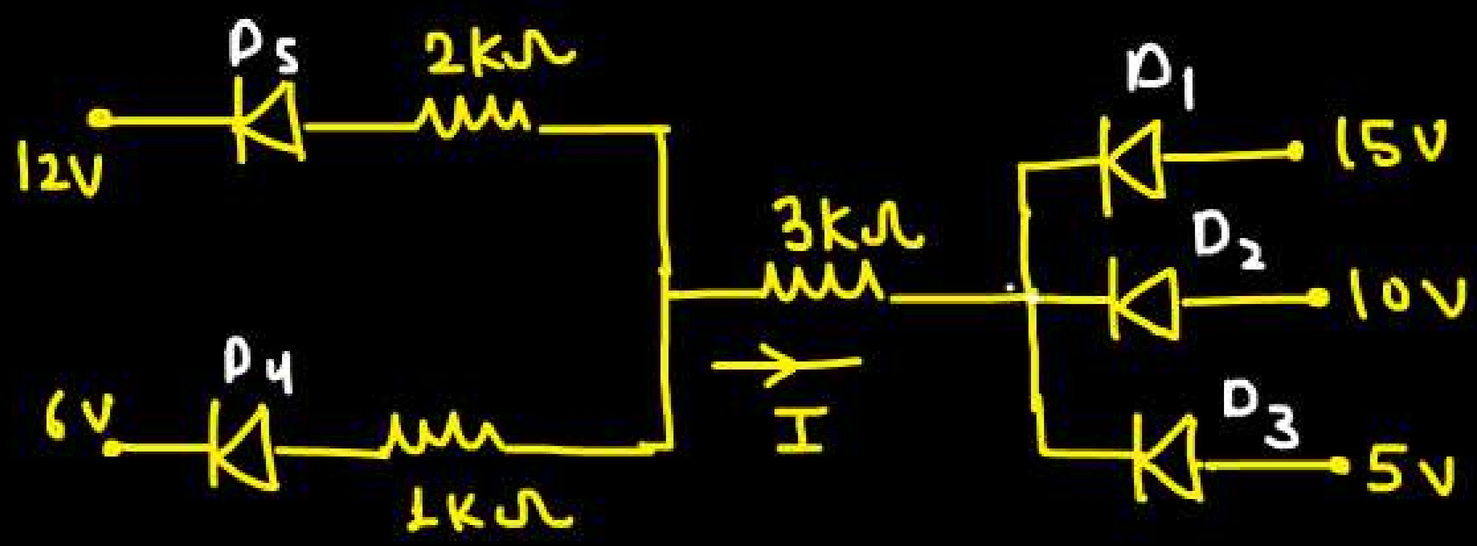


$\Rightarrow$



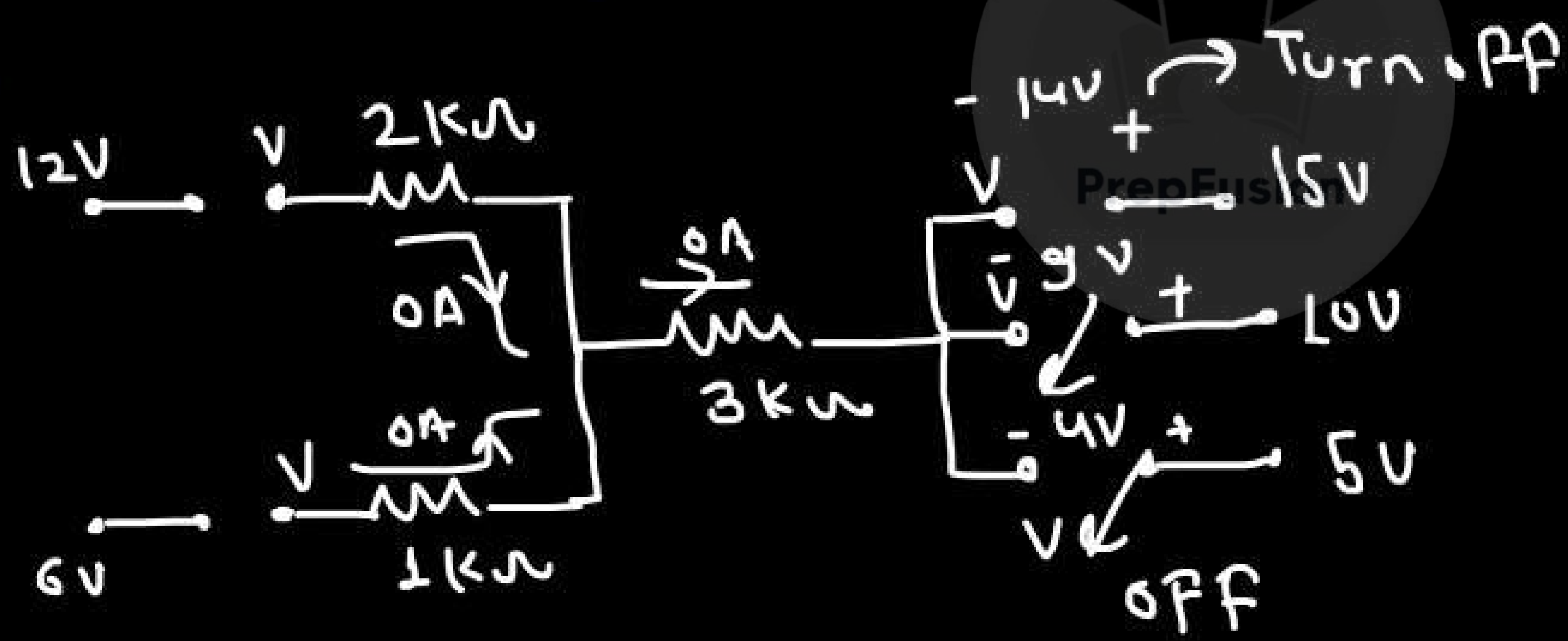
$$\boxed{\begin{array}{l} V = 1V \\ I = 1mA \end{array}}$$

Q.



Find current I.

→

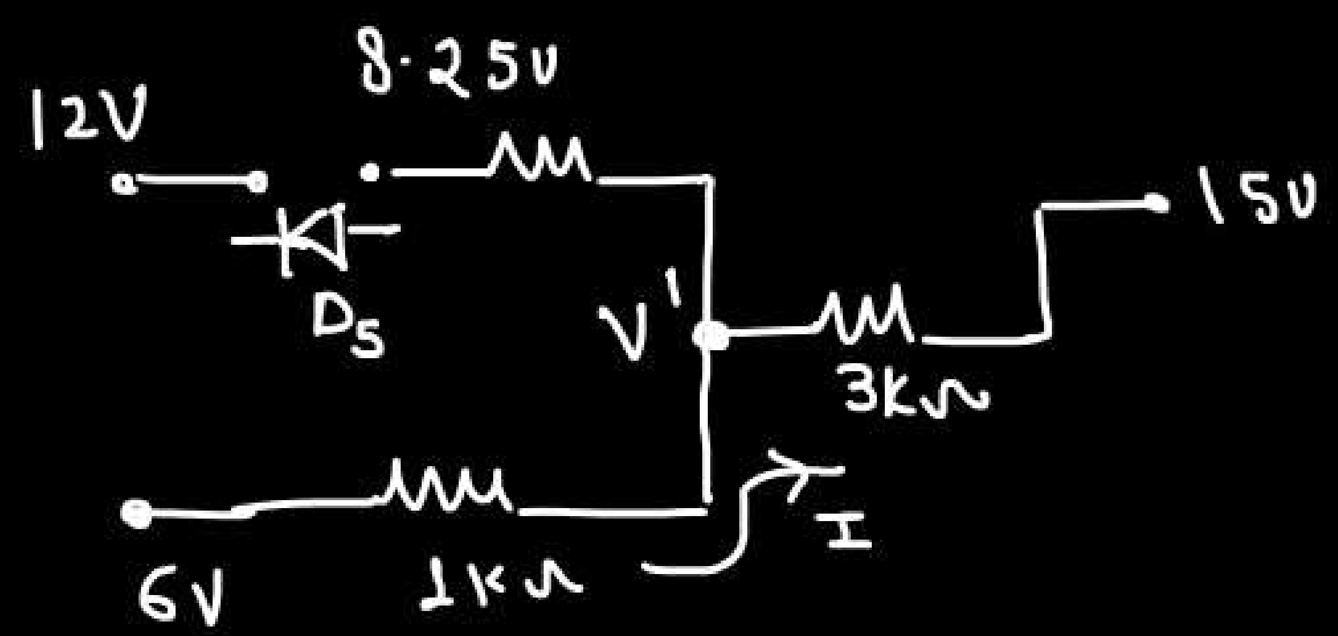


net V = 1V

$D_1 \rightarrow ON$

$D_2, D_3 \rightarrow OFF$

$D_4 \rightarrow ON$

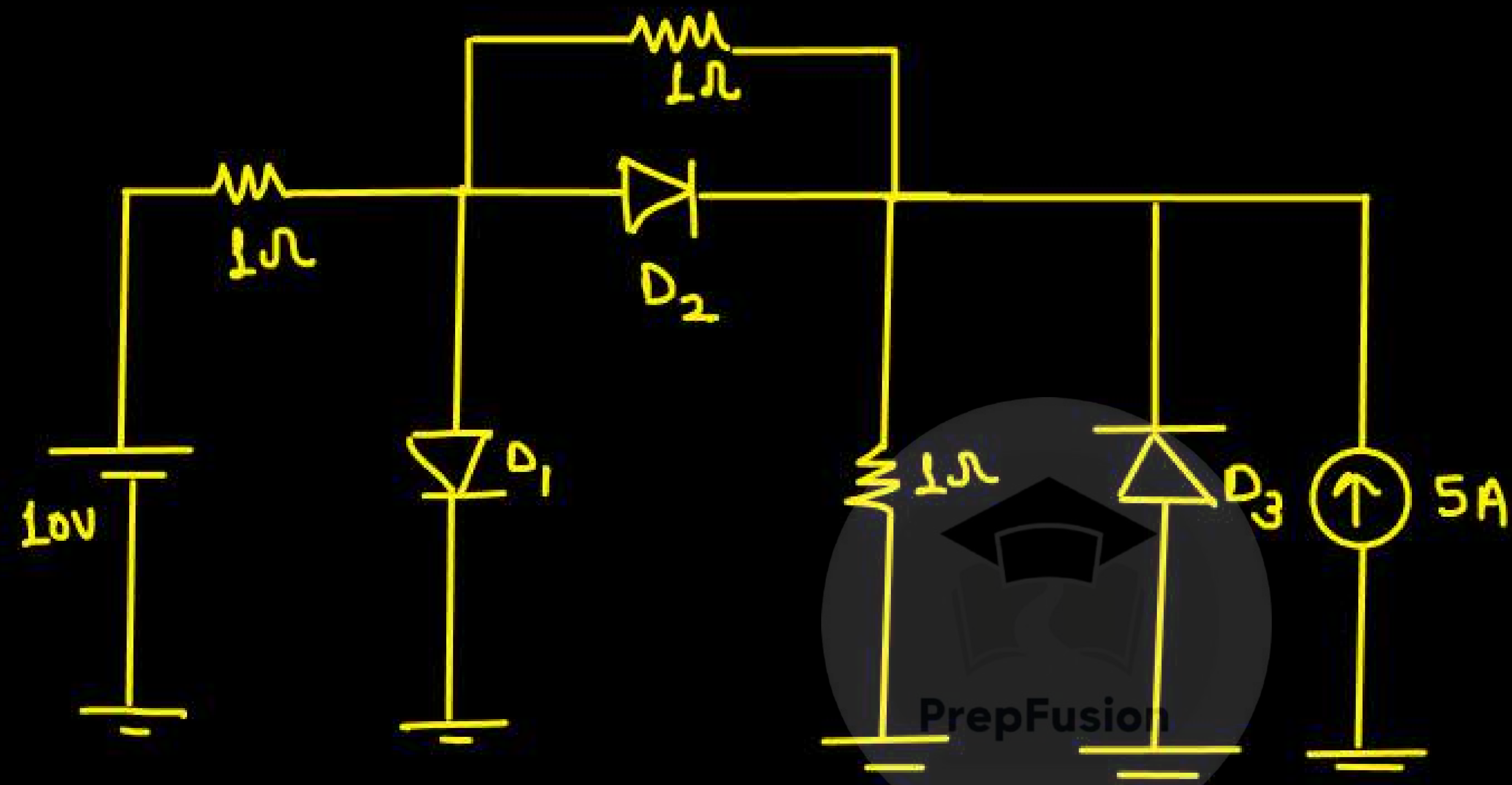


$$V' = \frac{(15 \times 1) + (6 \times 3)}{4} = \frac{33}{4} = \underline{\underline{8.25\,V}}$$

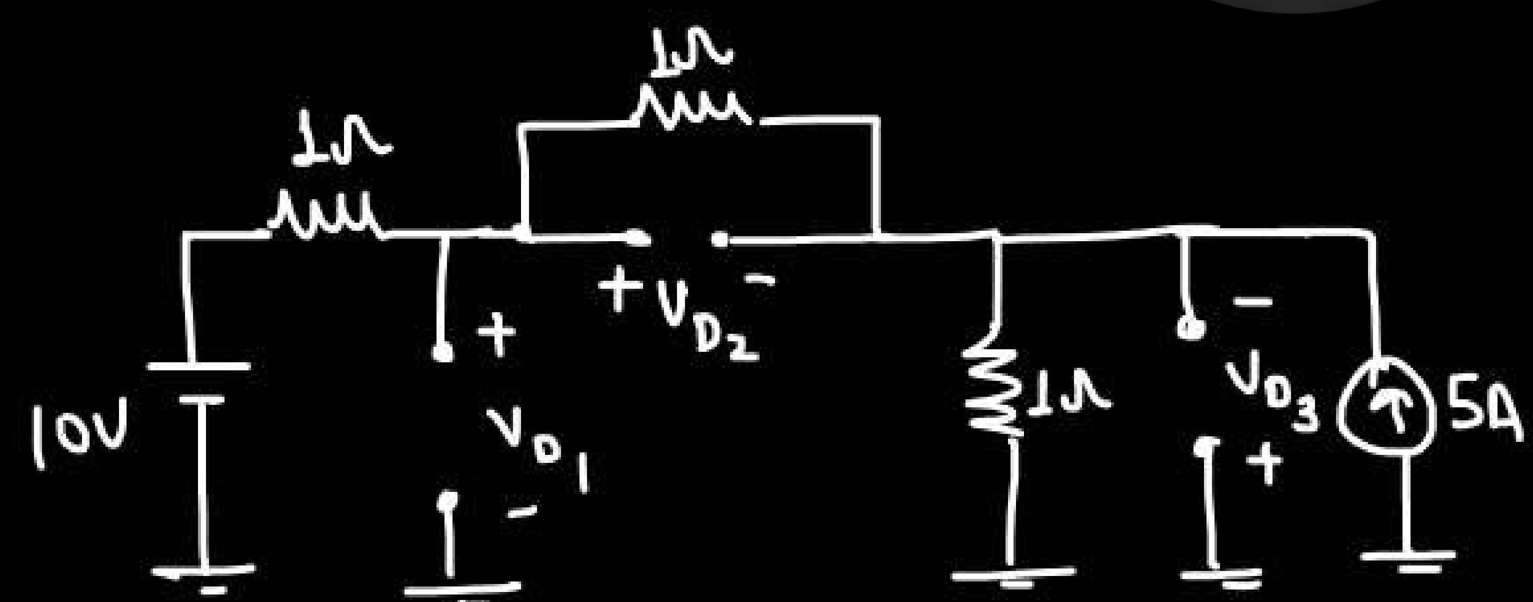
$\Rightarrow D_5$ is off

$$\boxed{I = \frac{6-15}{4K} = \frac{-9}{4} = -2.25\,mA}$$

Q. Find the states of diodes.



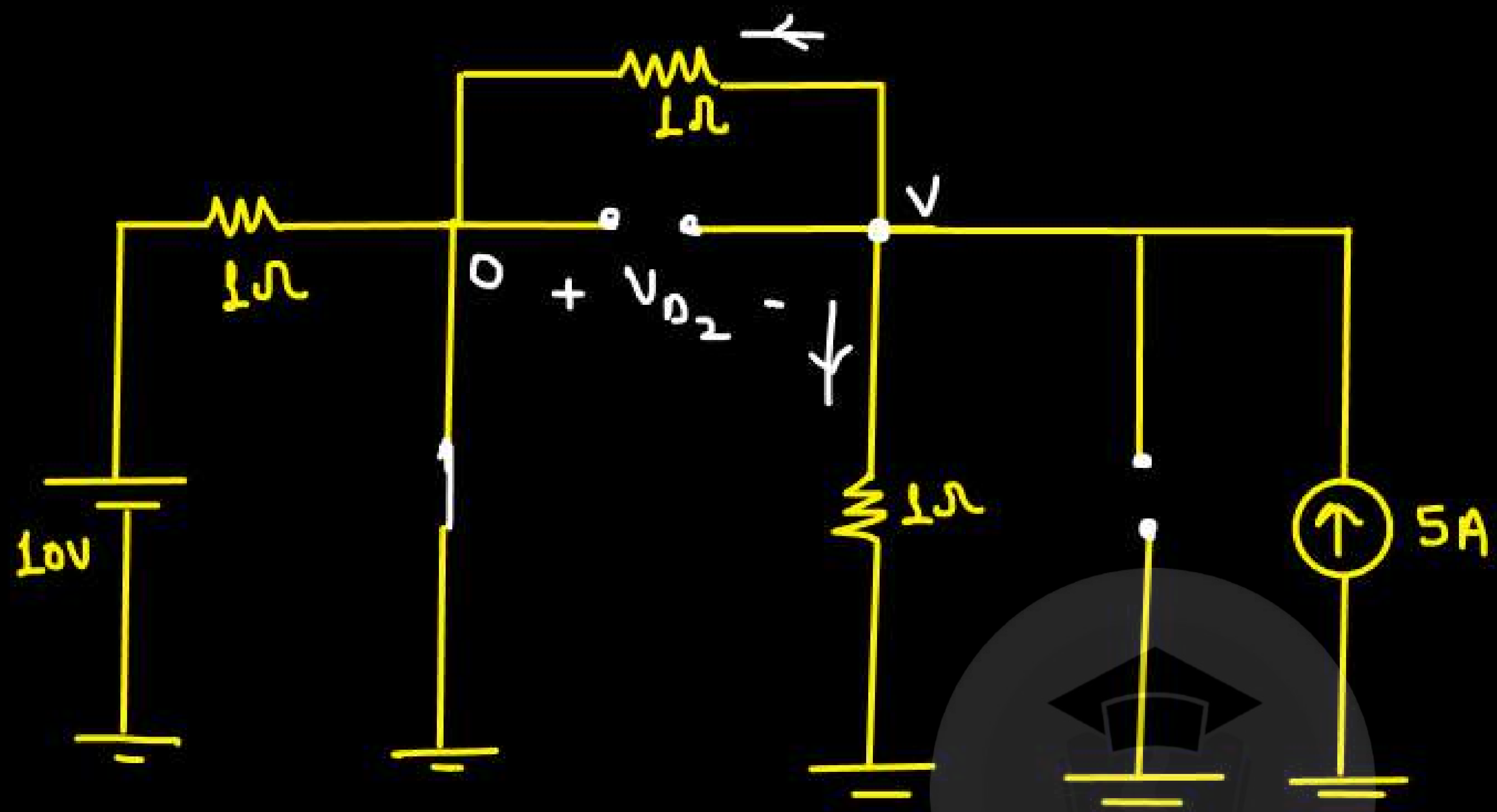
→



$V_{D_1} = \frac{20}{3} + \frac{5}{3} = \frac{25}{3} \rightarrow$ ON

$V_{D_2} = \frac{10}{3} - \frac{5}{3} = \frac{5}{3} \rightarrow$?

$V_{D_3} = -\frac{10}{3} - \frac{10}{3} = -\frac{20}{3} \rightarrow$ OFF



$$V + V = 5$$

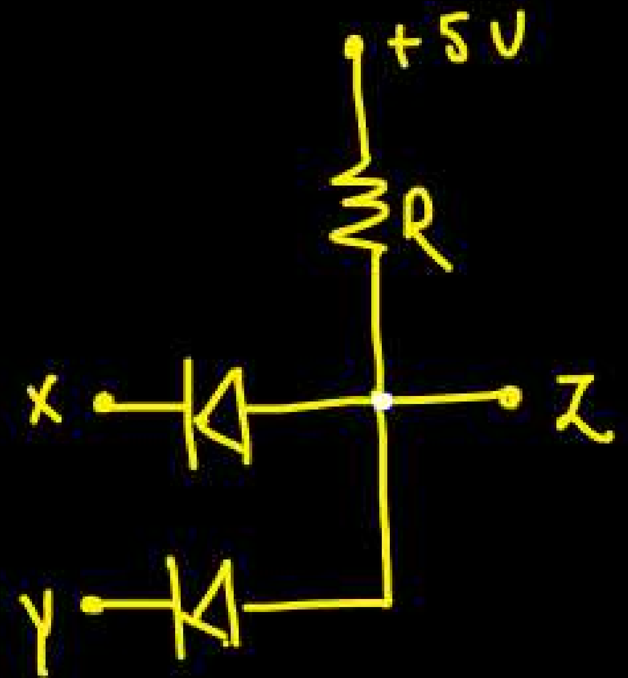
$$V = 2.5V$$

$$V_{D_2} = -2.5V$$

↪ D_2 is off

$$\Rightarrow \boxed{\begin{array}{l} D_1 = ON \\ D_2 = OFF \\ D_3 = OFF \end{array}}$$

Q. Find the logic level @ z

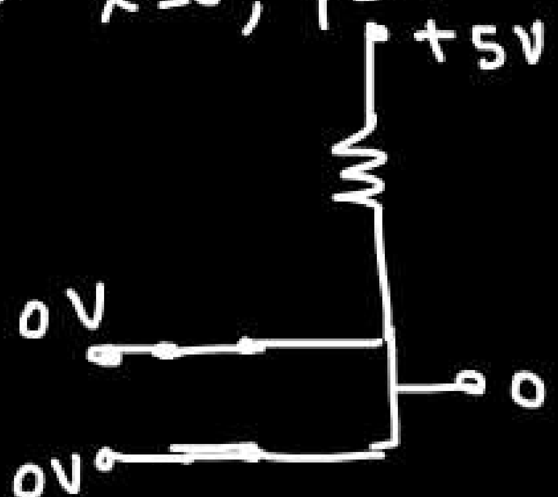


x	y	z
0	0	0
0	1	0
1	0	0
1	1	1

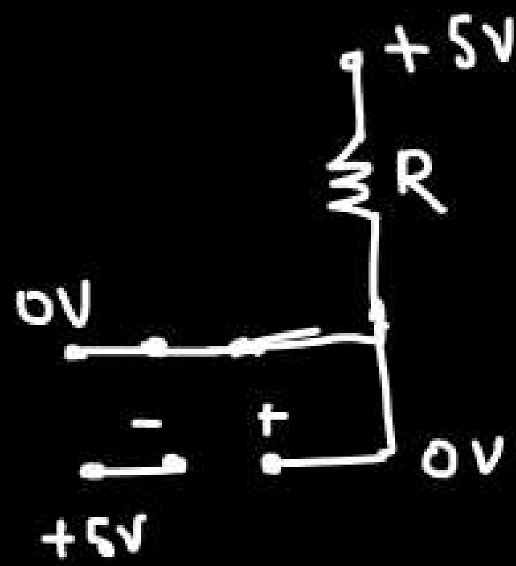
$1 \rightarrow +5V$

$0 \rightarrow gnd / -5V$

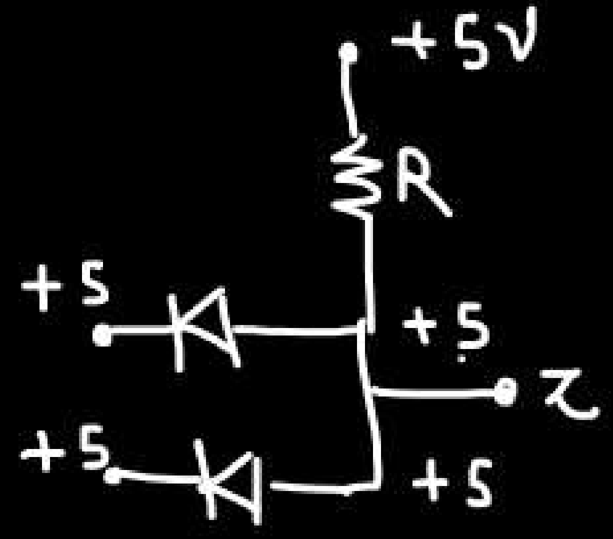
→ $X=0,\ Y=0$



$X=0,\ Y=1 \Rightarrow +5$

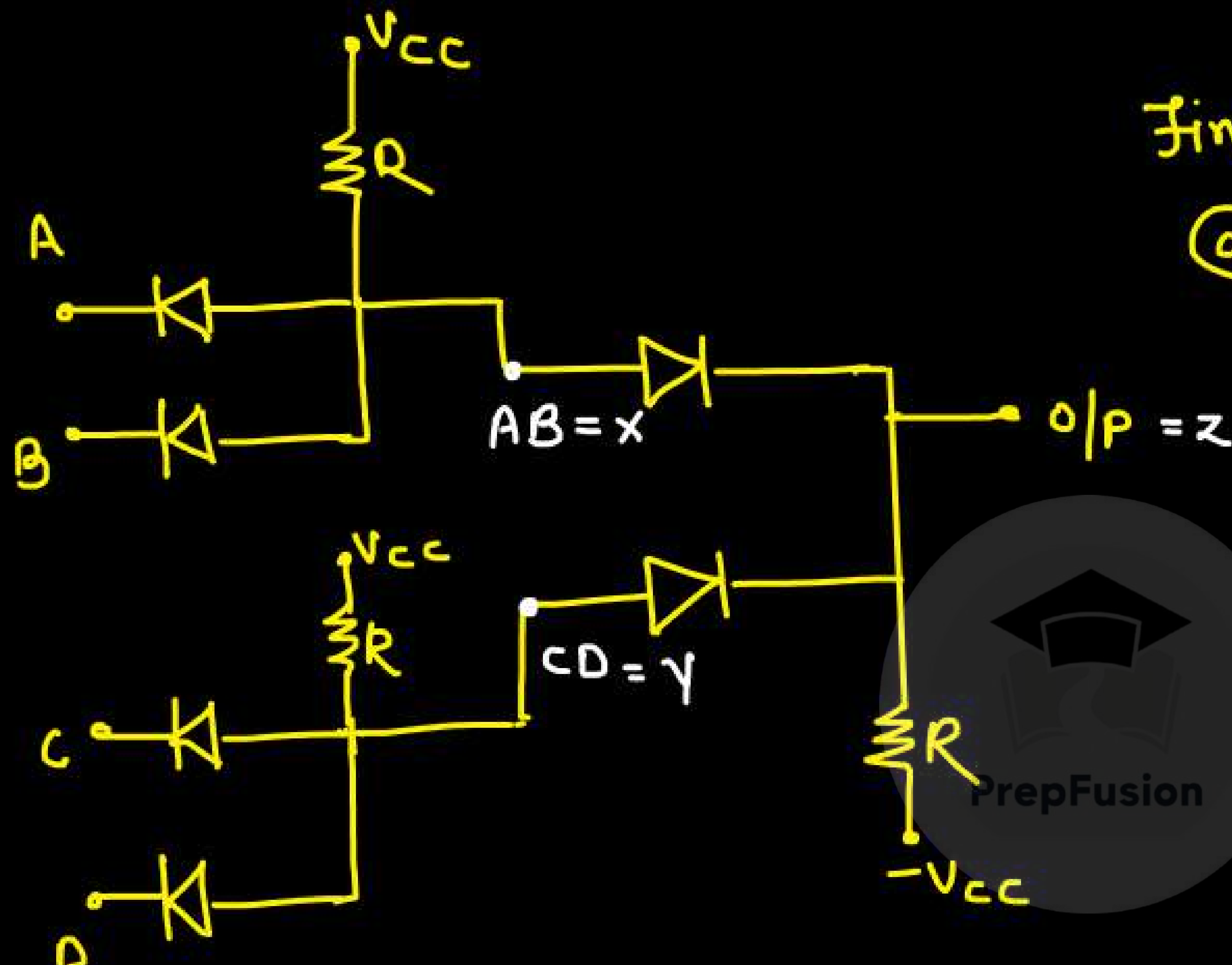


$X=1,\ Y=1$



$\boxed{Z = XY}$

Q.



Find logic level @ o/p.

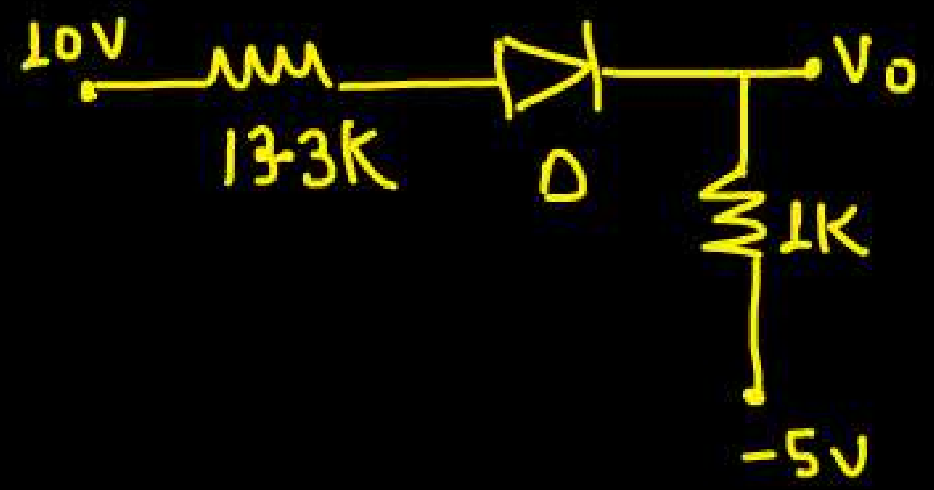
Logic 0 → $-V_{cc}$

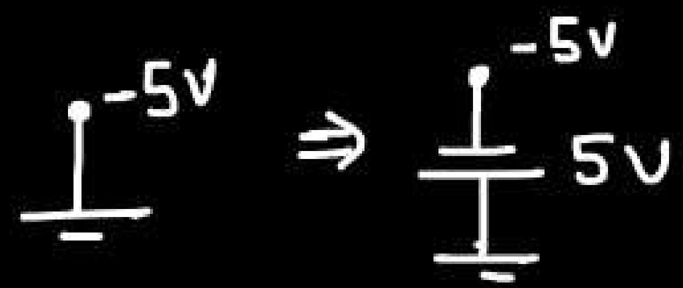
Logic 1 → $+V_{cc}$

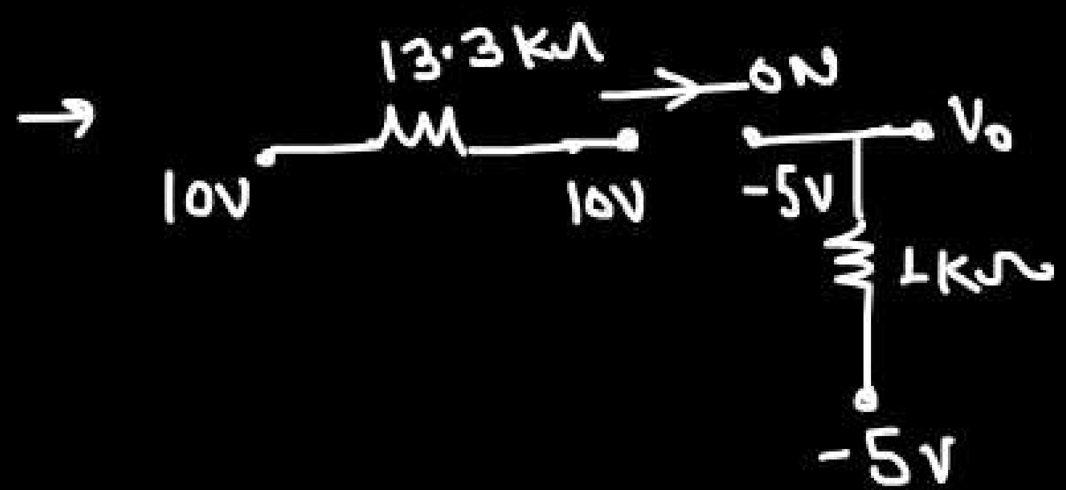
AB = X	CD = Y	o/p = Z
0	0	0
0	1	1
1	0	1
1	1	1

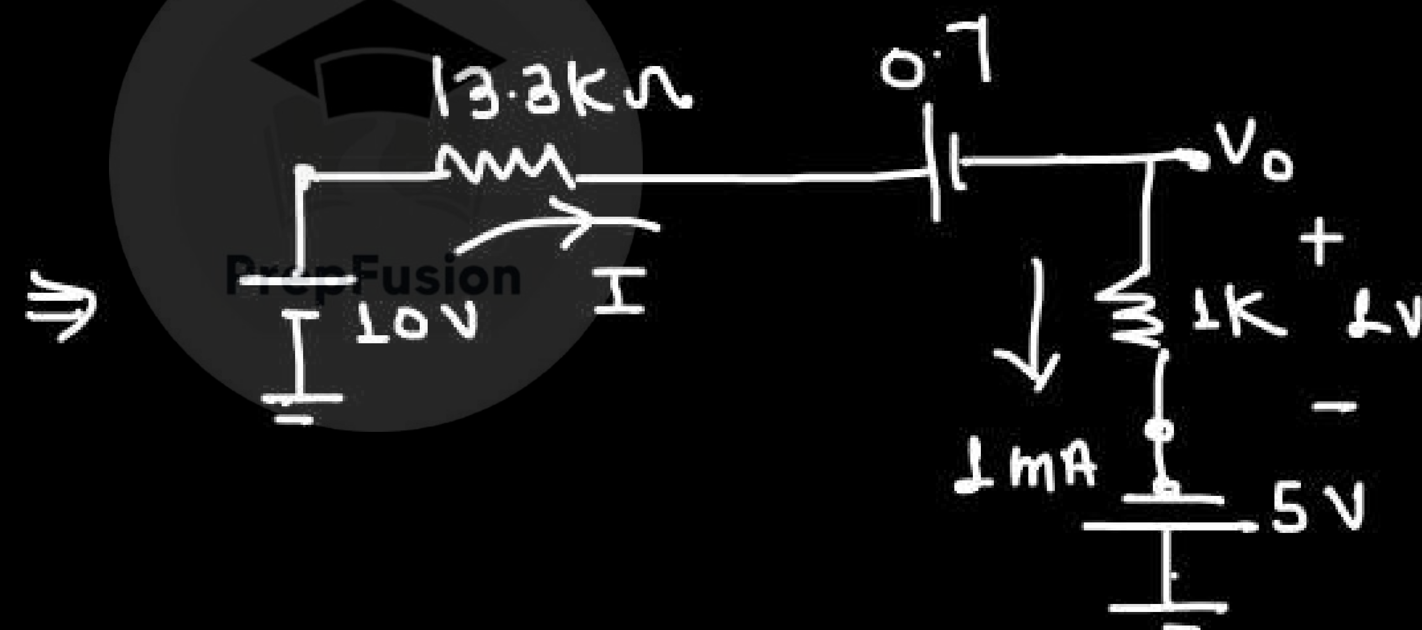
$$\boxed{Z = o/p = AB + CD}$$

Q. $V_\gamma = 0.7V$, find $V_o = ?$







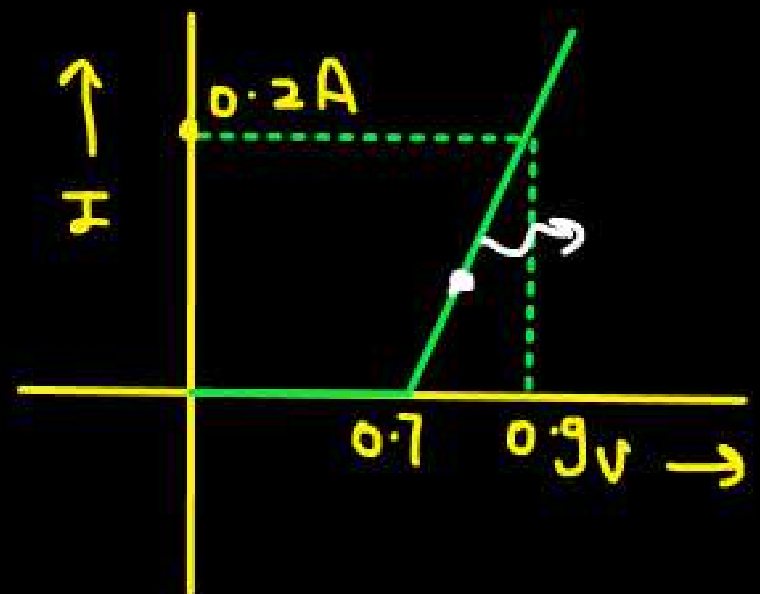


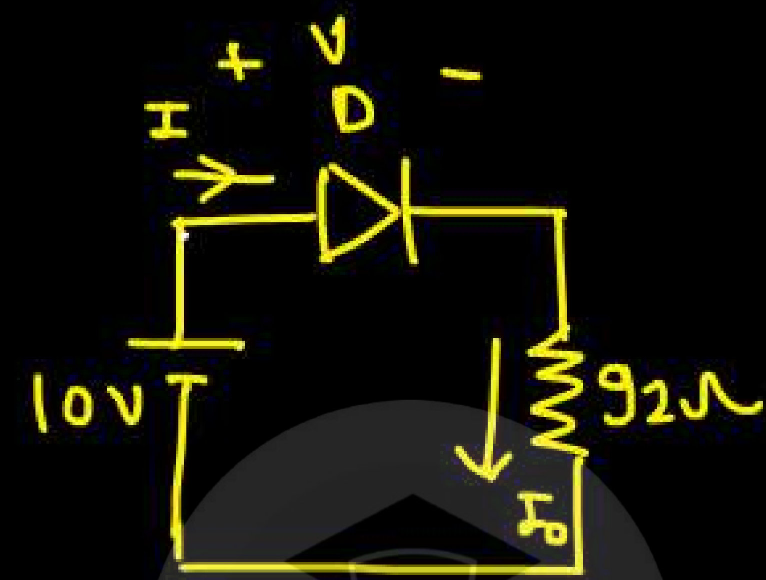
$$10 - 0.7 + 5 = (14.3k)\, I$$

$$\boxed{I = 1mA}$$

$$\boxed{\begin{aligned} V_o &= -5 + 1 \\ V_o &= -4V \end{aligned}}$$

Q. V-I characteristics of the diode is shown. Find current I_o.





M-I

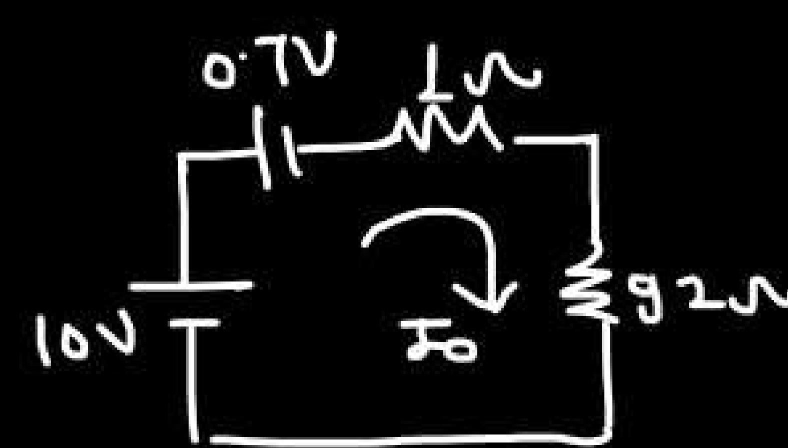
$\boxed{I = V - 0.7}$ — characteristic eq^n

$\boxed{10 - V = 92I}$ → load line

$10 - I - 0.7 = 92I$

$\boxed{I = 100\,mA}$

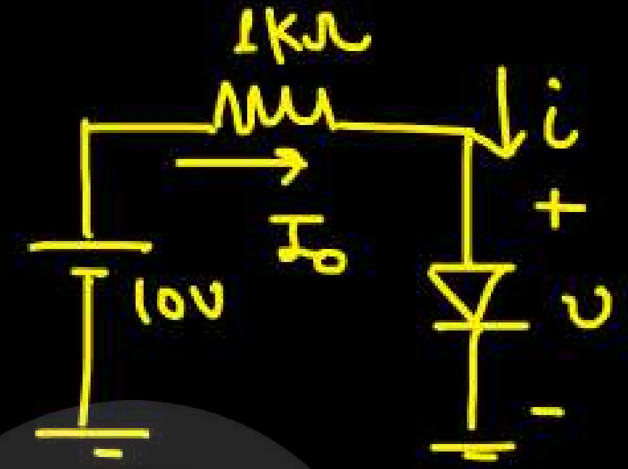
$V_\gamma = 0.7V$, $R_{ON} = 1\Omega$

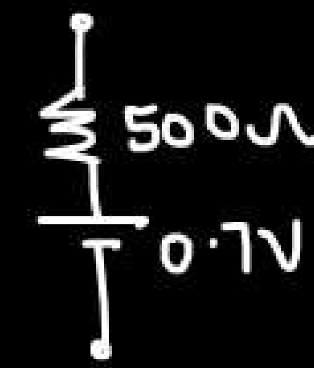


$\boxed{I_o = 100\,mA}$

Q. I-V characteristics are given. Find current I_o.

$$i = \begin{cases} \dfrac{V-0.7}{500}, & V \geq 0.7 \\ 0, & V < 0.7 \end{cases}$$





→ M-I

$i = \dfrac{V-0.7}{500}$ {Considering $V \geq 0.7$}

↳ characteristic eqn — (1)

$10 - V = 1000i$ — (2)

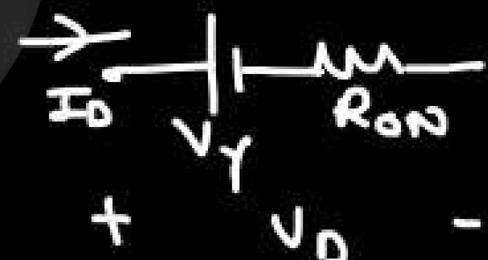
$10 - 500i - 0.7 = 1000i$

$\dfrac{9.3}{1500} = i \Rightarrow \boxed{i = 6.2\,mA}$

$\boxed{V = 3.8V}$

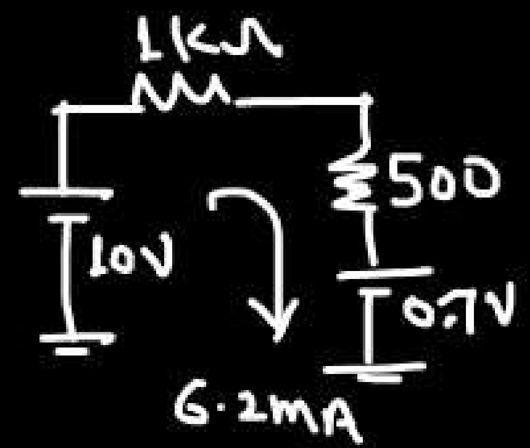
{$V > 0.7$}

M-II



$V_D - V_\gamma = I_D R_D$

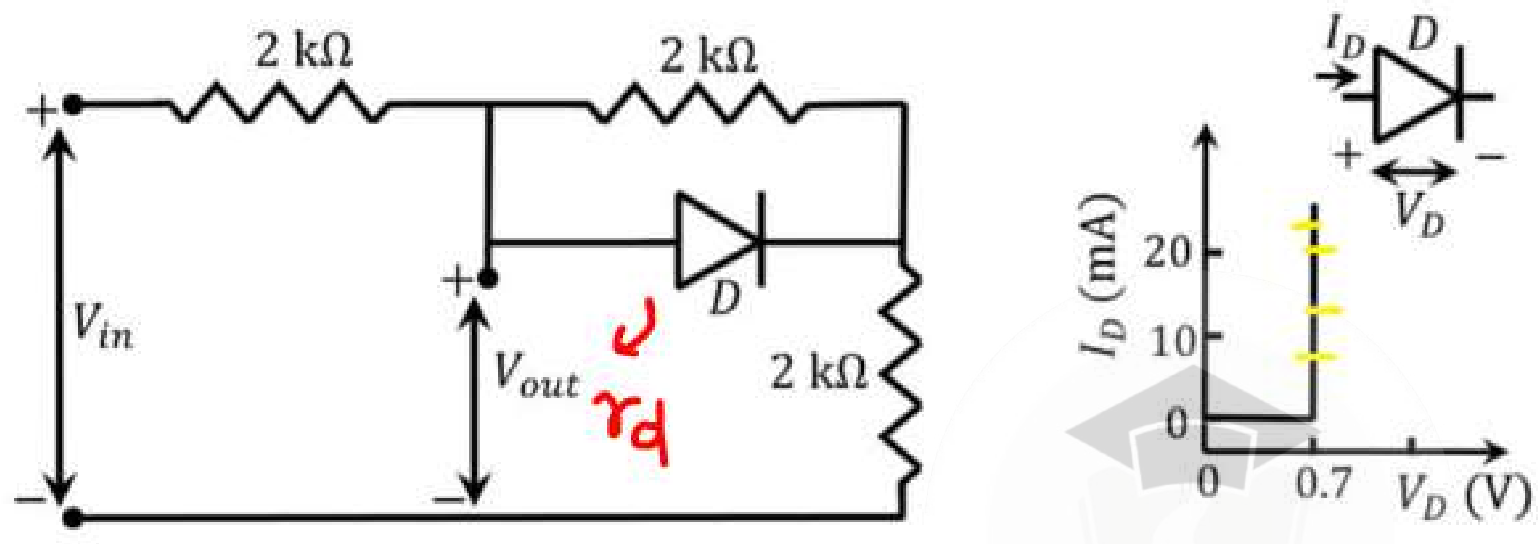
$$\boxed{I_D = \frac{V_D - V_\gamma}{R_D}}$$



$$\boxed{i = \frac{V-0.7}{500}}$$

Q.

Q.57 A circuit and the characteristics of the diode (D) in it are shown. The ratio of the minimum to the maximum small signal voltage gain $\frac{\partial V_{out}}{\partial V_{in}}$ is ________ (*rounded off to two decimal places*).



$$\boxed{r_d = \frac{\eta V_T}{I_{DC}}}$$

when $I_{DC} = 0 \Rightarrow \boxed{r_d = \infty}$

when $I_{DC} = \infty \Rightarrow \boxed{r_d = 0}$

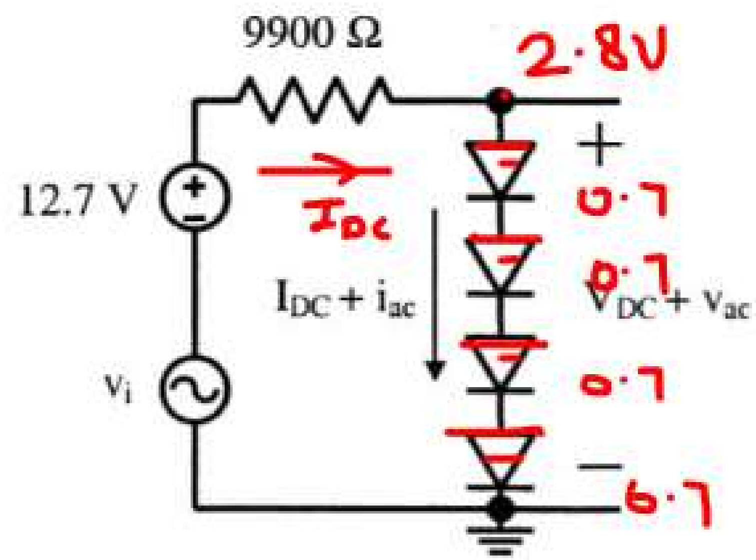
when $r_d = 0 \Rightarrow \boxed{\frac{V_o}{V_{in}} = \frac{1}{2}}$, when $r_d = \infty \Rightarrow \boxed{\frac{V_o}{V_{in}} = \frac{2}{3}}$

Ans. $= \frac{1/2}{2/3}$

$\boxed{\text{ratio} = 0.75}$

Q.

In the circuit shown below, assume that the voltage drop across a forward biased diode is 0.7 V. The thermal voltage $V_t = kT/q = 25\text{mV}$. The small signal input $v_i = V_p \cos(\omega t)$ where $V_p = 100$ mV.



Q.54 The bias current I_{DC} through the diodes is

(A) 1 mA (B) 1.28 mA (C) 1.5 mA (D) 2 mA

Q.55 The ac output voltage v_{ac} is

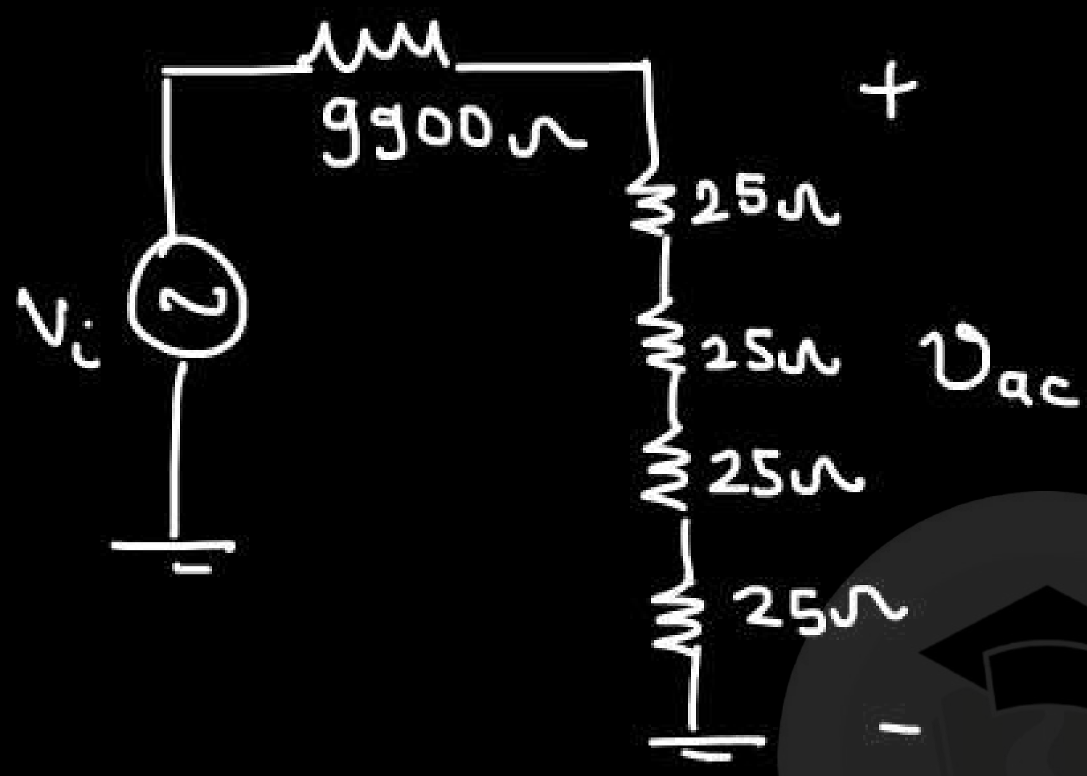
(A) $0.25\cos(\omega t)$ mV (B) $1\cos(\omega t)$ mV

(C) $2\cos(\omega t)$ mV (D) $22\cos(\omega t)$ mV

→ (i) $I_{DC} = \dfrac{12.7 - 2.8}{9900} = \dfrac{9.9}{9900} = 1\,\text{mA}$

(ii) $r_d = \dfrac{\eta V_T}{I_{DC}} = \dfrac{25\text{m}}{1\text{m}} = 25\,\Omega$

ac model



$$v_{ac} = \frac{100}{10000} \times v_i$$

$$v_{ac} = \frac{v_i}{100}$$

$$\boxed{v_{ac} = 1\,mV \cos\omega t}$$

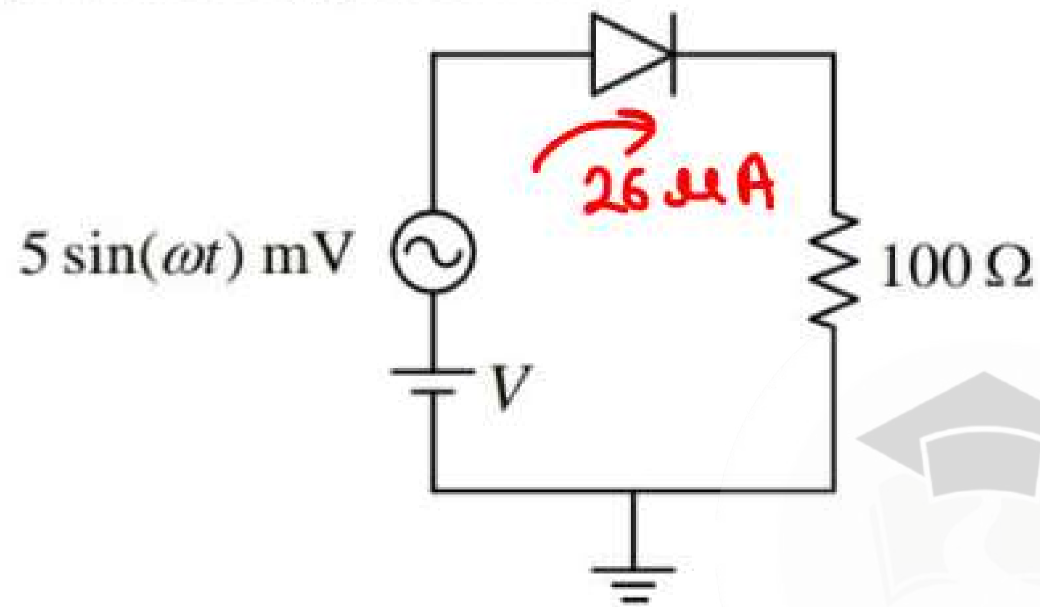
Q.

A dc current of $26\,\mu A$ flows through the circuit shown. The diode in the circuit is forward biased and it has an ideality factor of one. At the quiescent point, the diode has a junction capacitance of $0.5\,nF$. Its neutral region resistances can be neglected. Assume that the room temperature thermal equivalent voltage is $26\,mV$.

$R_{ON} = 0\,\Omega$

$\eta = 1$

$V_T = 26\,mV$

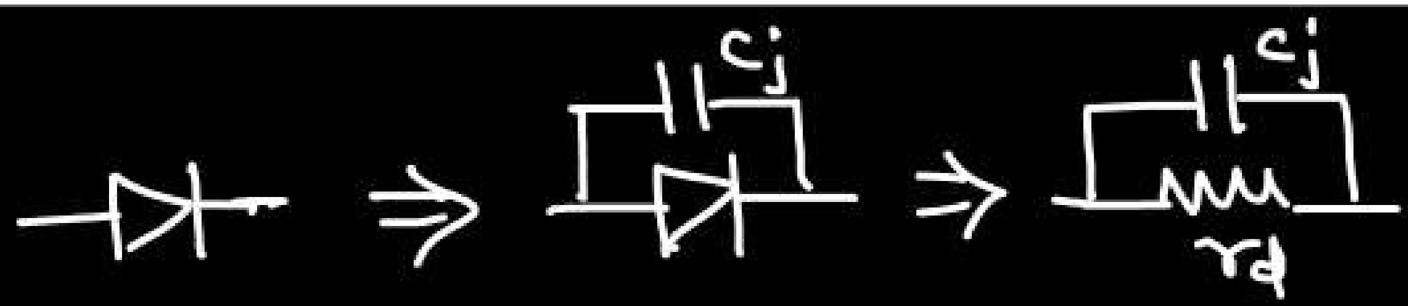


For $\omega = 2\times10^{6}$ rad/s, the amplitude of the small-signal component of diode current (in μA, correct to one decimal place) is _______.

Diode

Forward → Diffusion Cap. (Junction cap.)

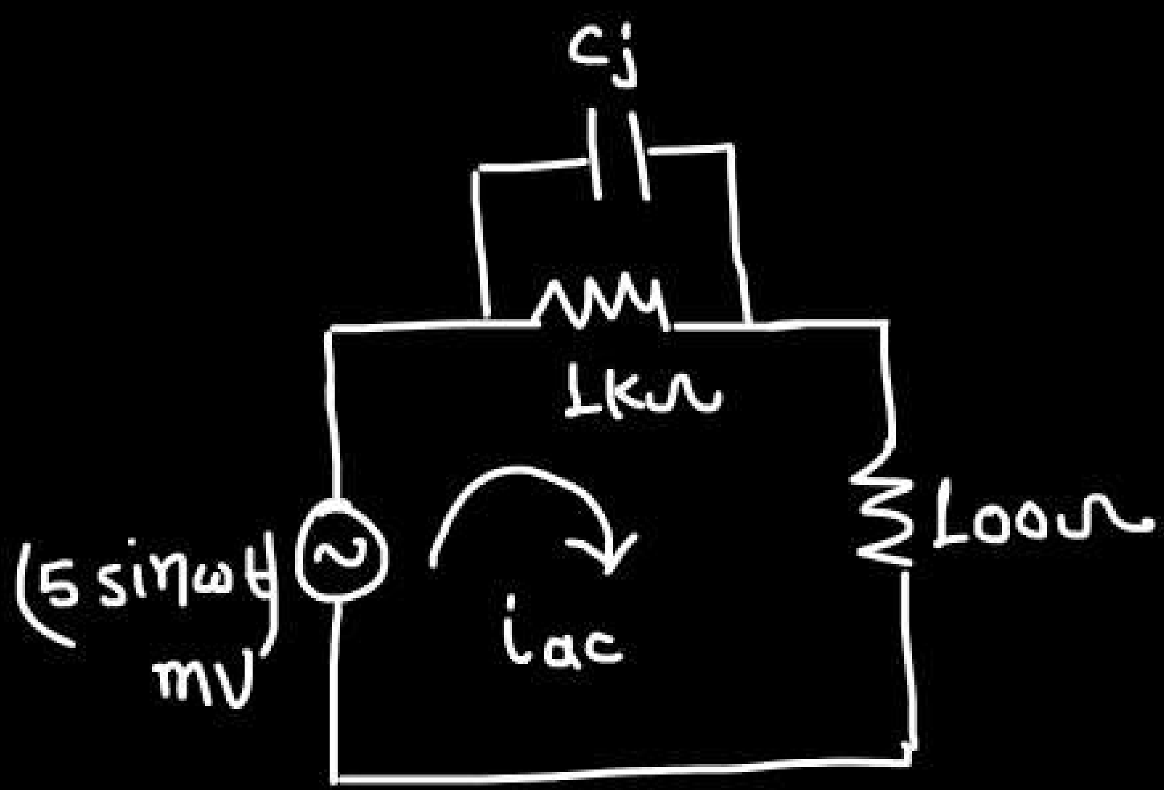
Reverse → Transition Cap.



$$r_d = \frac{\eta V_T}{I_{DC}} = \frac{26\,mV}{26\,\mu A} = 1000\,\Omega = 1\,k\Omega$$

$$C_j = 0.5\,nF$$

$$\hookrightarrow X_c = \frac{-j}{\omega C} = \frac{-j}{2\times 10^6 \times 0.5\times 10^{-9}}$$



$$X_c = -j\,1000\,\Omega$$

$$X_c \,||\, 1k\Omega = \frac{-j\,1k\Omega \times 1k\Omega}{-j\,1k\Omega + 1k\Omega} = \frac{-j\,1k\Omega}{-j+1}$$

$$i_{ac} = \frac{5\,mV}{100 + \frac{j\,1k}{j-1}} \times \sin\omega t$$

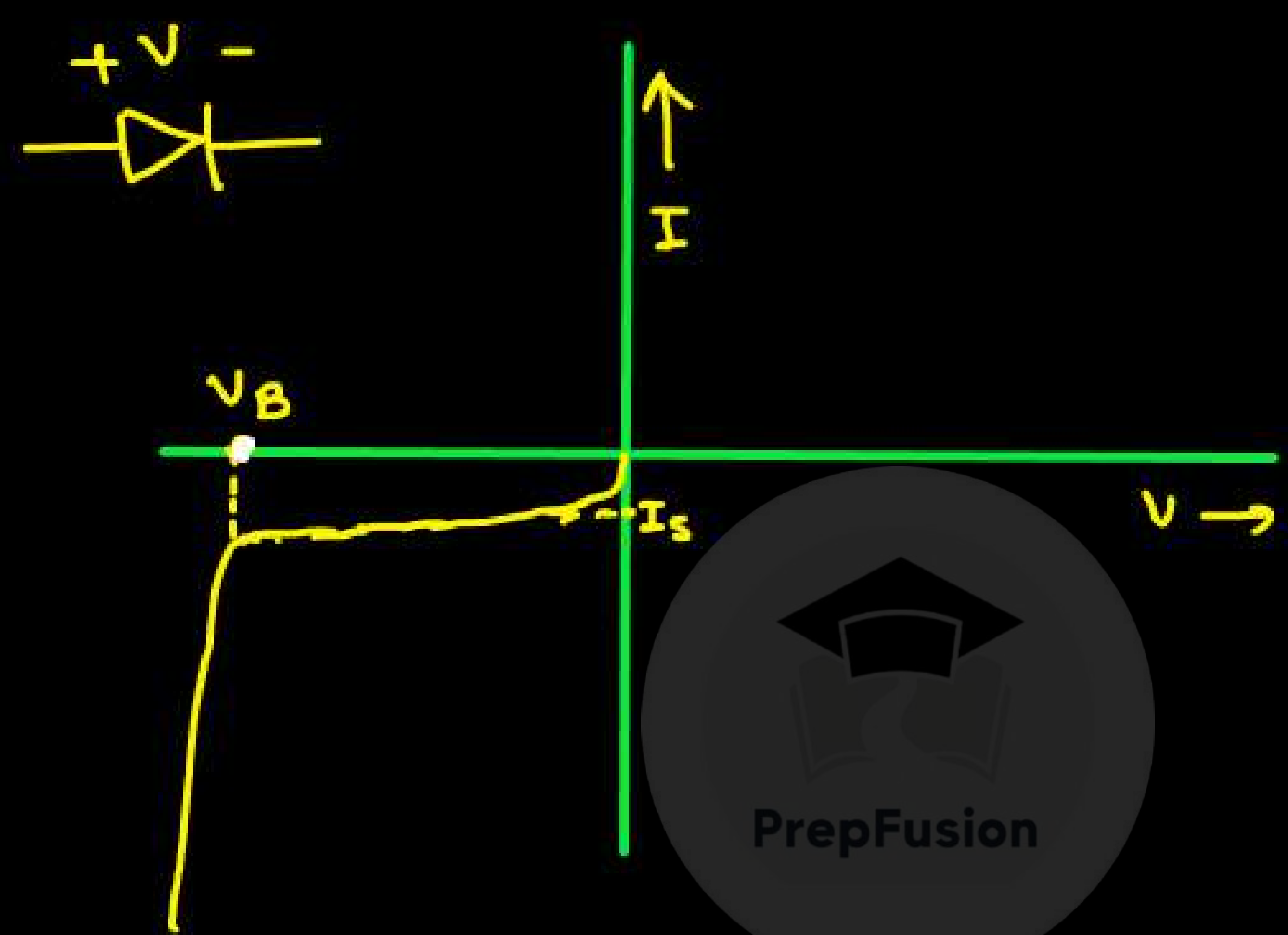
$$i_{ac} = \frac{5\,mV\,(j-1)}{100j - 100 + j1000} \times \sin\omega t$$

$$= \frac{5\,mV\,(j-1)}{1100j - 100} \times \sin\omega t$$

$$= \frac{5\sqrt{2}}{\sqrt{(1100)^2 + (100)^2}}\,mV \times \sin\omega t$$

$$\boxed{i_{ac} = 6.4\,\mu A\,\sin\omega t}$$

⇒ Diode in Reverse bias :-

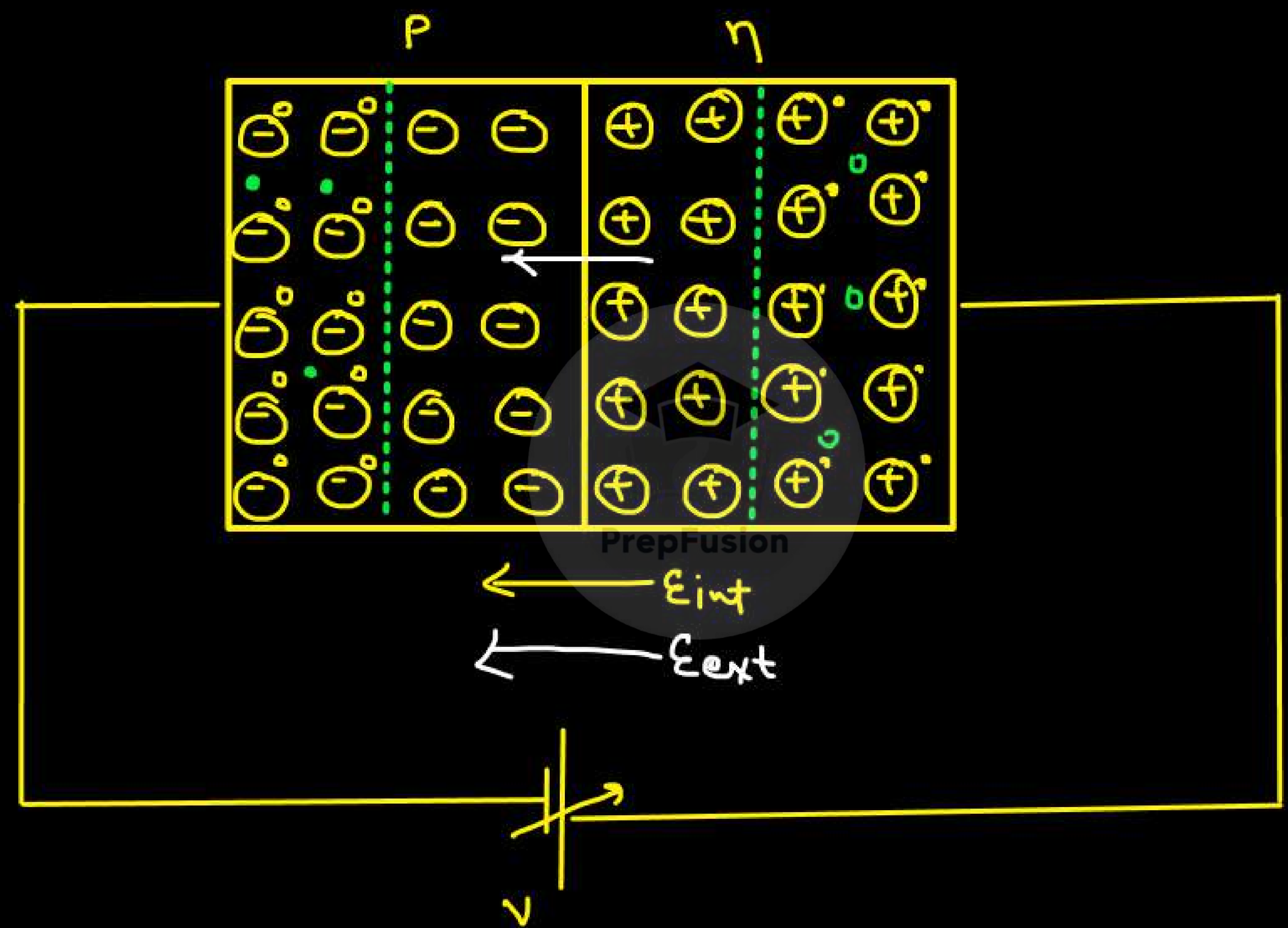


Breakdown

Avalanche

Zener

Avalanche Breakdown:-



@ a particular reverse bias voltage, (Breakdown voltage)

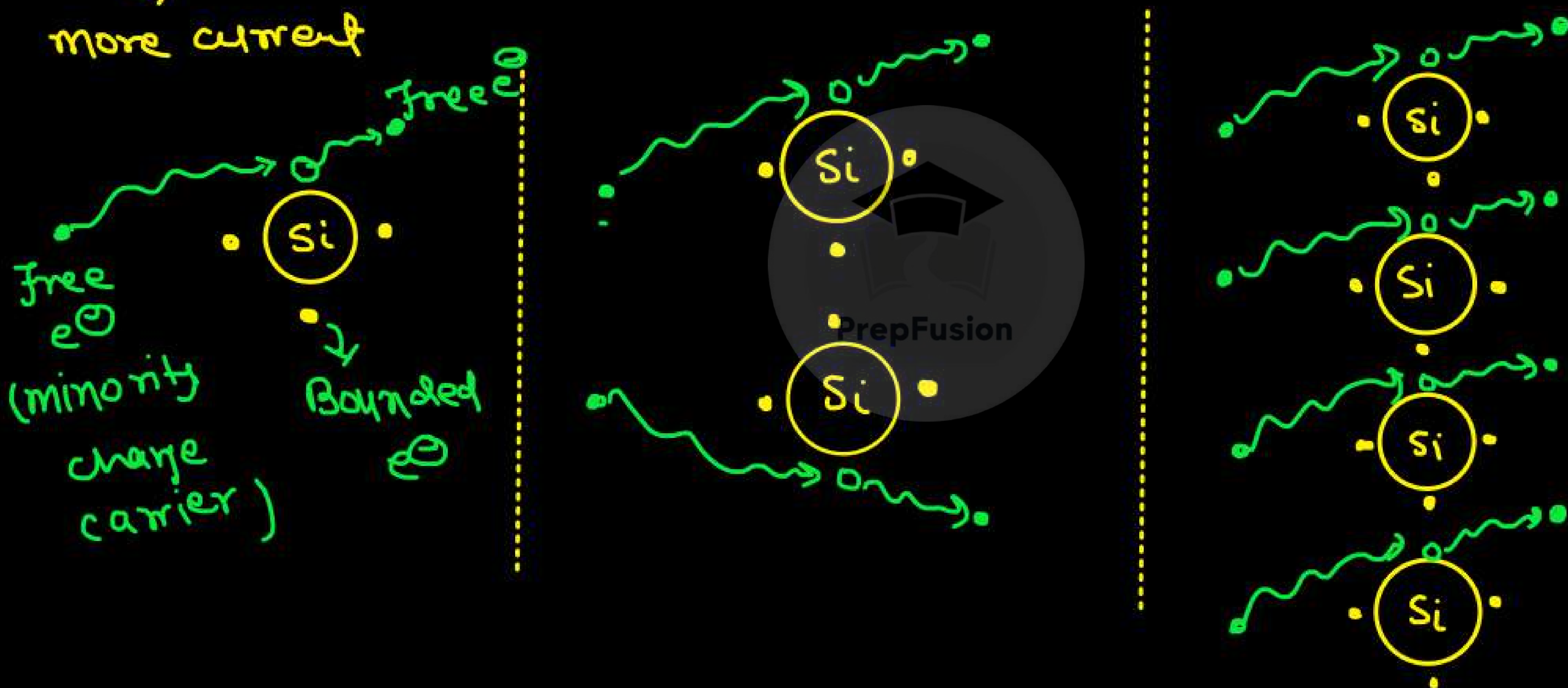
$\Rightarrow E_{int} \uparrow \Rightarrow$ Free $e^{\ominus}$ (minority) gets High kinetic energy

$\Downarrow$

more $e^{\ominus}$ $\Leftarrow$ High $e^{\ominus}$ knocks out bound $e^{\ominus}$ from Si

$\Downarrow$

more current



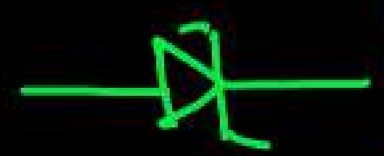
* High energy charge particle knocks out the bounded e^- from silicon atom and thus creating electron-hole pairs and the current increases. This phenomena is known as avalanche breakdown.

* If there is no limiting resistance, the device may burn out in breakdown region.

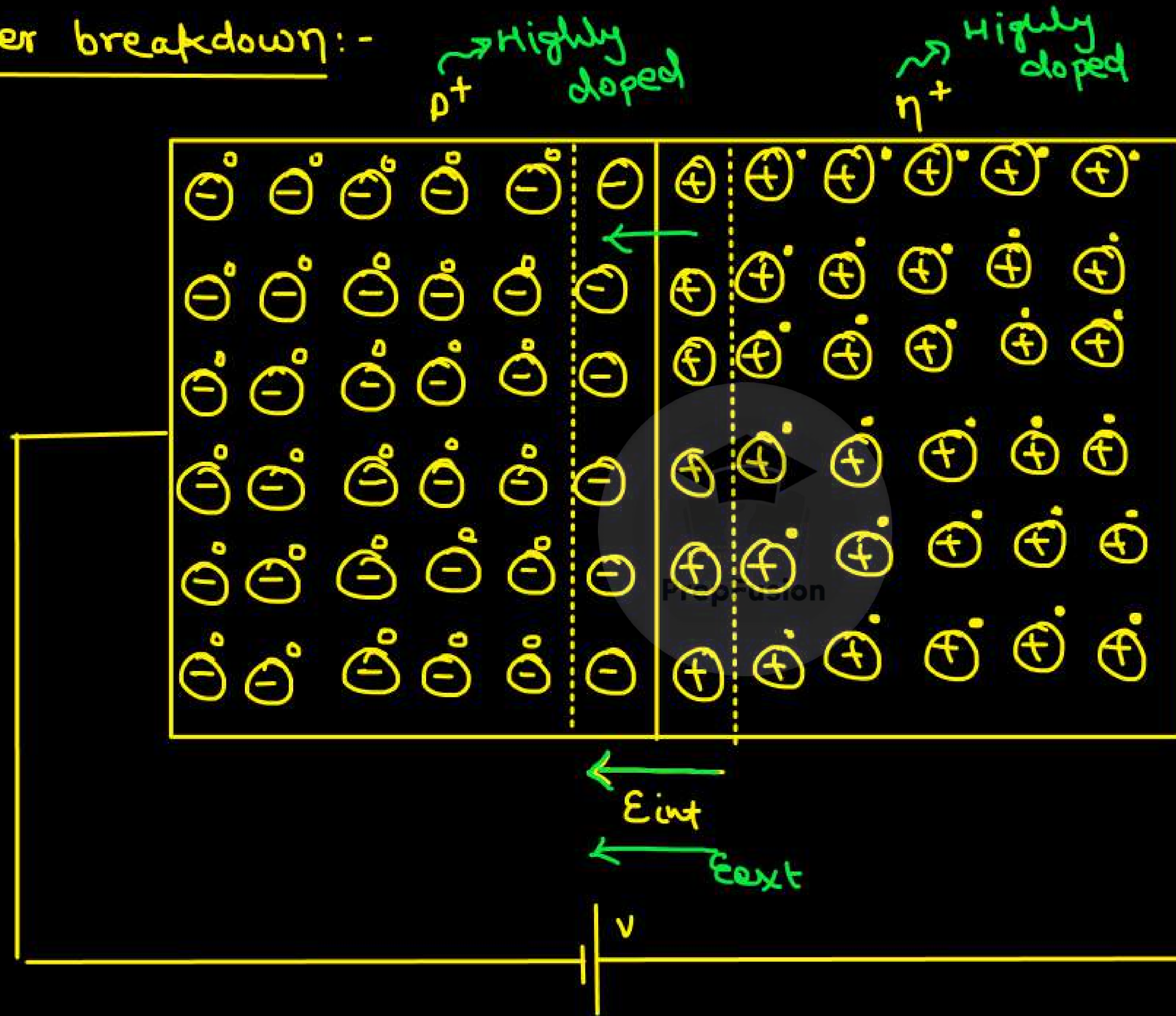
* There are some diodes which is meant to be operated in breakdown region.

↓

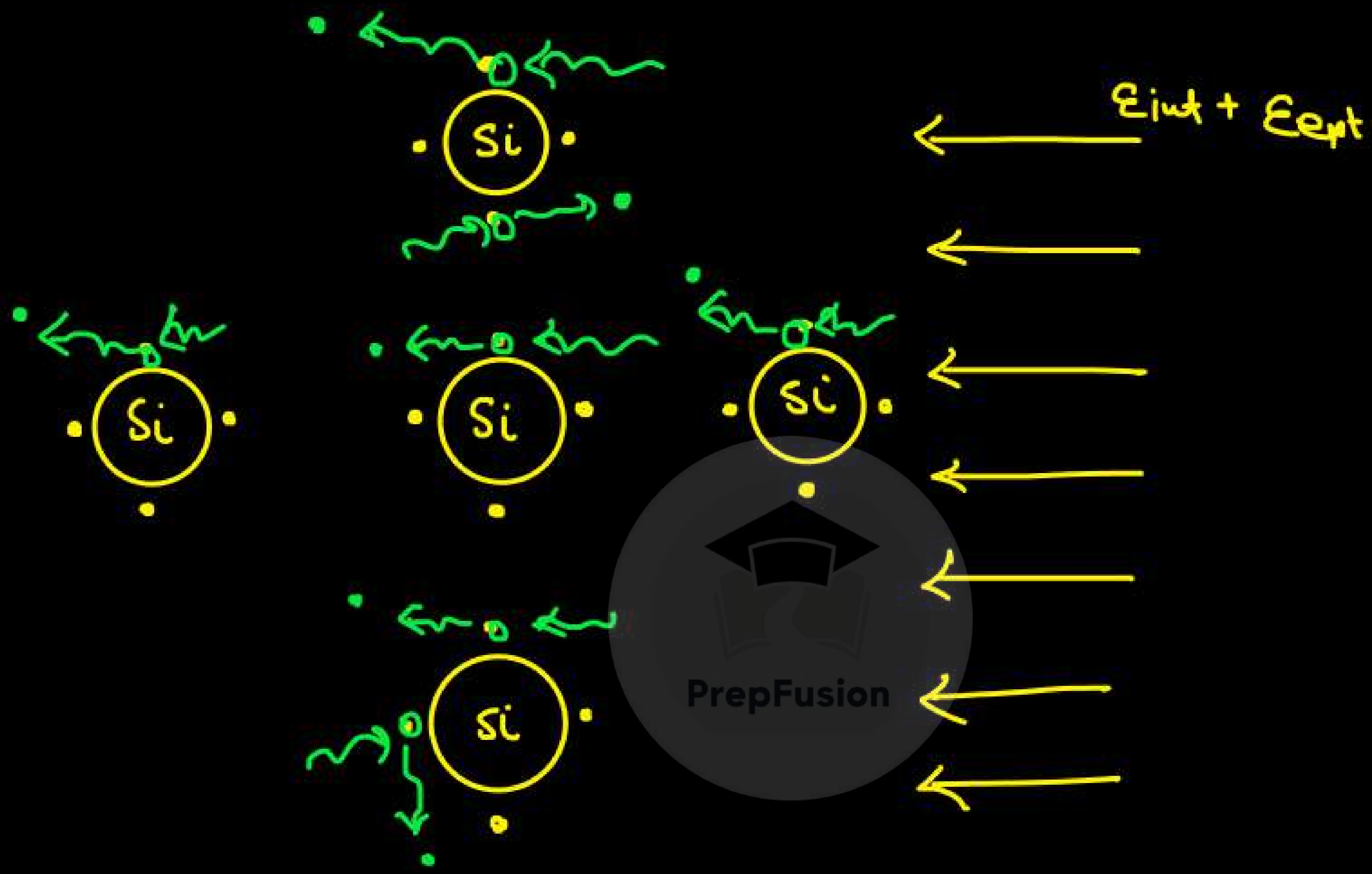
Zener diode

[Symbol → ]

Zener breakdown:-



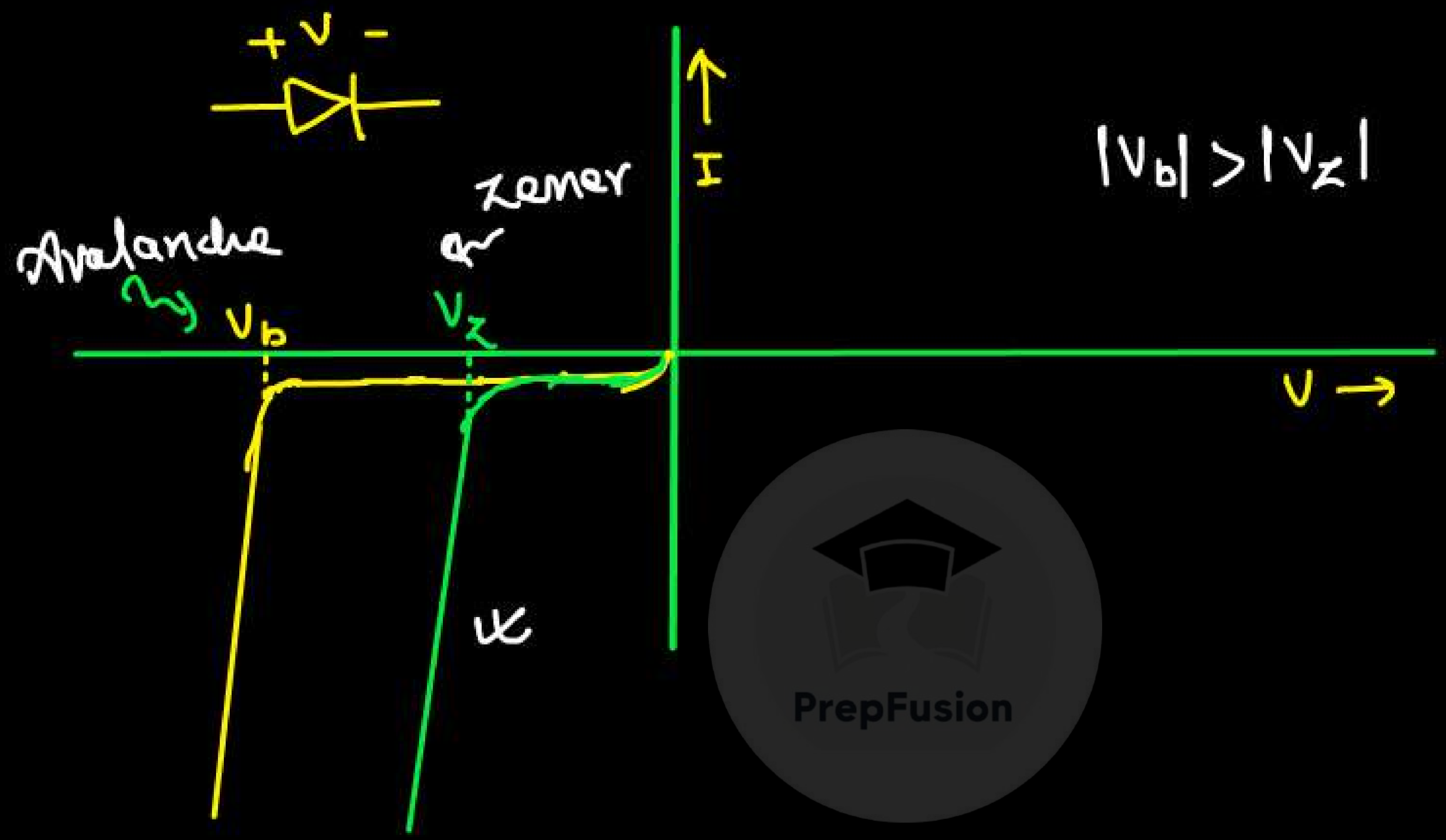
Here, because of more doping $\Rightarrow \varepsilon_{int}$ is very strong



$E_{int} + E_{ext}$ knocks out bounded e^- from silicon atoms $\Rightarrow$ free e^- $\uparrow$

$\Downarrow$

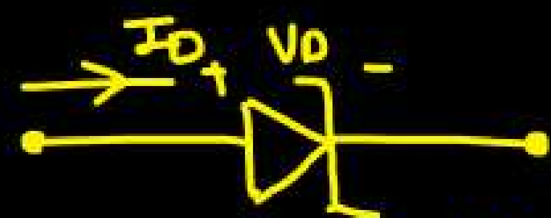
current $\uparrow$



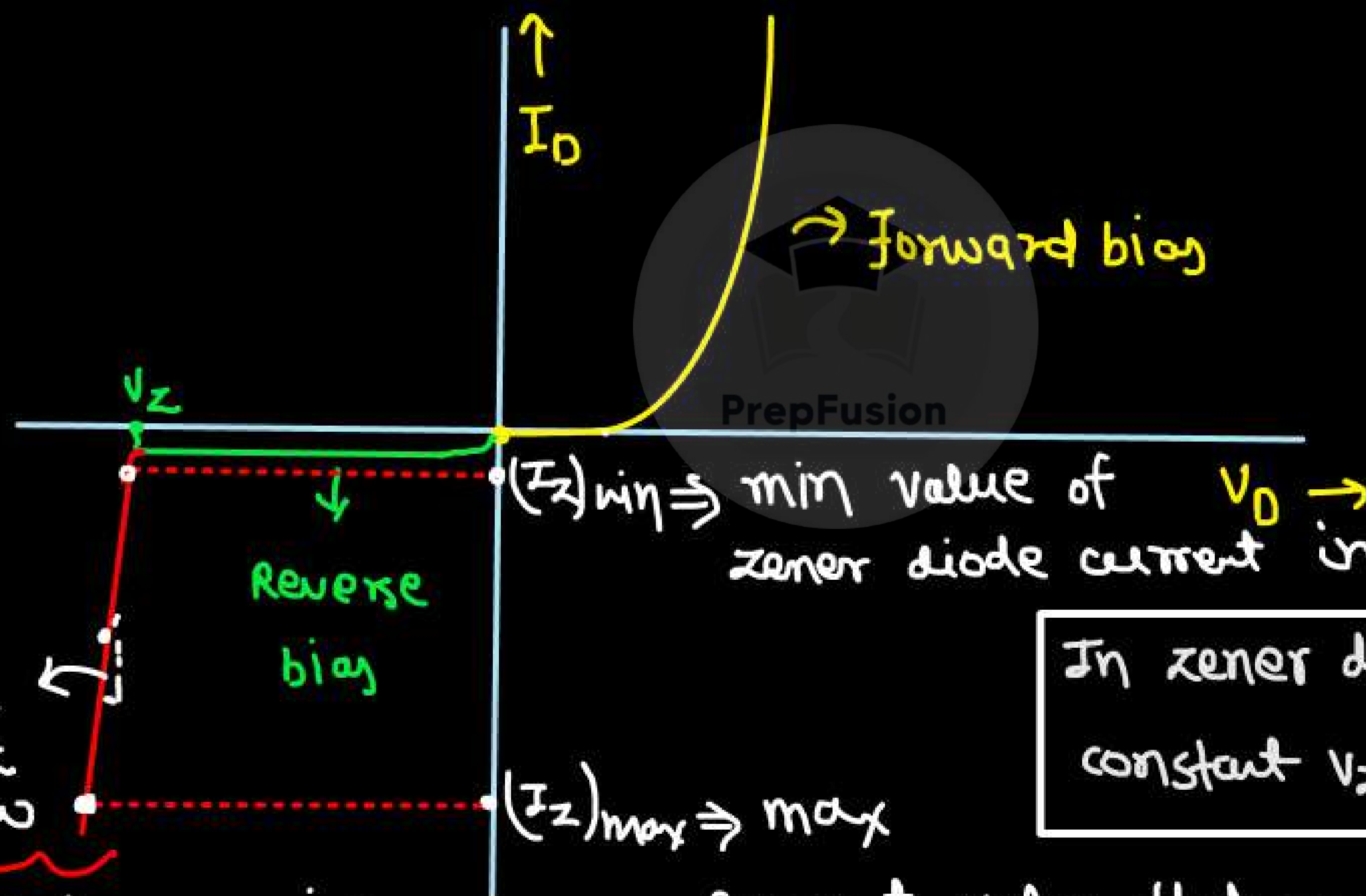
$|V_b| > |V_z|$

Zener breakdown occurs @ a lower breakdown voltage than the avalance breakdown.

Characteristics of zener diode:-



zener diode



$(I_z)_{min} \Rightarrow$ min value of zener diode current in breakdown region.

$\text{slope} = \frac{\partial I_D}{\partial V_D} = \frac{1}{r_z}$

$r_z \rightarrow$ very low

Breakdown region

$(I_z)_{max} \Rightarrow$ max current value that zener diode can take.

In zener diode, we can get constant V_z after breakdown.

$(I_z)_{min}$ ⇒ when zener is in Breakdown, the min. current it will have.

$(I_z)_{max}$ ⇒ when zener is in Breakdown, the max. current it can have.

if $I_z > (I_z)_{max}$ ⇒ device will burn out.

r_z ⇒ when zener is in breakdown, the resistance it provides.

V_z ⇒ Breakdown voltage of zener diode.

⇒ Power rating of zener diode:-

Power rating $= V_z \cdot (I_z)_{max}$ = Maximum power a zener diode can handle in breakdown region.

Eg. → ① A zener diode has $V_z = 5V$

$(I_z)_{min} = 5mA$, $(I_z)_{max} = 40mA$.

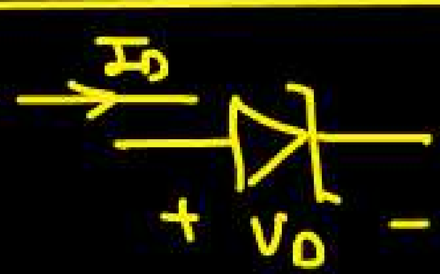
What is the min power rating of zener diode?

→ $5 \times 40m = \underline{\underline{200mW}}$

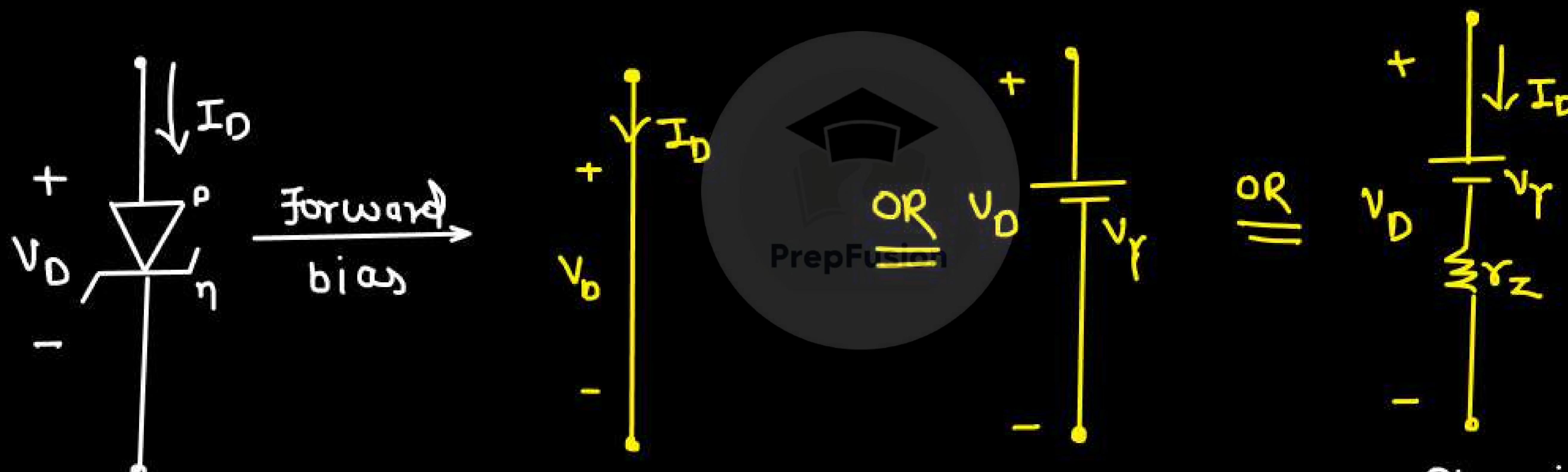
② A zener diode has $V_z = 5V$ and power rating of 40mW. What is the max^m current it can take?

→ $\frac{40m}{5} = 8mA$ ⇐ max^m 8mA current should flow through zener diode.

⇒ Zener diode in forward bias :-



⇒ Acts as normal forward bias diode.

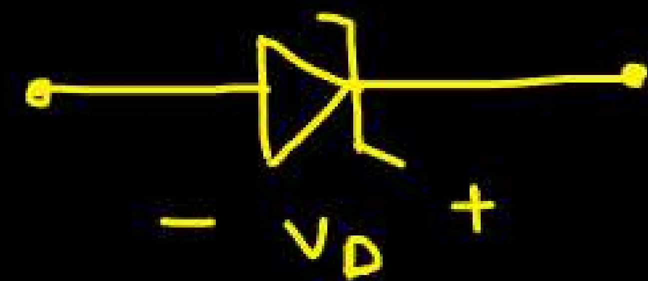


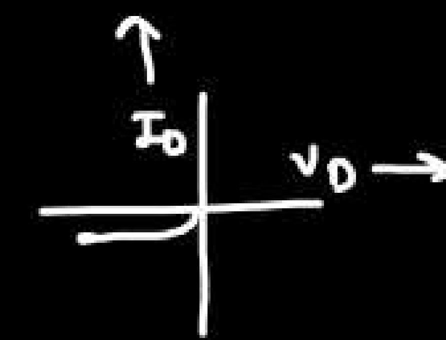
Ideal

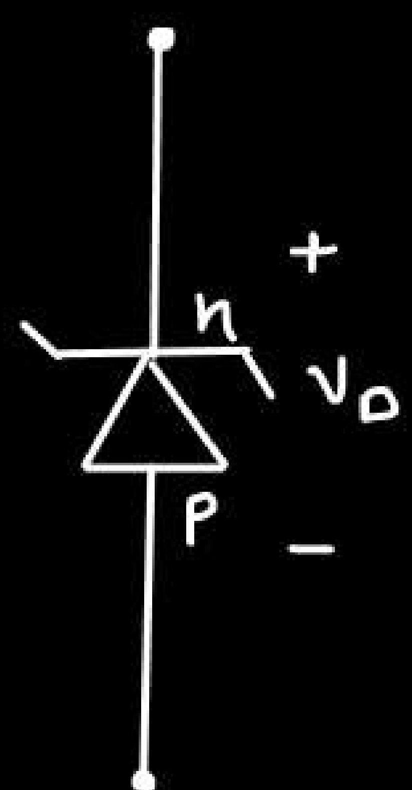
Constant voltage drop

Piecewise Linear Model

⇒ Zener diode in reverse bias :-
(Before Breakdown)

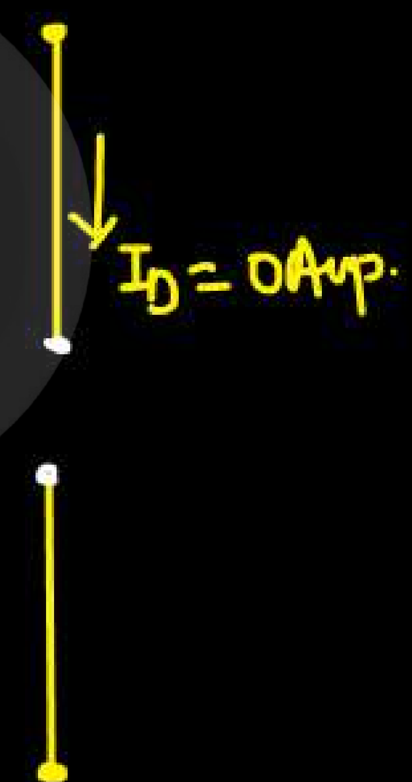




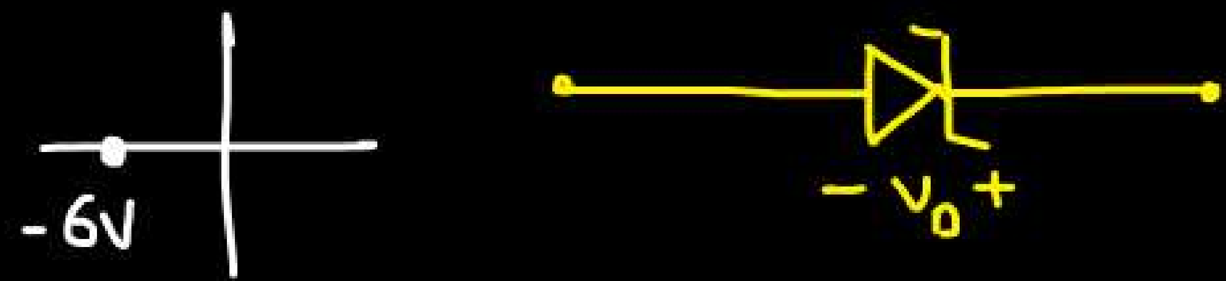


$\xrightarrow{\text{Reverse bias}}$

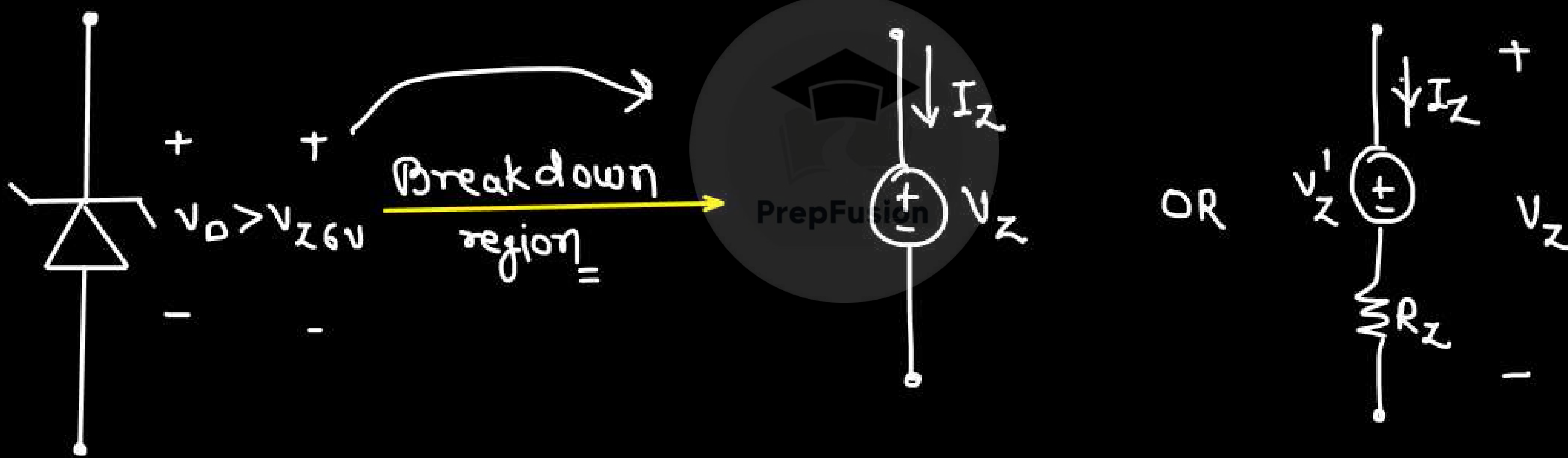
[Before breakdown
$V_D < V_Z$]



⇒ Zener diode in Breakdown:-

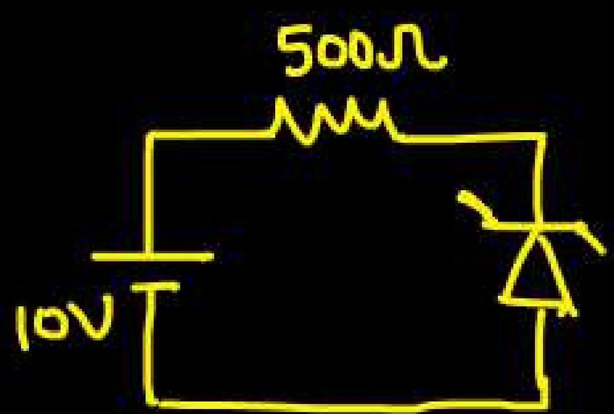


$\{V_0 > V_z\}$

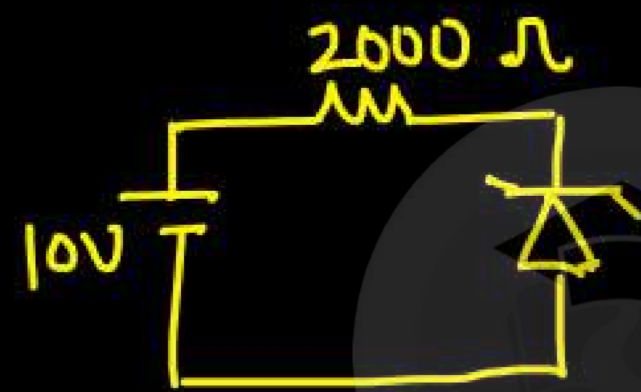


$$\boxed{V_z = V_z' + I_z R_z}$$

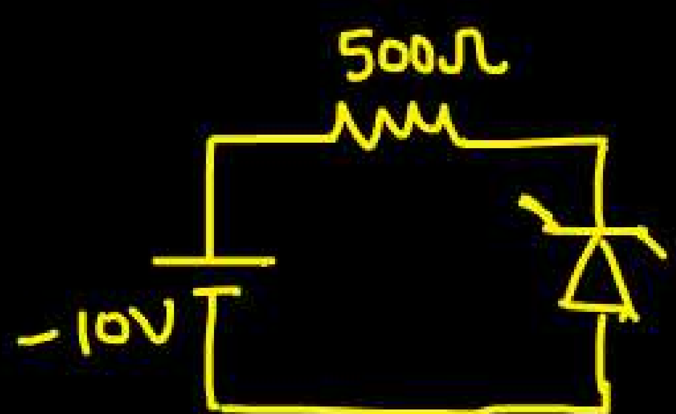
Q. The zener diode has breakdown voltage of 5V. $(I_z)_{min} = 5mA$. check if zener goes in breakdown region or not.



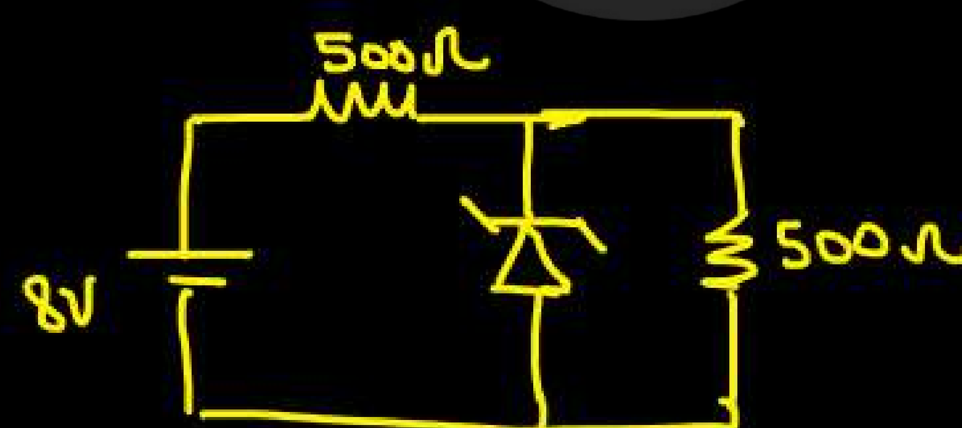
(a)



(b)

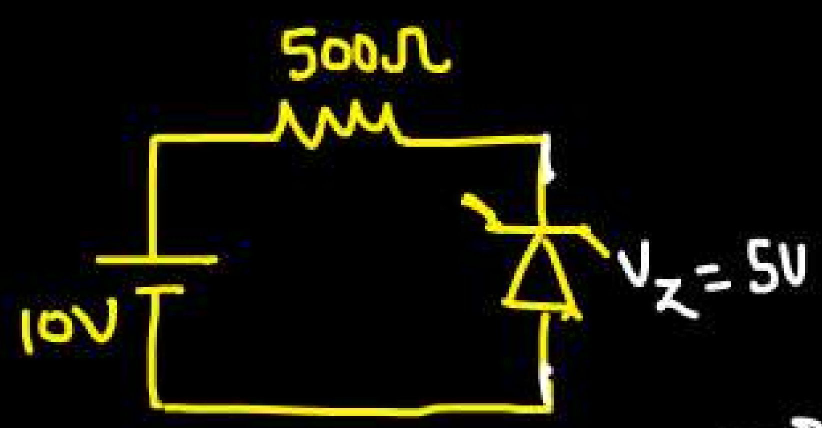


(c)

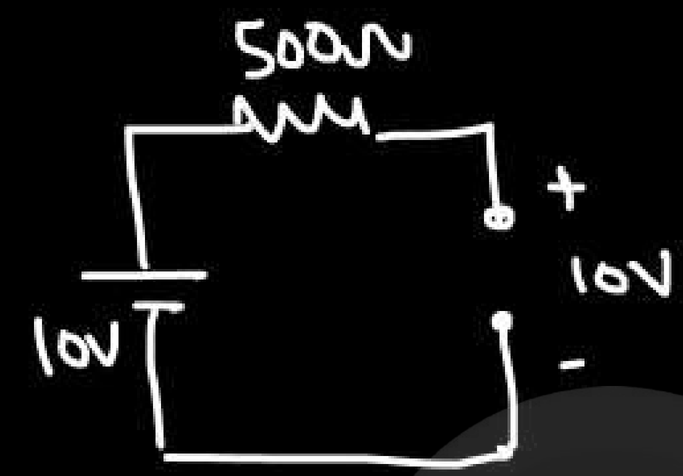


(d)

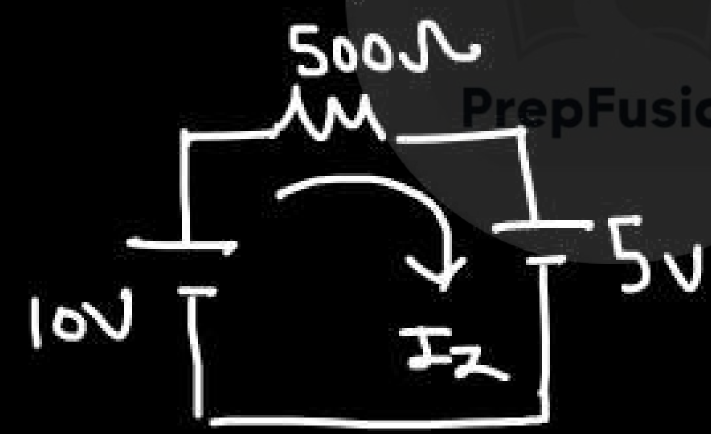
$V_Z = 5V$, $(I_Z)_{min} = 5mA$



(a)

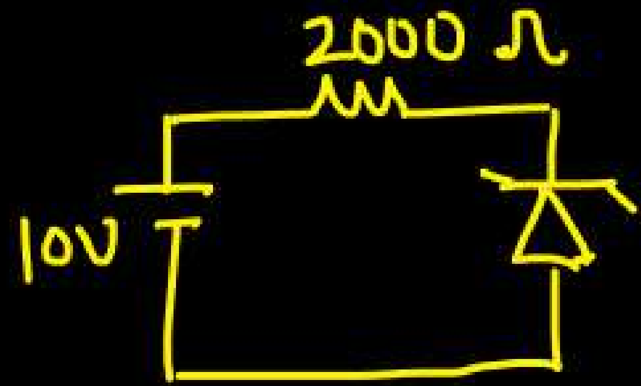


⇒ Zener can go into breakdown region



$$I_Z = \frac{5}{500} = 10mA > I_{Z\,min}$$

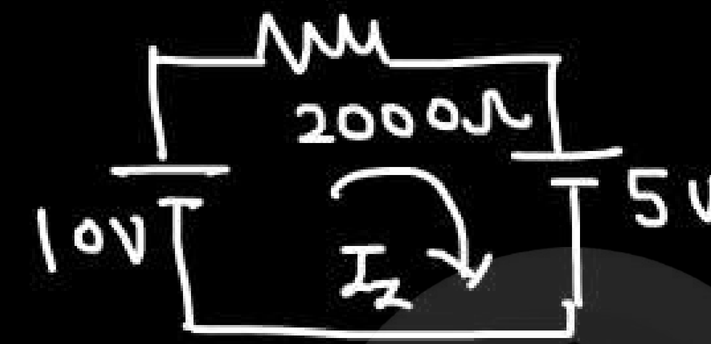
⇒ Zener goes into breakdown



(b)

$V_z = 5V$, $(I_z)_{min} = 5mA$

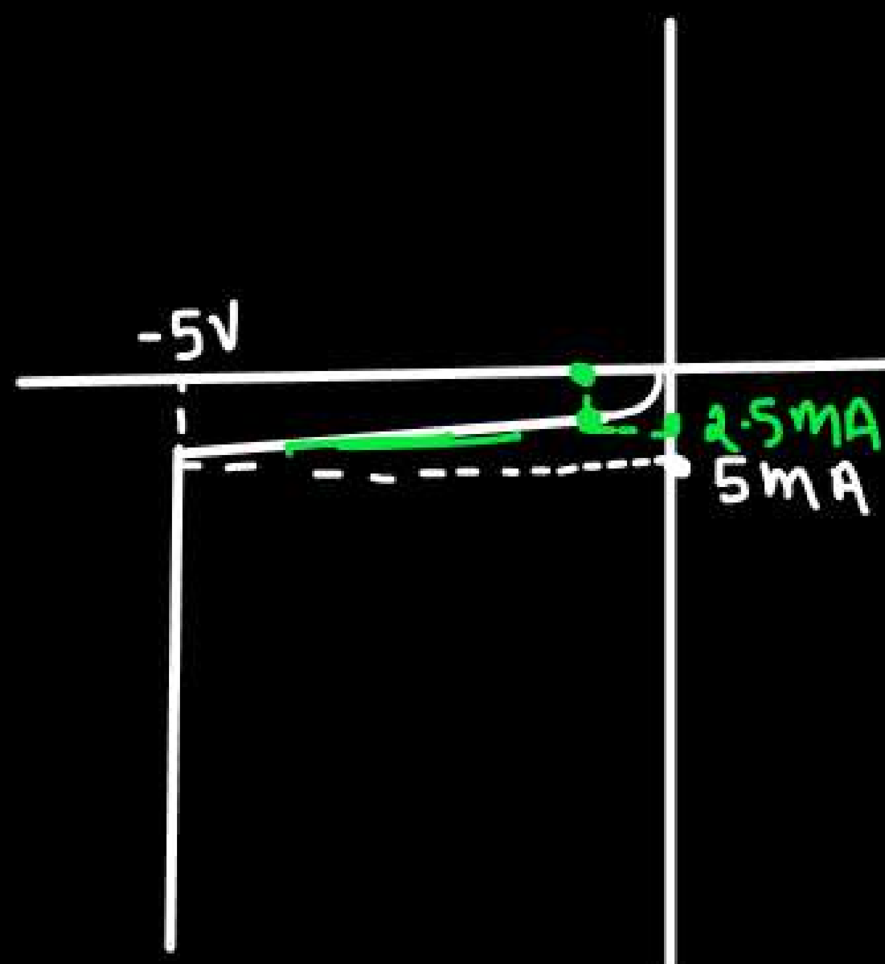
→ it may go into breakdown



$$I_z = \frac{5}{2000} = 2.5mA < (I_z)_{min}$$

$\Downarrow$

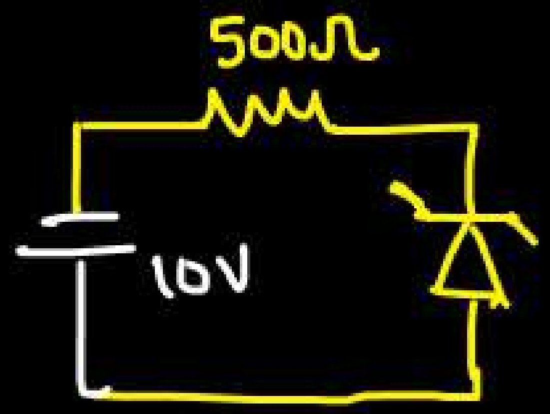
no, zener doesn't go into breakdown.



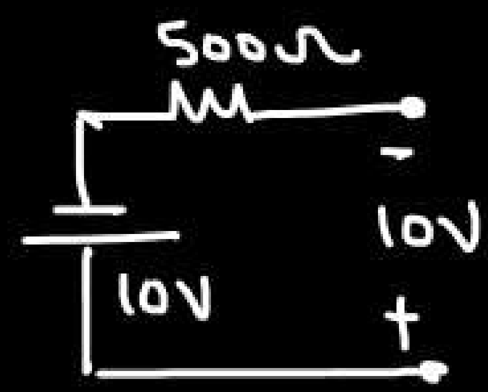
$\Downarrow$

zener is in reverse bias only.

$V_z = 5V, \quad (I_z)_{min} = 5\,mA$



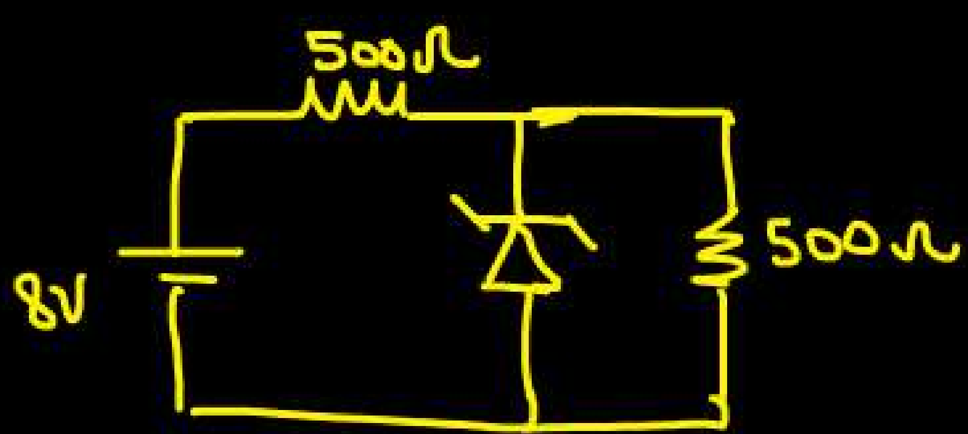
c)



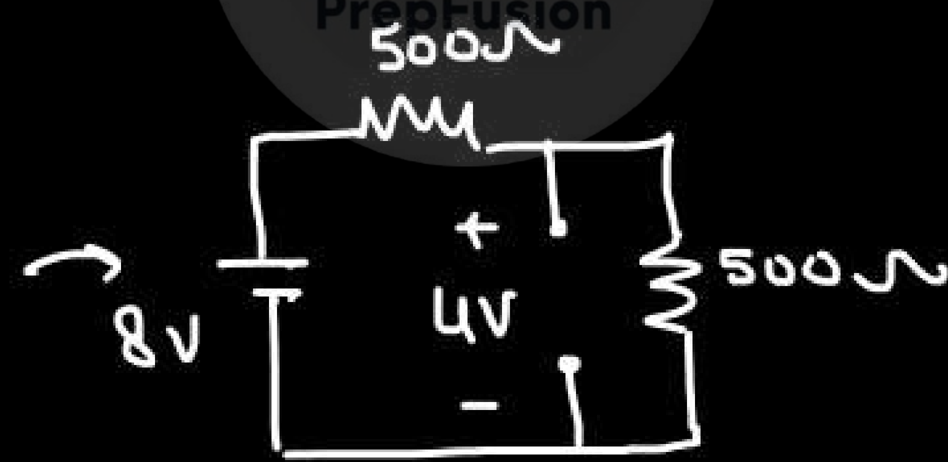
← Forward biased

⇓

zener is forward biased.



(d)



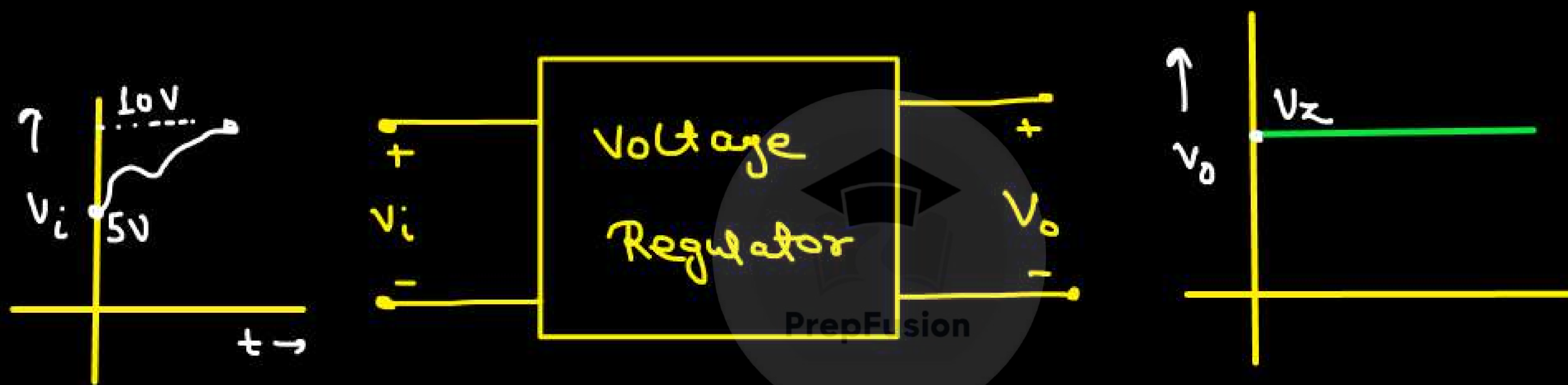
$V_{zener} = 4V < V_Z$

⇓

zener is in reverse bias (not in breakdown)

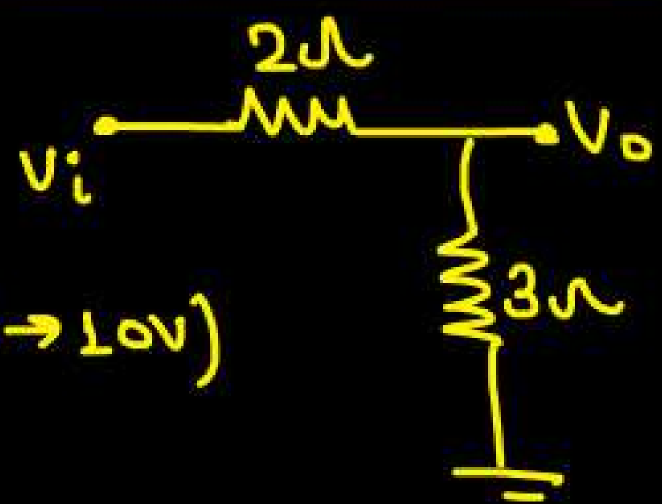
⇒ Zener diode as a voltage regulator:-

voltage regulator:- Having a constant / regulated voltage o/p.



Voltage regulation is required in these condⁿ :-

① Line (Supply) variation



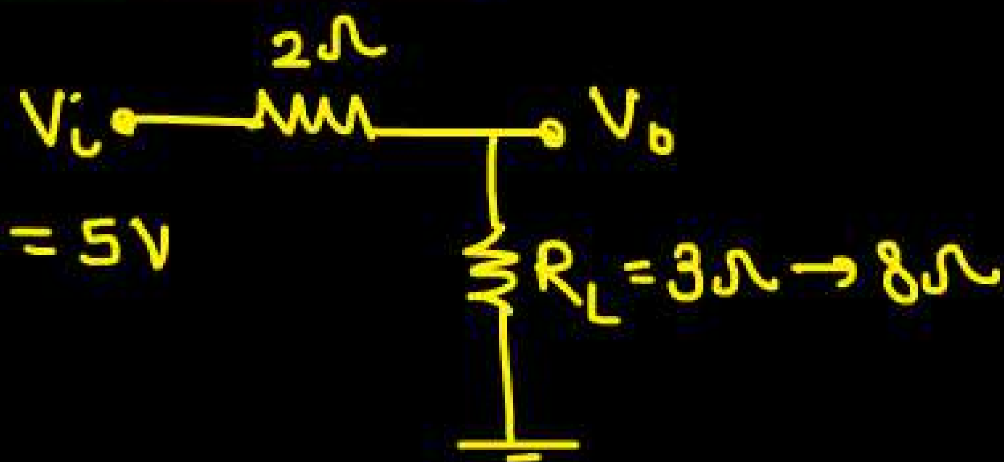
(5V → 10V)

when $V_i = 5V \Rightarrow V_o = \frac{3}{5} \times 5 = 3V$

when $V_i = 10V \Rightarrow V_o = 6V$

$\Rightarrow \boxed{V_o = 3V \rightarrow 6V}$

② Load variation :-



$= 5V$

when $R_L = 3\Omega$, $V_o = 3V$

$R_L = 8\Omega$, $V_o = 4V$

$\boxed{V_o = 3V \rightarrow 4V}$

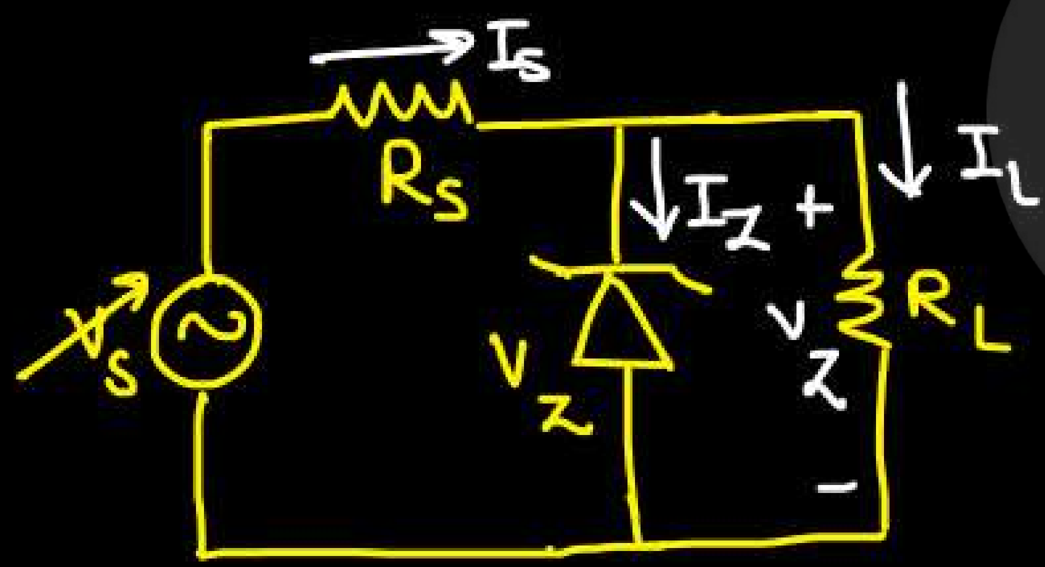
→ You want constant o/p voltage.

Here, your o/p is varying, but you want a regulated o/p (fixed o/p).

$\Downarrow$

Use Zener diode

(i) When supply varies:-



Considering zener in breakdown.

$$I_L = \frac{V_Z}{R_L} \Rightarrow \text{fixed} \quad \text{— (1)}$$

$$I_S = I_Z + I_L \quad \text{——} \quad (2)$$

$$I_S = \frac{V_S - V_Z}{R_S} \quad \text{——} \quad (3)$$

if $V_S \rightarrow \min \Rightarrow I_S \rightarrow \min \Rightarrow I_Z \rightarrow \min$

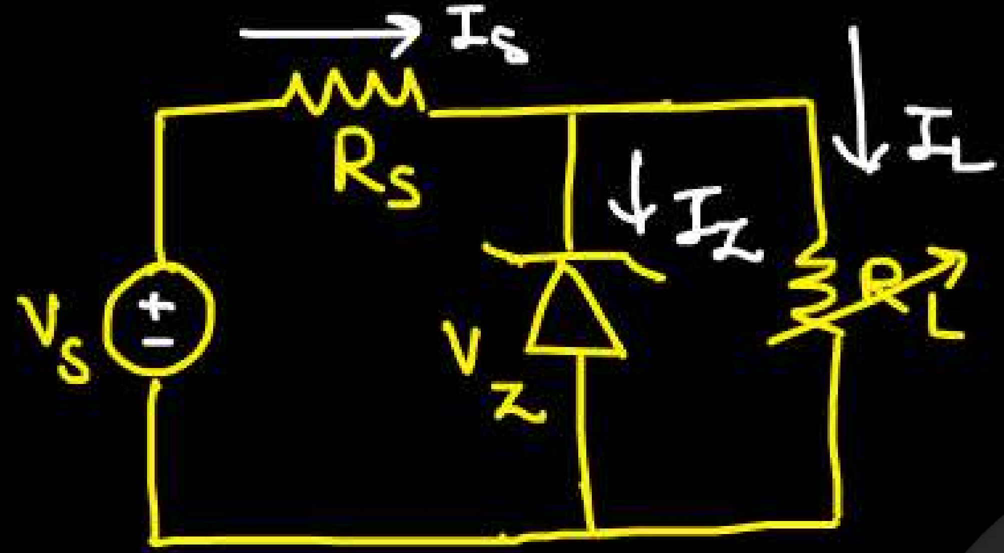
☆☆☆

if zener is having minimum current ⇒ supply is also @ minimum

if zener is having maximum current ⇒ supply is also @ maximum

zener current ∝ supply voltage (Analogy)

When load varies:-



Considering zener in breakdown.

$$I_s = \frac{V_s - V_z}{R_s} \rightarrow \text{Fixed} \quad \text{——} \; (1)$$

$$I_L = \frac{V_z}{R_L} \quad \text{——} \; (2)$$

$$I_s = I_z + I_L \quad \text{——} \; (3)$$

If $R_L \to \max \Rightarrow I_L \to \min \Rightarrow I_Z \to \max$

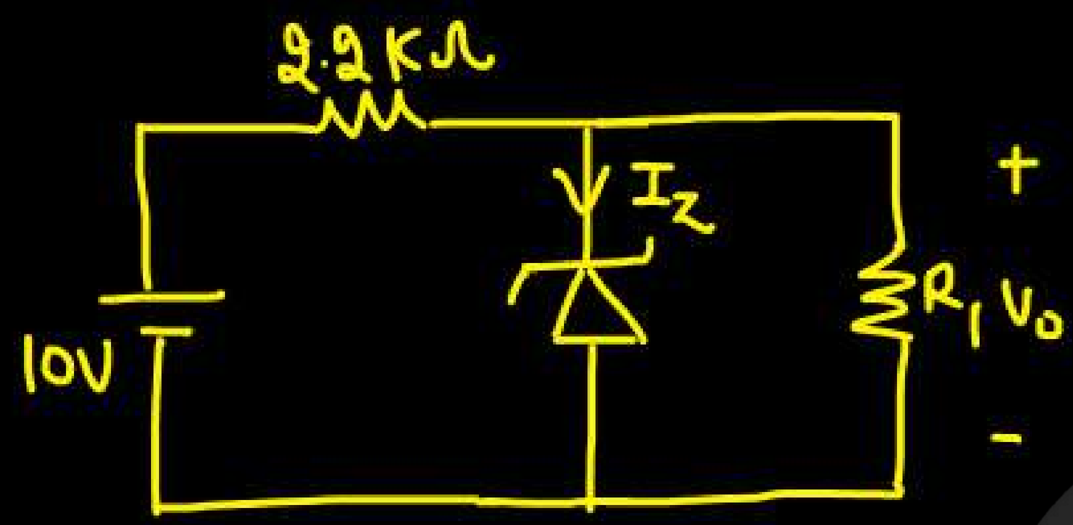
if $R_L \to \min \Rightarrow I_L \to \max \Rightarrow I_Z \to \min$

if load current is min, zener current would be maximum.

if load current is max, zener current would be minimum.

$$I_L \propto \frac{1}{I_Z} \text{ (Analogy)}$$

Q. Find the current through zener diode.

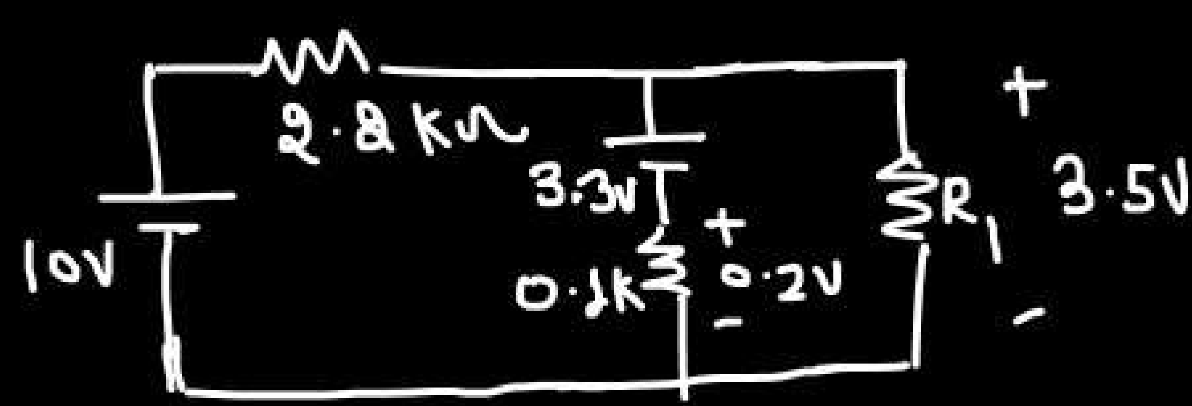


(i) $V_0 = 3.5V$

(ii) $V_0 = 3V$

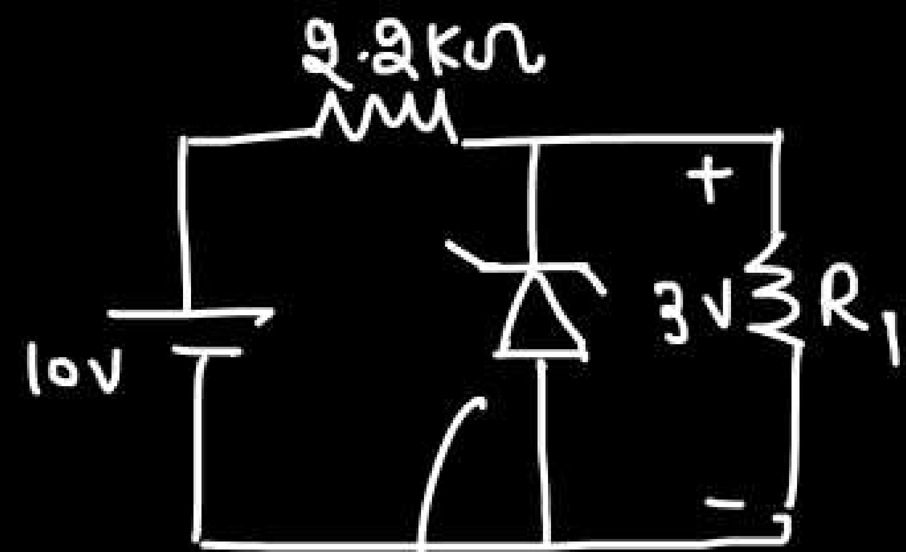
$V_z = 3.3V$, $R_z = 0.1k\Omega$

→ (i) $V_0 = 3.5V$



$$\boxed{I_z = \frac{0.2}{0.1K} = 2mA}$$

(ii)

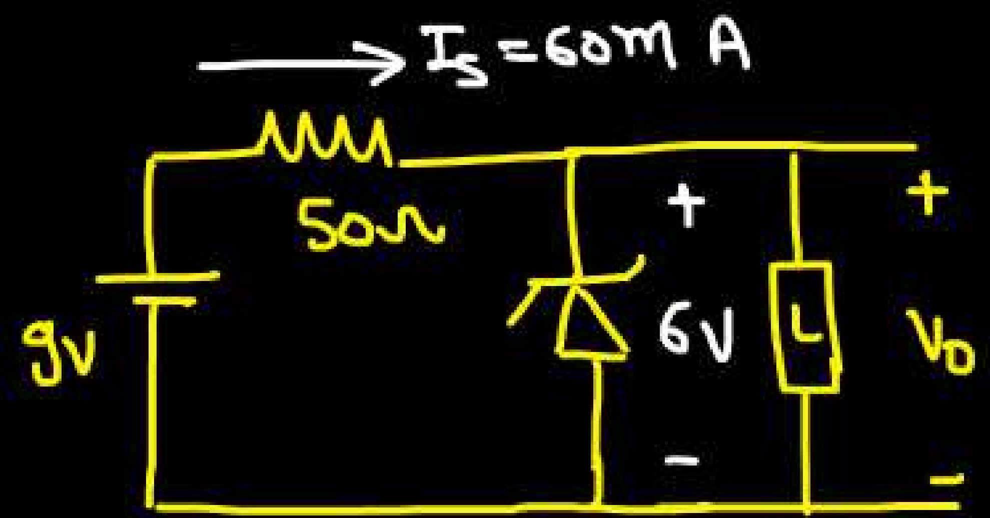


zener is in reverse bias not in breakdown.

$\downarrow I_Z$

$$\boxed{I_Z = 0 \text{ Ap.}}$$

Q.



→ Load variation

min current

The Zener diode in the circuit shown in the figure has a knee current of 5 mA, and a maximum allowed power dissipation of 300 mW. What are the minimum and maximum load currents that can be drawn safely from the circuit, keeping the output voltage V0 constant at 6 V?

→ $\boxed{(I_Z)_{min} = 5mA}$,

$V_Z = 6V$

$P_{max} = 300mW$

$6 \times (I_Z)_{max} = 300m$

$\boxed{(I_Z)_{max} = 50mA}$

$I_S = \frac{3}{50} = \underline{\underline{60mA}}$

(i) if I_Z is min ⇒ I_L will be max.

$I_S = I_Z + I_L$

$60mA = (I_Z)_{min} + (I_L)_{max}$

$\boxed{(I_L)_{max} = 55mA}$

$60mA = (I_Z)_{max} + (I_L)_{min}$

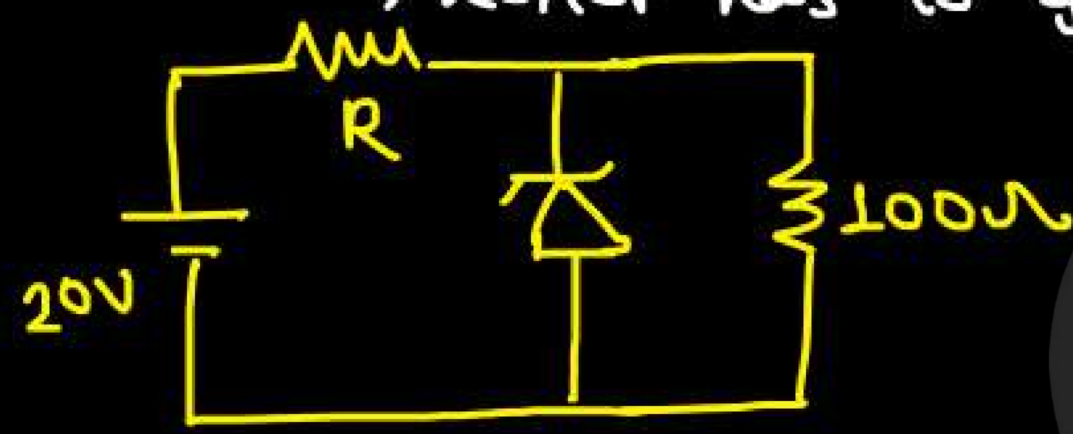
$\boxed{(I_L)_{min} = 10mA}$

Q. $(I_z)_{min} = 25\,mA$, $(I_z)_{max} = 50\,mA$

The value of R required for satisfactory voltage regulation of the ckt is →

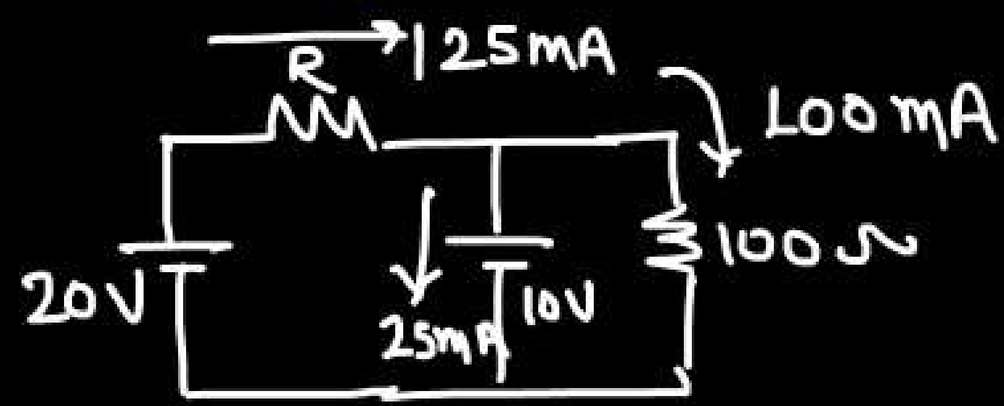
↳ minimum cond^n

↳ zener has to go into B.D.



$V_z = 10V$

→



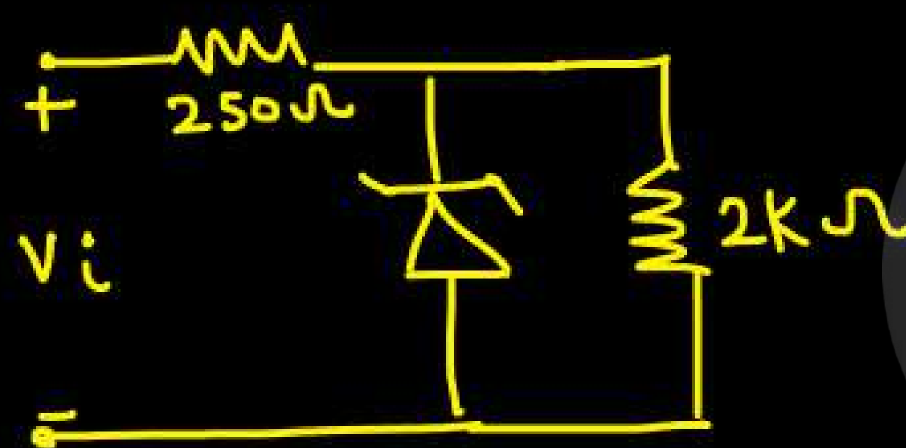
$$\frac{20-10}{R} = 125\,m$$

$$\boxed{R = 80\Omega}$$

Q. Find the range of V_i for the zener to remain in "ON & Safe" state.

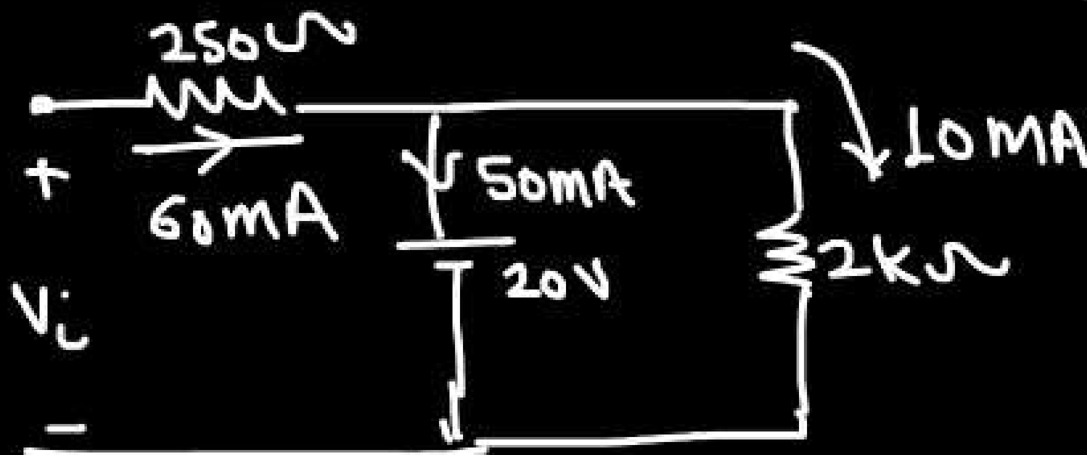
min cond^n ← → max^m cond^n

$V_Z = 20V$, $(I_Z)_{max} = 50mA$



→ Supply variation

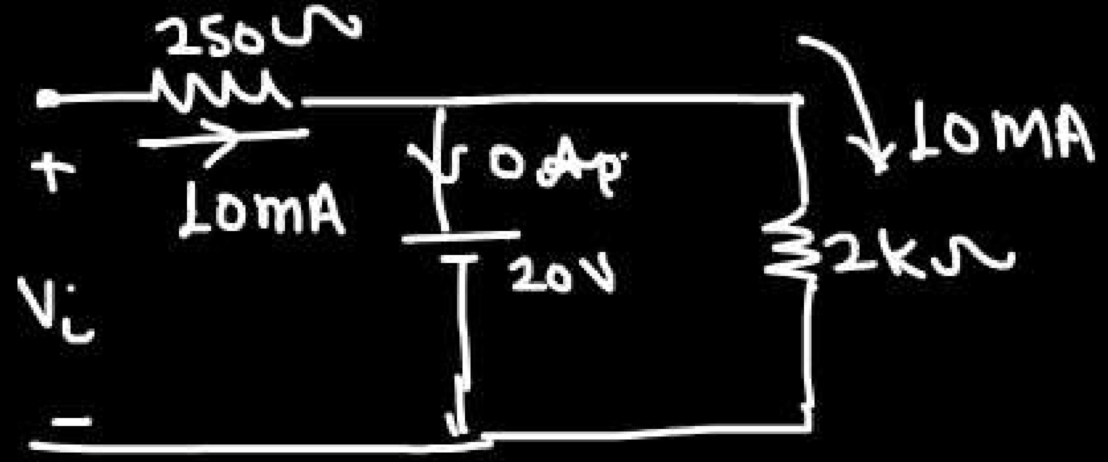
→



if $I_Z \to max \Rightarrow V_i \to max$

$$\frac{V_i - 20}{250} = 60mA$$

$$\boxed{(V_i)_{max} = 35V}$$



$(I_z)_{min} \rightarrow$ not mentioned

$(I_z)_{min} = 0$ Amp.

$I_z \rightarrow min \Rightarrow V_i \rightarrow min$

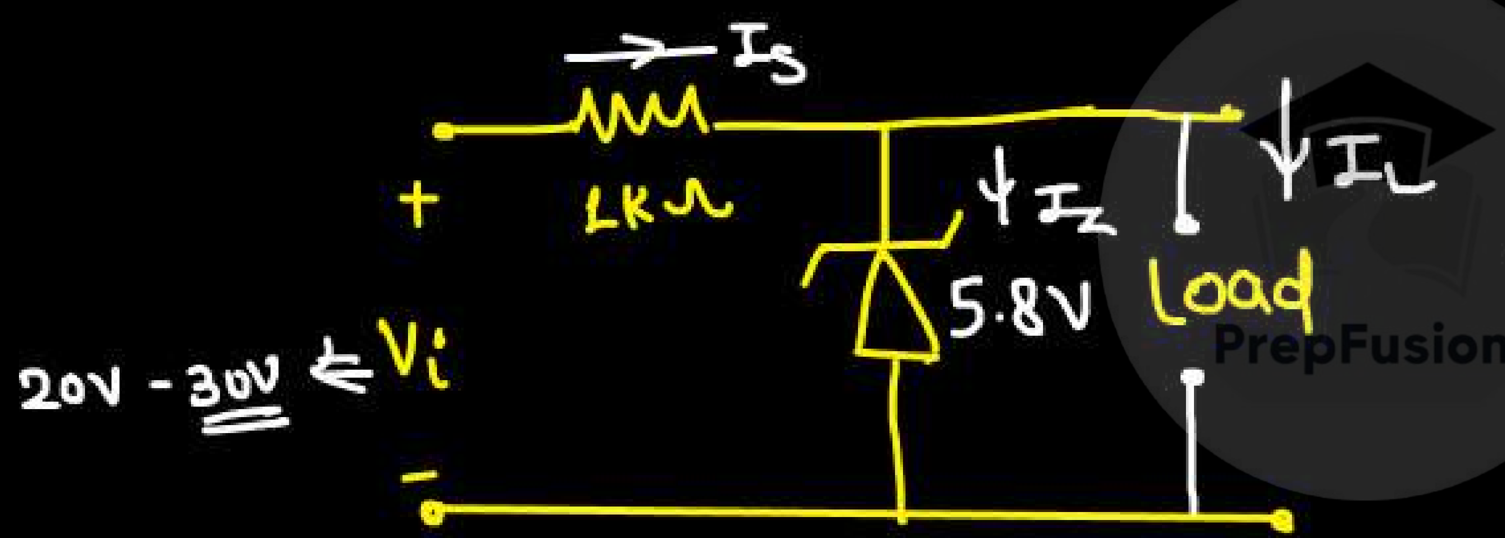
$$\frac{(V_i)_{min} - 20}{250} = 10mA$$

$$\boxed{(V_i)_{min} = 22.5V}$$

Q. $V_Z = 5.8V$, $(I_Z)_{min} = 0.5mA$, $(I_Z)_{max} = 20mA$

Find the max and min current drawn by the load.

Input voltage ranges from 20V to 30V.

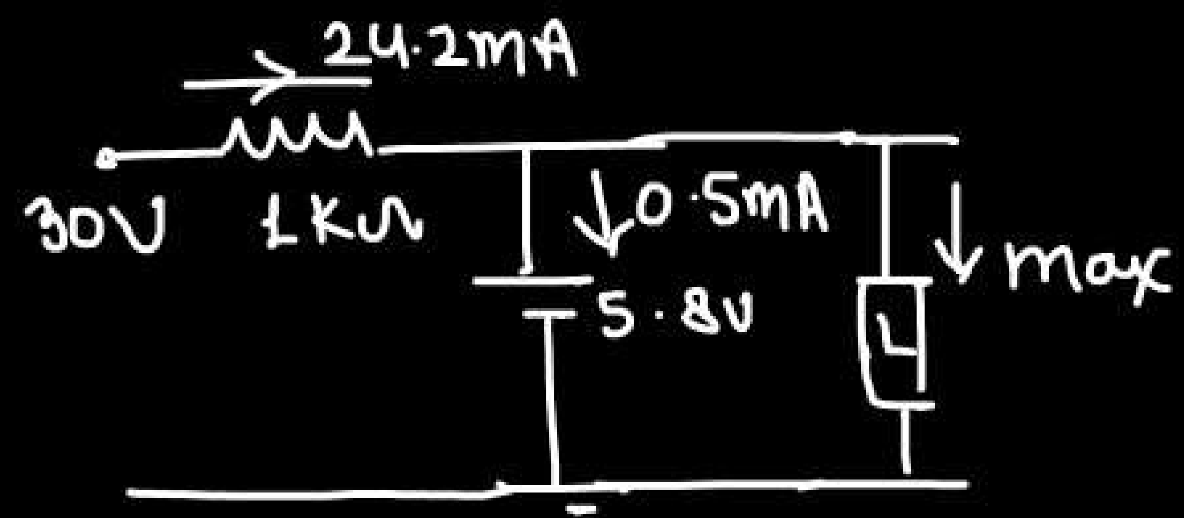


0.5mA

→ load variation + supply variation

⇒ Load current min ⇒ zener current max ⇒ supply voltage max
load current max ⇒ zener current min ⇒ supply voltage min

(i) max load current

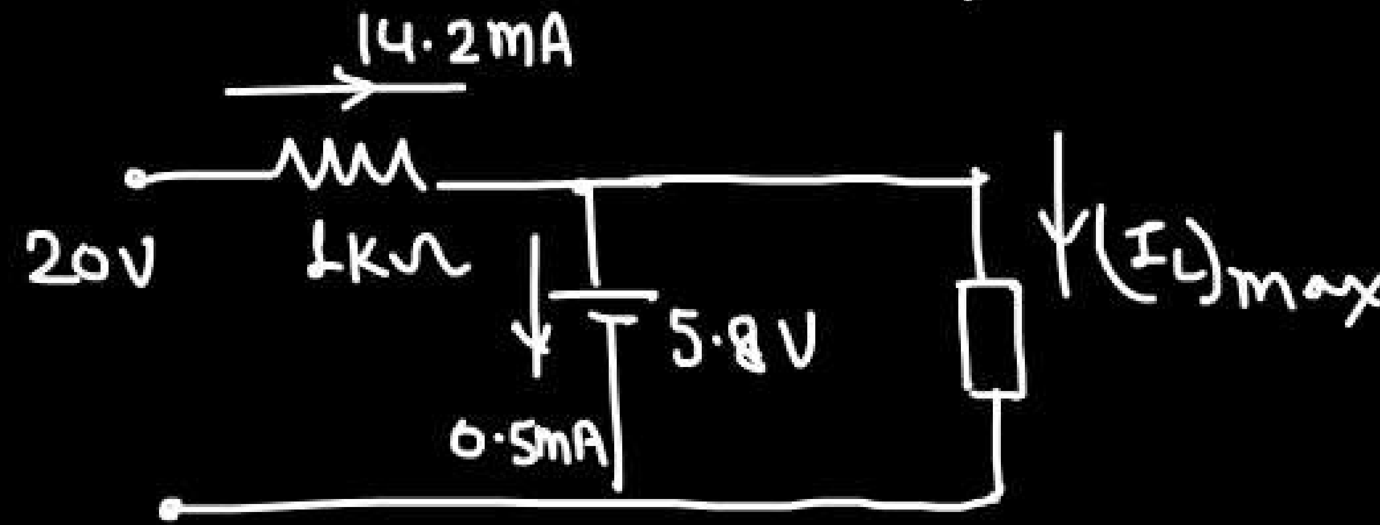


For max current, I will take supply to be max

$$\boxed{(I_L)_{max} = 23.7\text{ mA}}$$

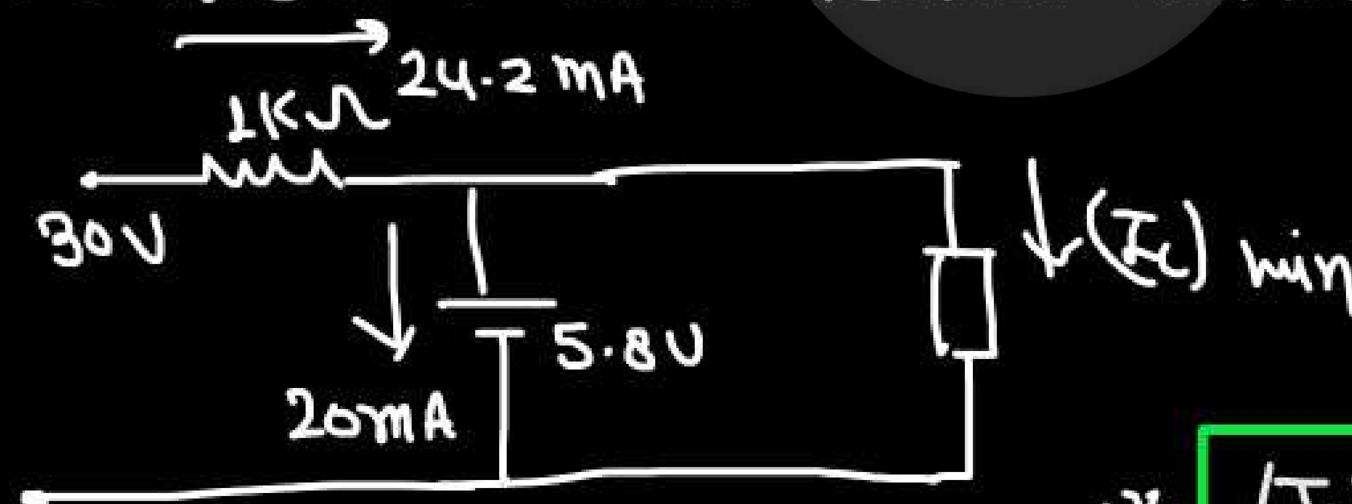
When you supply is max, then zener current will certainly be max ⇒ if zener current is max^m, the load current would be min

(i) max load current ⇒ min zener current ⇒ min supply



∴ $\boxed{(I_L)_{max} = 13.7\ mA}$

(ii) min load current ⇒ max zener current ⇒ max supply



∴ $\boxed{(I_L)_{min} = 4.2\ mA}$

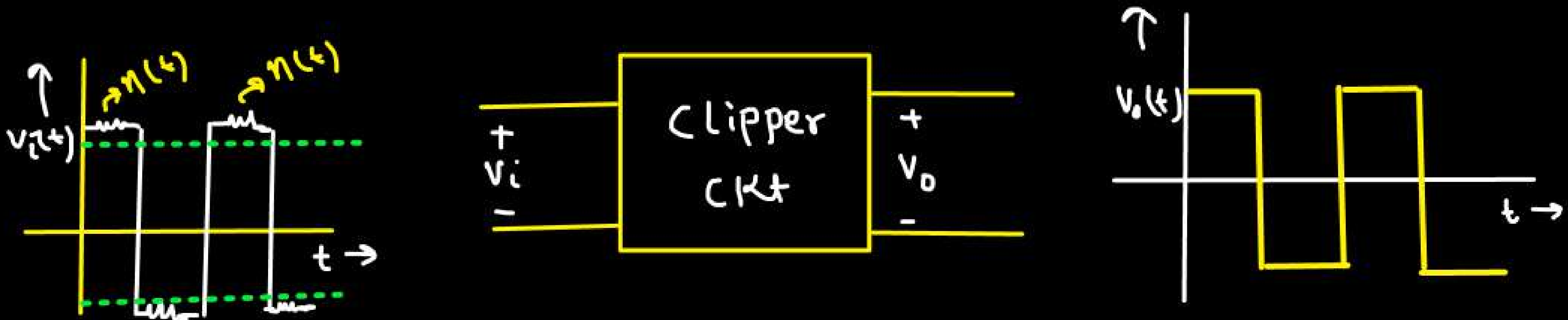
Clipper Circuits

What is cliper Circuits?

↳ diode ckts can be used to clip a certain portion of input signal without distorting the remaining part of the signal.

Any application?

↳ To remove noise from a signal

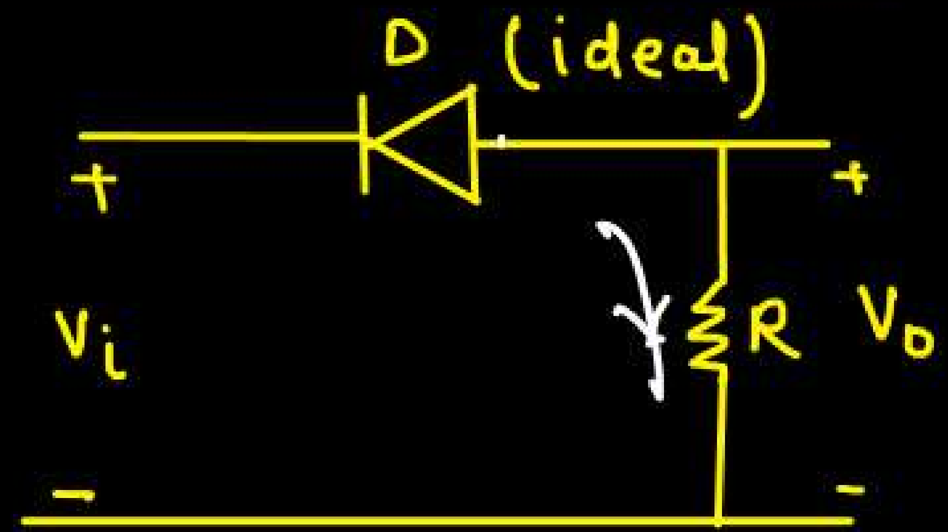


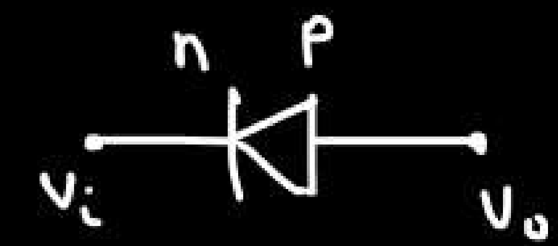
Types of Clipper ckt (Single level)

- Series → o/p and diode will be in series
  - Positive
    - Biased
      - +ve
      - -ve
    - Unbiased
  - Negative
    - Biased
      - +ve
      - -ve
    - Unbiased
- Shunt → o/p and diode will be in parallel.
  - Positive
    - Biased
      - +ve
      - -ve
    - Unbiased
  - Negative
    - Biased
      - +ve
      - -ve
    - Unbiased

1. Positive series Clipper (Unbiased):-

(a)

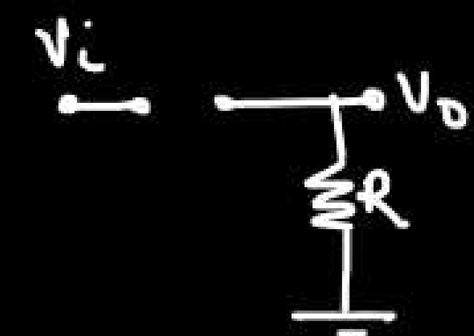




(I) $V_i > 0$

$\Rightarrow$ diode off

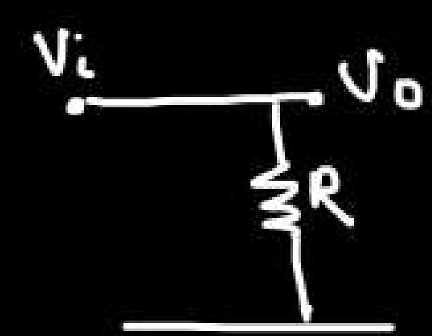
$V_o = 0\,V$



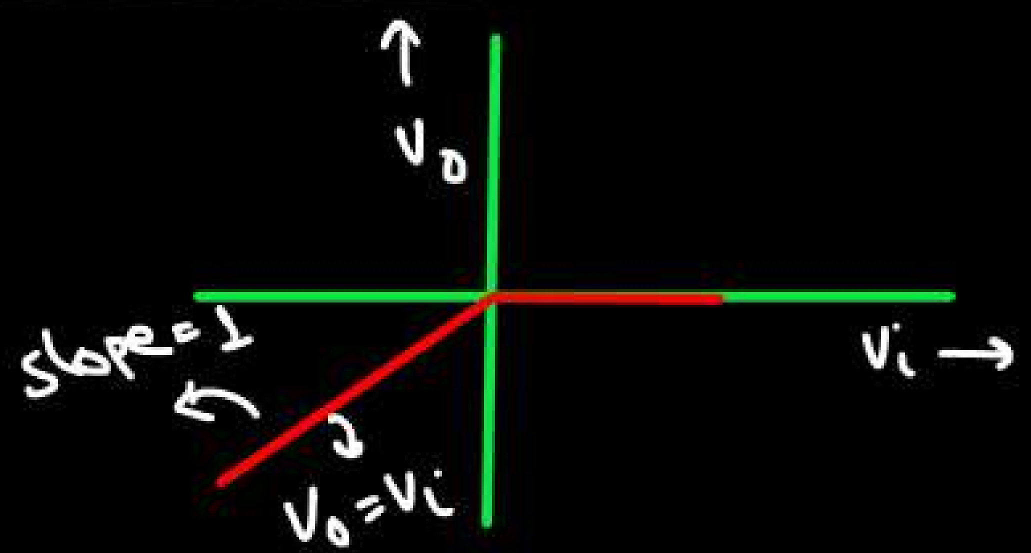
(II) $V_i < 0$

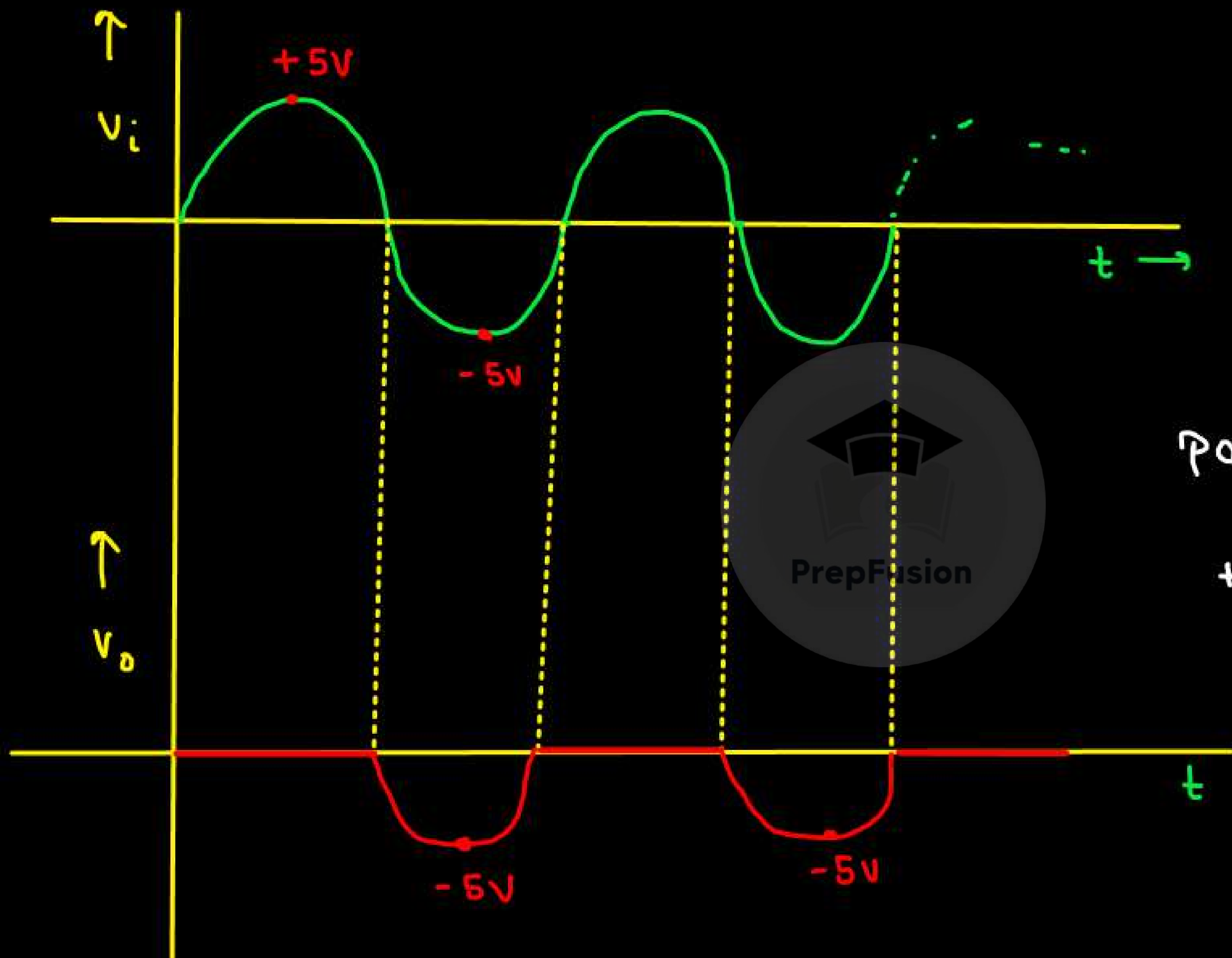
$\Rightarrow$ diode ON

$V_o = V_i$



Voltage Transfer Characteristics (VTC)

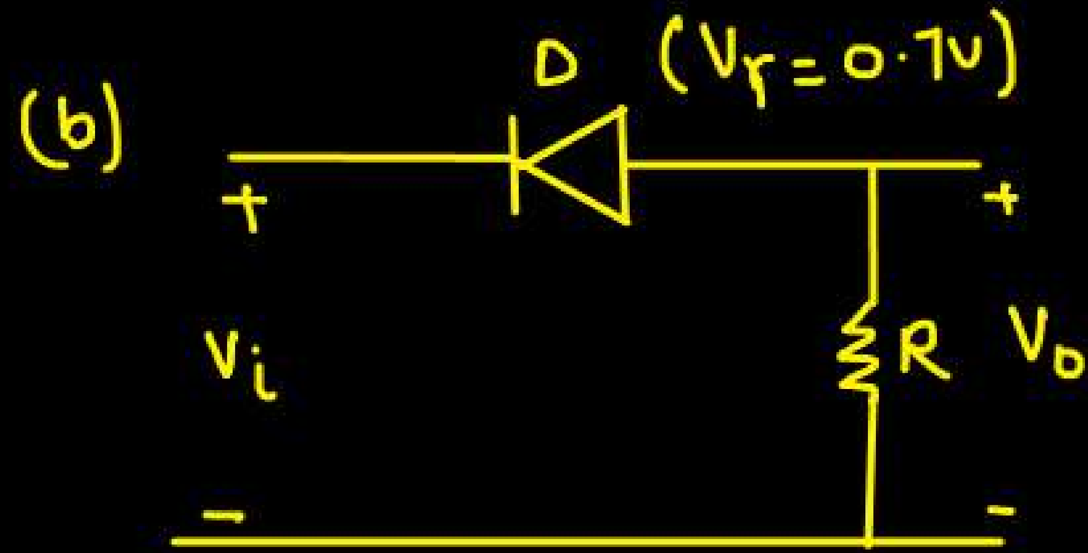




positive clipper

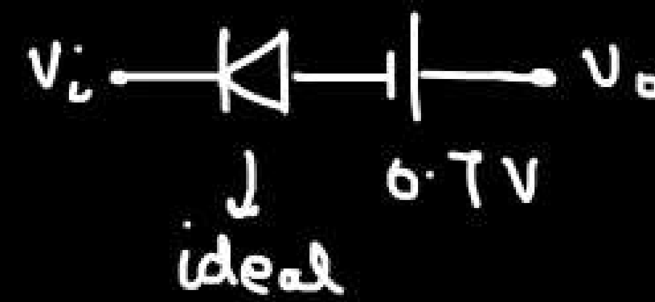
⇓

+ve part of i/p signal is clipped off in the o/p.

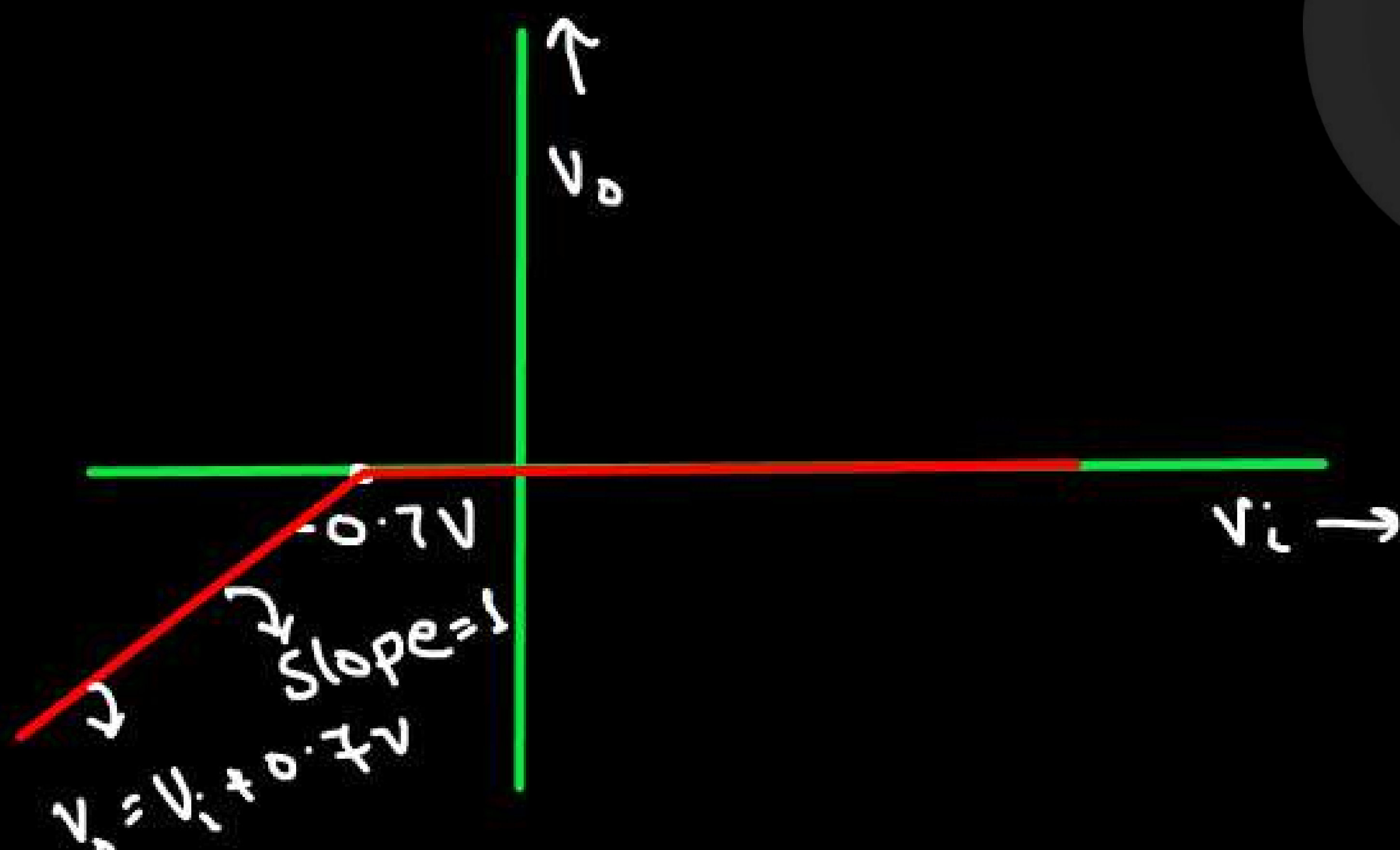


Draw VTC

→



O.C. Test



(i) $V_i > -0.7V$

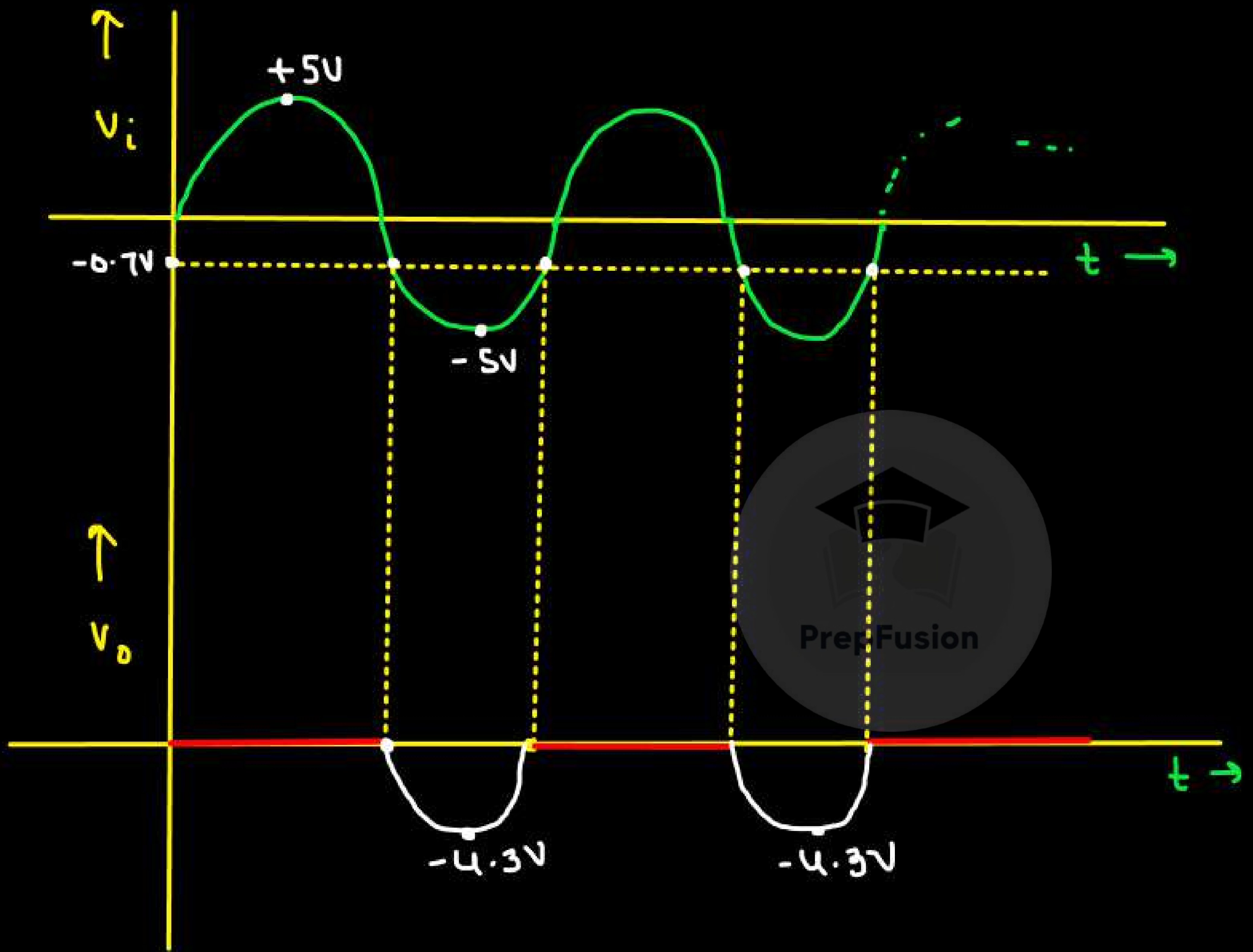
$\Rightarrow$ diode off

$\Rightarrow$ $\boxed{V_o = 0V}$

(ii) $V_i < -0.7V$

$\Rightarrow$ diode ON

$\boxed{V_o = V_i + 0.7V}$



+5V
Vi
-0.7V
-5V
t
Vo
-4.3V
-4.3V
t

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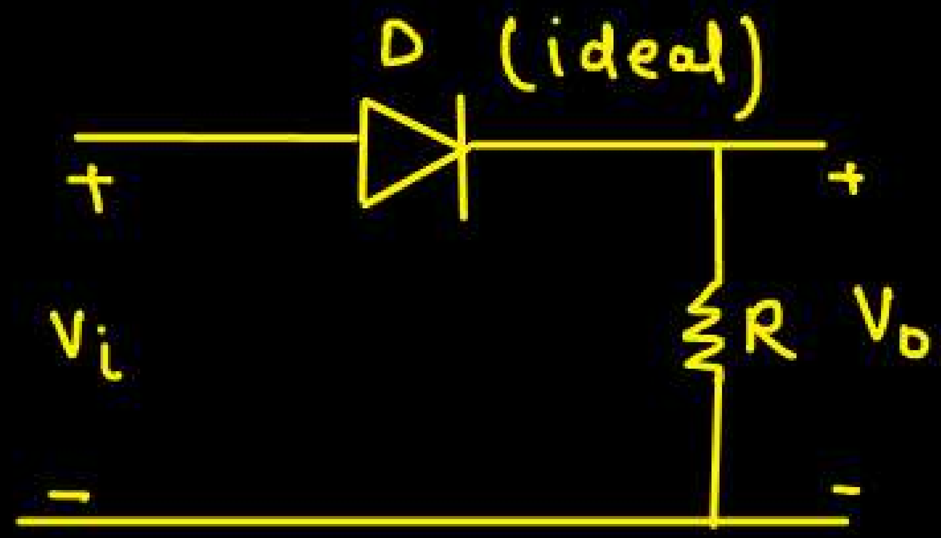
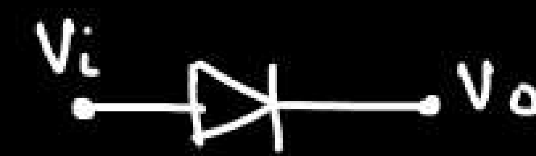
2. Negative series clipper circuit (Unbiased):-

(a)



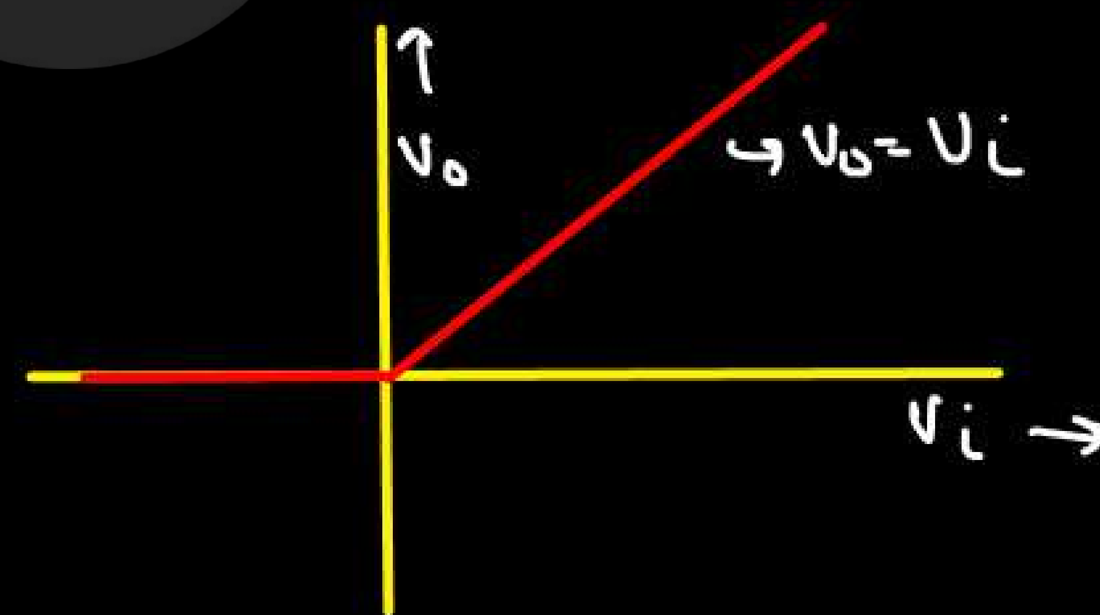


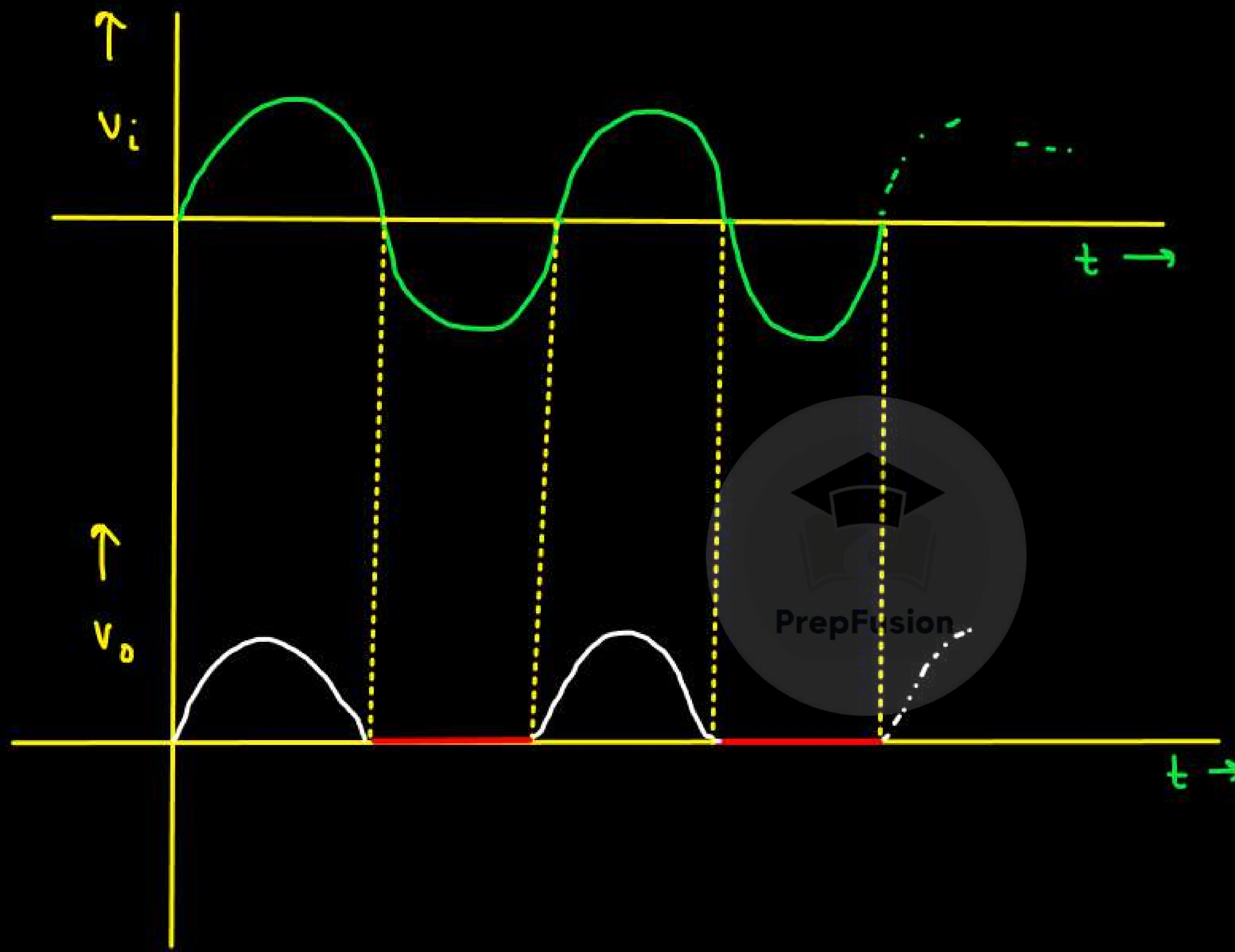
(i) $V_i > 0 \Rightarrow$ diode ON

$V_o = V_i$

(ii) $V_i < 0 \Rightarrow$ diode off

$V_o = 0$





V_i
$t \rightarrow$
V_o
$t \rightarrow$

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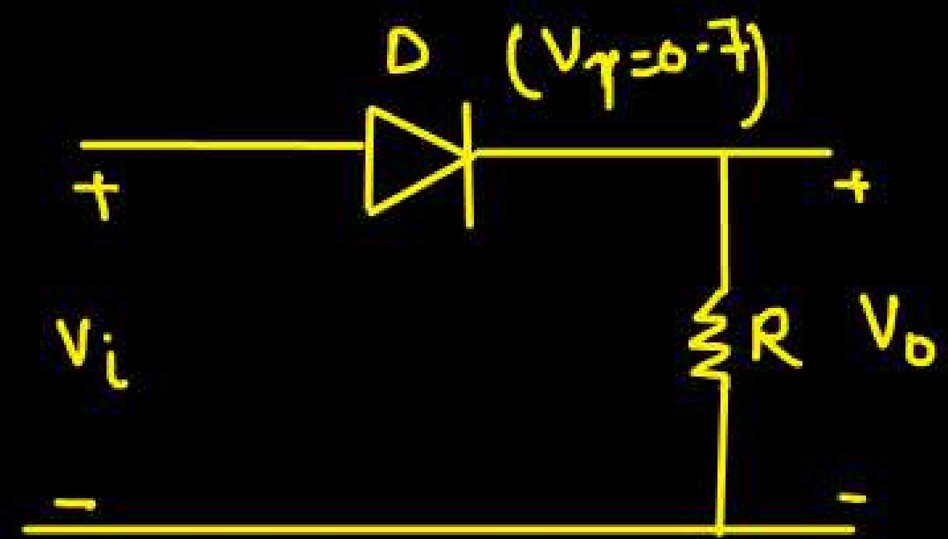
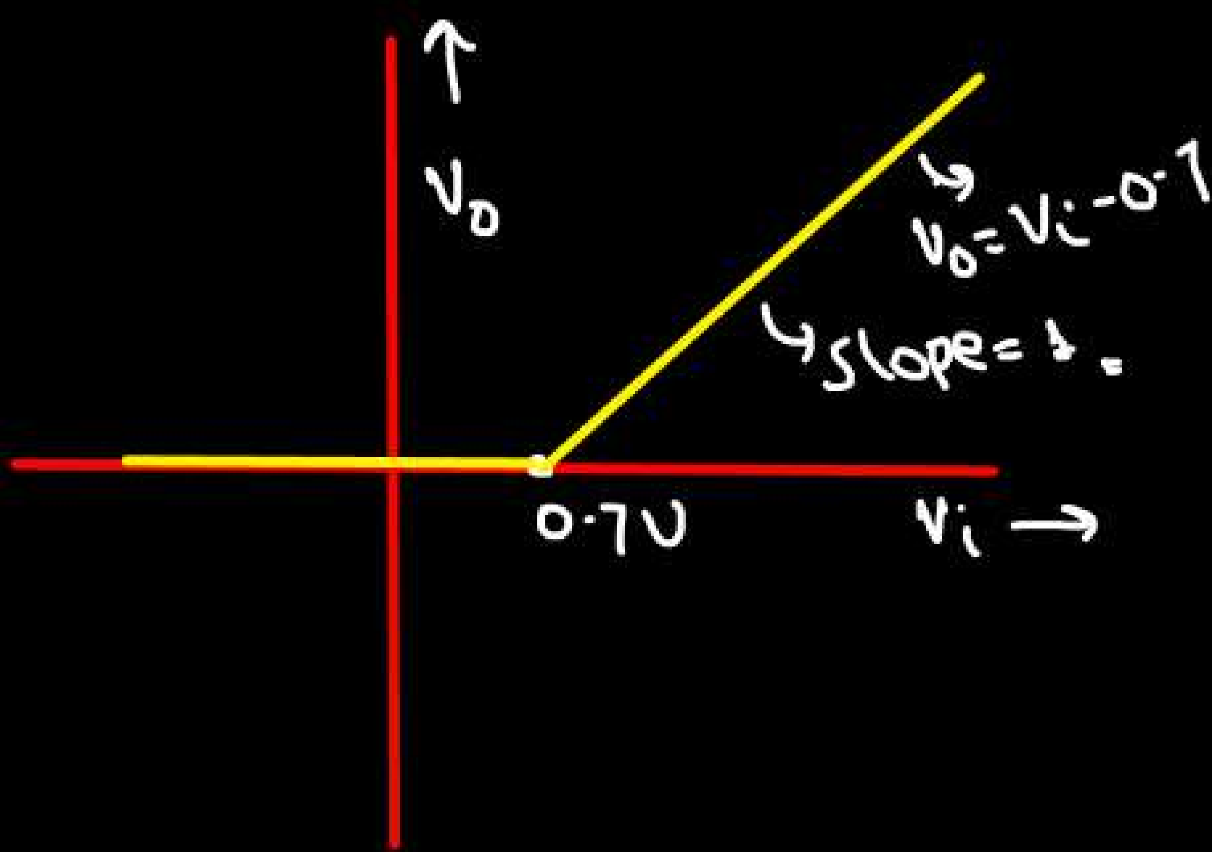
(b)



Draw VTC

$\rightarrow$

Applying O.C. Test



(i) $V_i > 0.7V$

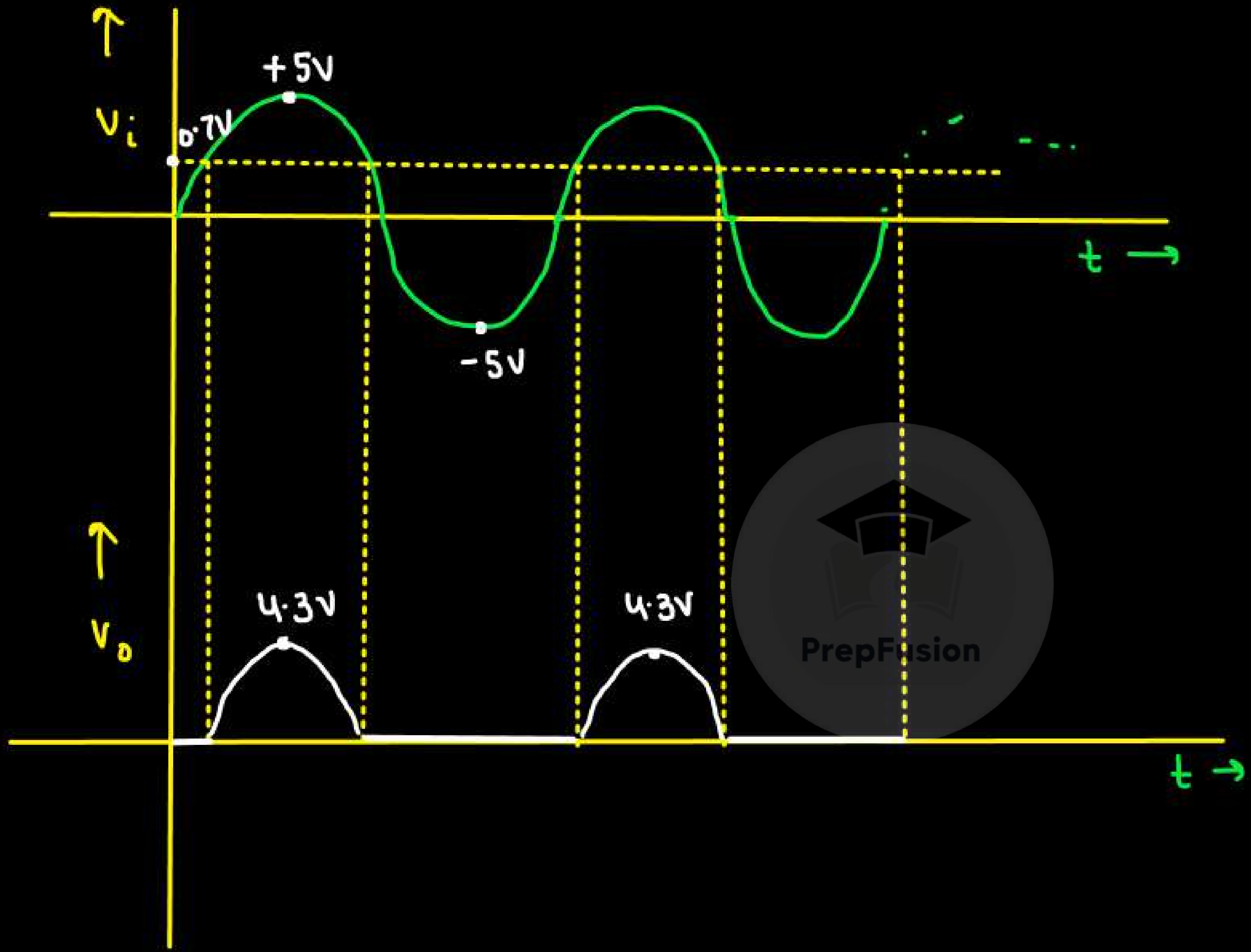
$\Rightarrow$ diode ON

$\Rightarrow$ $\boxed{V_o = V_i - 0.7}$

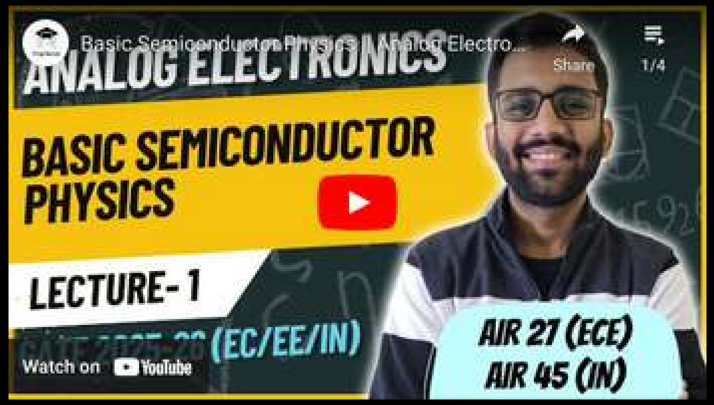
(ii) $V_i < 0.7V$

$\Rightarrow$ diode off

$\boxed{V_o = 0V}$



V_i
+5V
0.7V
-5V
t
V_o
4.3V
4.3V
t



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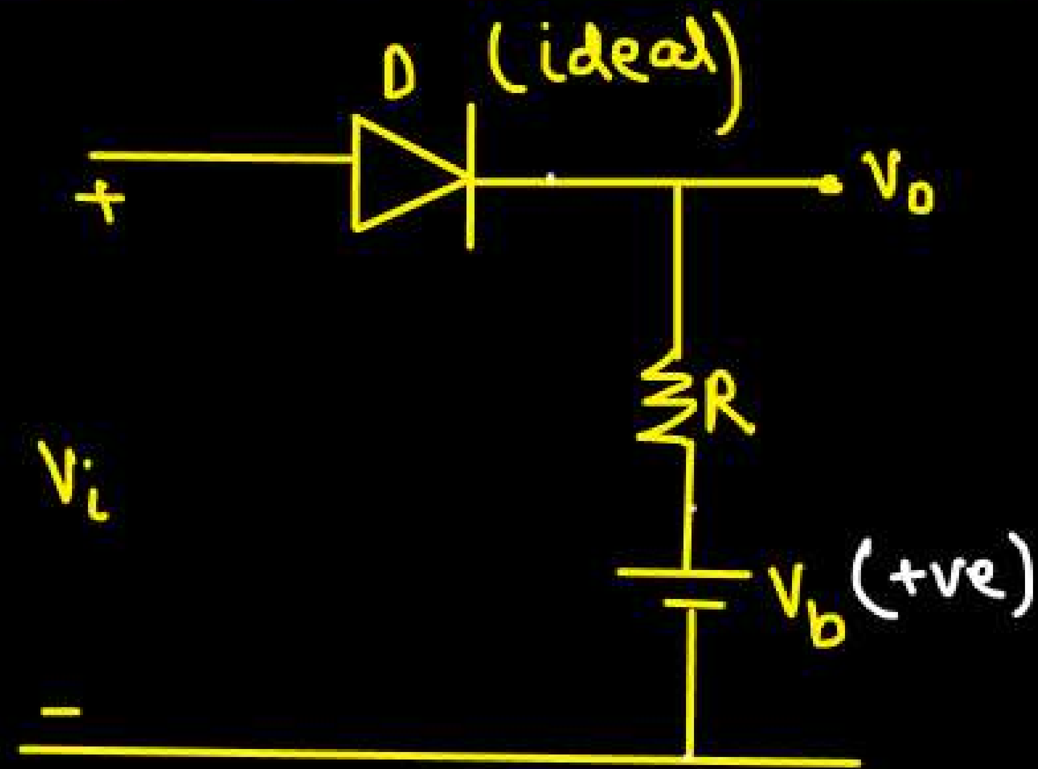
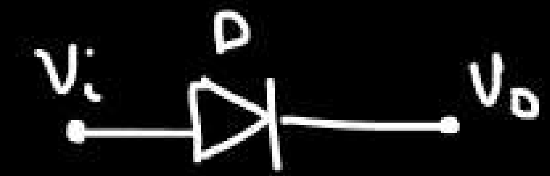
3. Negative Series Clipper Circuit (Positive bias):-

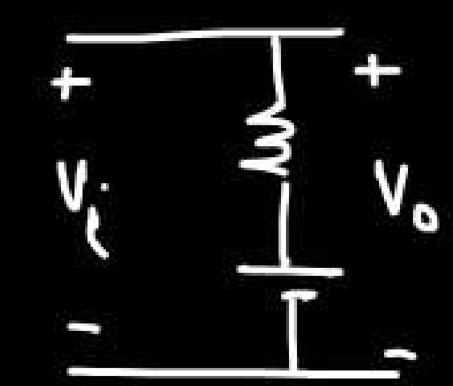




Apply O.C. Test

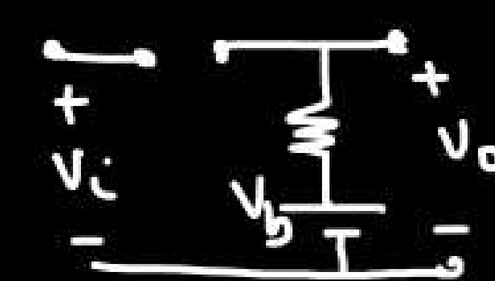
(i) $V_i > V_b \Rightarrow$ diode ON

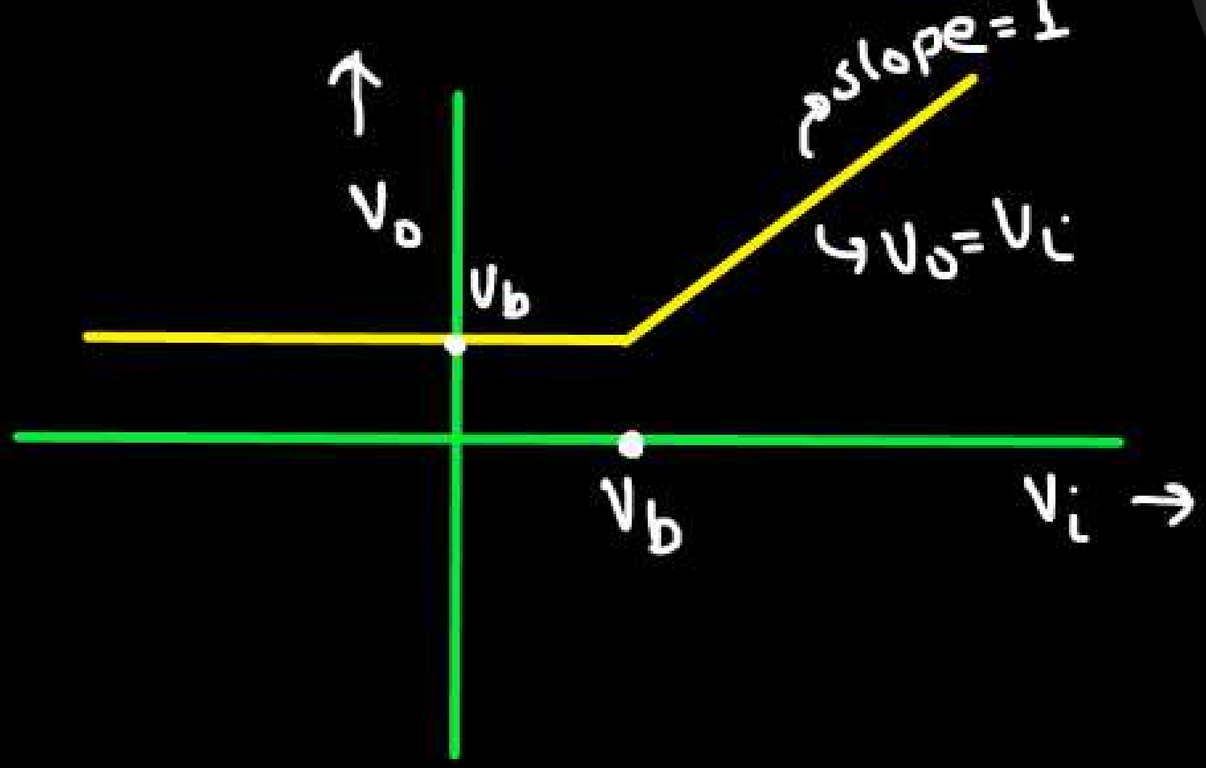
$\boxed{V_o = V_i}$

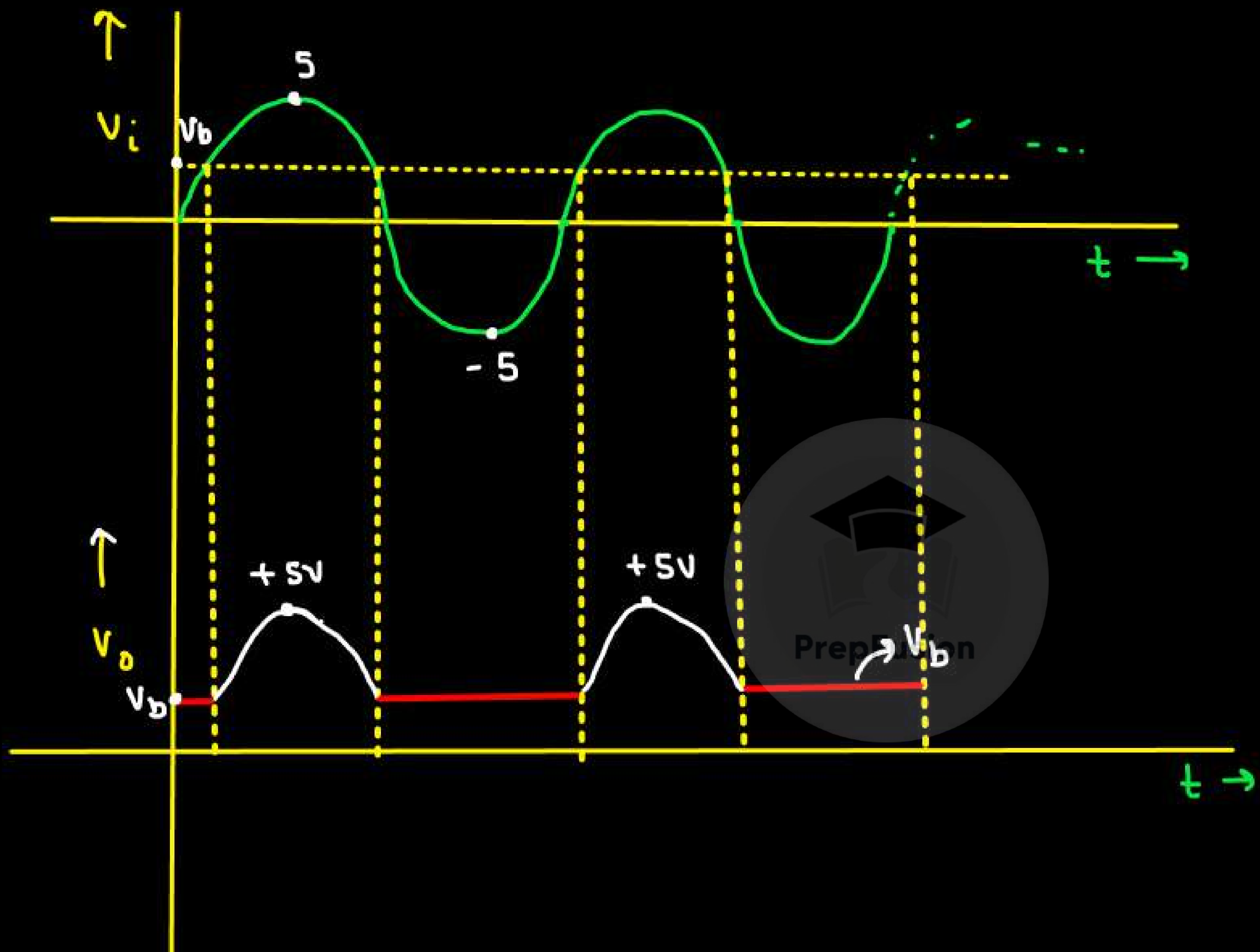


(ii) $V_i < V_b \Rightarrow$ diode off

$\boxed{V_o = V_b}$







5
Vi
Vb
t →
-5
+5V
+5V
V0
Vb
Vb
t →

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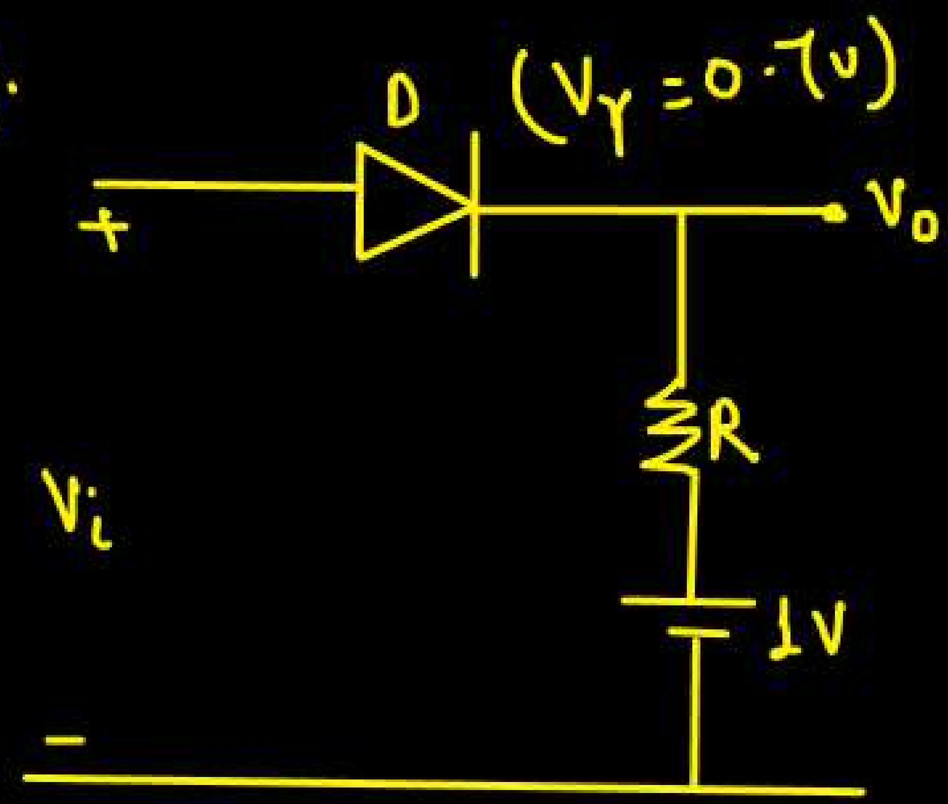
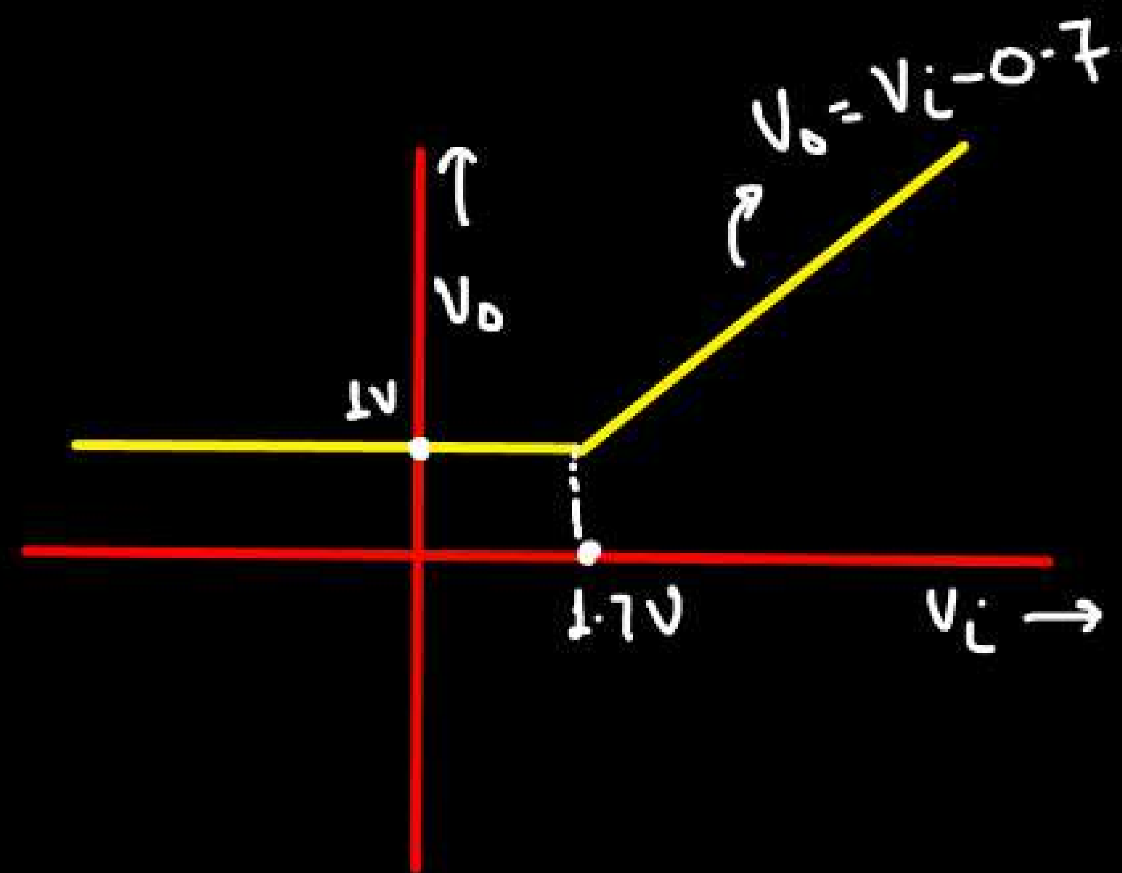
Q.



Draw Transfer characteristics.

→ O.C. Test



(i) $V_i > 1.7V \Rightarrow$ diode ON

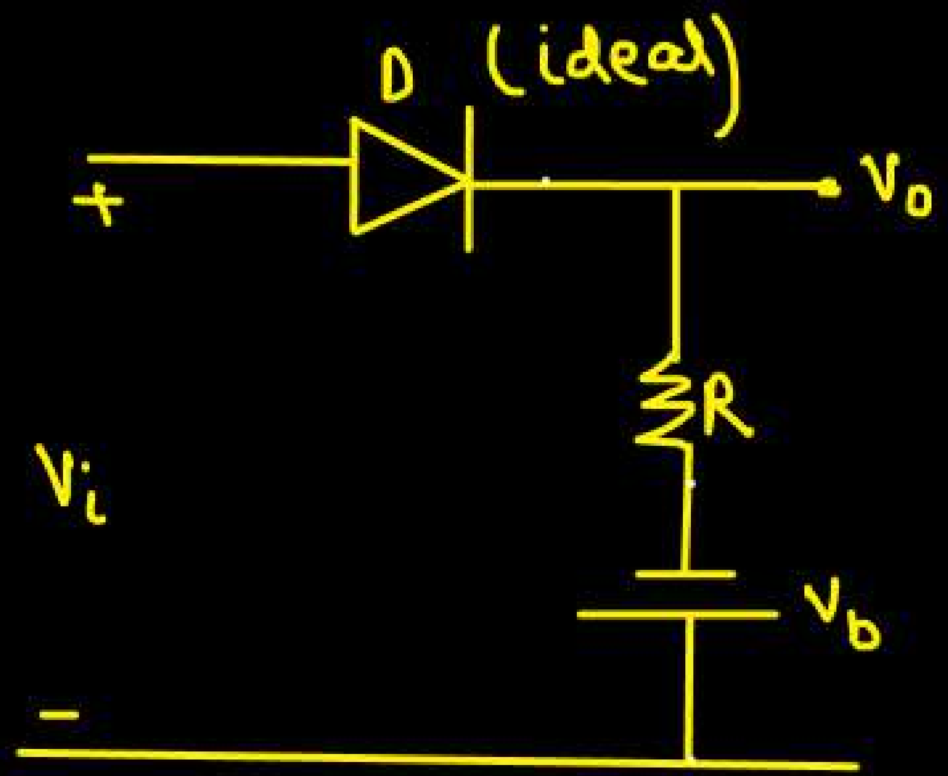
$$\boxed{V_o = V_i - 0.7V}$$

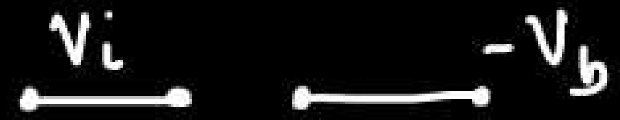
(ii) $V_i < 1.7V \Rightarrow$ diode off

$$\boxed{V_o = 1V}$$

4. Negative Clipper Circuit (Negative bias):-

↳ series



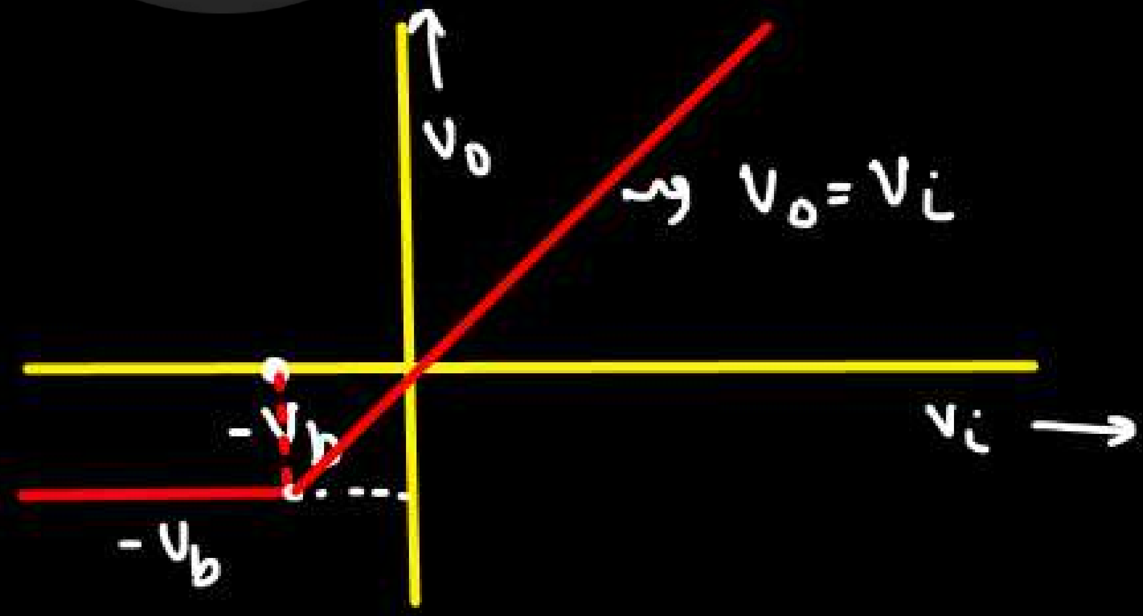


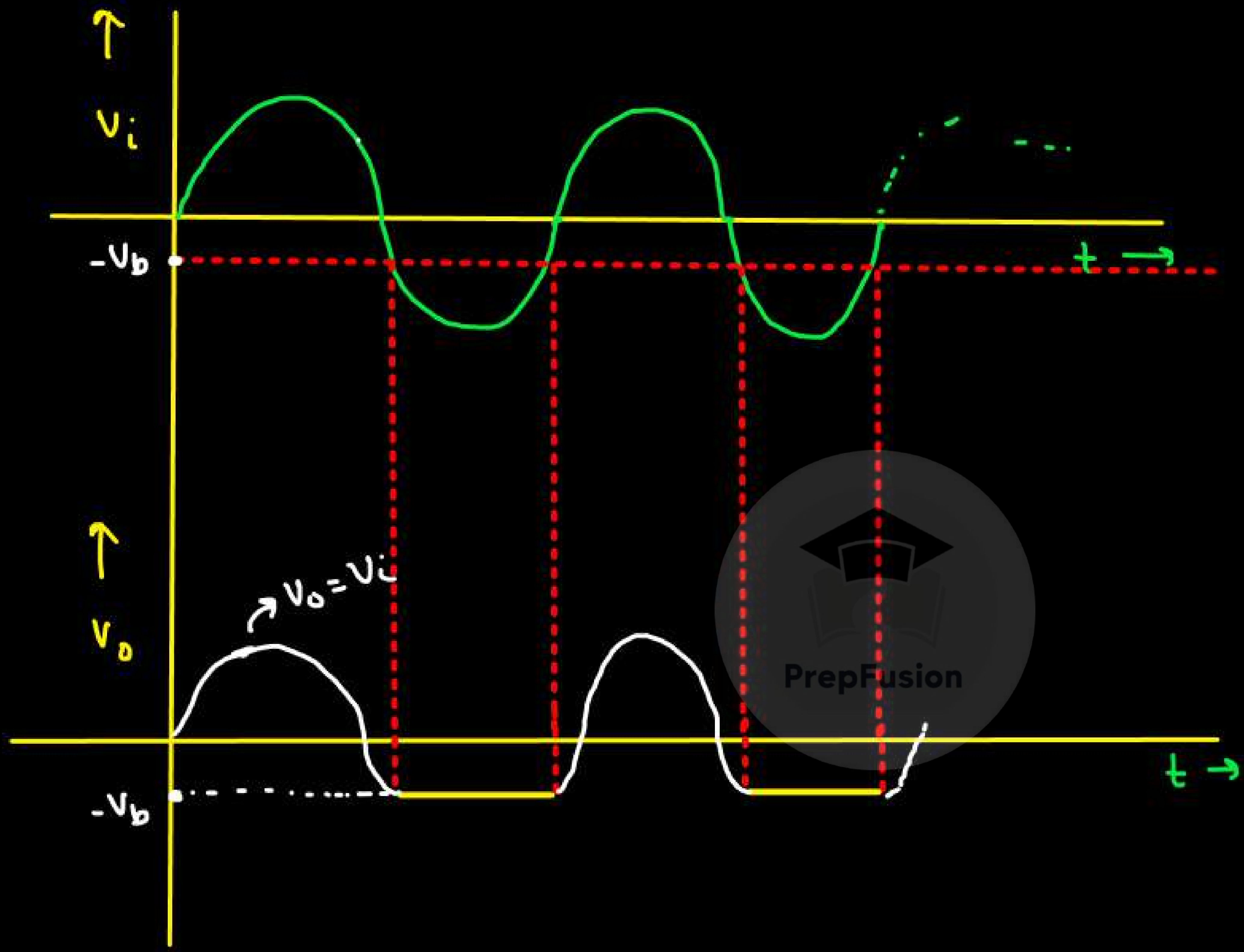
(i) $V_i > -V_b \Rightarrow$ diode ON

$$\boxed{V_0 = V_i}$$

(ii) $V_i < -V_b \Rightarrow$ diode off

$$\boxed{V_0 = -V_b}$$





Vi
-Vb
t →
Vo
Vo=Vi
-Vb
t →

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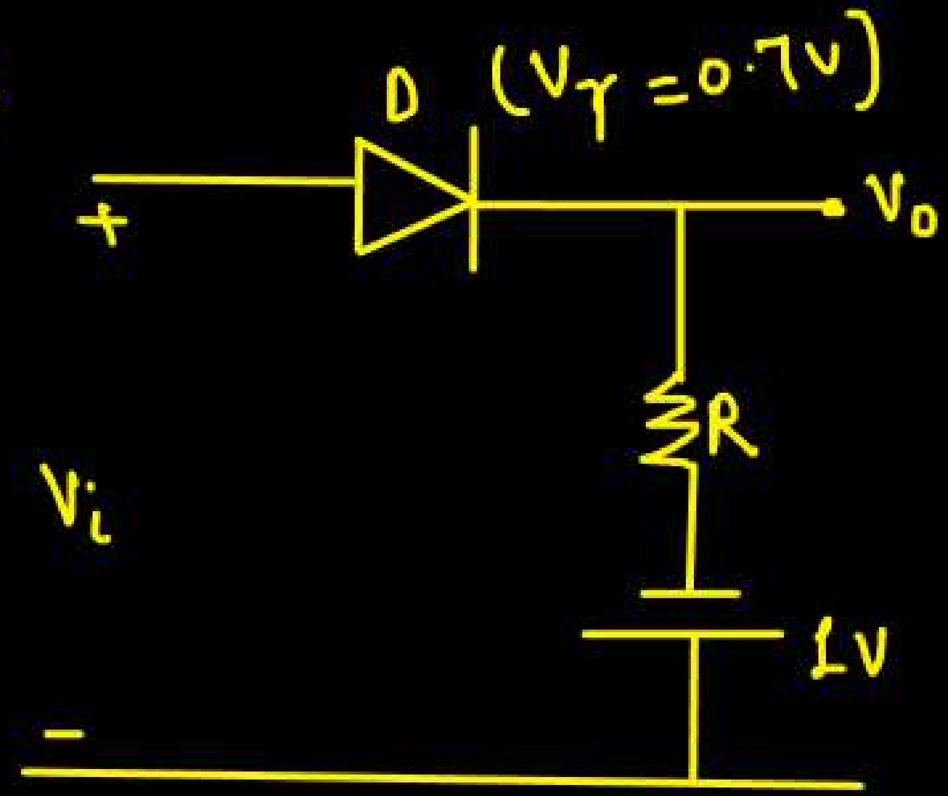
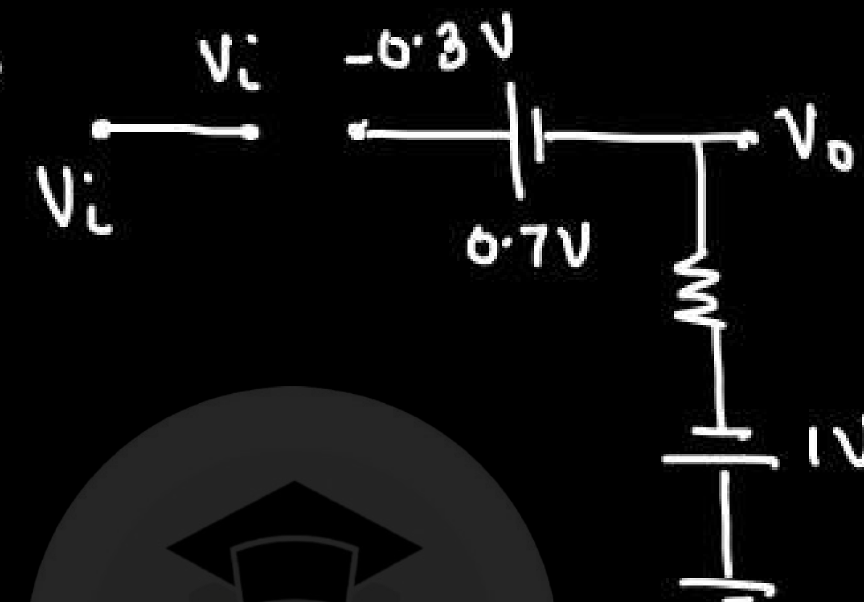
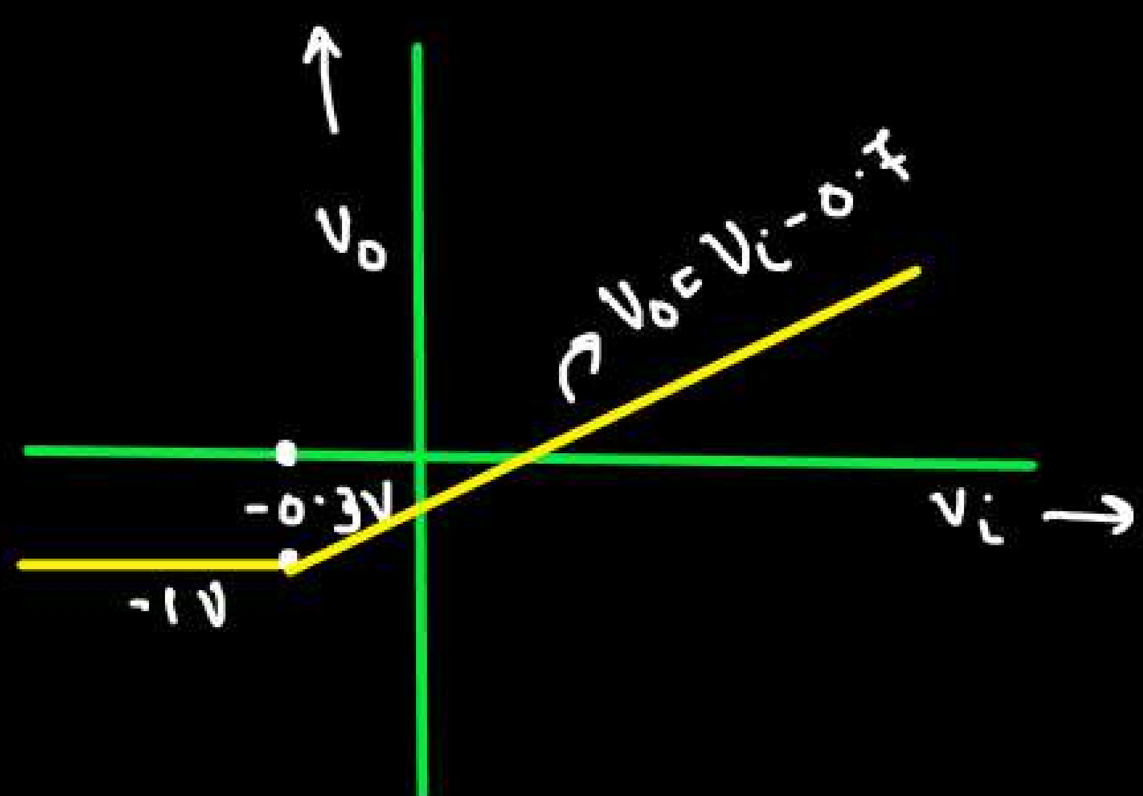


Draw Transfer characteristics.

→





(i) $V_i > -0.3V$

$\Rightarrow$ diode ON

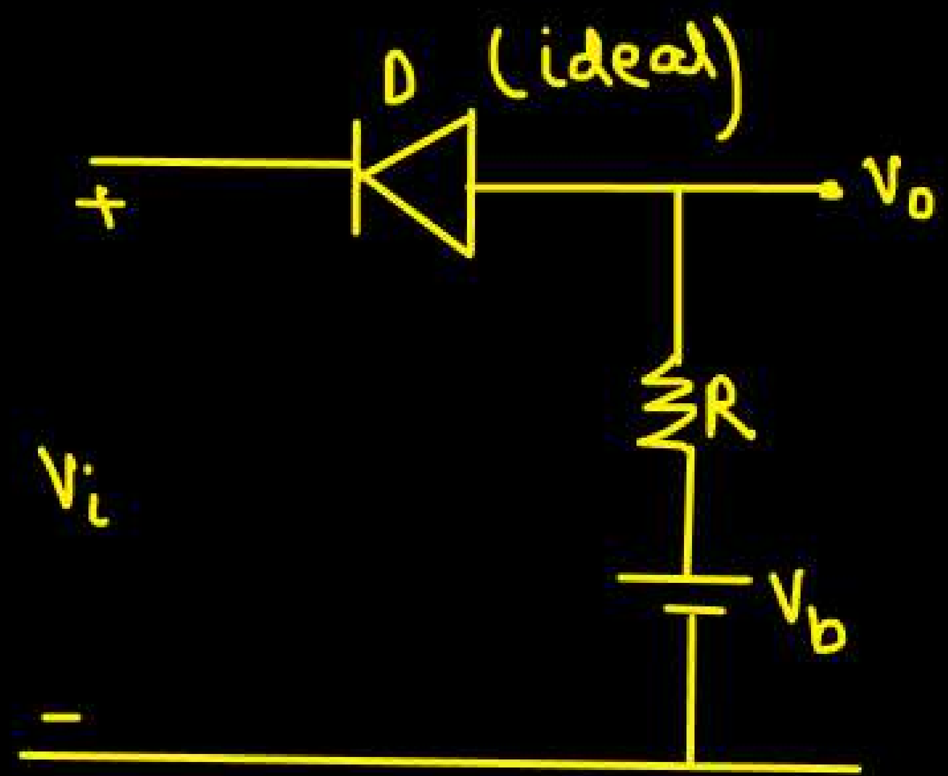
$\Rightarrow$ $\boxed{V_o = V_i - 0.7}$

(ii) $V_i < -0.3V$

$\Rightarrow$ diode off

$\boxed{V_o = -1V}$

5. Positive Series Clipper ckt (Positive bias):-



$\rightarrow$ V_i o—o o—o V_b

(i) $V_i > V_b$

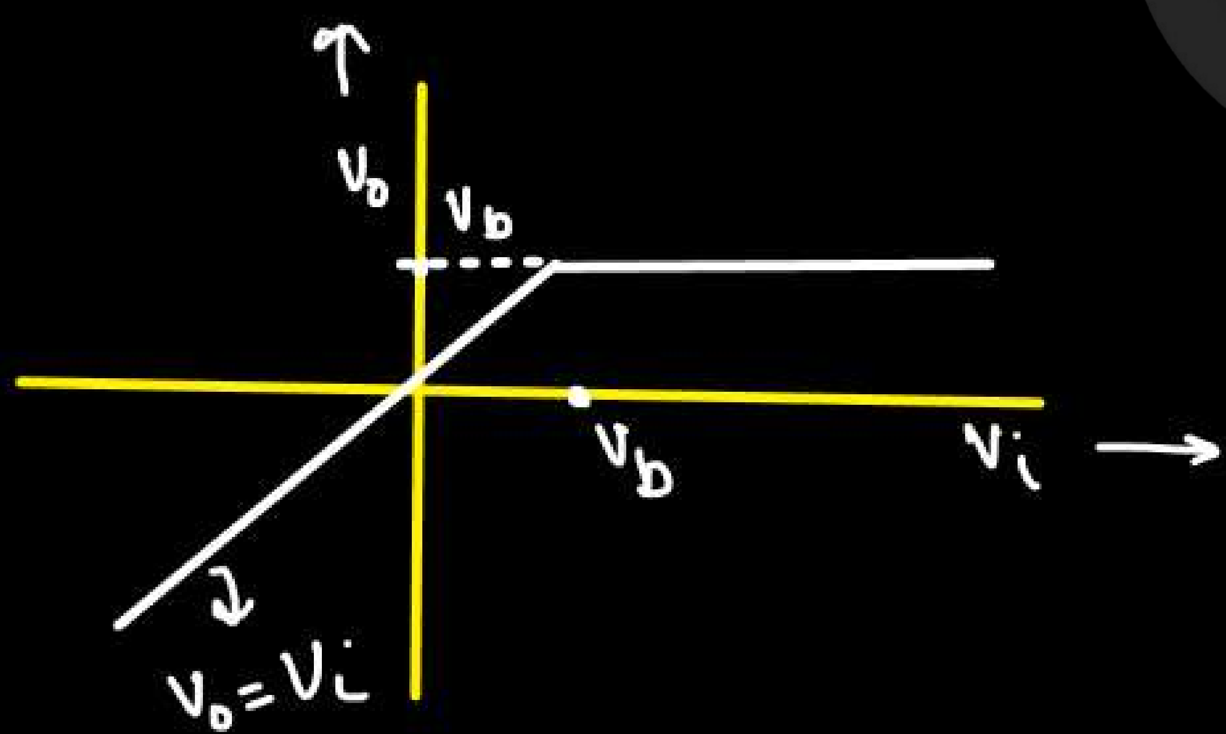
$\Rightarrow$ diode off

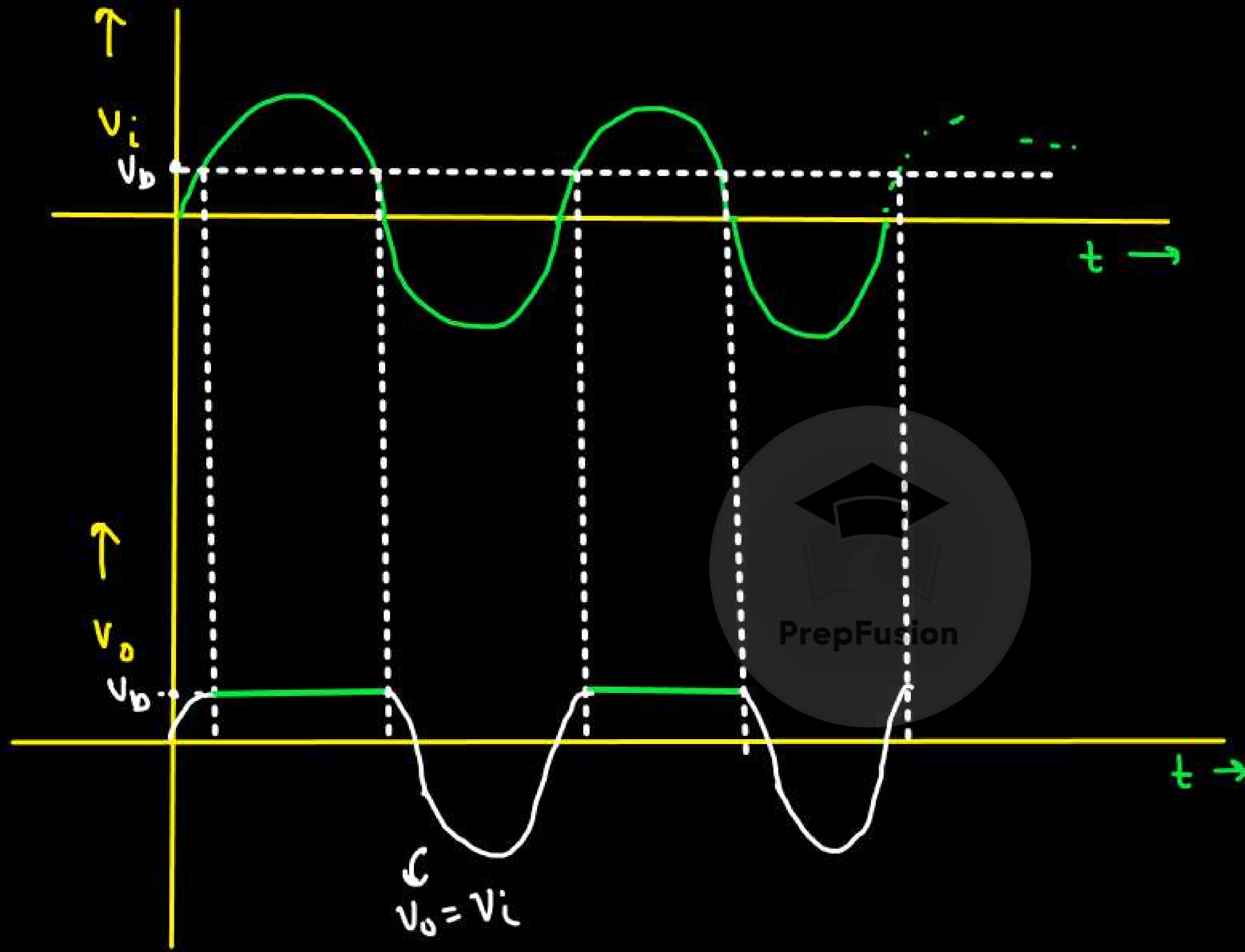
$\boxed{V_0 = V_b}$

(ii) $V_i < V_b$

$\Rightarrow$ diode ON

$\boxed{V_0 = V_i}$





Vi
VD
t →
Vo
VD
t →
Vo = Vi

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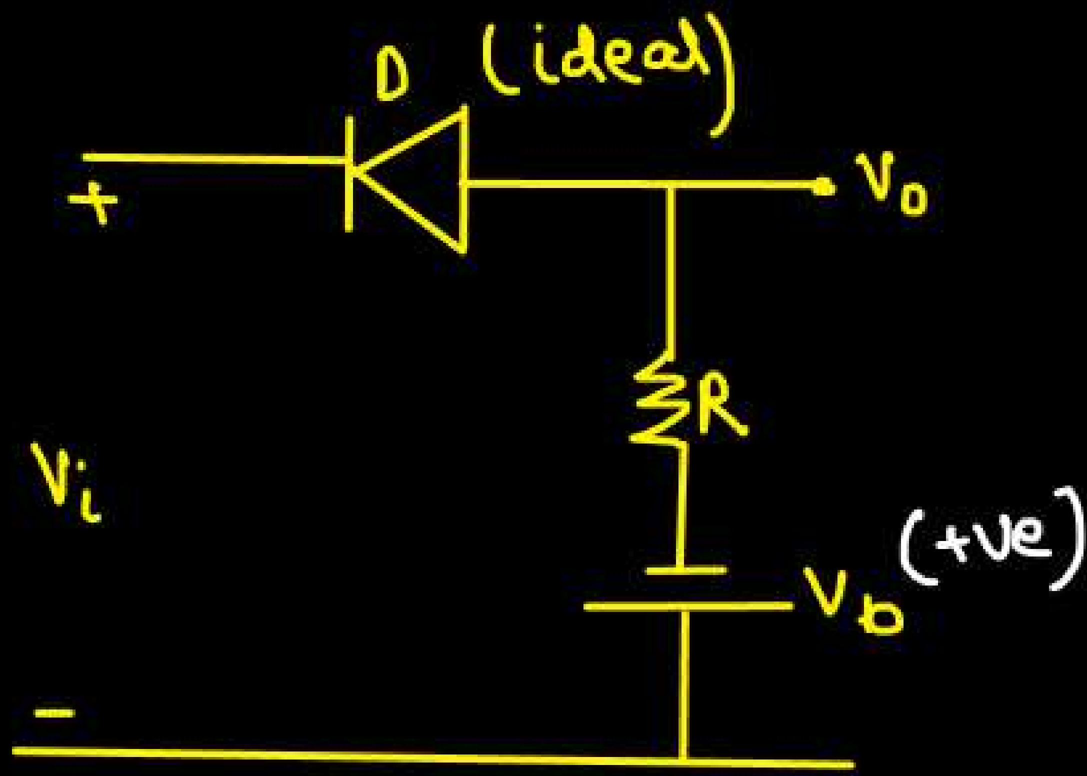
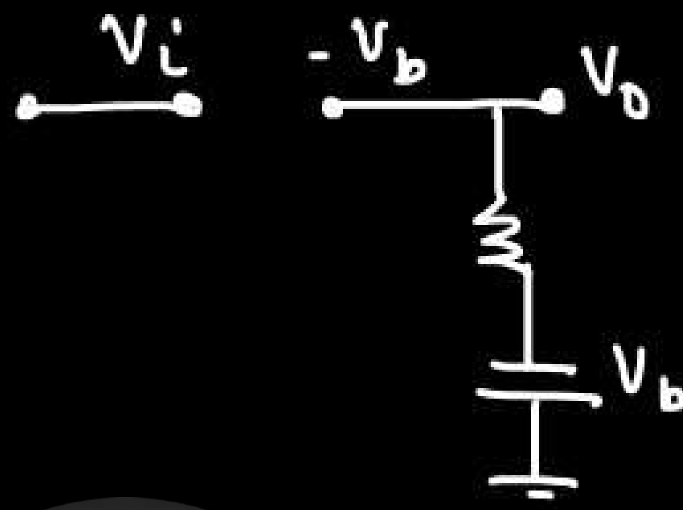
6. Positive series Clipper ckt (Negative bias):-





(i) $V_i > -V_b$

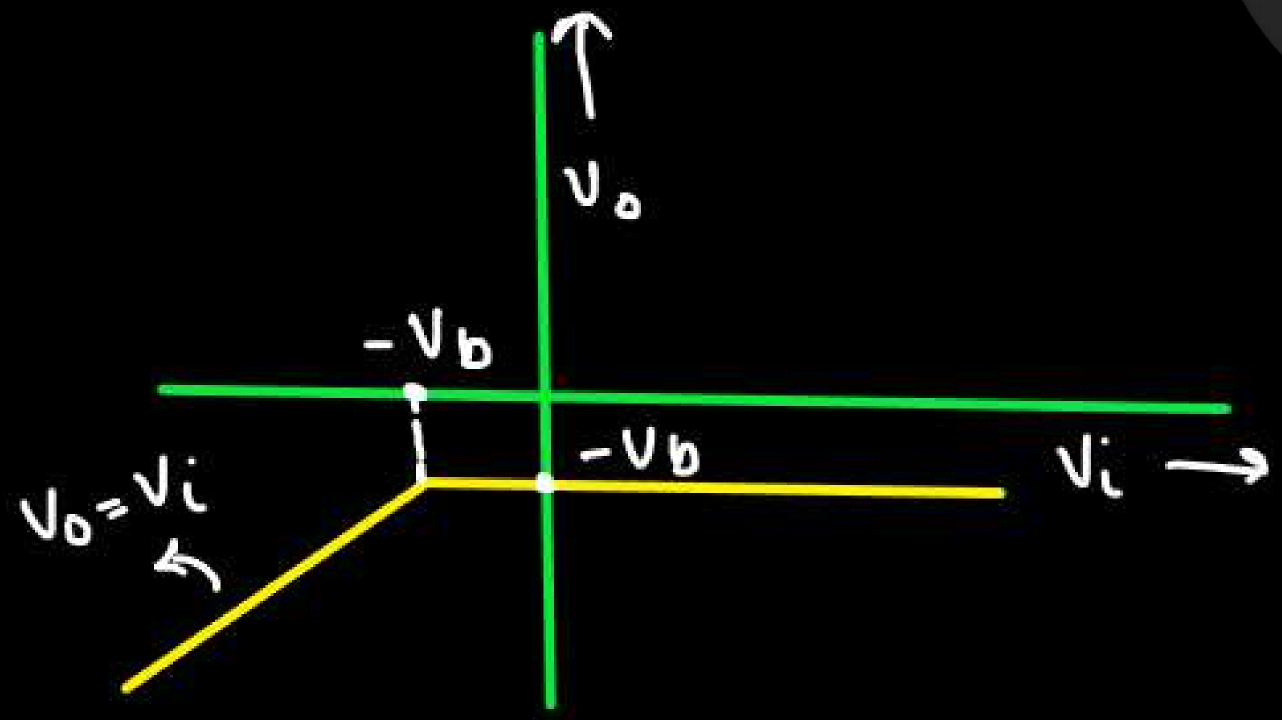
$\Rightarrow$ diode off

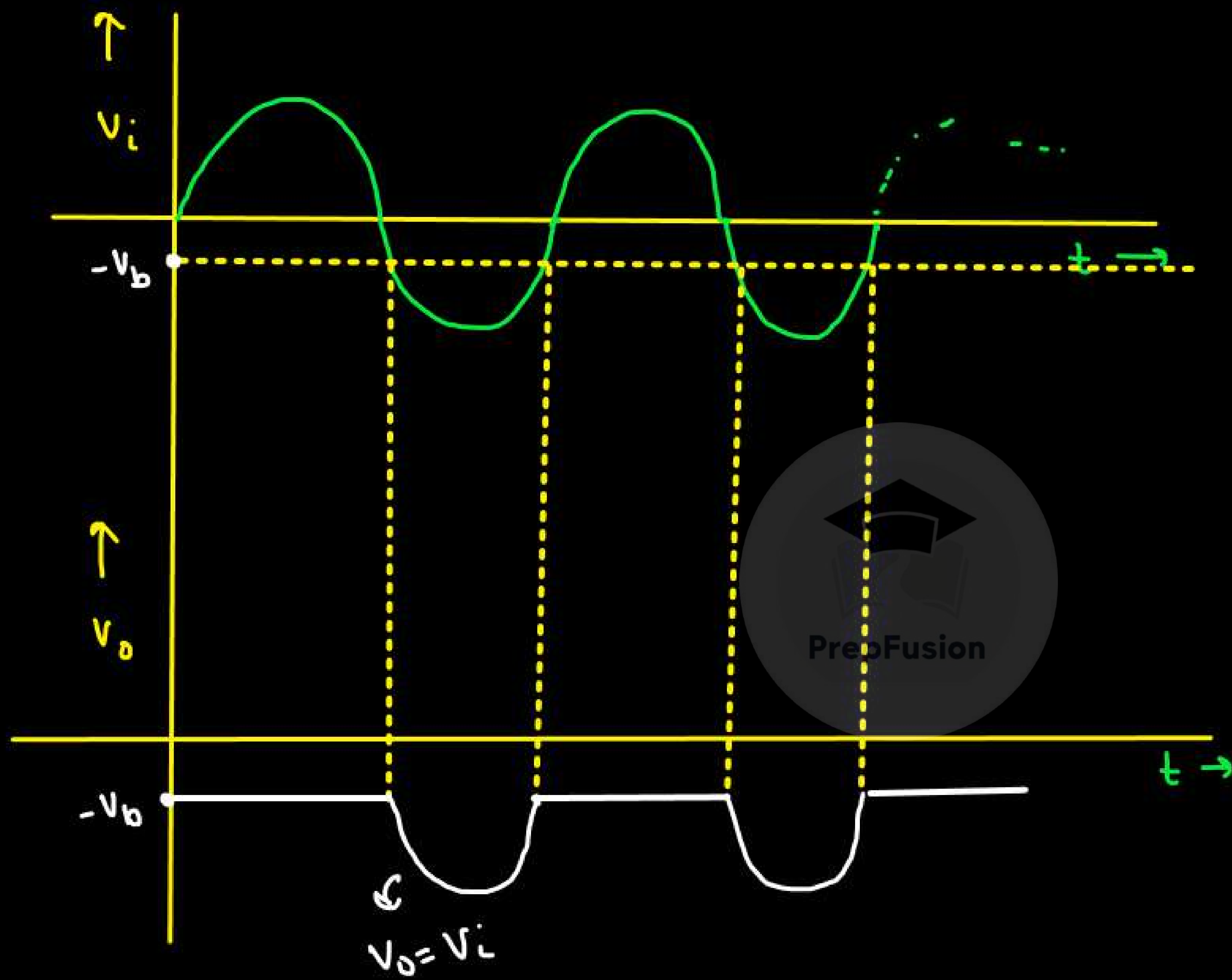
$\boxed{V_o = -V_b}$

(ii) $V_i < -V_b$

$\Rightarrow$ diode ON

$\boxed{V_o = V_i}$





V_i
$-V_b$
$t \rightarrow$
V_o
$-V_b$
$t \rightarrow$
$V_o = V_i$

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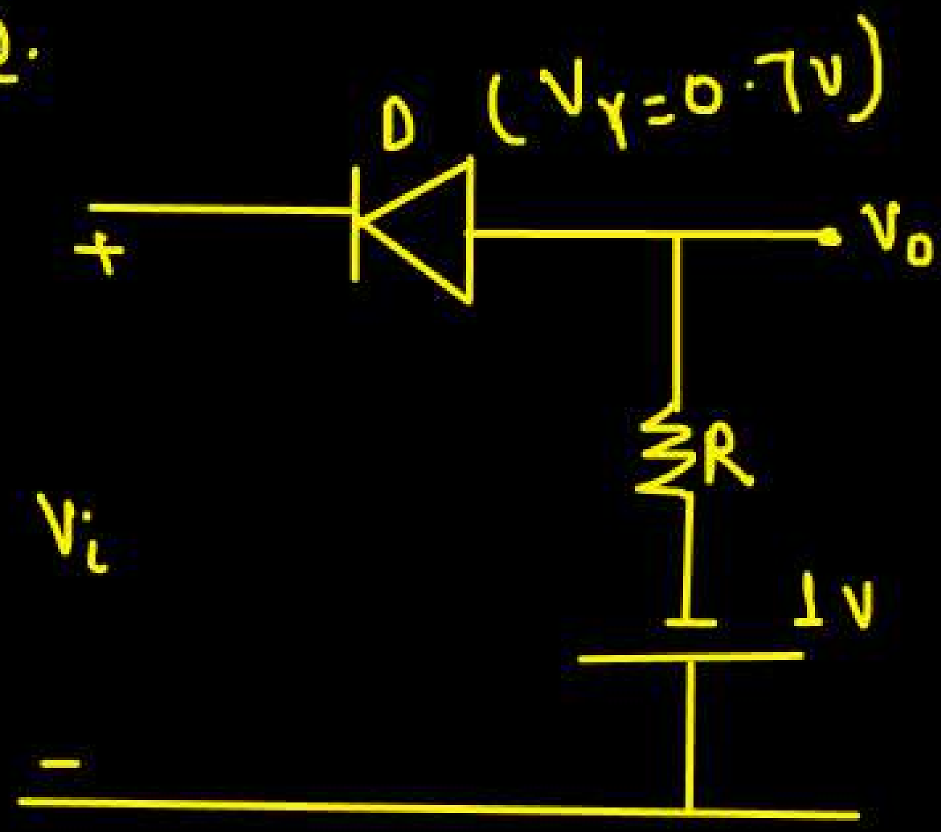
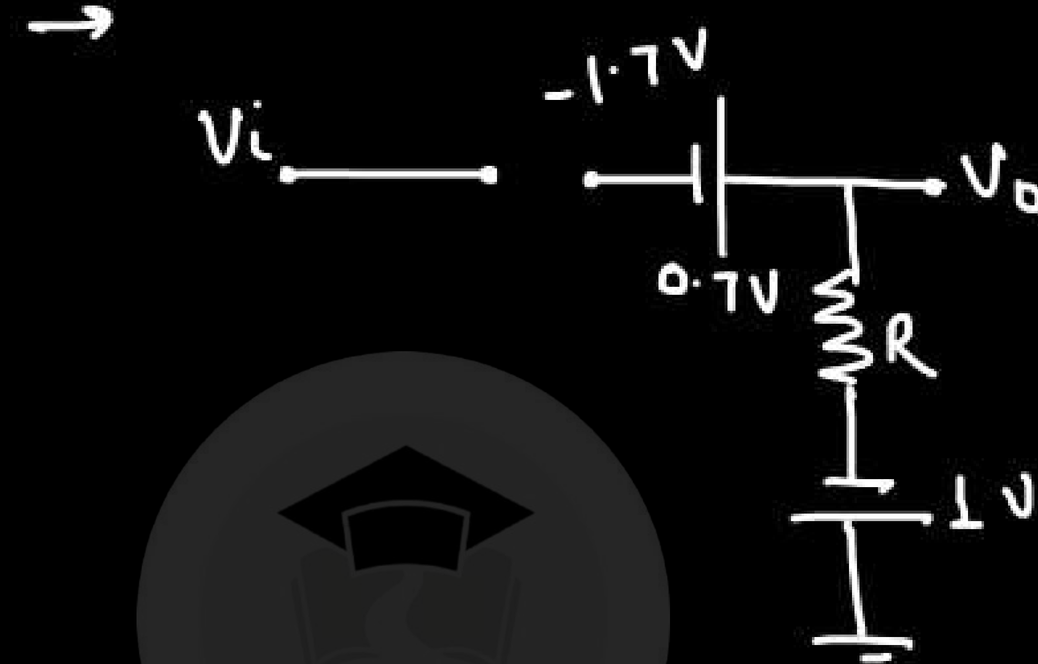
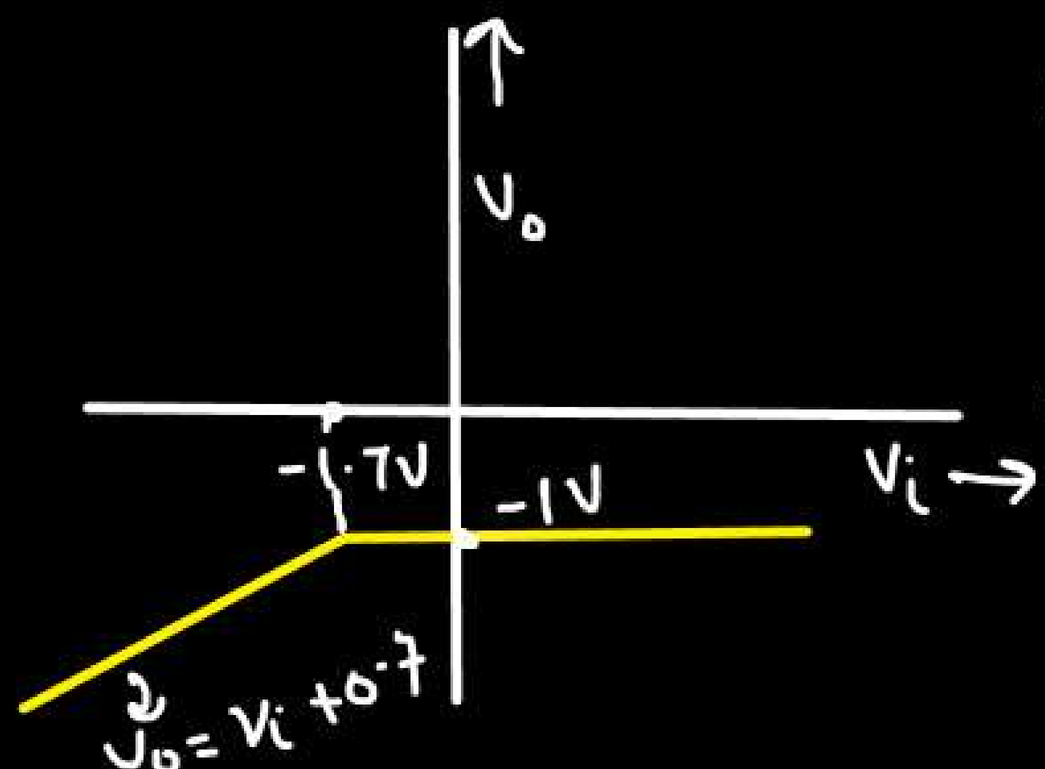


Draw Transfer characteristics.



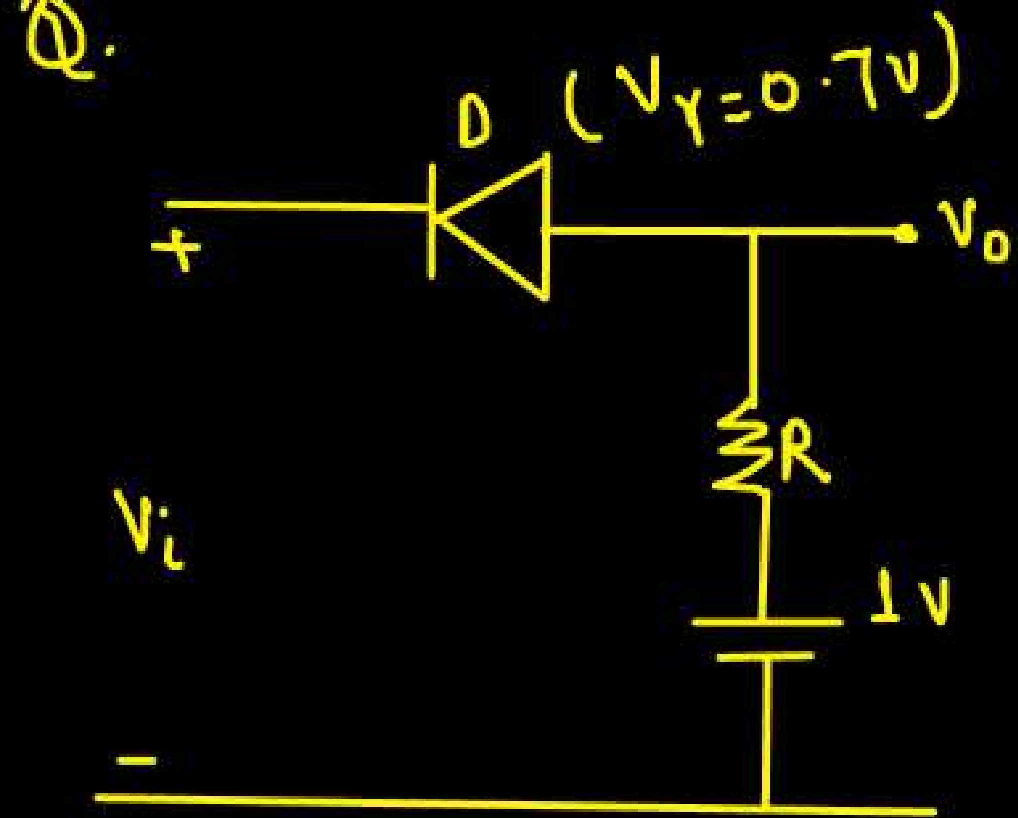


(i) $V_i > -1.7V \Rightarrow$ diode off

$\boxed{V_0 = -1V}$

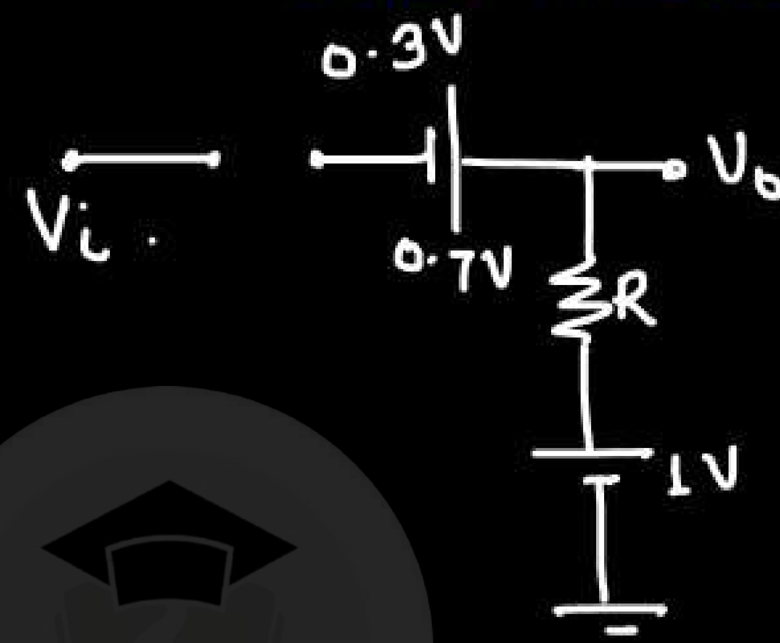
(ii) $V_i < -1.7V \Rightarrow \boxed{V_0 = V_i + 0.7}$

Q.



Draw Transfer characteristics.

→

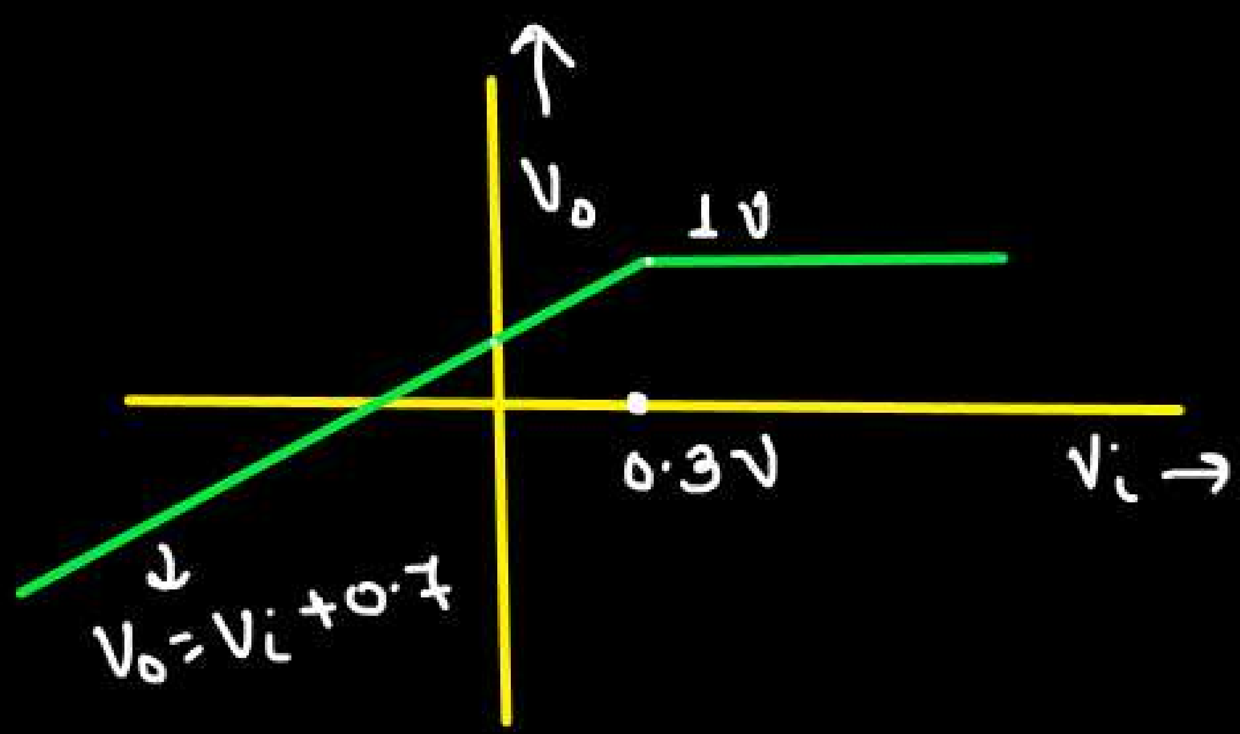


(i) $V_i > 0.3V$

$\Rightarrow$ diode off $\Rightarrow$ $\boxed{V_0 = 1V}$

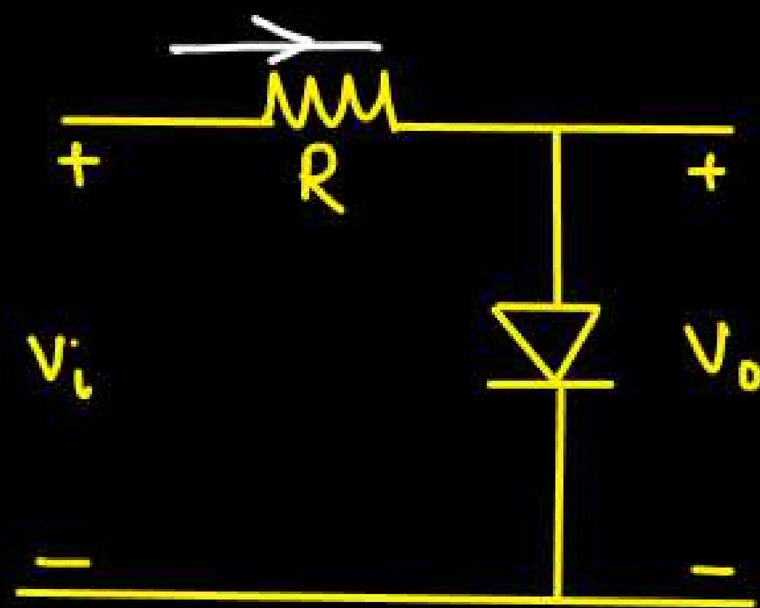
(ii) $V_i < 0.3V$

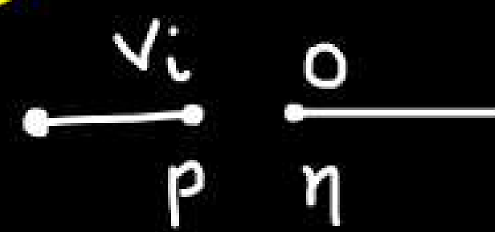
$\Rightarrow$ diode ON $\Rightarrow$ $\boxed{V_0 = V_i + 0.7V}$



1. Positive Shunt Clipper Ckt:-

(Unbiased)



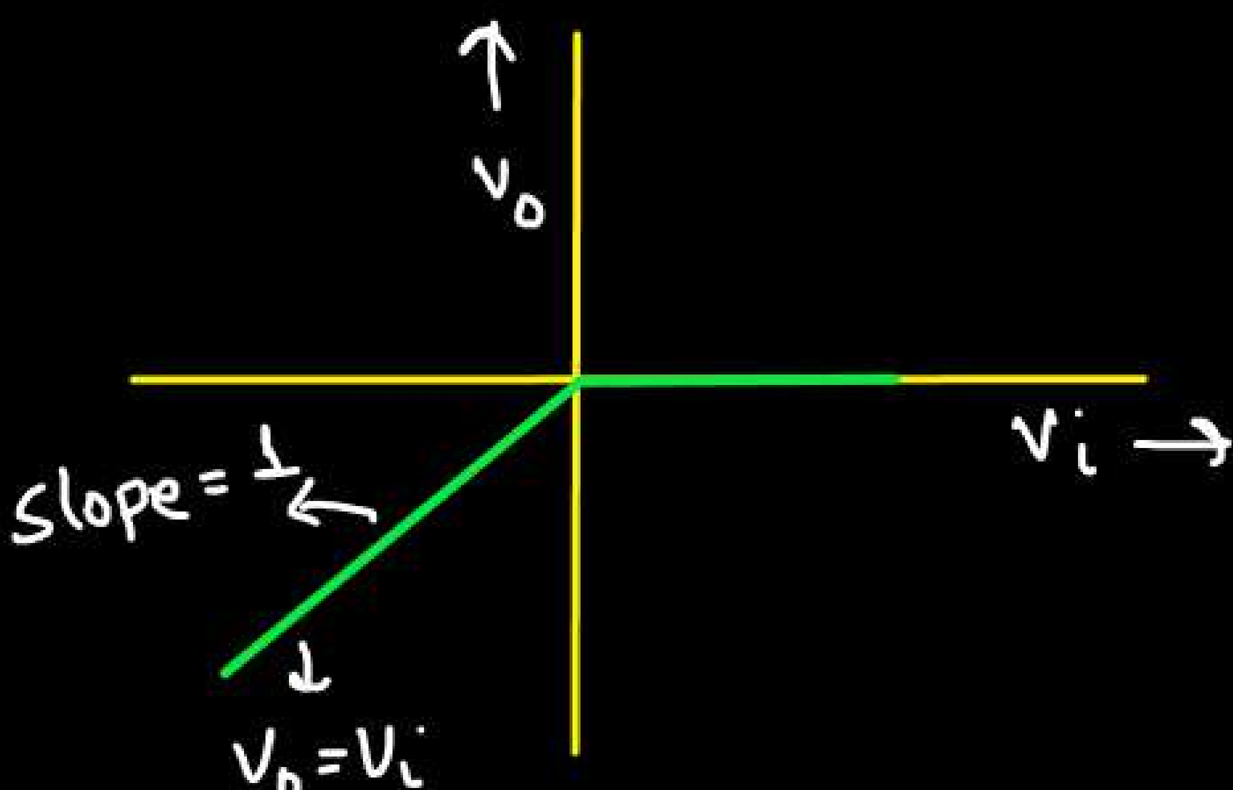


(i) $V_i > 0 \Rightarrow$ diode ON

$\boxed{V_o = 0\,V}$

(ii) $V_i < 0 \Rightarrow$ diode off

$\boxed{V_o = V_i}$



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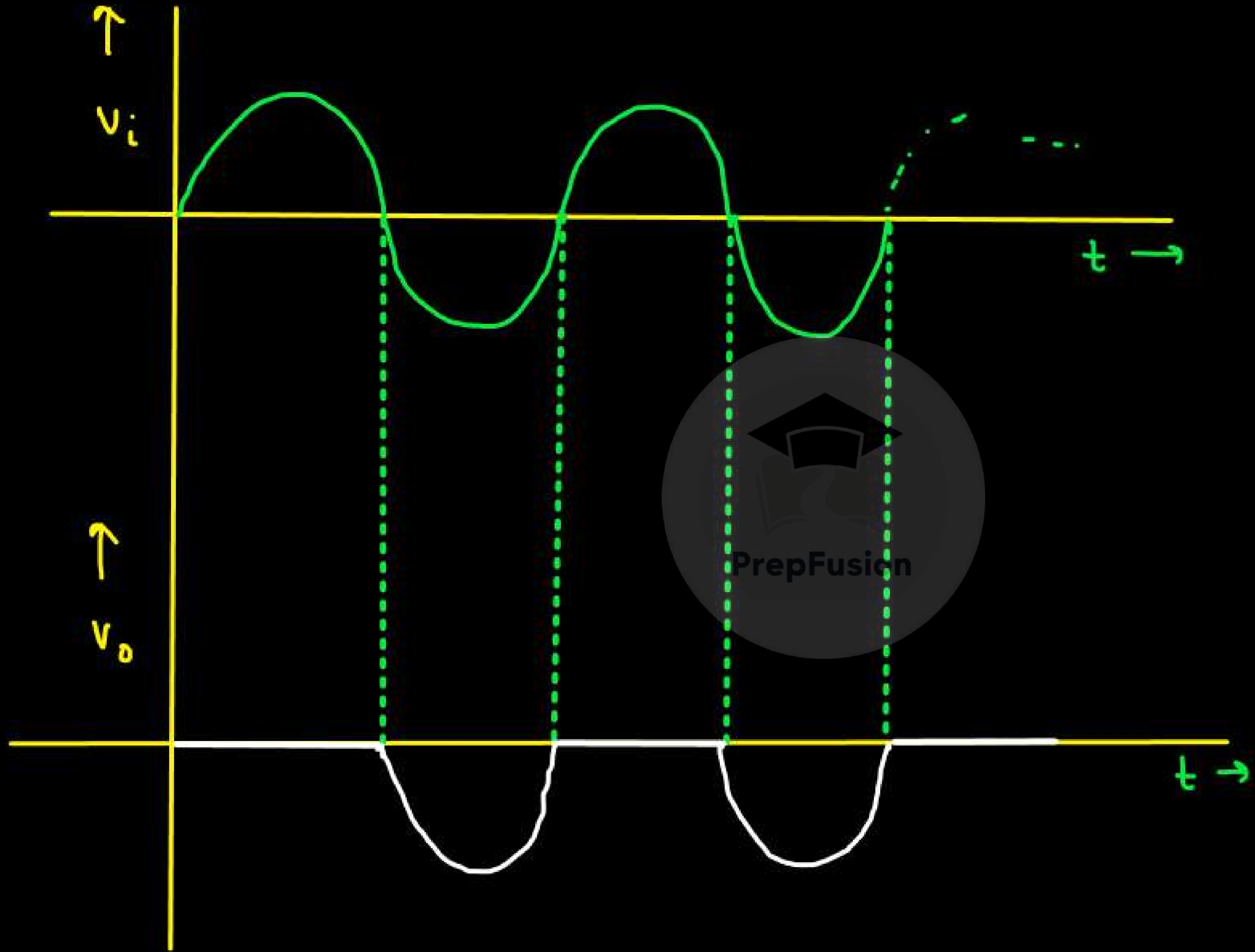
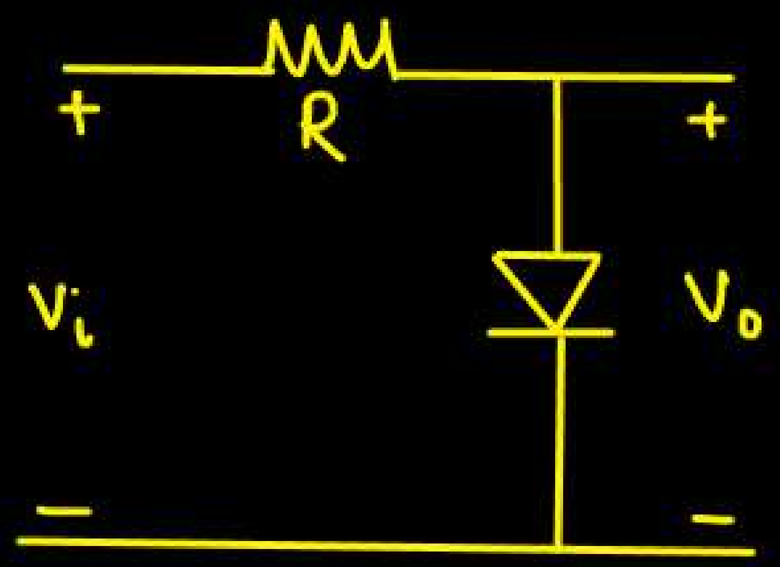


V_i
$t \rightarrow$
V_o
$t \rightarrow$

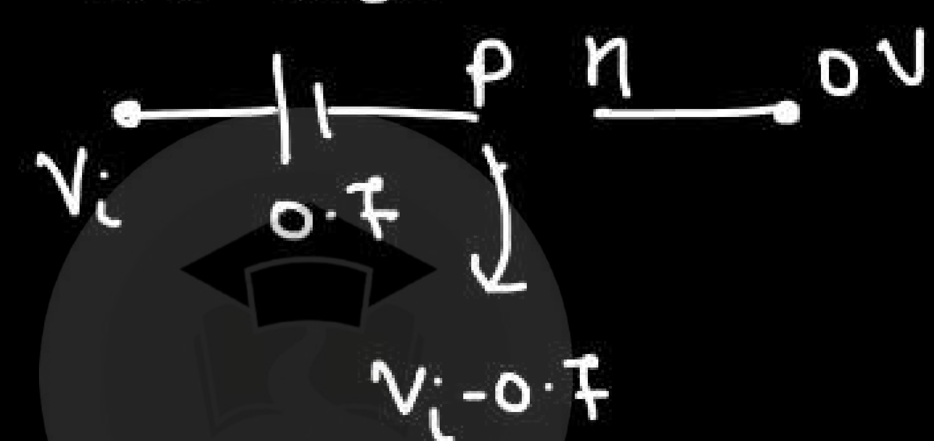
Q.



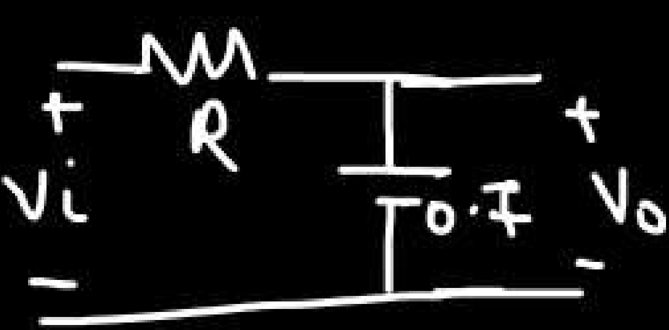
$V_\gamma = 0.7V$

Draw Trasfer characteristics.

→ O.C. Test



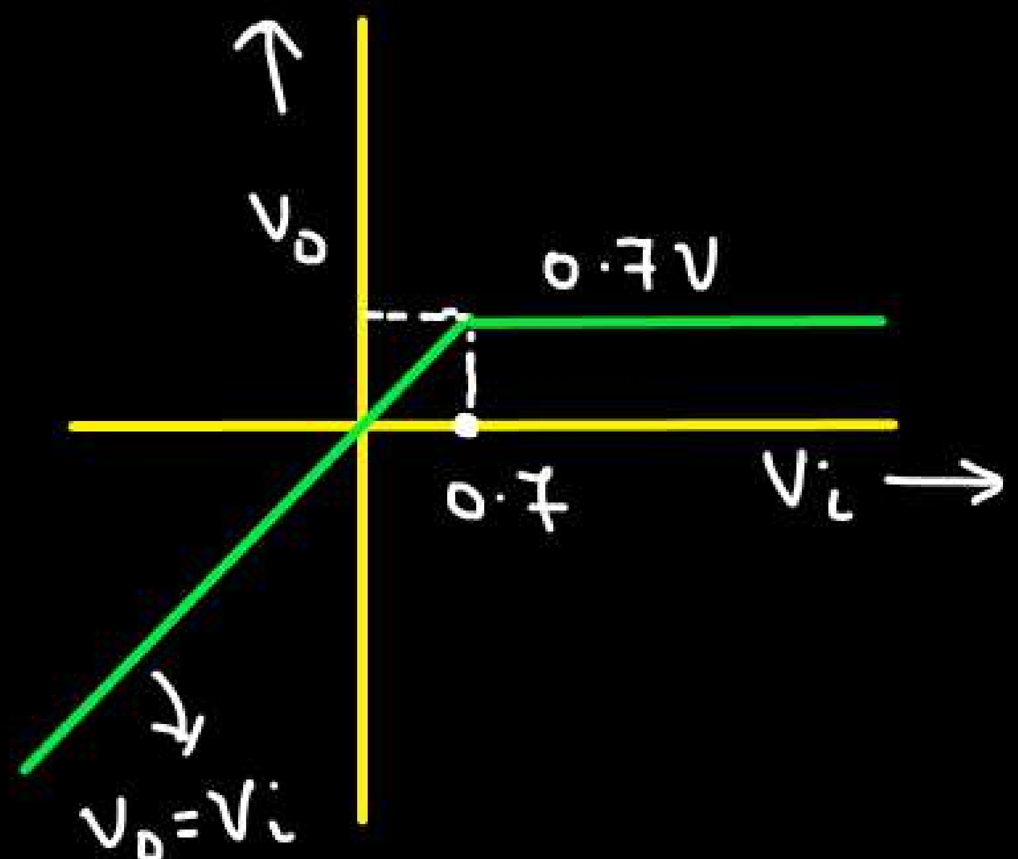
(i) $V_i - 0.7 > 0 \Rightarrow V_i > 0.7 \Rightarrow$ diode ON



$\boxed{V_o = 0.7V}$

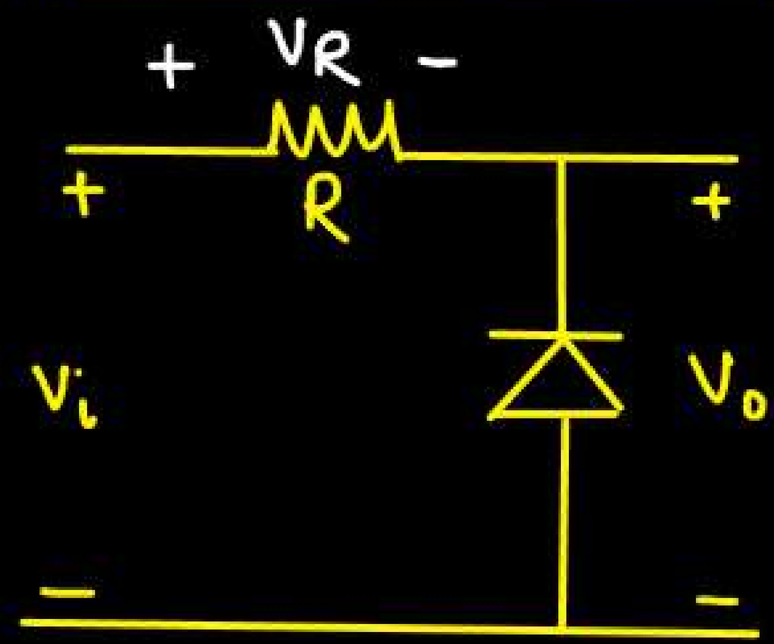
(ii) $V_i < 0.7 \Rightarrow$ diode off

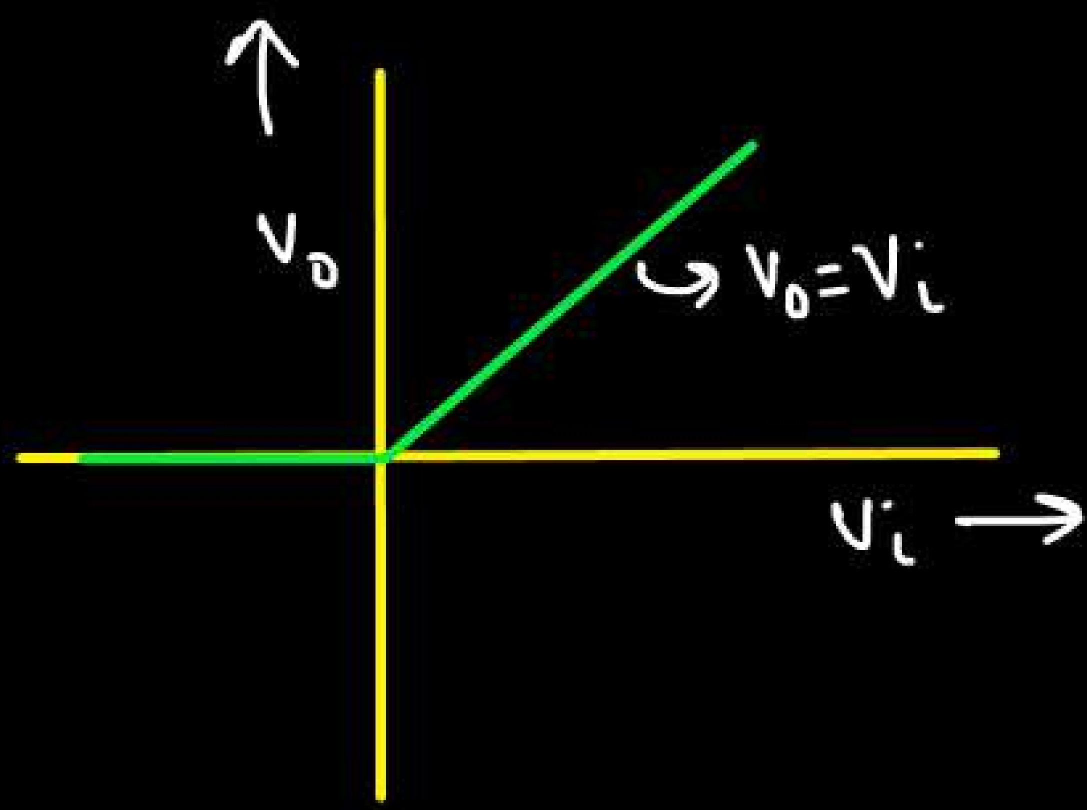
$\boxed{V_o = V_i}$



2. Negative Shunt Clipper Ckt:-

(Unbiased)

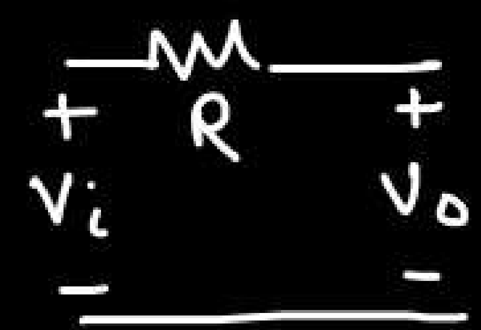




→ O.C. Test:-

(i) $V_i > 0V \Rightarrow$ diode off

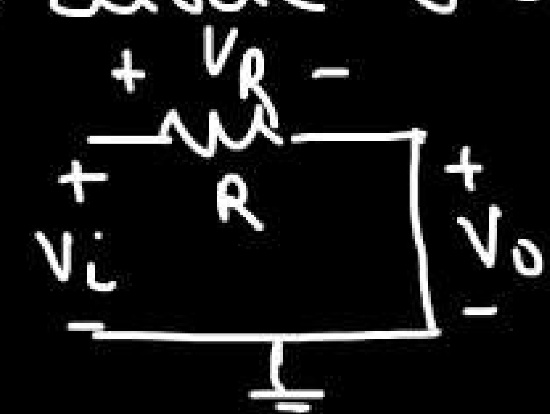
$\boxed{V_o = V_i}$



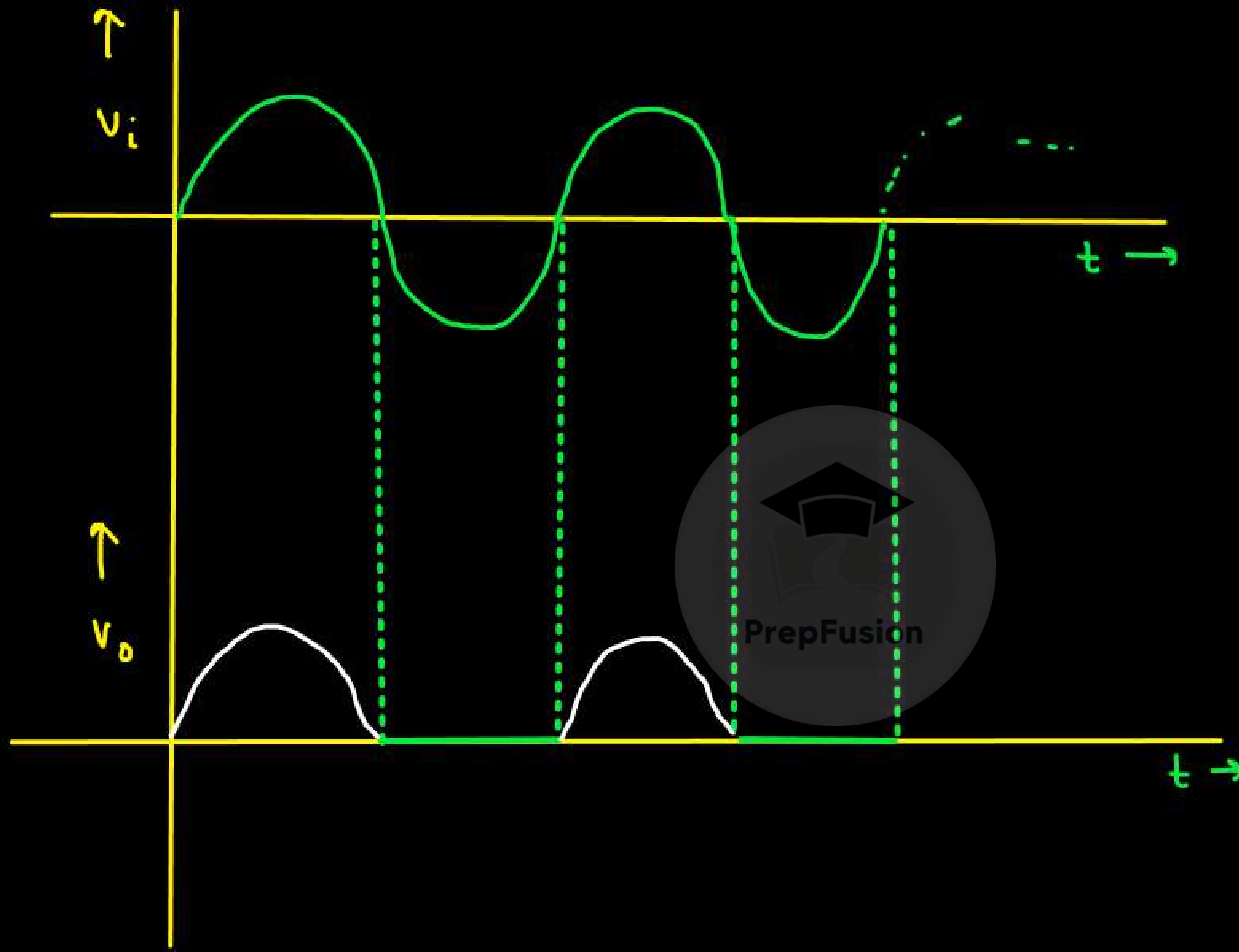
$\Rightarrow \boxed{V_R = 0V}$

(ii) $V_i < 0V \Rightarrow$ diode ON

$\boxed{V_o = 0V}$



$\Rightarrow \boxed{V_R = V_i}$


V_i
$t \rightarrow$
V_o
$t \rightarrow$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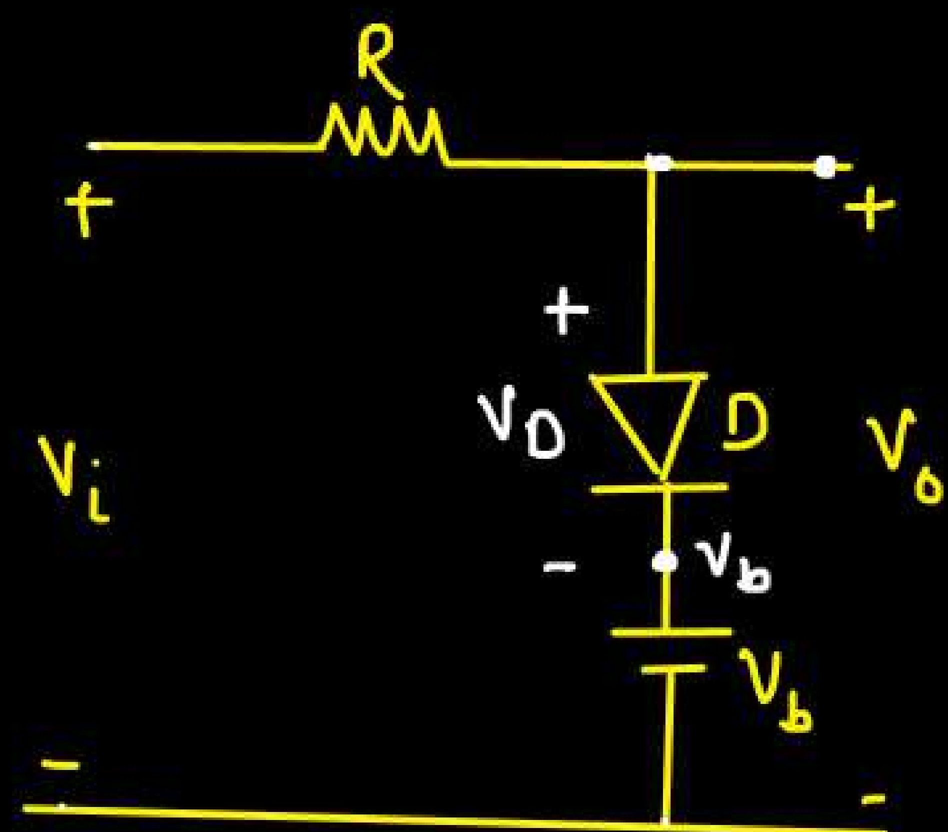
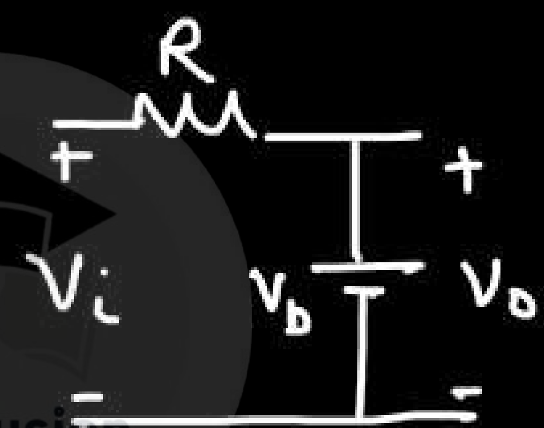
3. Positive shunt Clipper ckt (Positive bias):-



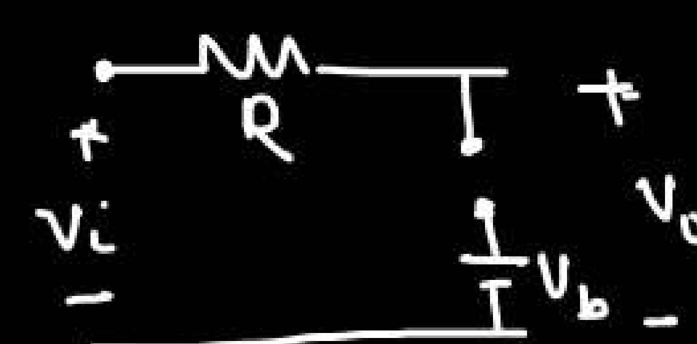
(i) $V_i > V_b \Rightarrow$ diode ON



$$\boxed{V_D = 0V}$$

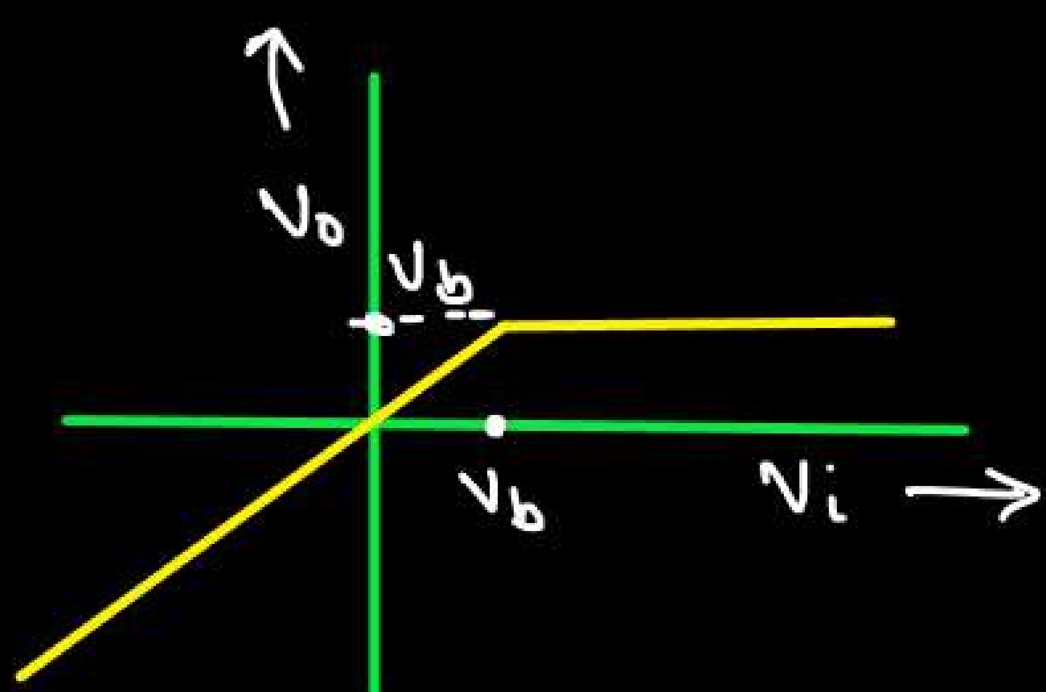
$$\boxed{V_o = V_b}$$

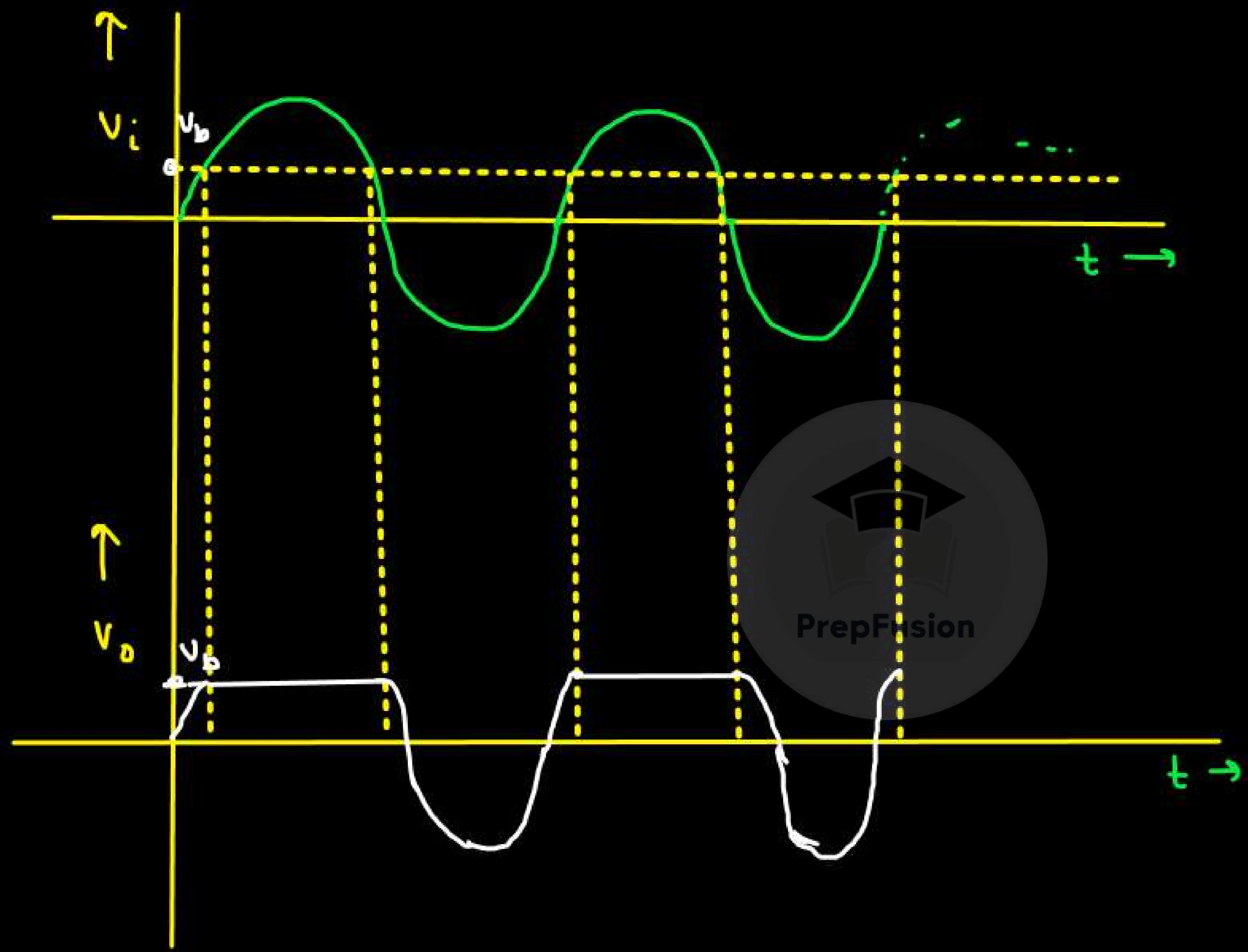
(ii) $V_i < V_b \Rightarrow$ diode OFF



$$\boxed{V_o = V_i}$$

$$\boxed{V_D = V_i - V_b}$$





Vi
Vb
t
Vo
Vb
t
PrepFusion

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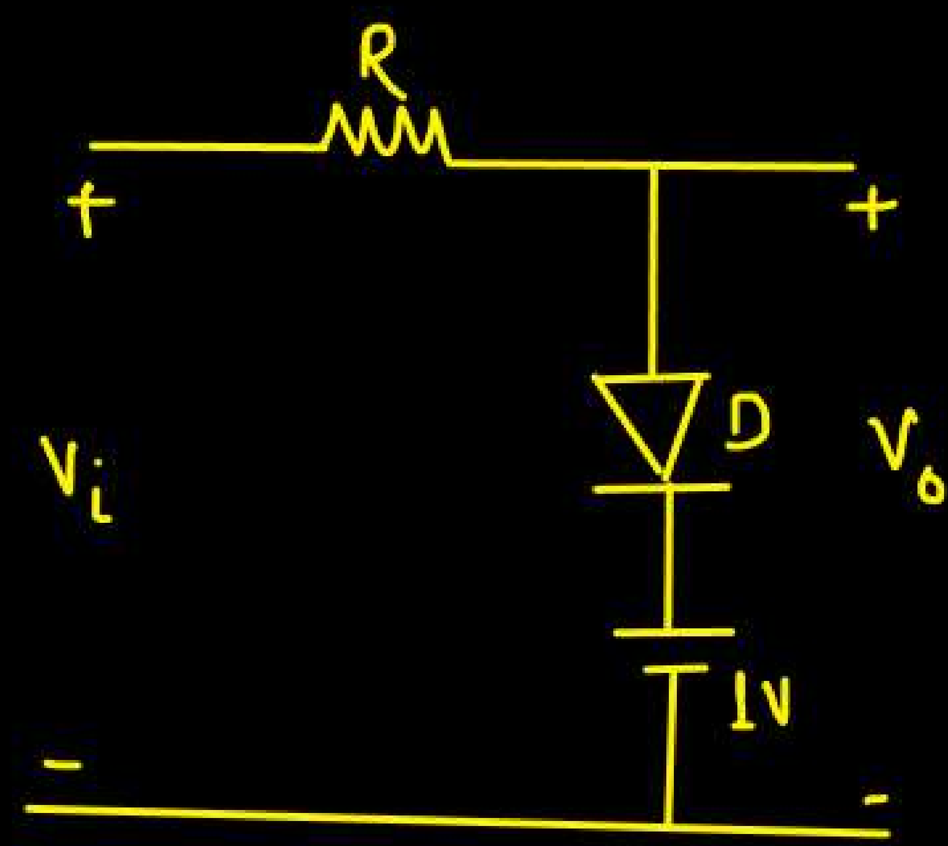
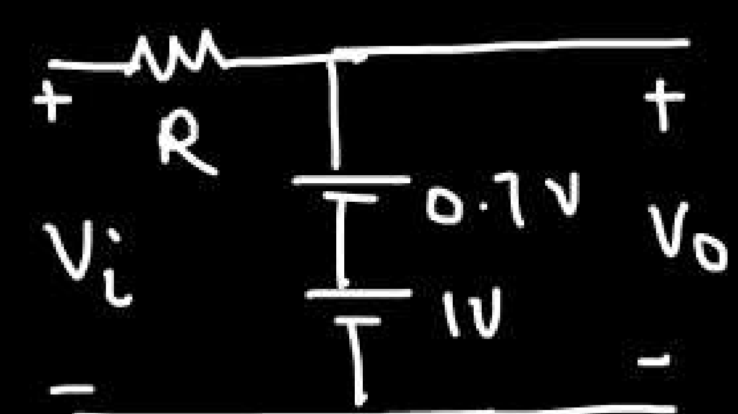


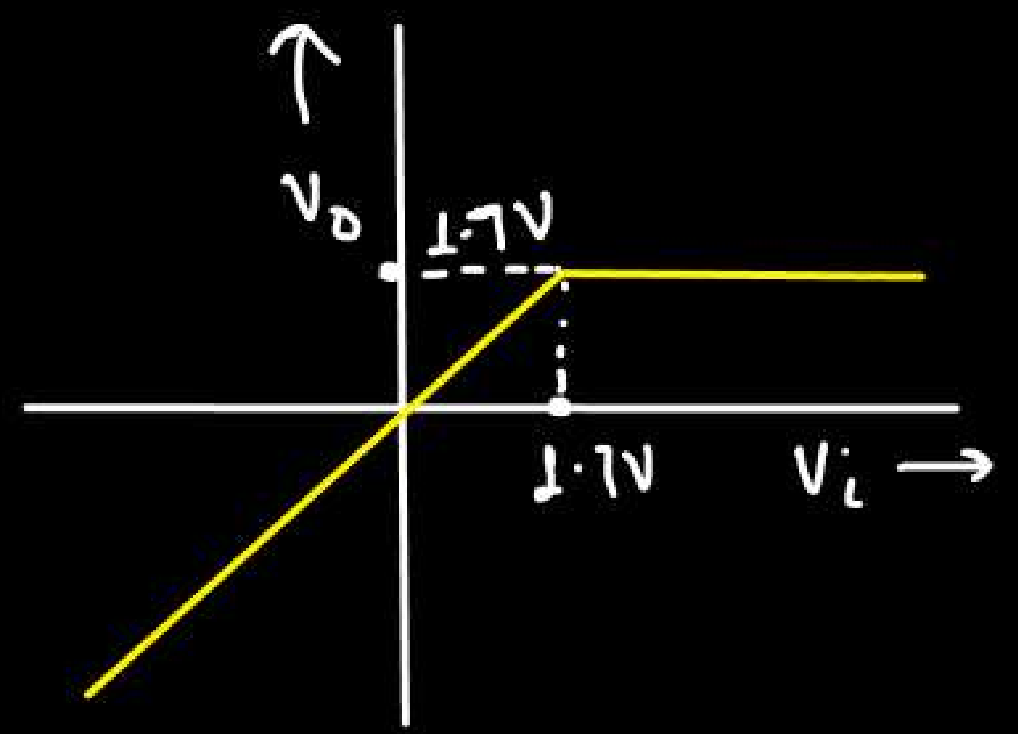
$V_\gamma = 0.7V$

Draw Transfer characteristics.

(i) $V_i > 1.7V \Rightarrow$ diode ON

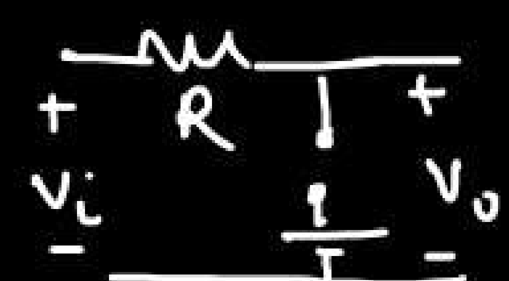
$\boxed{V_o = 1.7V}$



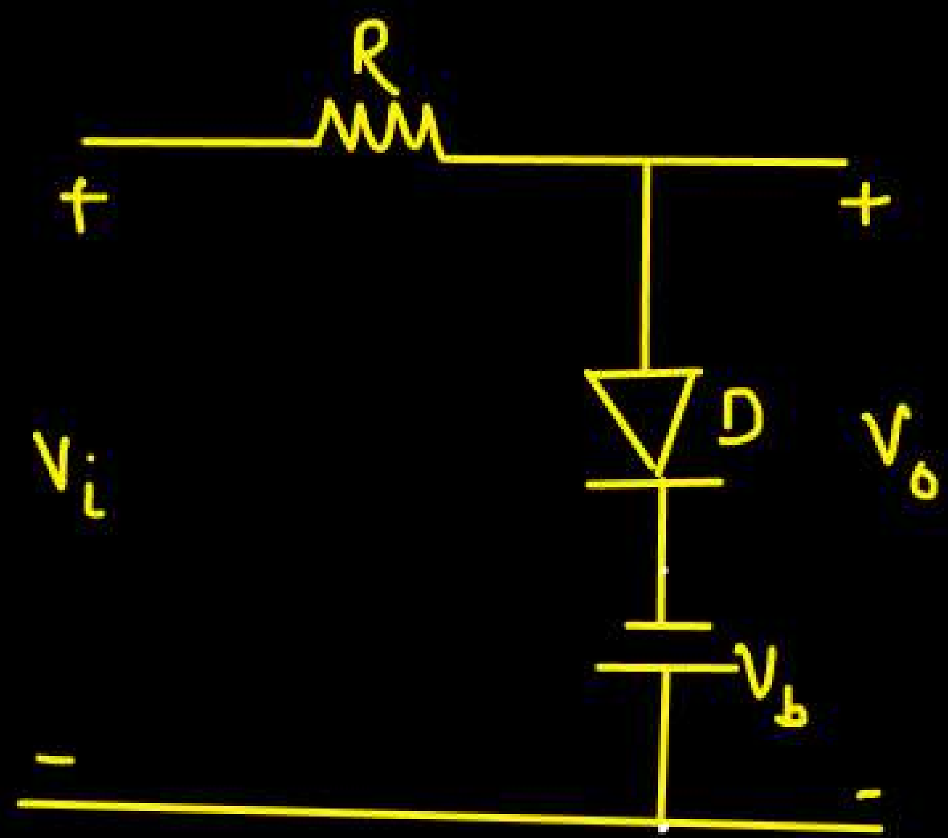


(ii) $V_i < 1.7V \Rightarrow$ diode off

$\boxed{V_o = V_i}$



4. Positive shunt Clipper ckt (Negative bias):-



★ O.C. Test

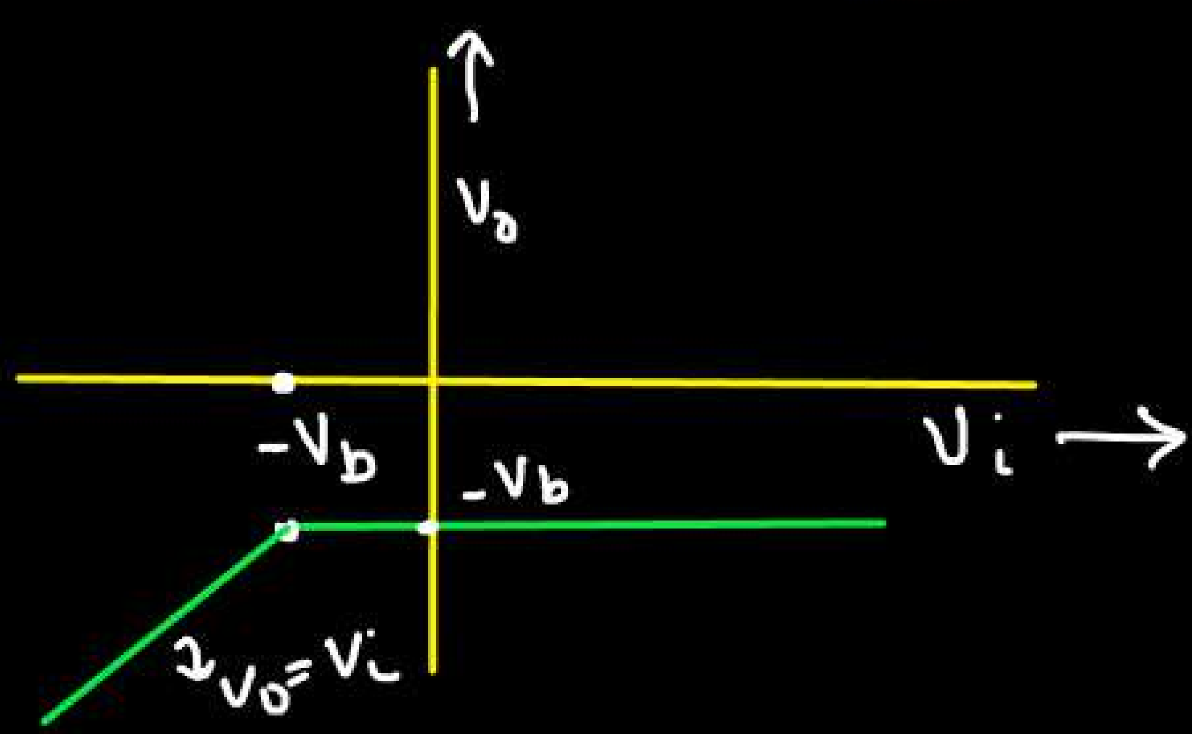
V_i p n $-V_b$

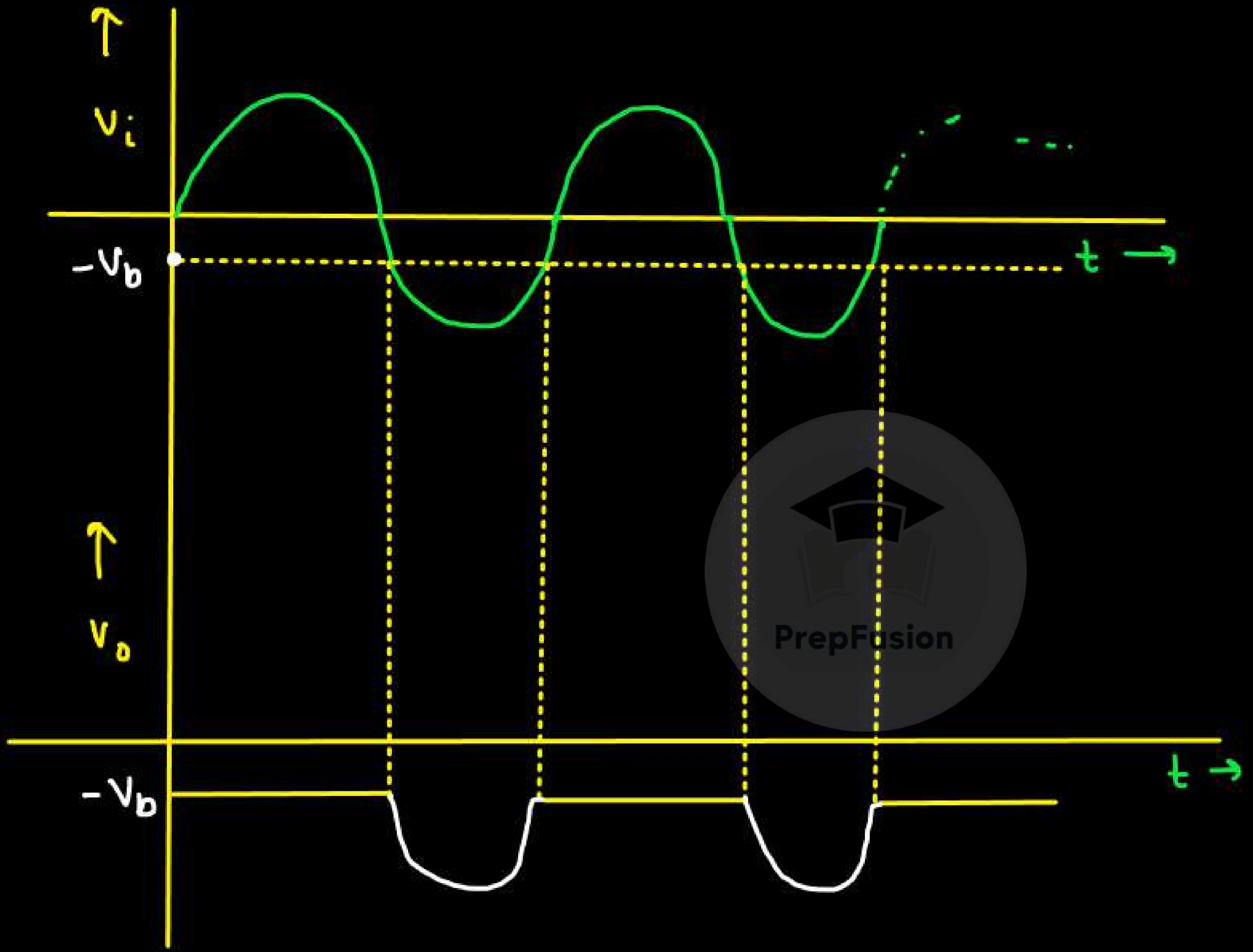
(i) $V_i > -V_b \Rightarrow$ diode ON

$\Rightarrow \boxed{V_o = -V_b}$

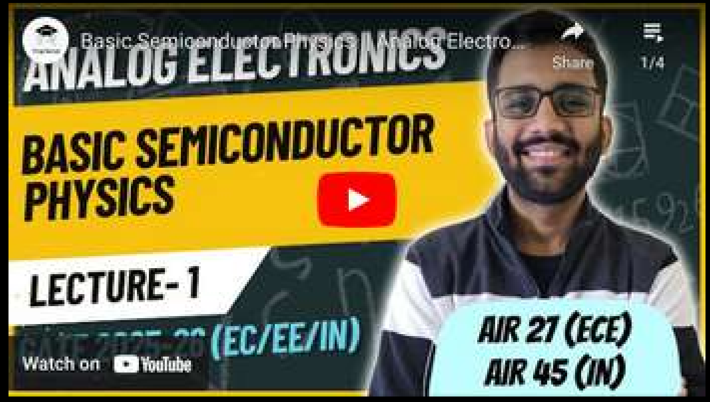
(ii) $V_i < -V_b \Rightarrow$ diode OFF

$\boxed{V_o = V_i}$





Vi
-Vb
t →
Vo
-Vb
t →



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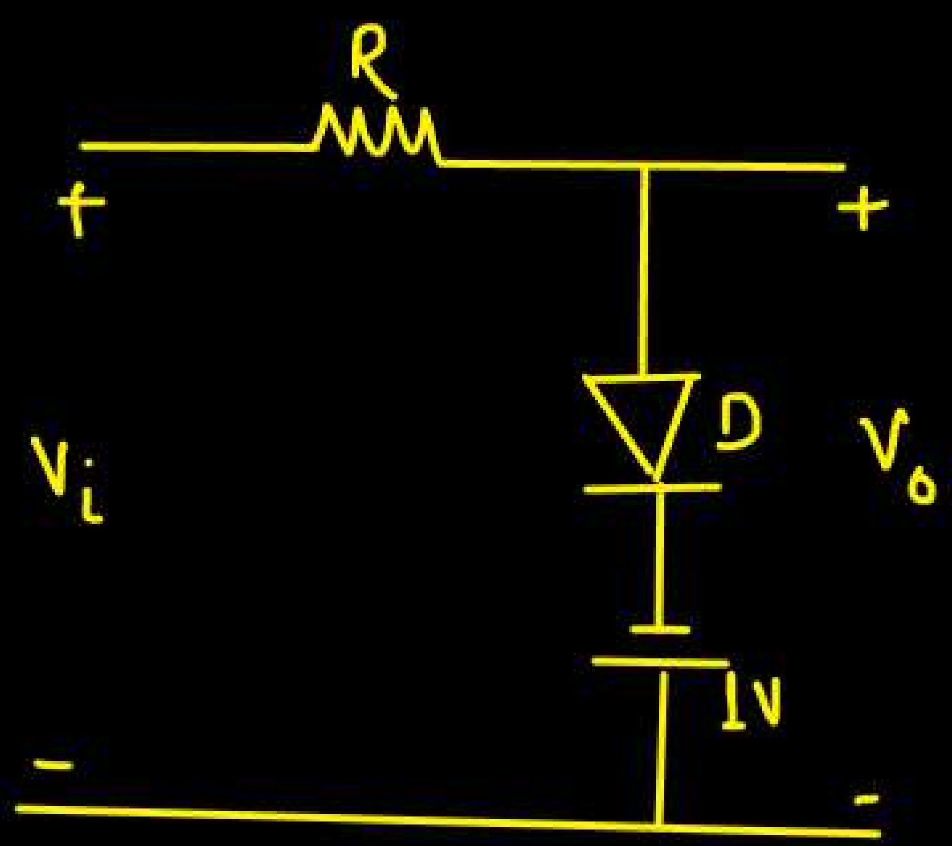
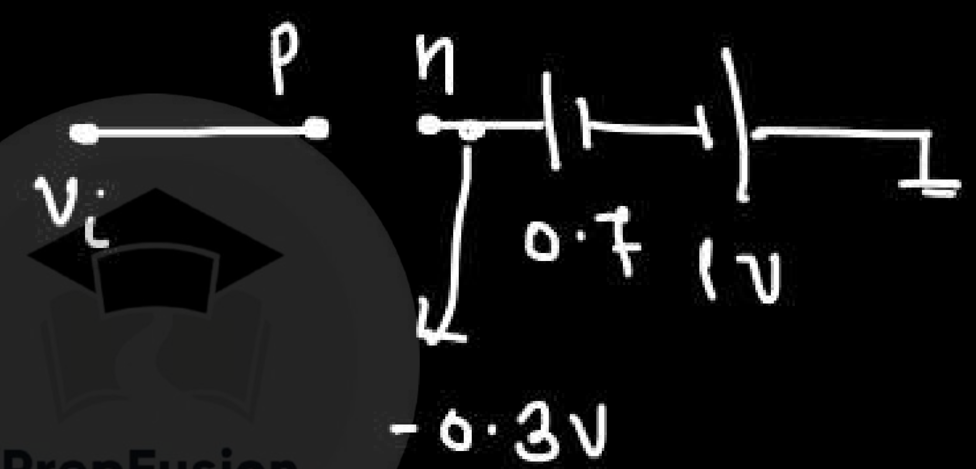


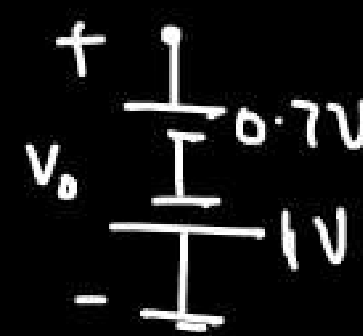
$V_\gamma = 0.7V$

Draw Transfer characteristics.



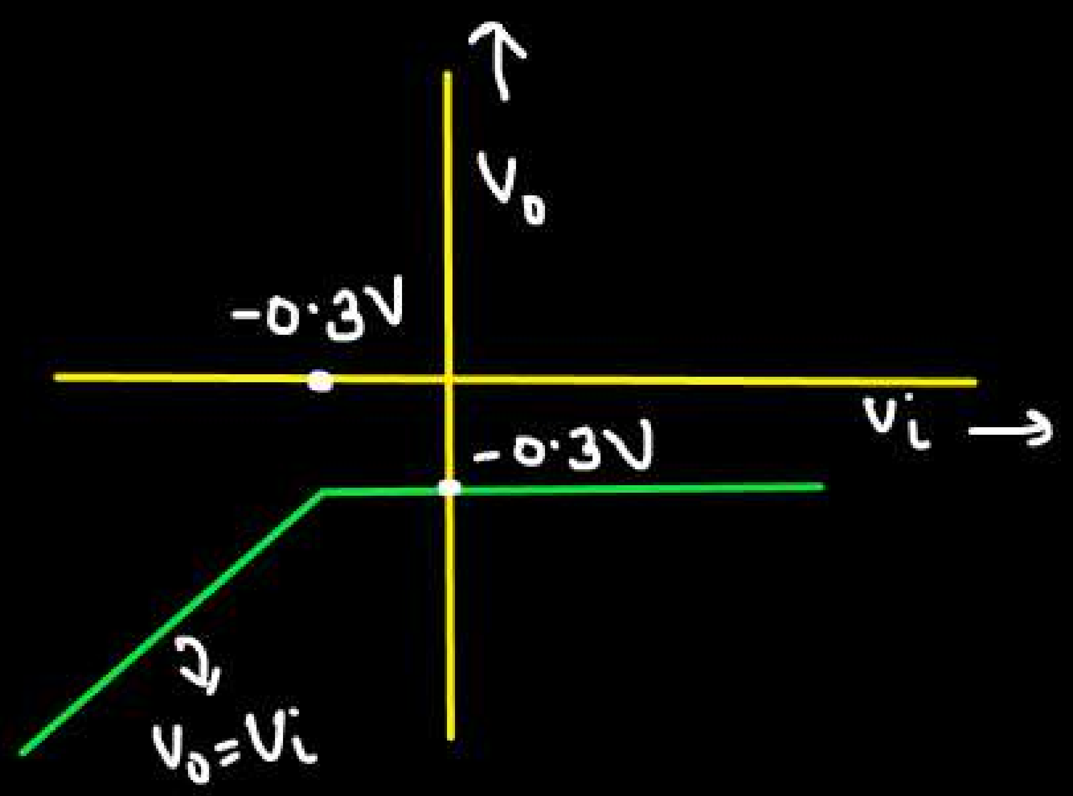
(i) $V_i > -0.3V \Rightarrow$ diode ON

$$\boxed{V_o = -0.3V}$$

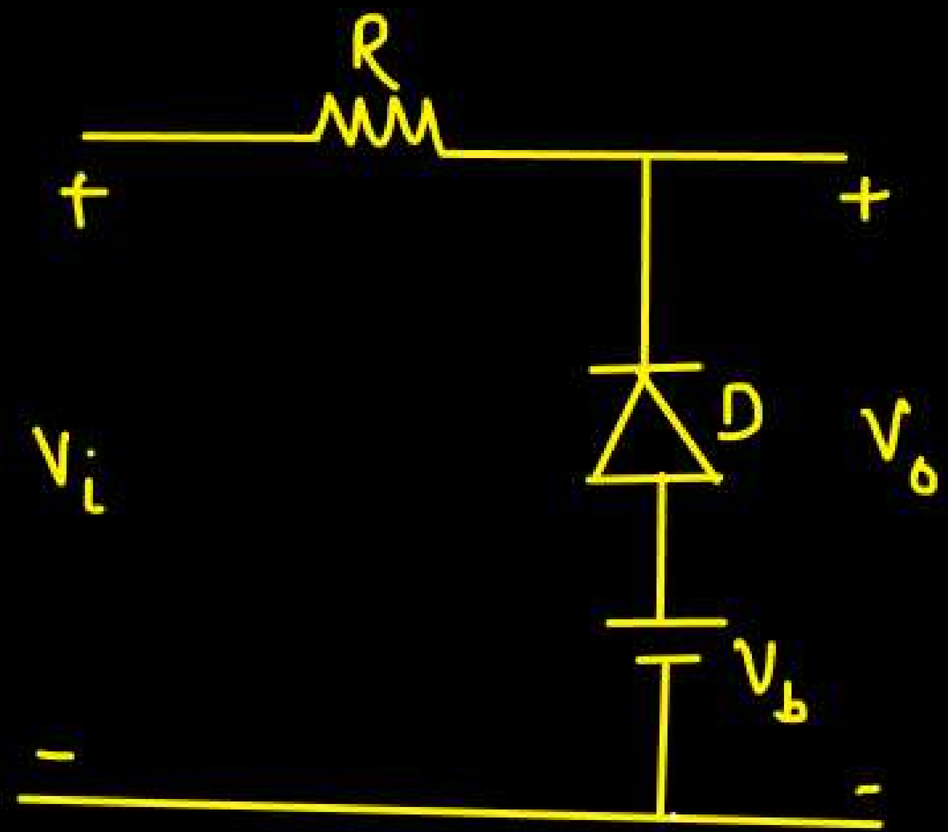


(ii) $V_i < -0.3V \Rightarrow$ diode OFF

$$\boxed{V_o = V_i}$$



5. Negative shunt Clipper ckt (Positive bias):-

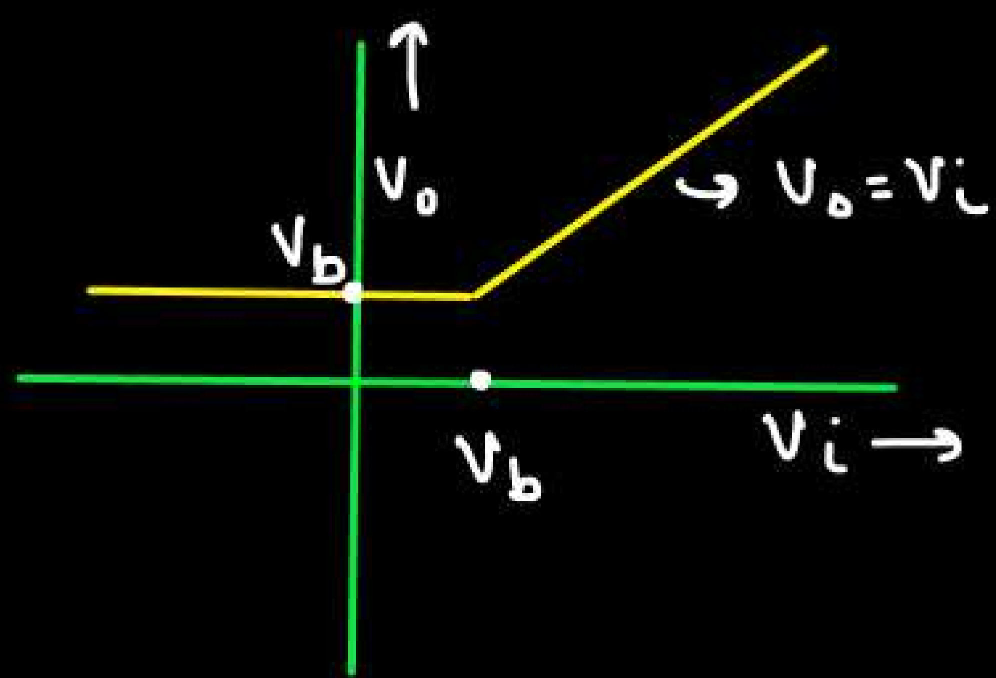


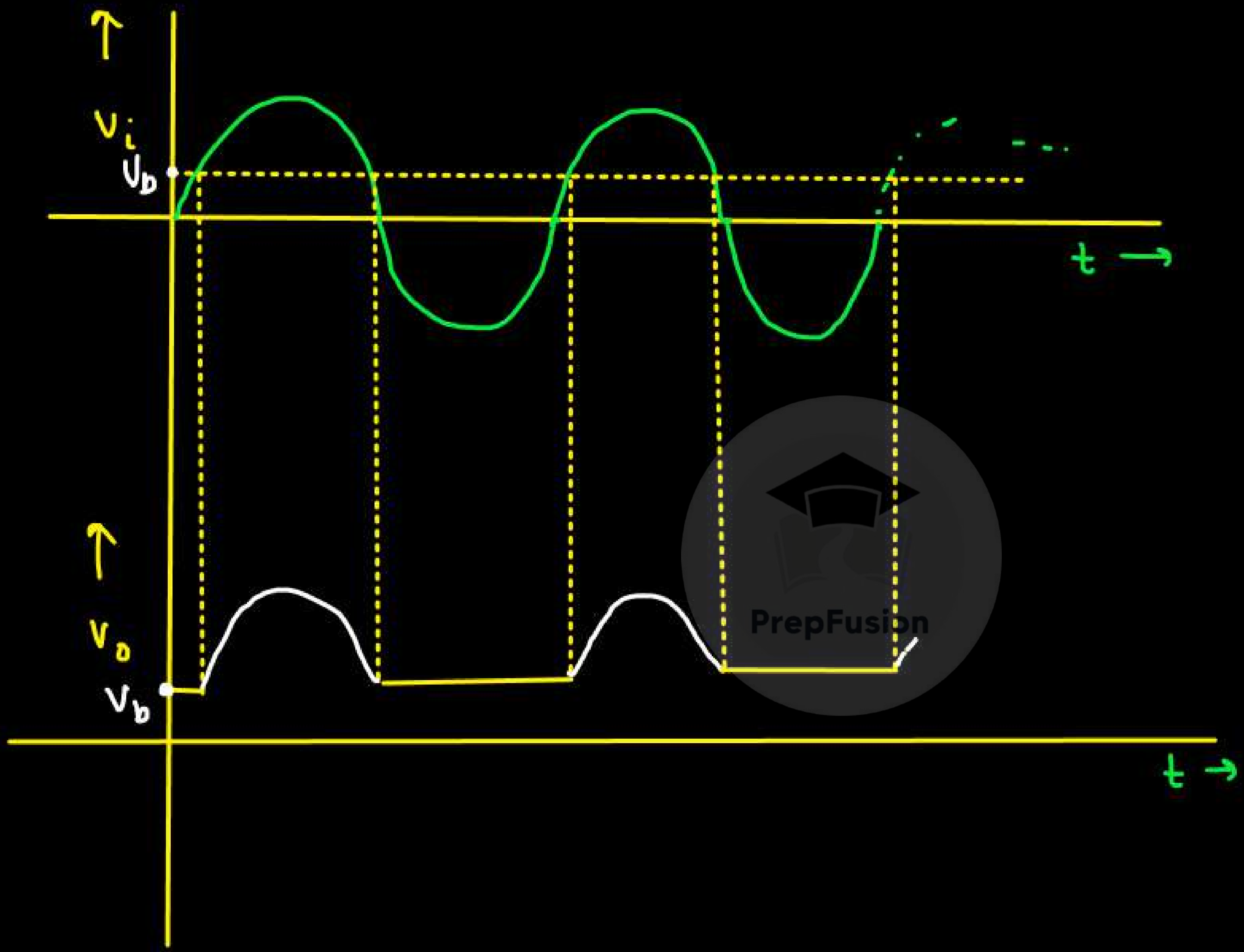
(i) $V_i > V_b \Rightarrow$ diode off

$$\boxed{V_o = V_i}$$

(ii) $V_i < V_b \Rightarrow$ diode ON

$$\boxed{V_o = V_b}$$





V_i
V_D
$t \rightarrow$
V_o
V_b
$t \rightarrow$

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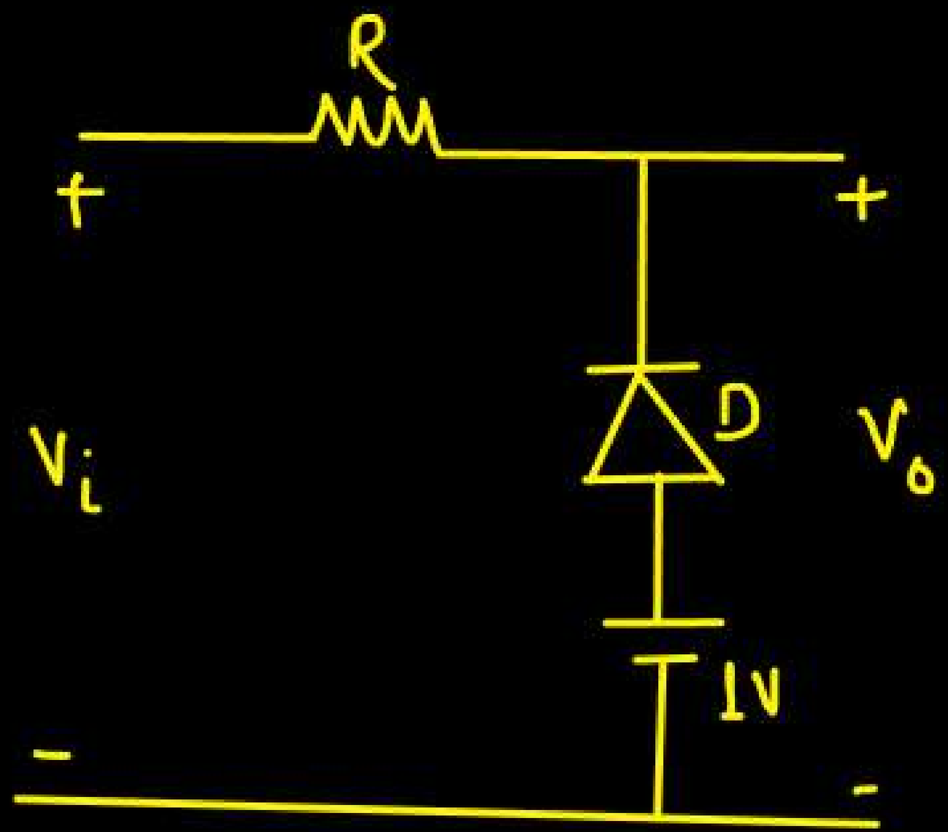
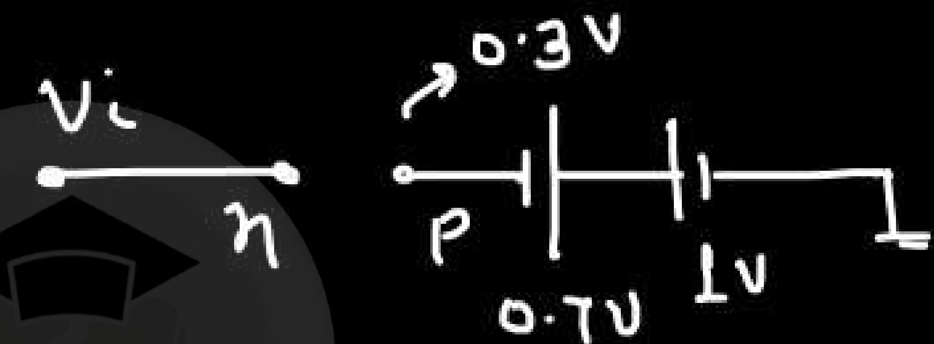


$V_\gamma = 0.7V$

Draw Transfer characteristics.

→

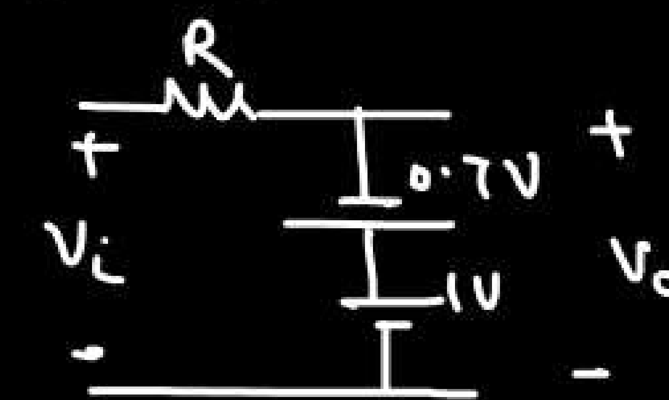


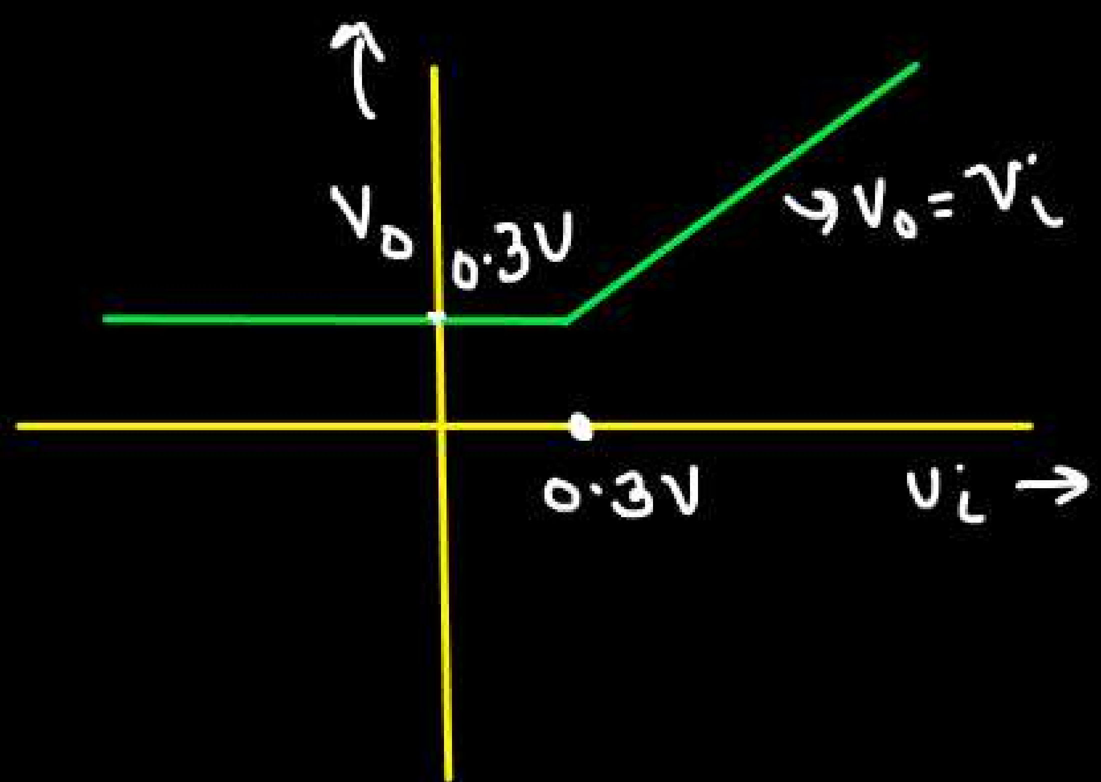
(i) $V_i > 0.3V \Rightarrow$ diode off

$\boxed{V_o = V_i}$

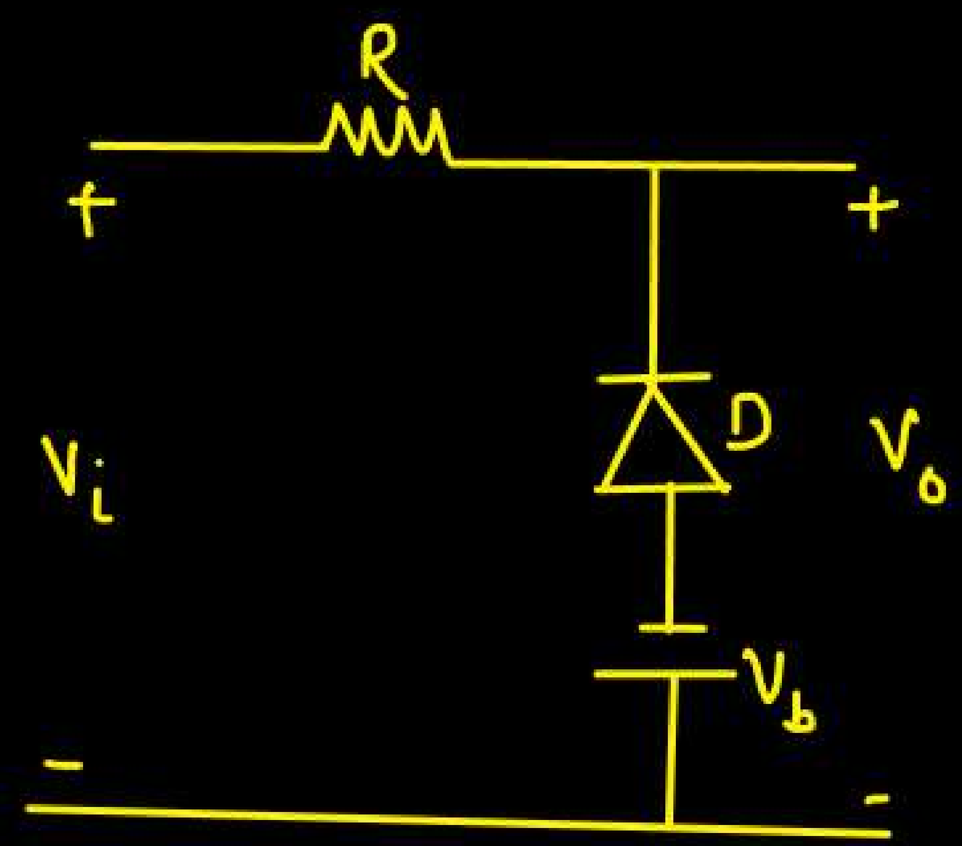
(ii) $V_i < 0.3V \Rightarrow$ diode ON

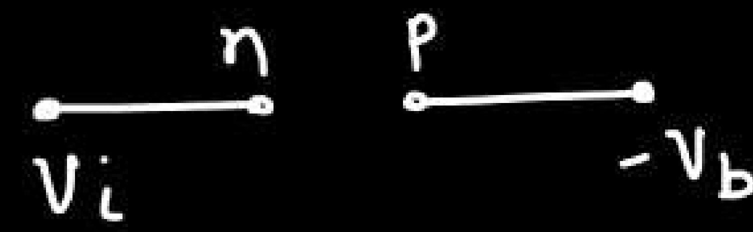
$\boxed{V_o = 0.3V}$





5. Negative shunt Clipper ckt (Negative bias):-



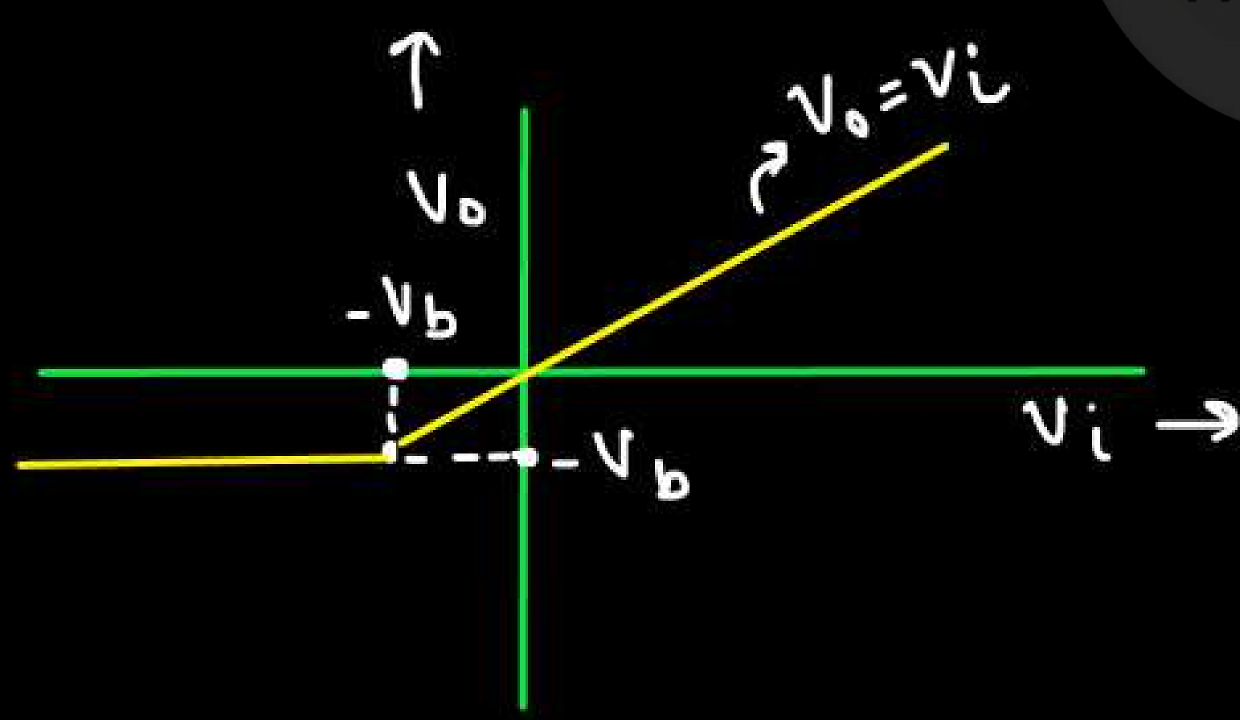


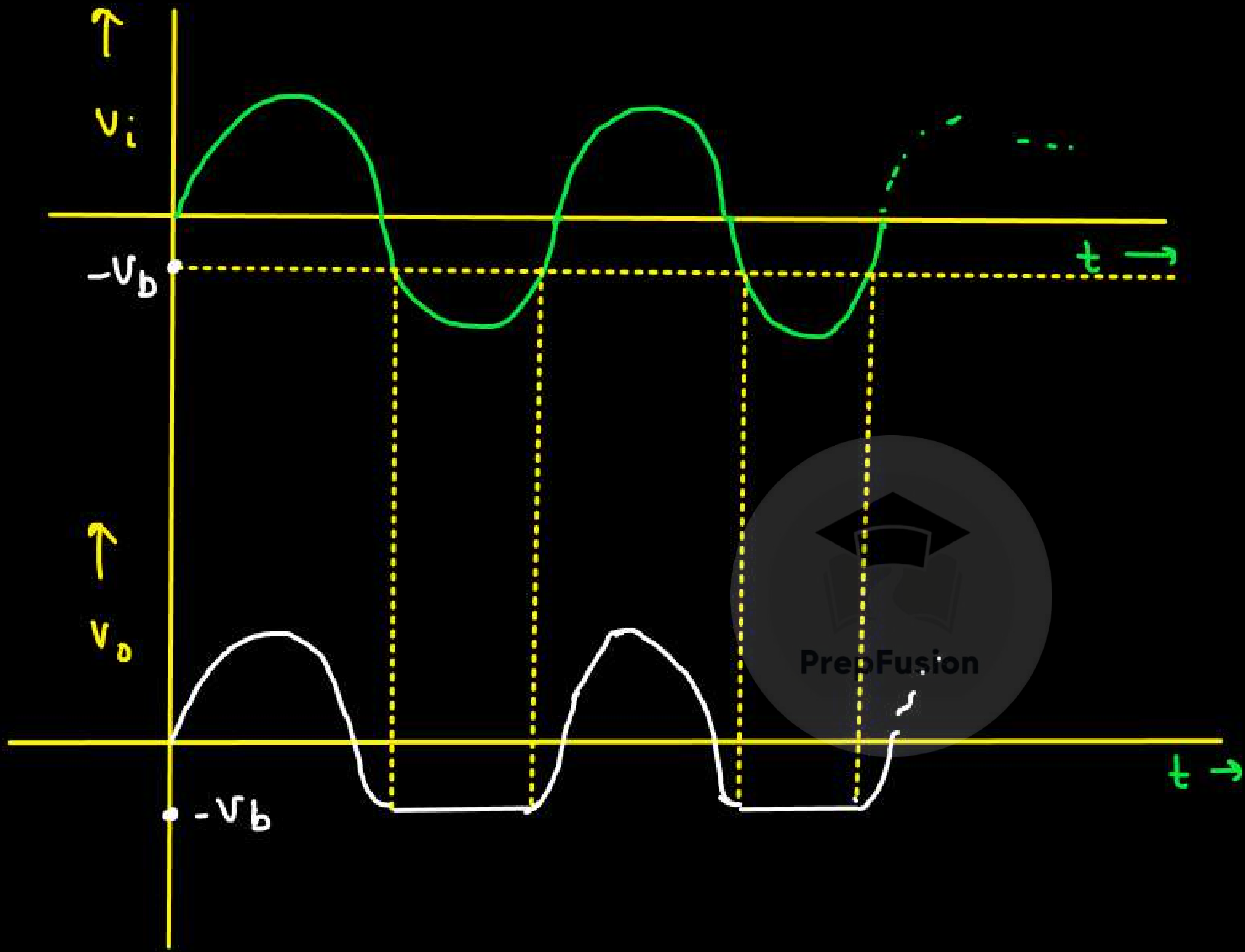
(i) $V_i > -V_b \Rightarrow$ diode off

$$\boxed{V_o = V_i}$$

(ii) $V_i < -V_b \Rightarrow$ diode ON

$$\boxed{V_o = -V_b}$$





Vi
-Vb
t →
Vo
-Vb
t →

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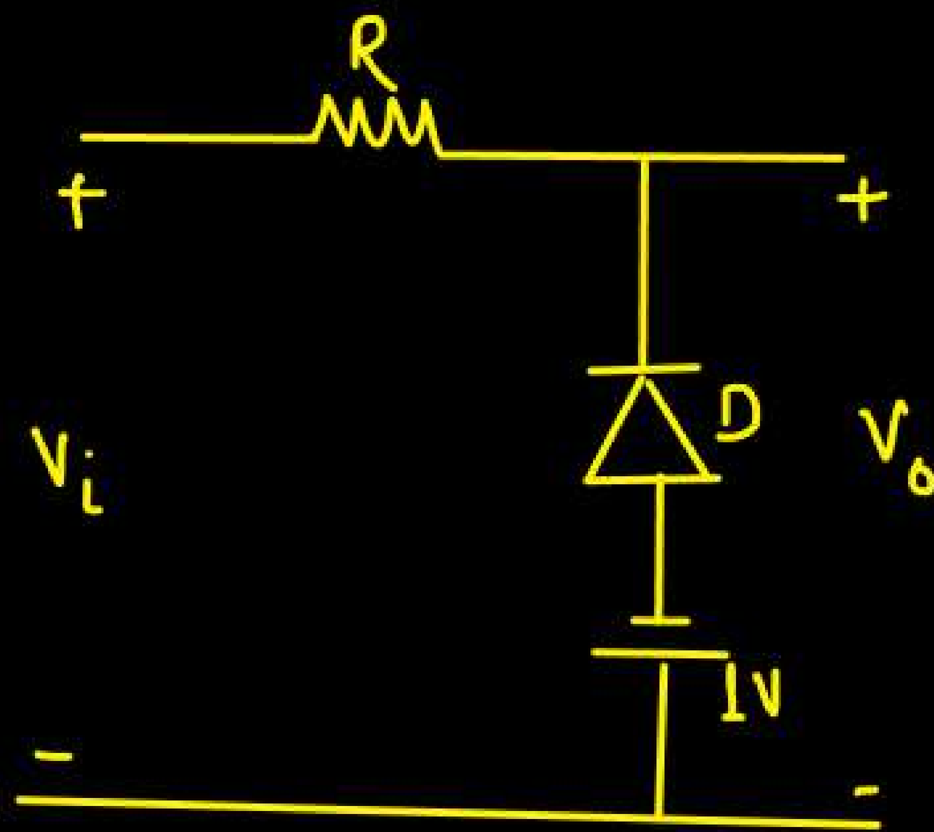
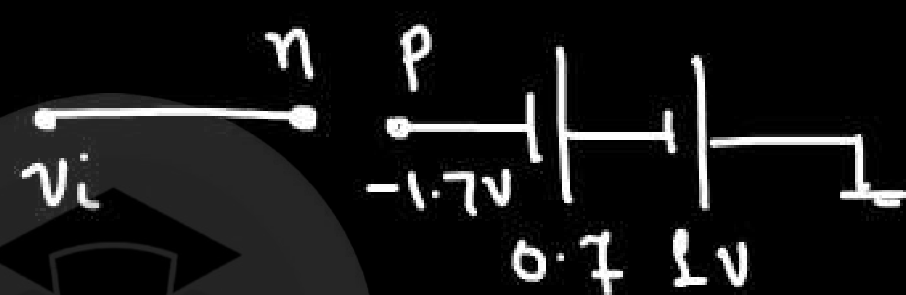


$V_\gamma = 0.7V$

Draw Transfer characteristics.

→

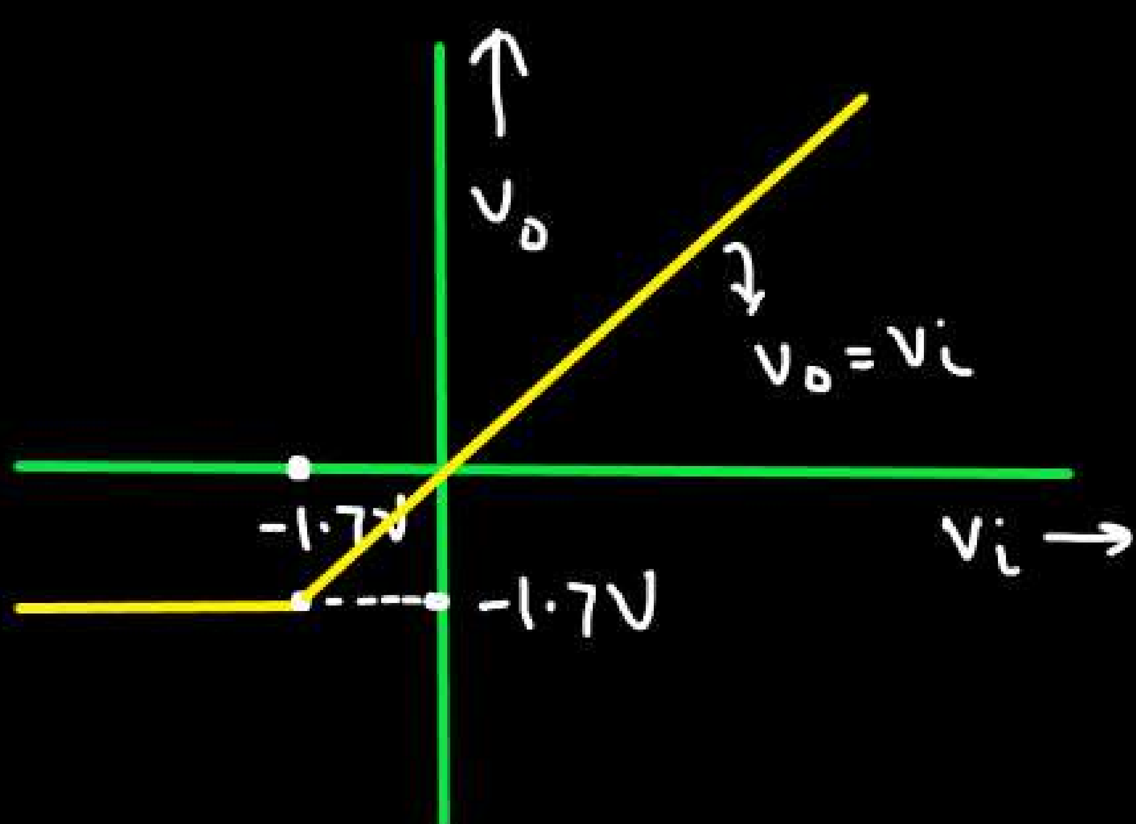


(i) $V_i > -1.7V \Rightarrow$ diode OFF

$\Rightarrow \boxed{V_o = V_i}$

(ii) $V_i < -1.7V \Rightarrow$ diode ON

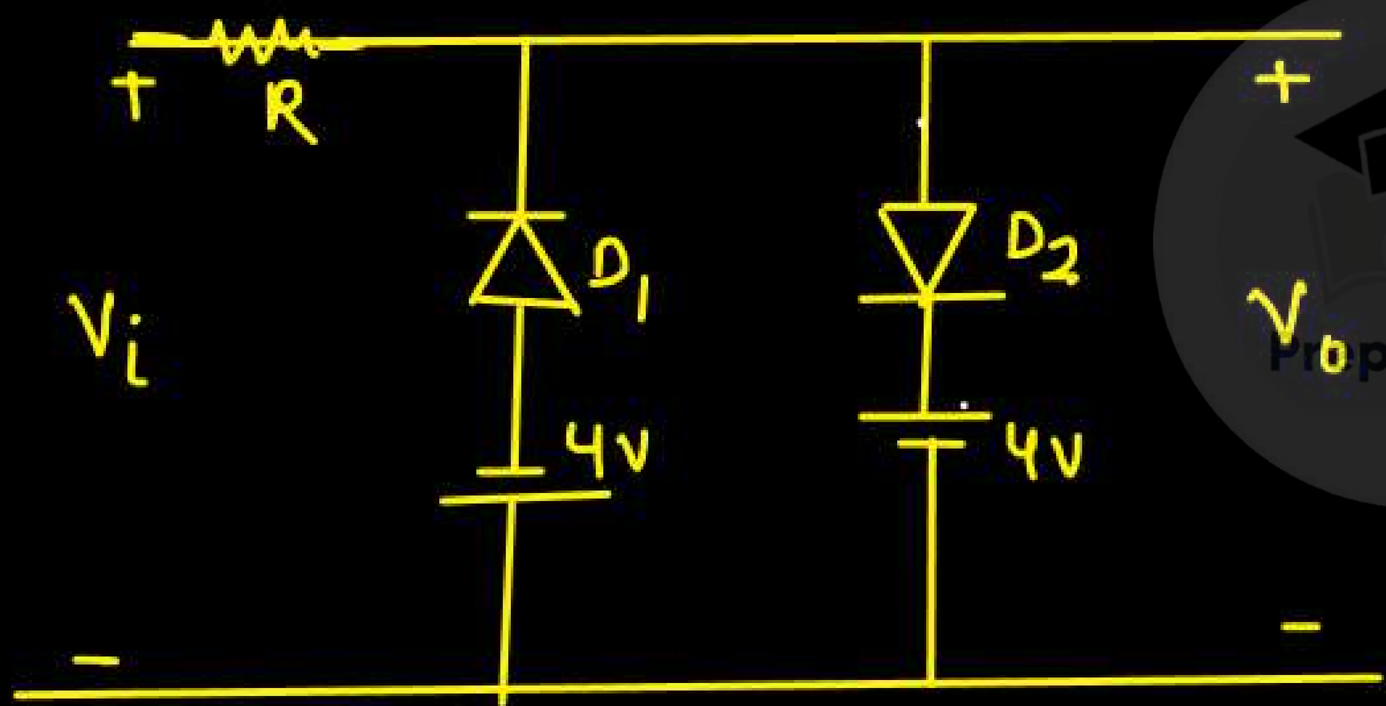
$\Rightarrow \boxed{V_o = -1.7V}$



Examples of Two level clipper ckt:-

Q. $V_{in} = 10 \sin\omega t$

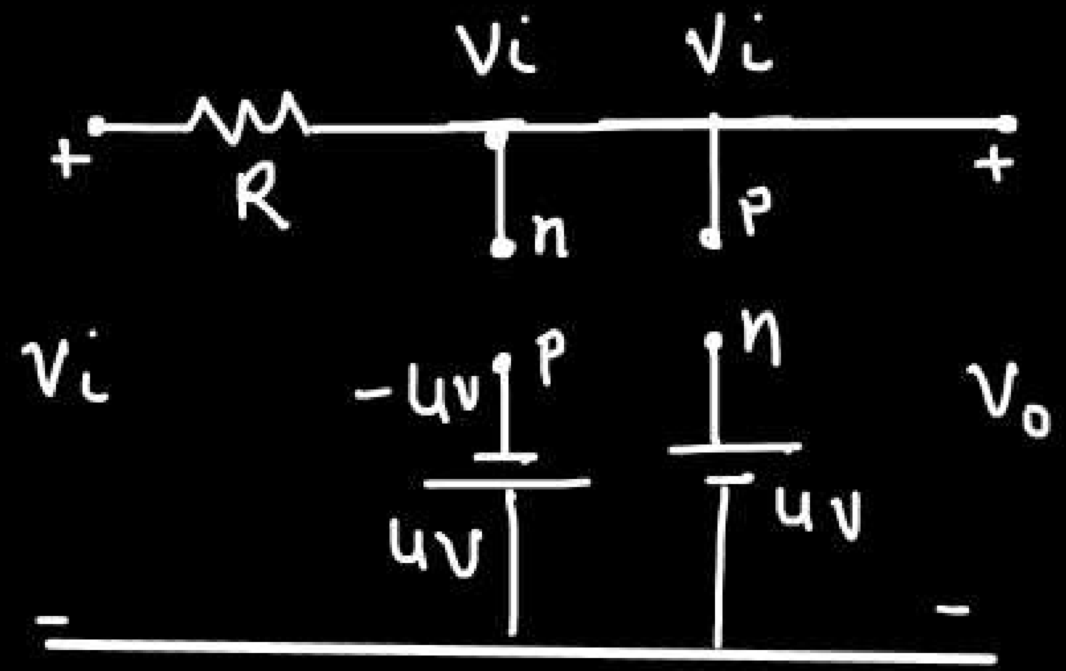
Draw VTC and find max & min value of V_0.



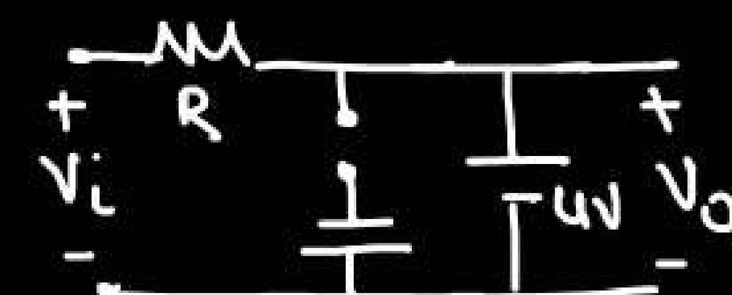
(ii) $V_i \le -4V \Rightarrow D_1$ ON, D_2 OFF

$\boxed{V_0 = -4V}$

$\Rightarrow$



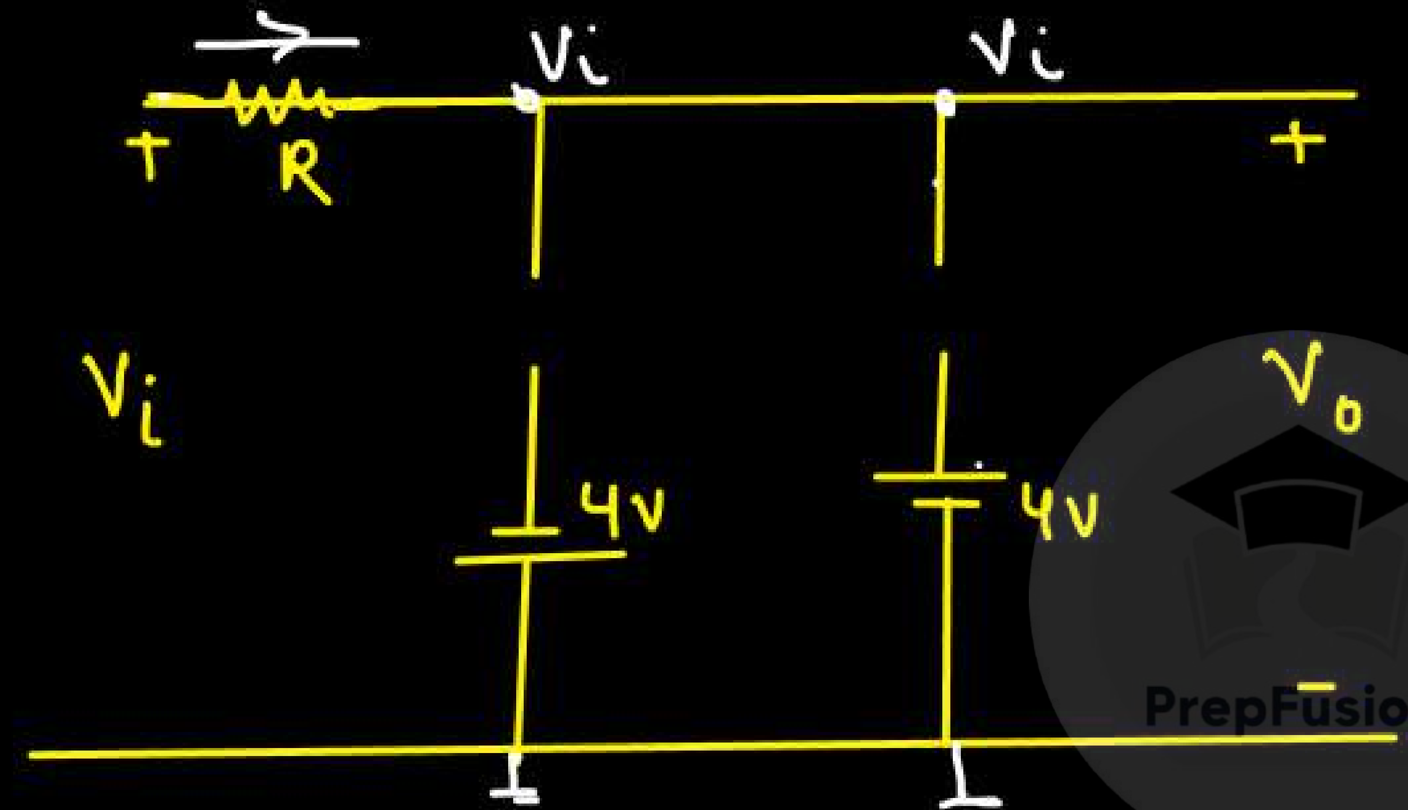
(i) $V_i \ge 4V \Rightarrow D_2$ ON, D_1 OFF



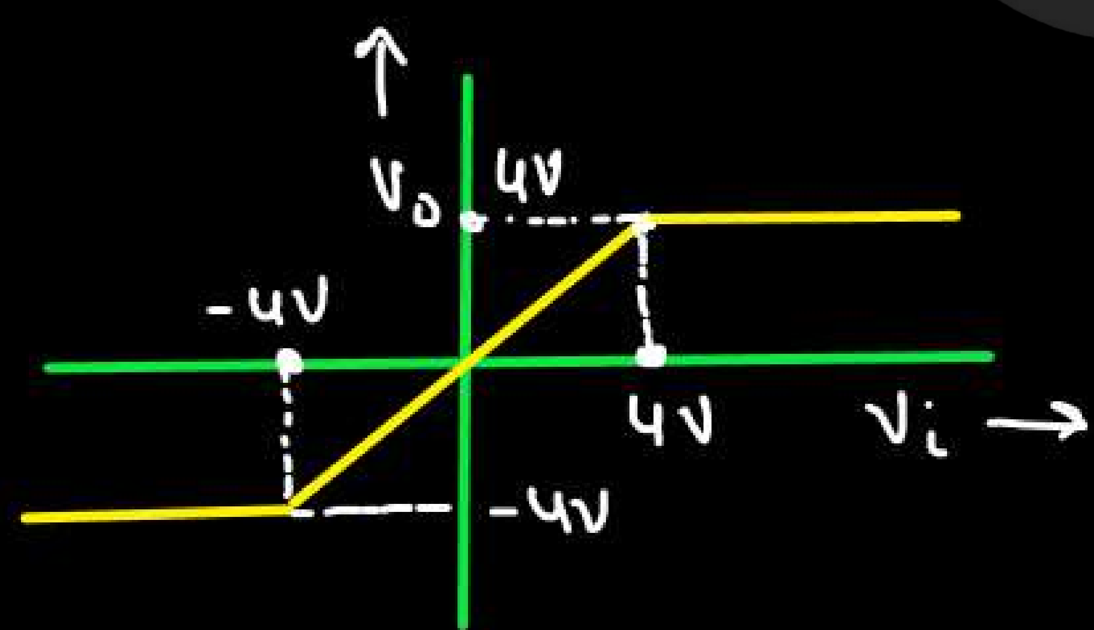
$\Rightarrow \boxed{V_0 = 4V}$

(iii) $-4 < V_i < 4$

$\Rightarrow D_1$ and D_2 are off



$$\boxed{V_o = V_i}$$



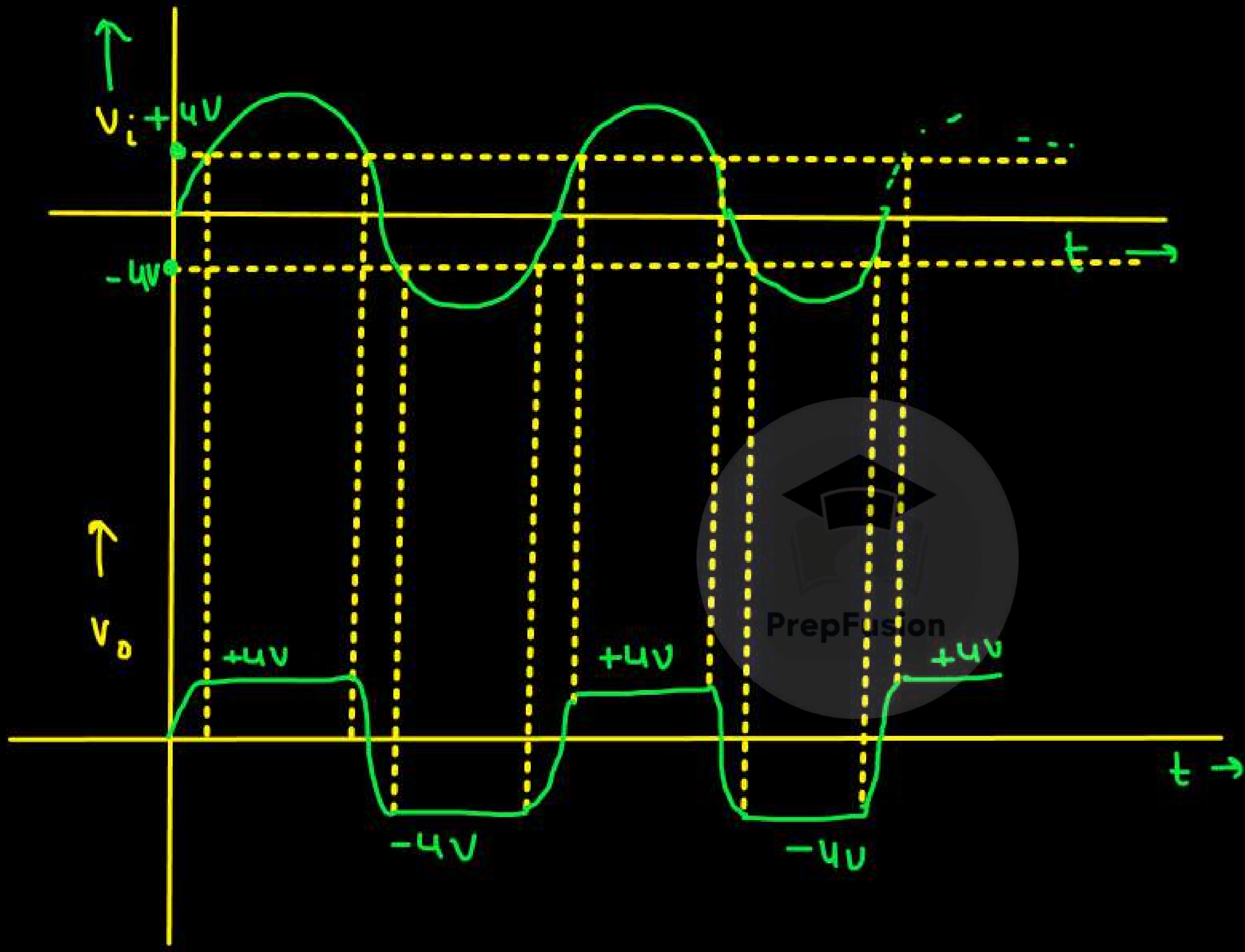
conclusion:-

(i) $V_i \geq 4V \Rightarrow V_o = 4V$

(ii) $V_i \leq -4V \Rightarrow V_o = -4V$

(iii) $-4V \leq V_i \leq 4V \Rightarrow V_o = V_i$

$$\boxed{\begin{array}{l} max = +4V \\ min = -4V \end{array}}$$



V_i
+4V
-4V
t
V_o
+4V
+4V
+4V
-4V
-4V
t

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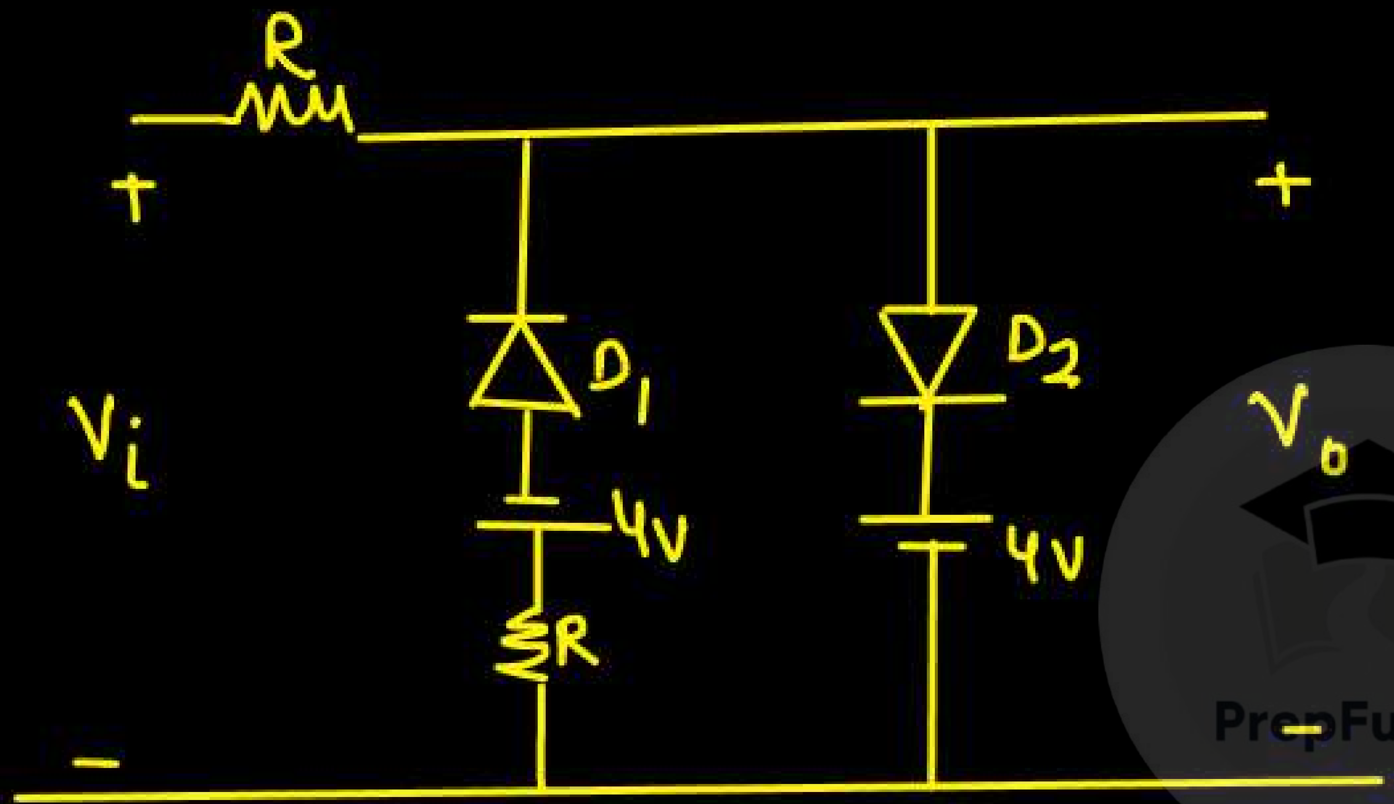
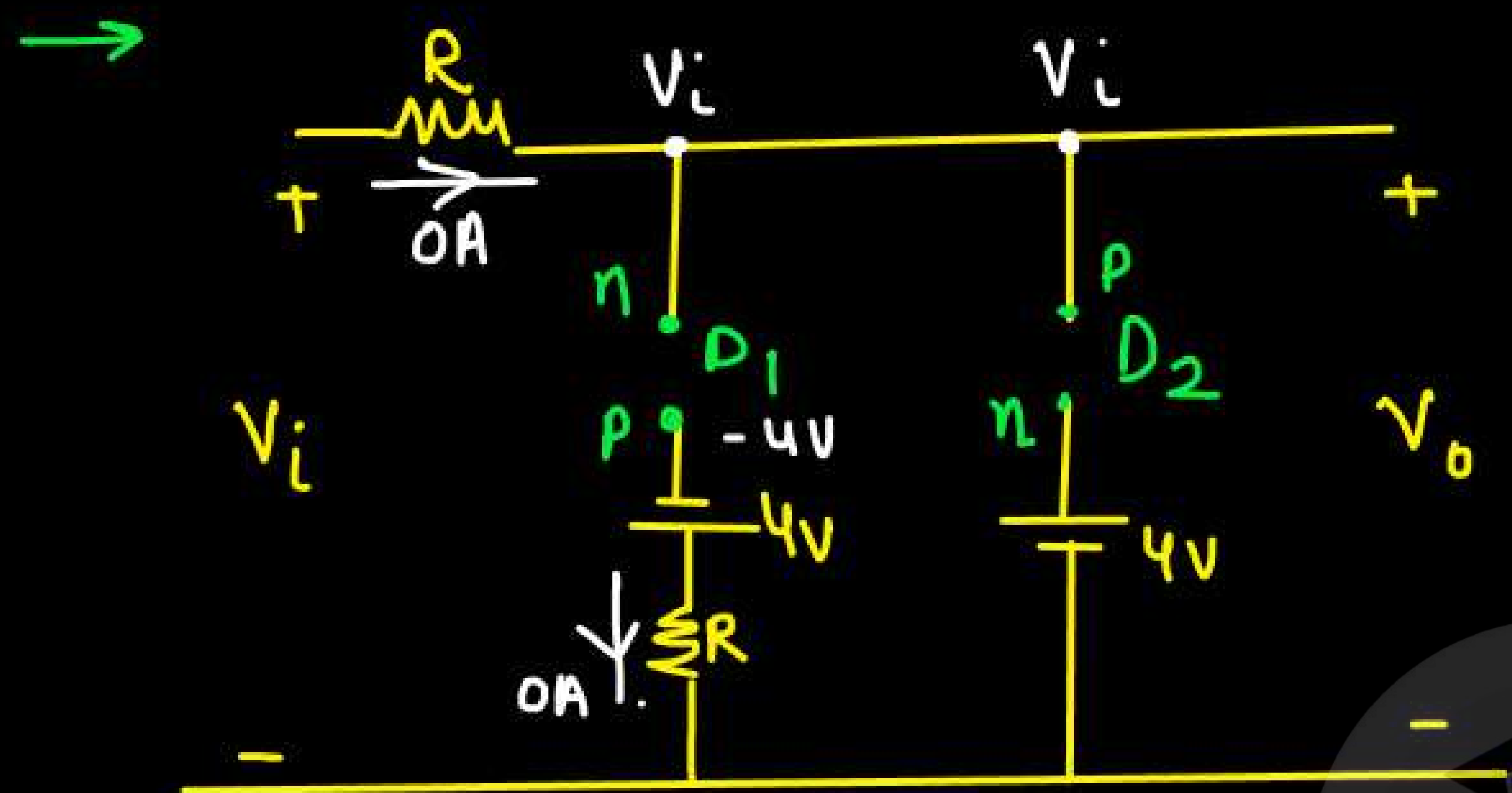
Q. $V_{in} = 10 \sin\omega t$

Draw VTC and find max & min value of V_0.





(i) $V_i \geq 4V$

$\Rightarrow$ diode D_2 ON

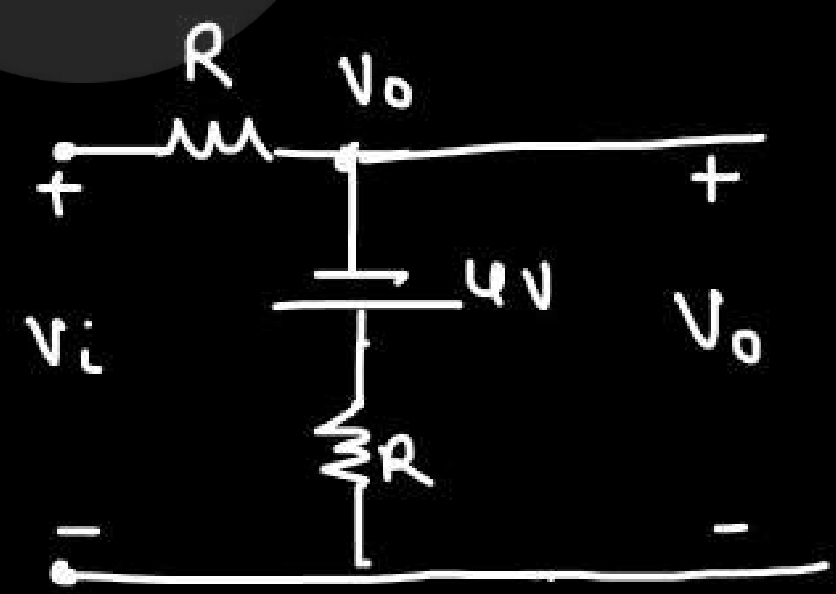
diode D_1 OFF

$$\boxed{V_0 = 4V}$$

(ii) $V_i \leq -4V$

$\Rightarrow$ diode D_1 ON

diode D_2 OFF



$$\frac{V_o - V_i}{R} + \frac{V_o + 4}{R} = 0$$

$$\boxed{V_o = \frac{V_i - 4}{2}}$$

(iii) $-4V < V_{in} < 4V$

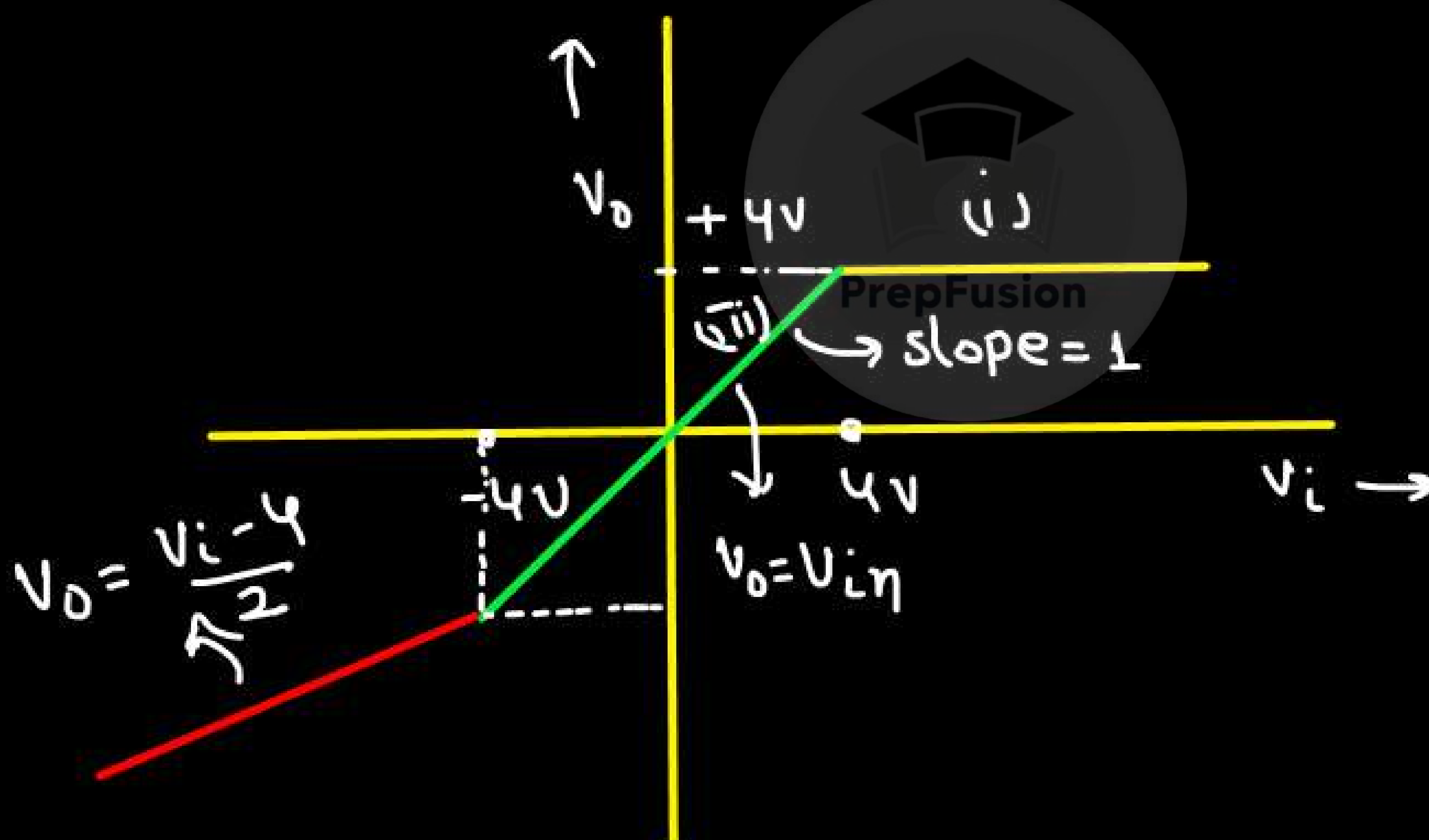
$\Rightarrow$ D_1 and D_2 OFF

$$\boxed{V_o = V_{in}}$$

(i) $V_{in} \geq 4V \Rightarrow V_0 = 4V$

(ii) $V_{in} \leq -4V \Rightarrow V_0 = \frac{V_i - 4}{2}$

(iii) $-4V < V_{in} < 4 \Rightarrow V_0 = V_{in}$



$$\boxed{max = 4V}$$

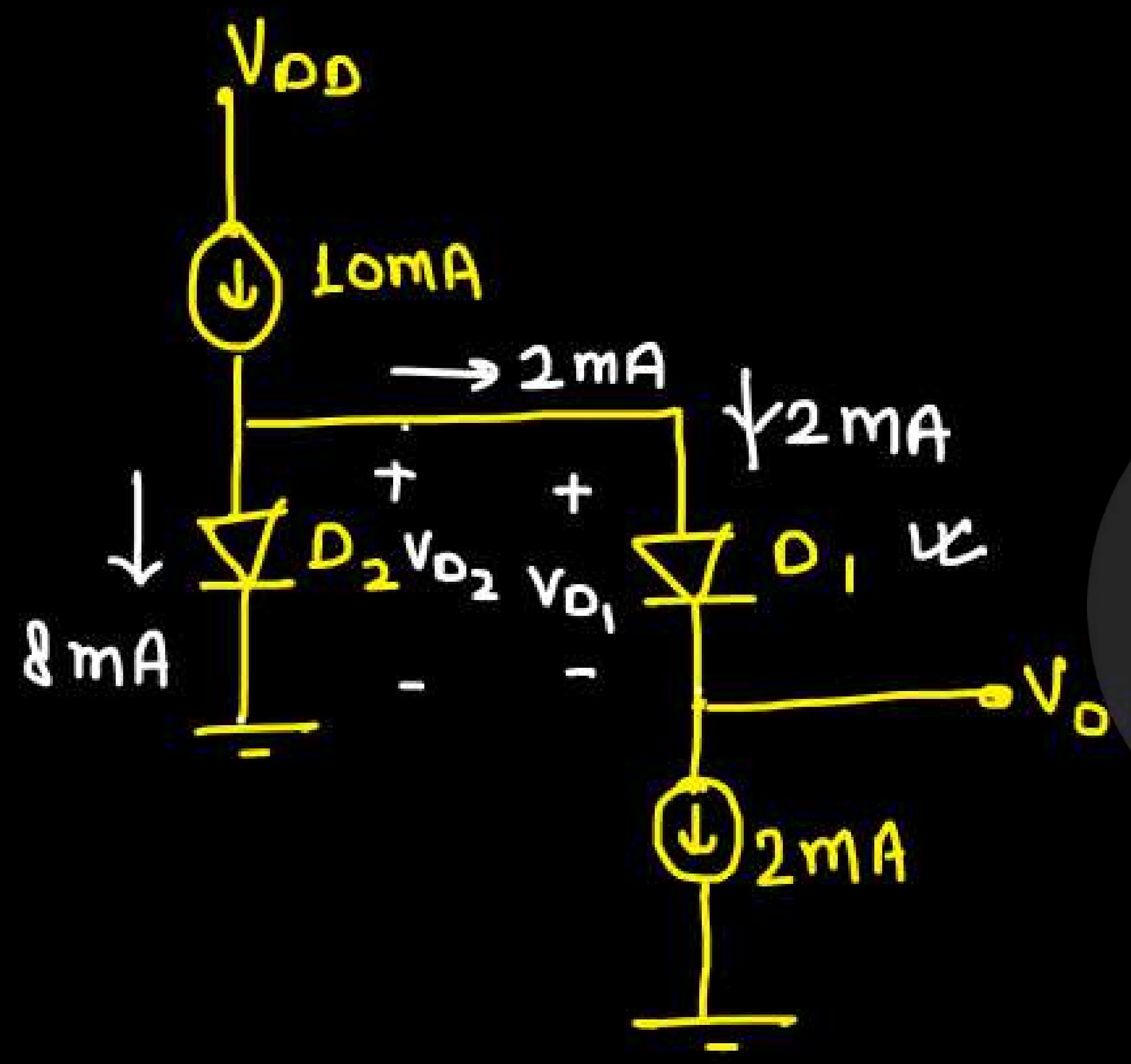
$$min = \frac{(V_i)_{min} - 4}{2}$$

$$= \frac{-10 - 4}{2}$$

$$\boxed{min = -7V}$$

Assignment - 2

Q.



D_1 has 10 times the J^n area of D_2.

Find V_0.

→ $I_S \propto J^n$ Area (A)

$A_{D_1} = 10 A_{D_2}$

$I_{S_1} = 10 I_{S_2}$ =

$I_{D_1} = 2mA = I_{S_1} e^{V_{D1}/V_T}$ — ①

$I_{D_2} = 8mA = I_{S_2} e^{V_{D2}/V_T}$ — ②

$0 + V_{D_2} - V_{D_1} = V_0$

$$\boxed{V_0 = V_{D_2} - V_{D_1}}$$

$2 \div 1$

$$4 = \frac{I_{s_2}}{I_{s_1}} e^{(V_{D_2} - V_{D_1})/V_T}$$

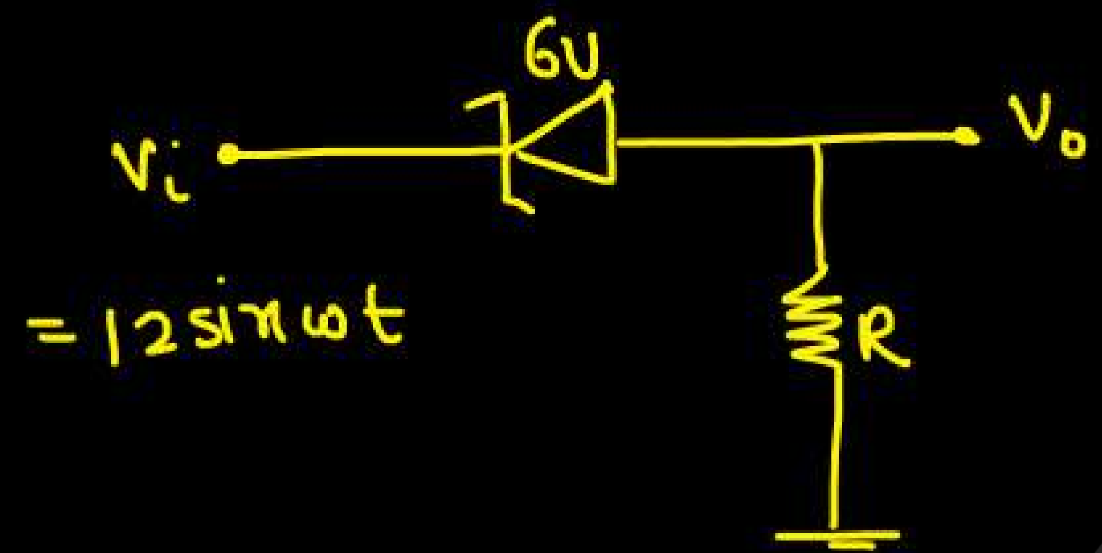
$$4 = \frac{1}{10} e^{V_0/V_T}$$

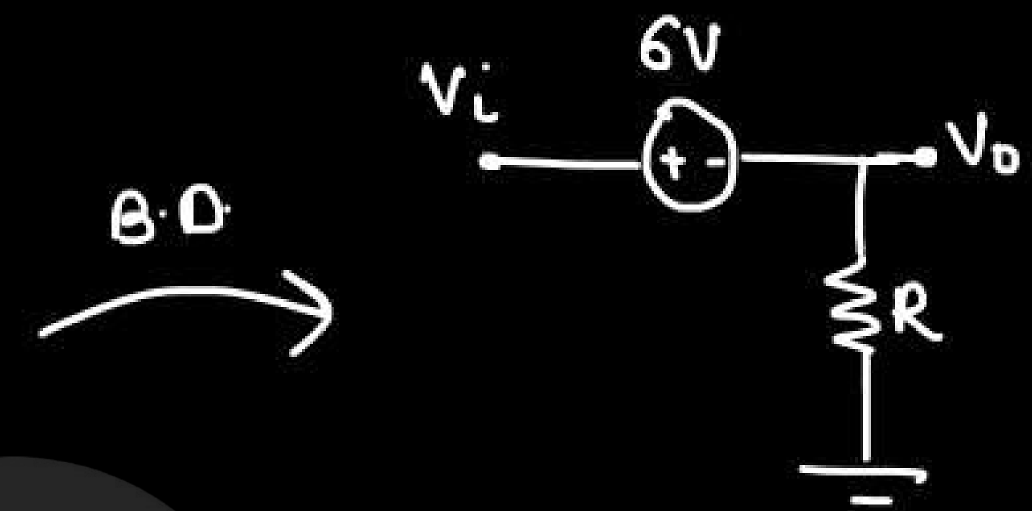
$$V_0 = V_T \ln(40)$$

$$V_0 = 26 \ln(40) \text{ mV}$$

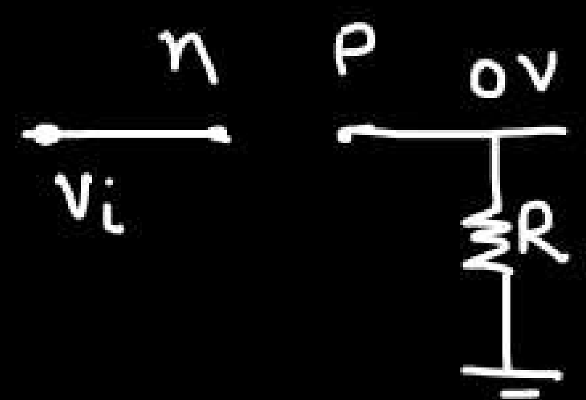
$$\boxed{V_0 \simeq 96 \text{ mV}}$$

Q. $V_Z = 6V$, Draw V_0.





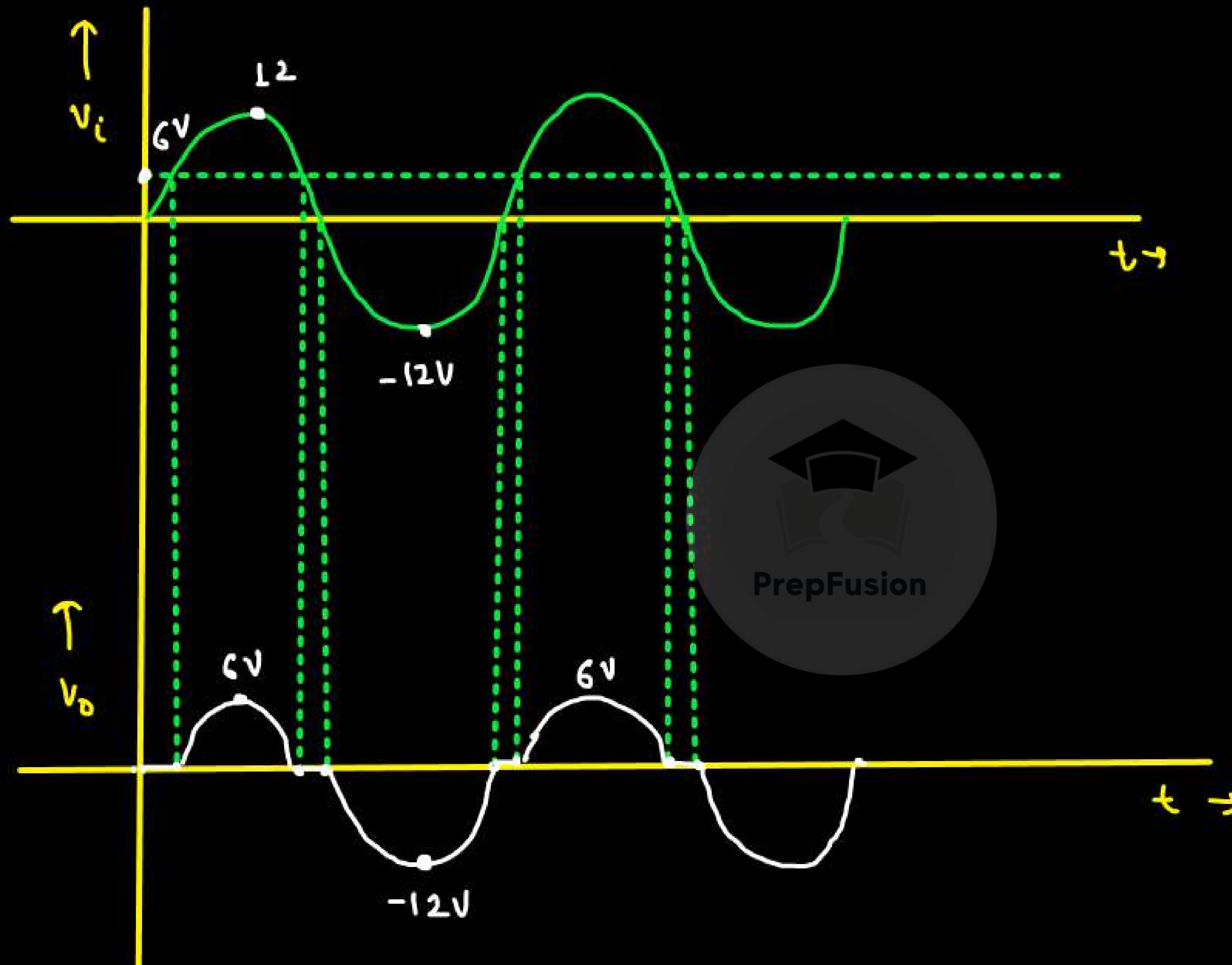
→



$V_i < 0 \Rightarrow$ diode ON $\Rightarrow$ S.C. $\Rightarrow \boxed{V_0 = V_i}$

$6V > V_i > 0 \Rightarrow$ diode R.B. and not in B.D. $\Rightarrow$ diode O.C. $\Rightarrow \boxed{V_0 = 0}$

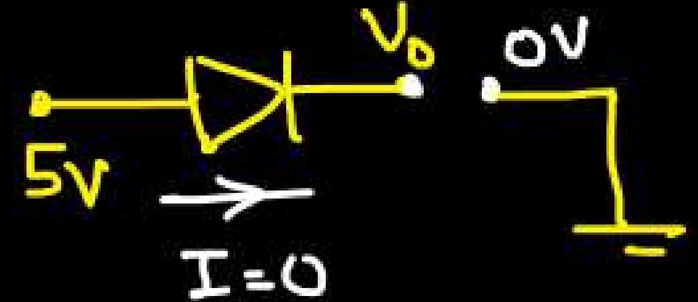
$V_i > 6V \Rightarrow$ diode goes into B.D. $\Rightarrow \boxed{V_0 = V_i - 6}$



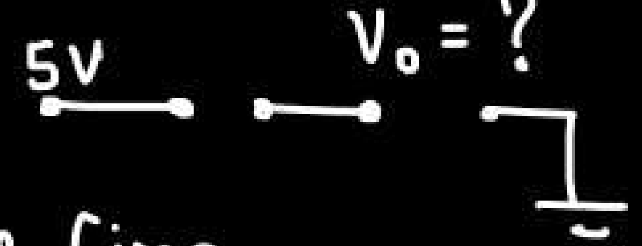
v_i
6V
12
-12V
t
v_o
6V
6V
-12V
t
PrepFusion

Q Tell whether the diode is ON, off or Breakdown. Find V_0.

①

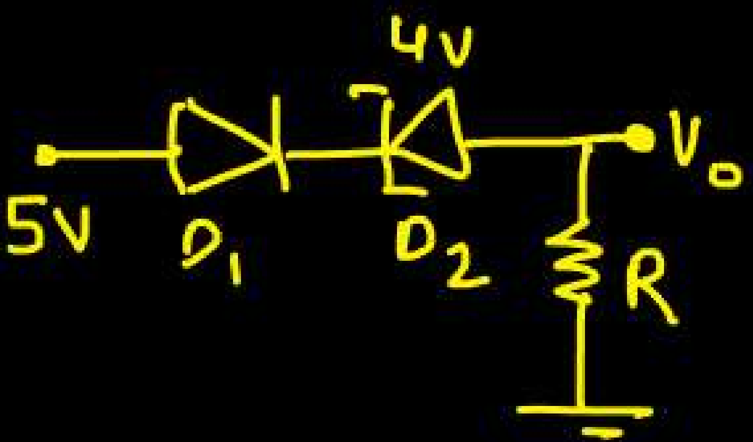


→ diode off

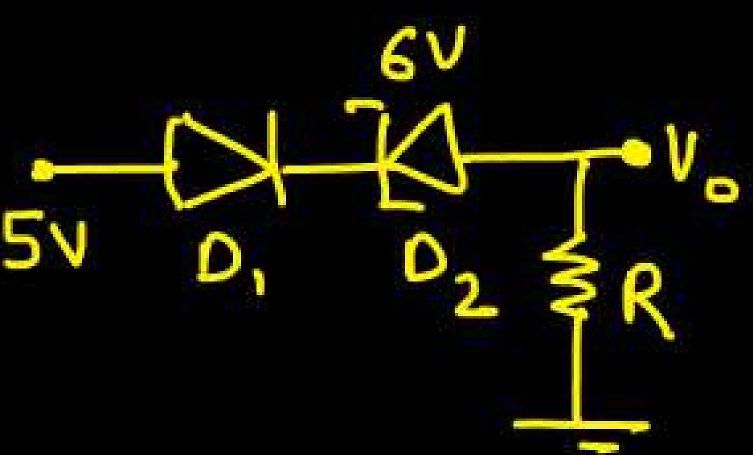


V_0 = Can't define

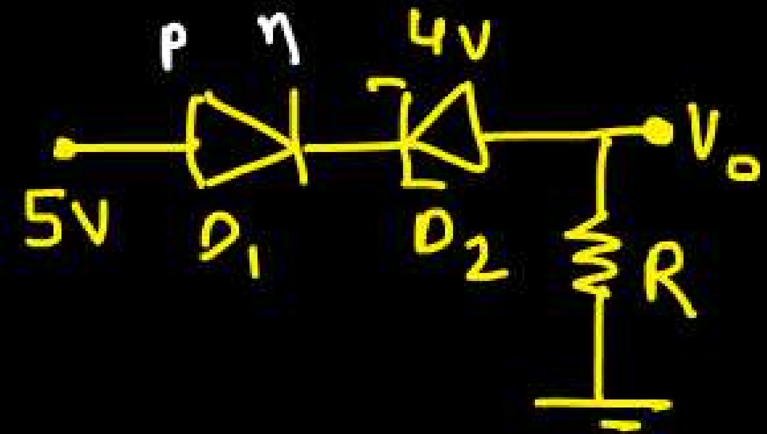
②



③

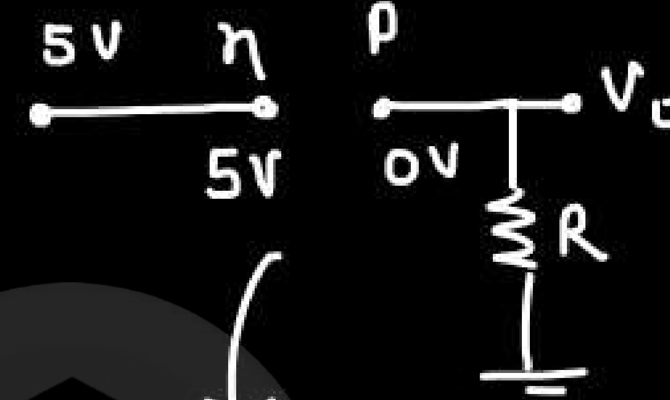


(2)



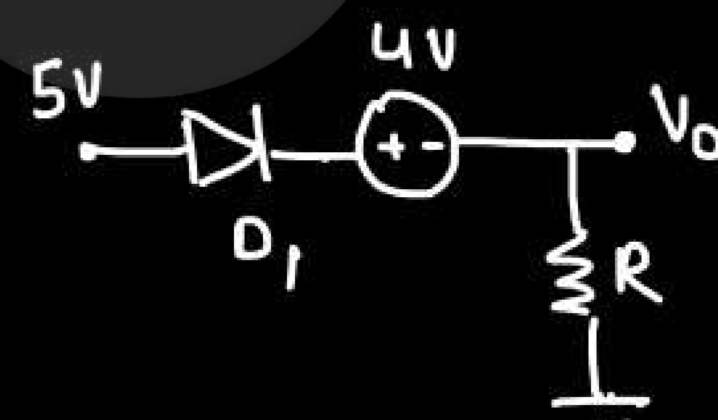
Assume D_1 is ON

and Apply O.C. Test ON D_2



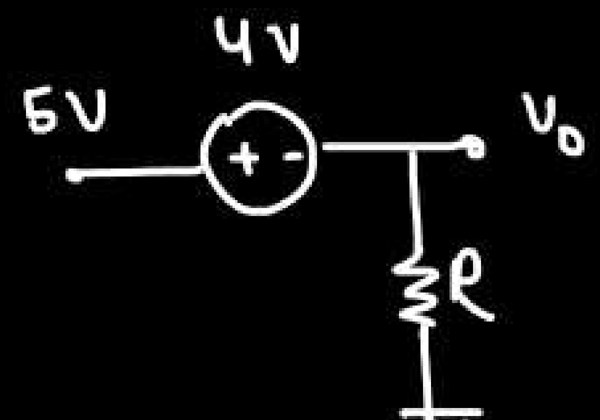
R.B. ⇒ B.D.

⇓



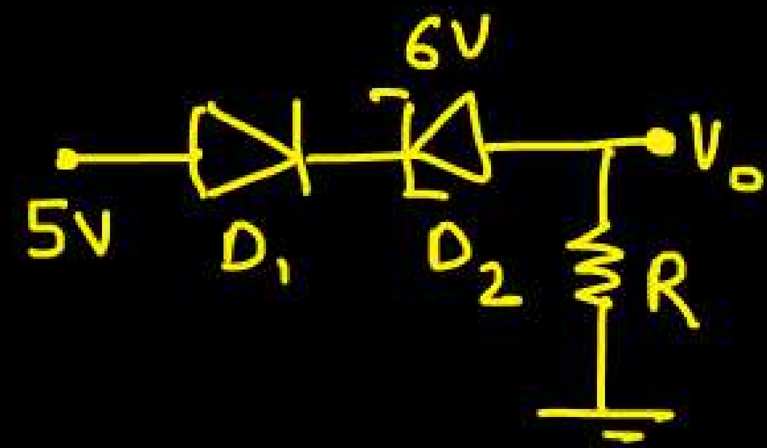
By apply S.C./O.C. Test on D_1, I can see that diode D_1 is ON ⇒ Assumption was correct.

⇐

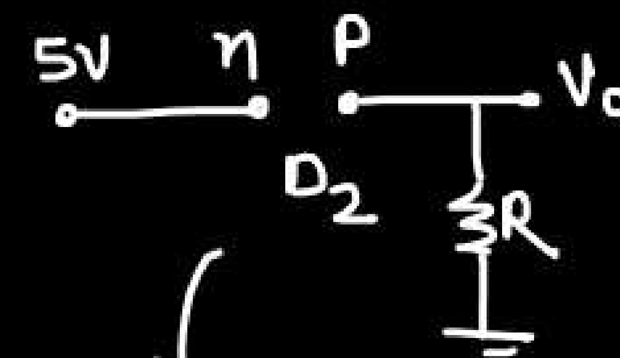


$\boxed{V_o = 1V}$

3



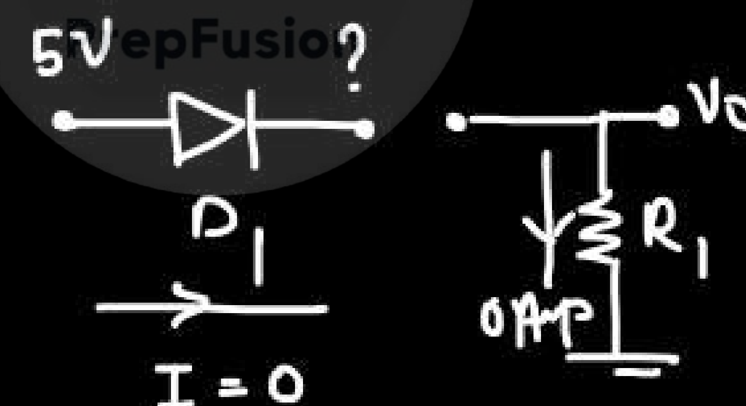
Assume D_1 is ON.



D_2 is R.B. and not in B.D.

$\Downarrow$

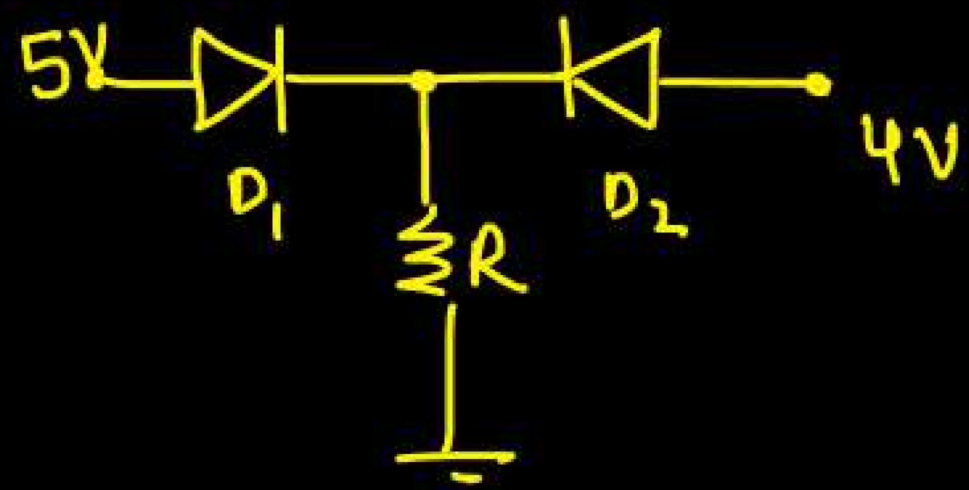
diode $D_2 \rightarrow$ OFF $\Rightarrow$ D_2 O.C.



D_1 will also be off.

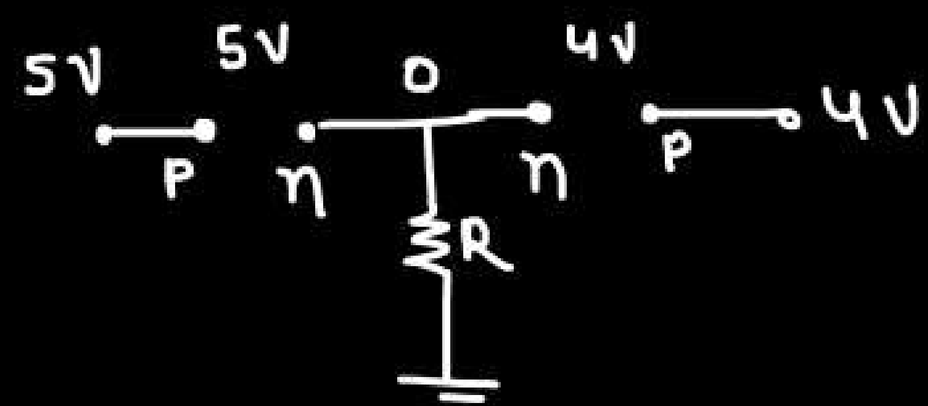
$\boxed{V_0 = 0V}$

Revision Question:-



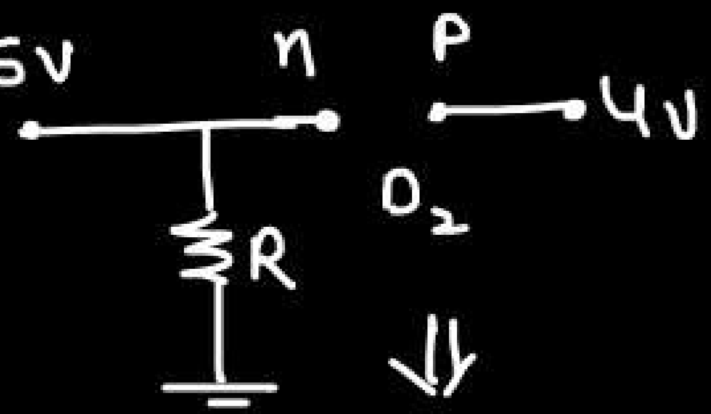
op^r $cond^n$ of D_1 & D_2?

→



D_1 will be turned on initially.

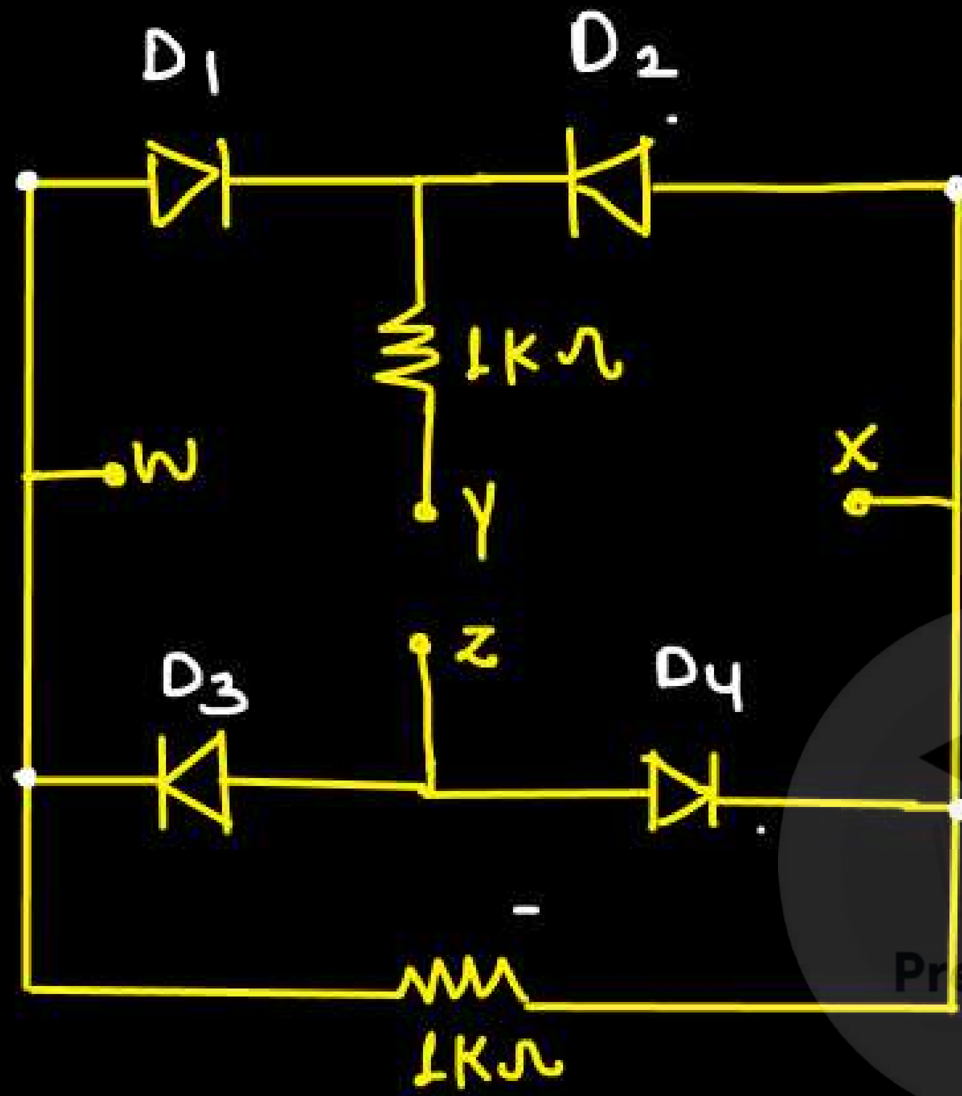
⇒



⇓

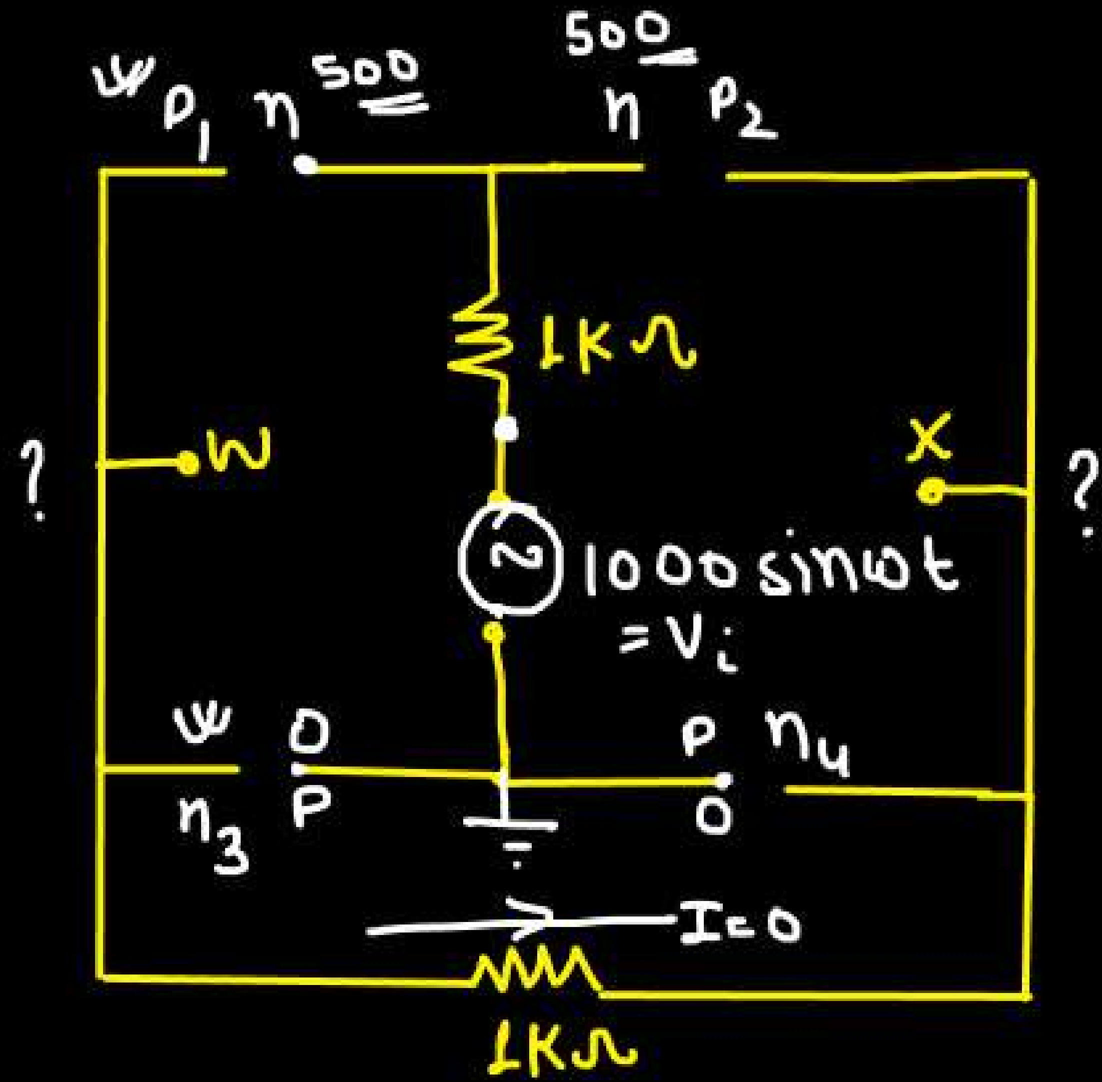
D_2 will be off

Q.



$V_{YZ} = 100 \sin\omega t$

Find $V_{WX} = ?$



For $V_i > 0$

$V_{n_3} = V_{n_4} = V_{P_1} = V_{P_2}$

⇒ By ckt analysis,

D_1, D_2, D_3, D_4 all are off

$V_W = V_{n_3} = V_{P_1}$

$V_X = V_{n_4} = V_{P_2}$

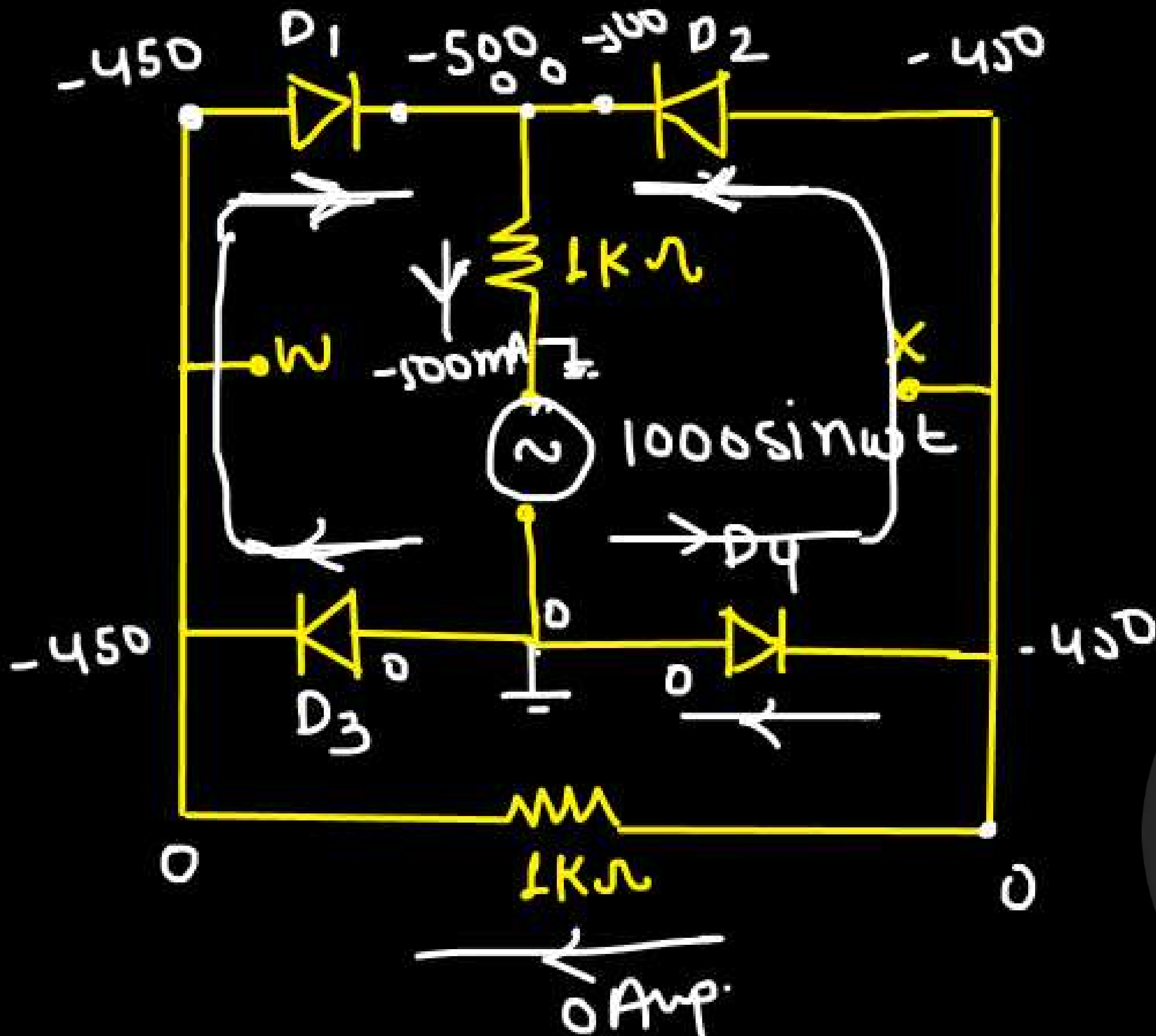
if all diode are off,

then $V_{n_3} = V_{P_1} = V_{n_4} = V_{P_2}$

⇒ $\boxed{V_W = V_X}$ ⇒ $\boxed{V_{WX} = 0V}$

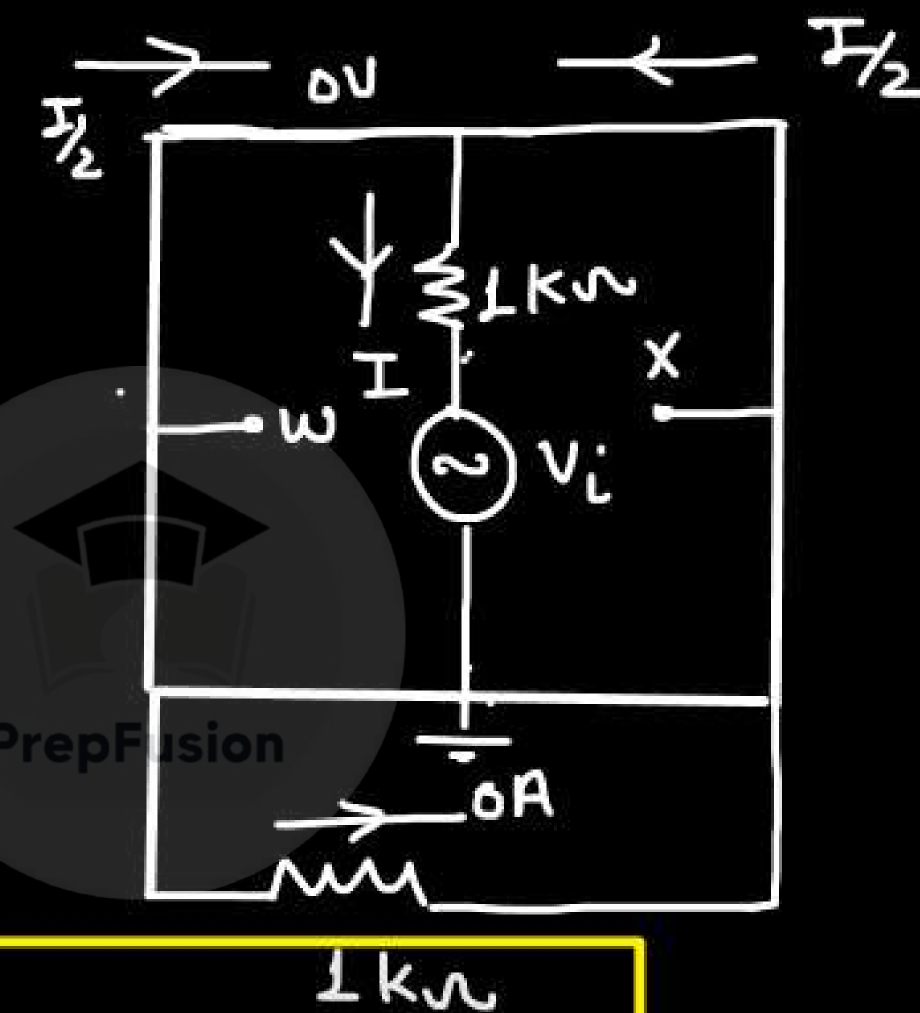
X wrong

$\boxed{\begin{matrix} V_W = 0V \\ V_X = 0V \end{matrix}}$



for $V_i < 0$

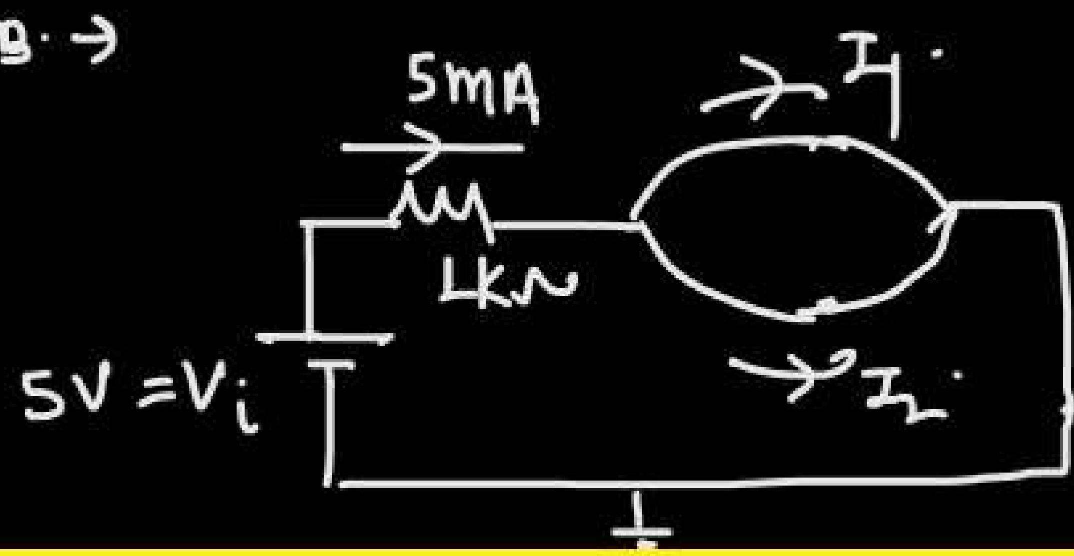
$\Rightarrow D_1, D_2, D_3, D_4$ all are ON



$\boxed{V_W = V_X}$

$\boxed{V_{WX} = 0V}$

N.B. →



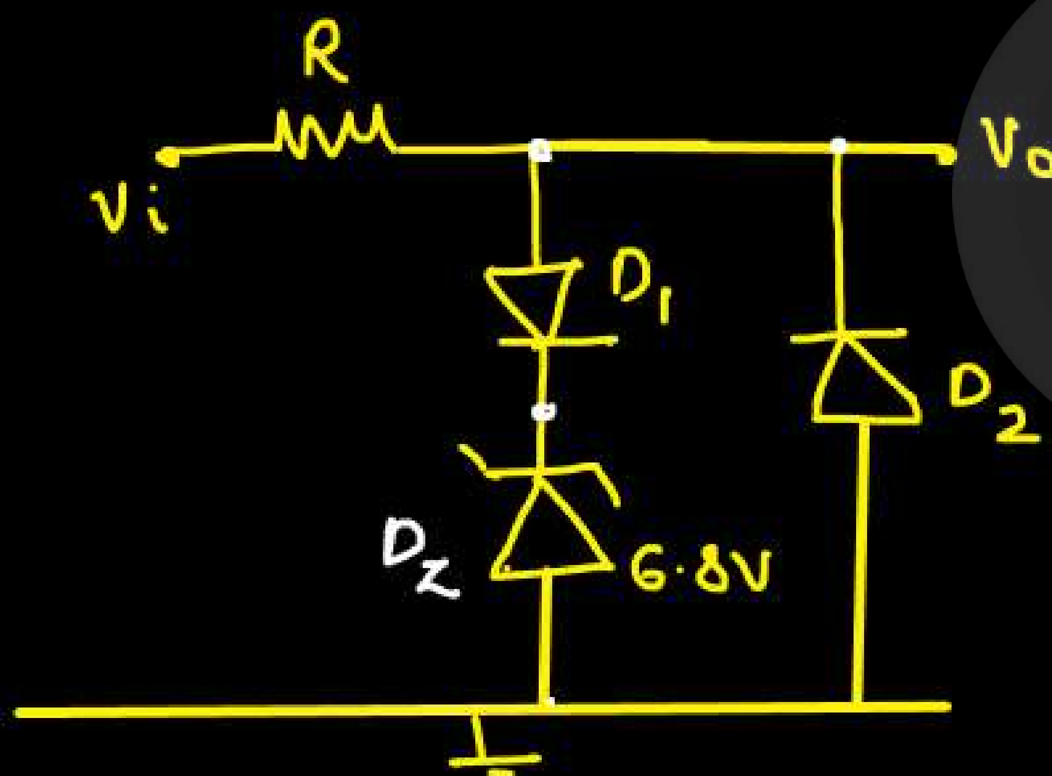
$\boxed{I_1 = 2.5 mA = I_2}$

Q. For zener, $V_Z = 6.8V$

For all the diodes $V_\gamma = 0.7V$

$V_i = 10 \sin 100\pi t$

Find max and min values of o/p voltage.



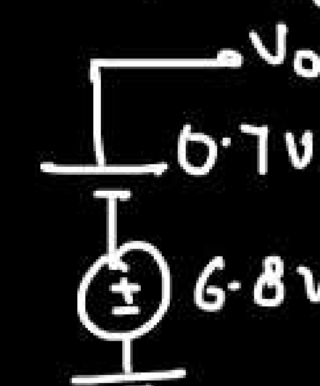
→ when $V_i > 0$ & $V_i < 7.5V$

$\Rightarrow$ diode D_2, D_1 and D_Z are off

$$\boxed{V_o = V_i}$$

↳ $V_i > 7.5V \Rightarrow D_Z$ and D_1 turns ON

D_2 is off

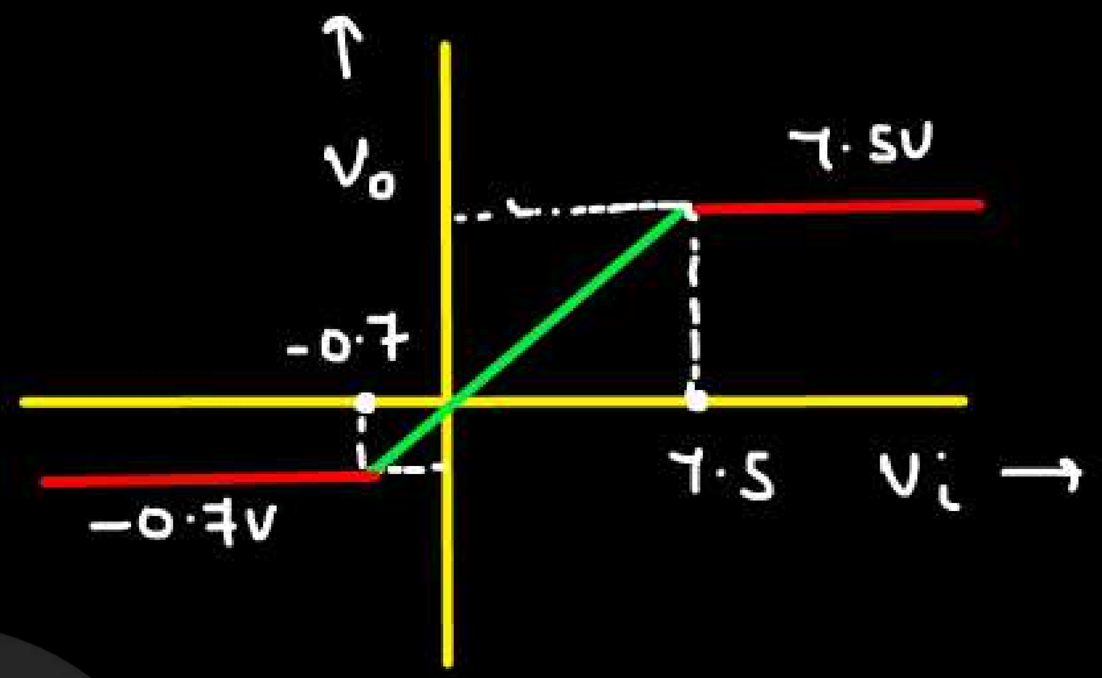


$$\boxed{V_o = 7.5V}$$ → max

For $V_i < 0$ & $V_i > -0.7V$

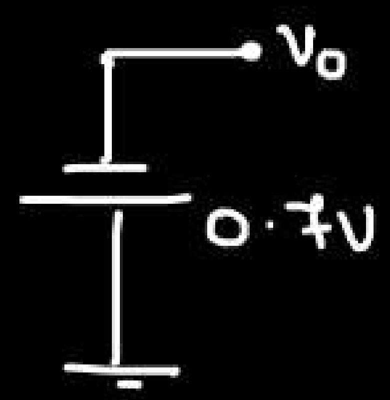
D_1, D_2 and D_Z are off

$$\boxed{V_o = V_i}$$



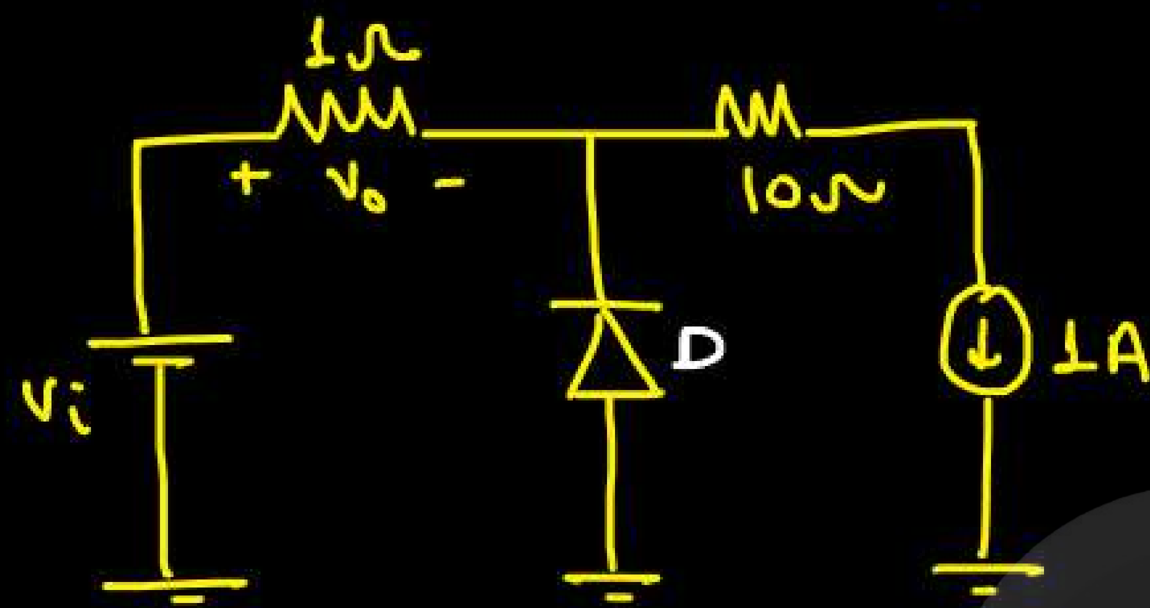
When $V_i < -0.7V$

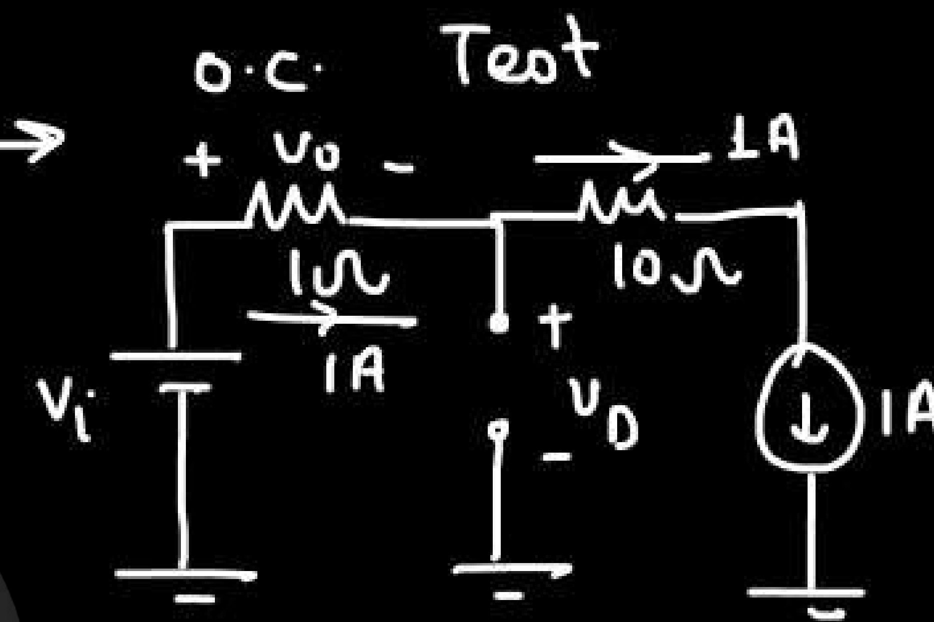
diode D_2 turns on



$\boxed{V_o = -0.7V} \rightarrow$ min

Q. In the ckt the voltage V_0 is given by→



→ 

(a) min $(V_i, 1)$

(b) min $(-V_i, 1)$

(c) max $(V_i, 1)$

$$\boxed{(V_D)_{o.c.} = V_i - 1}$$

↳ if $V_i < 1V \Rightarrow (V_D)_{o.c.} = -ve$

⇓

$\boxed{V_0 = V_i}$ ⇐ diode ON

↳ $\boxed{\text{if } V_i < 1V \Rightarrow V_0 = V_i}$

if $V_i > 1V \Rightarrow (V_D)_{o.c.} = +ve$

$\Downarrow$

diode Turns off

$$\boxed{V_o = 1 \times 1A = 1V}$$

$$\boxed{\begin{array}{l} V_i > 1V \Rightarrow V_o = 1V \\ V_i < 1V \Rightarrow V_o = V_i \end{array}}$$

option 1: $V_o = \min(V_i, 1)$

let $V_i = 0.5V \Rightarrow V_o = 0.5V$

$\Rightarrow V_o = \min(0.5, 1) = 0.5V$

let $V_i = 2V \Rightarrow V_o = 1V$

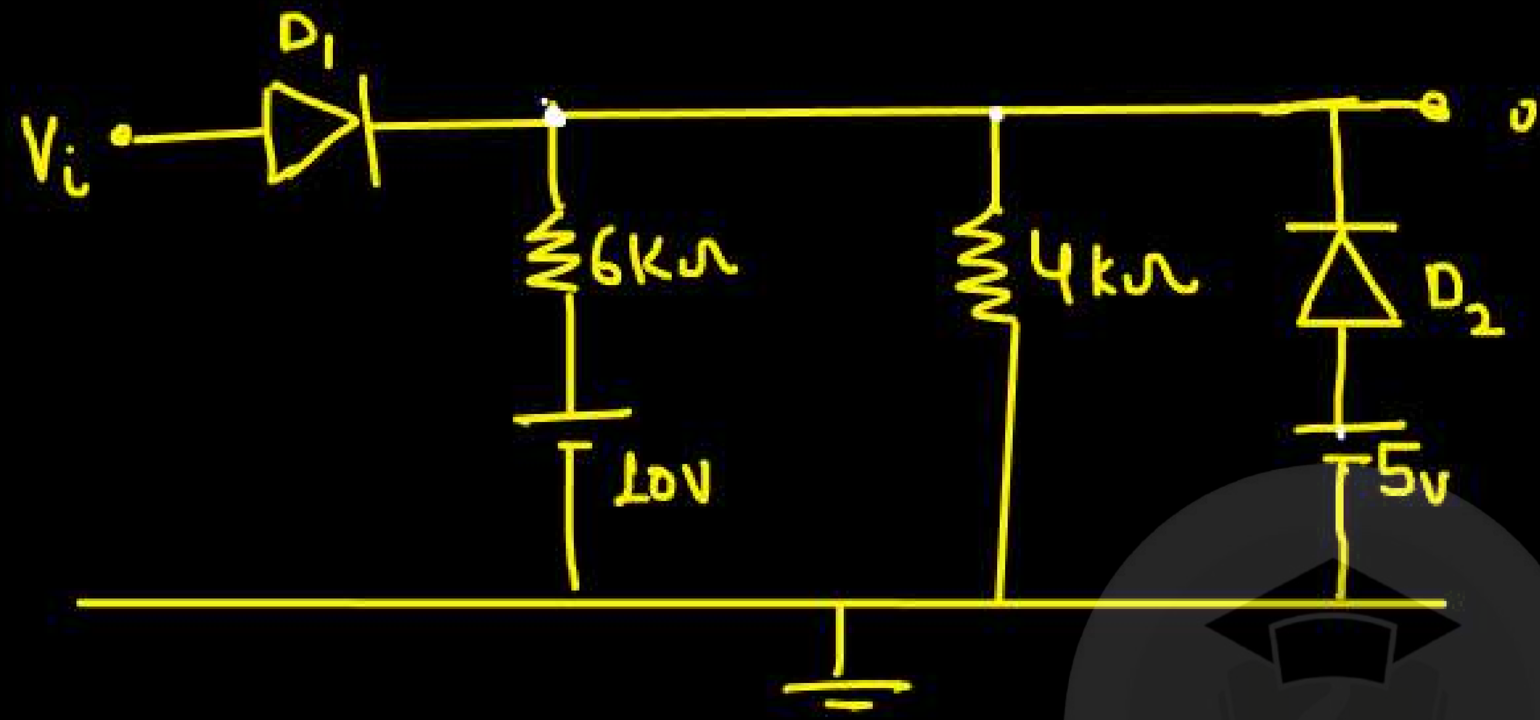
$V_o = \min(2, 1) = 1V$

$$\boxed{V_o = \min(V_i, 1)}$$

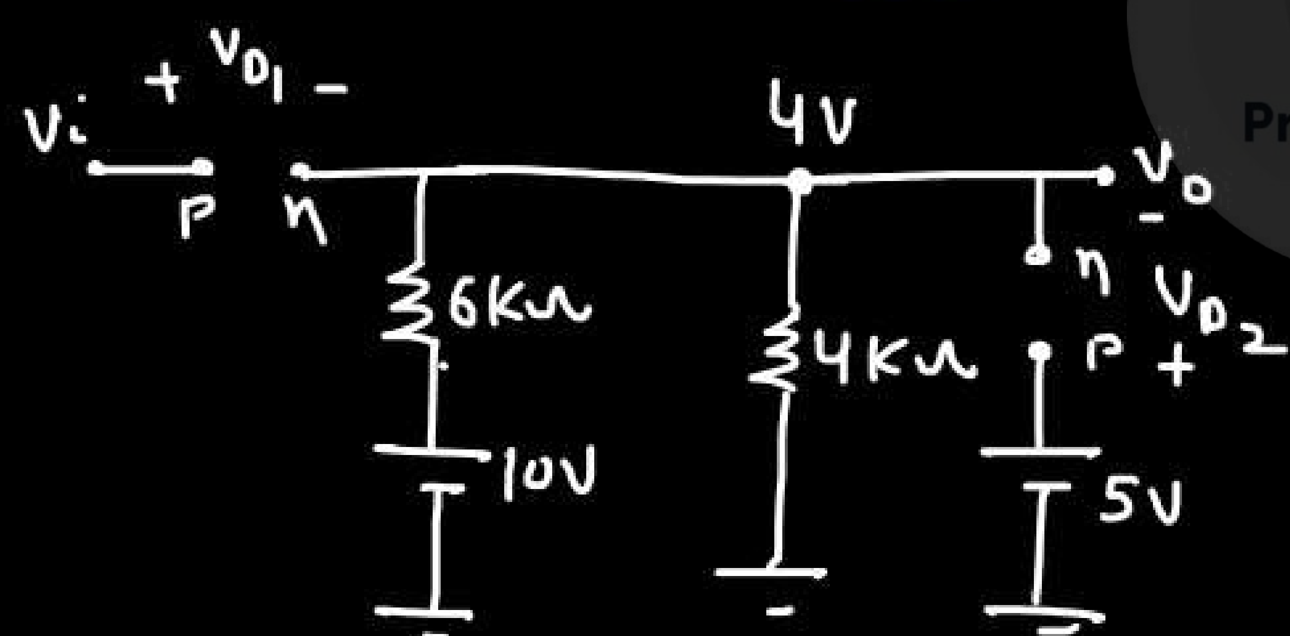
✓

PrepFusion

Q. Draw VTC.



→

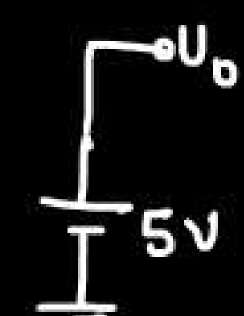


$V_{D_1} = V_i - 4$

$V_{D_2} = 1V$

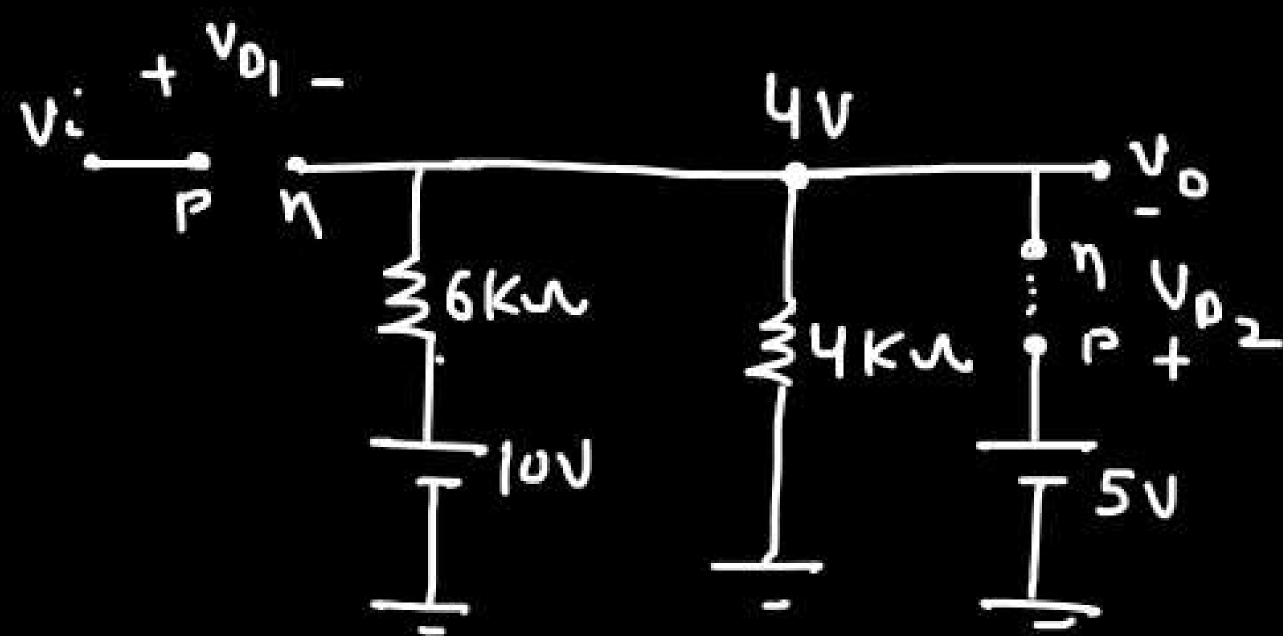
(i) $V_i < 4V \Rightarrow$ diode D_1 off

diode D_2 = ON



$\boxed{V_o = 5V}$

(ii) $4V < V_i < 5V$



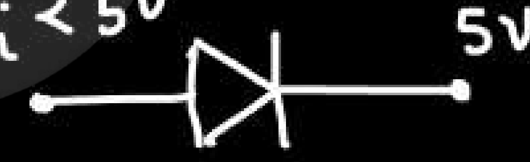
$V_{D_2} = 1V$

$V_{D_1} = V_i - 4$

$\{\text{if } 4 < V_i < 5 \Rightarrow V_{D_1} < 1V\}$

$\Downarrow$

D_2 will turn ON first and then we will decide the cond^n of D_1

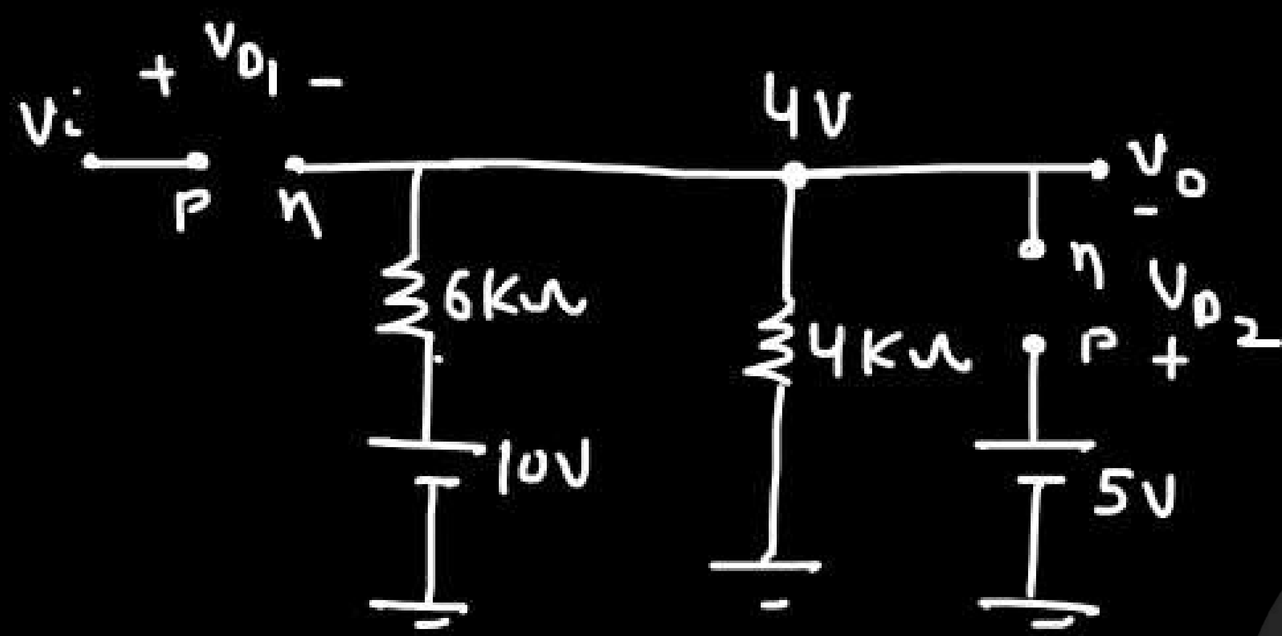


↳ diode D_1 goes off

$$\boxed{V_0 = 5V}$$

$$\Rightarrow \boxed{V_i < 5V \Rightarrow V_0 = 5V}$$

(iii) $V_i > 5V$



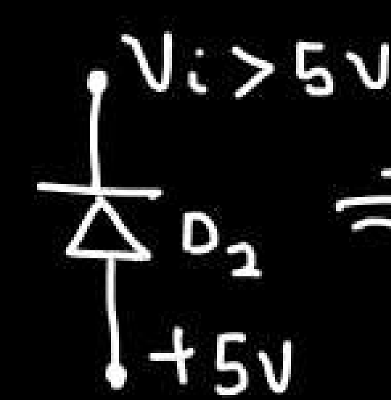
$V_{D_1} = V_i - 4$

$V_{D_2} = 1V$

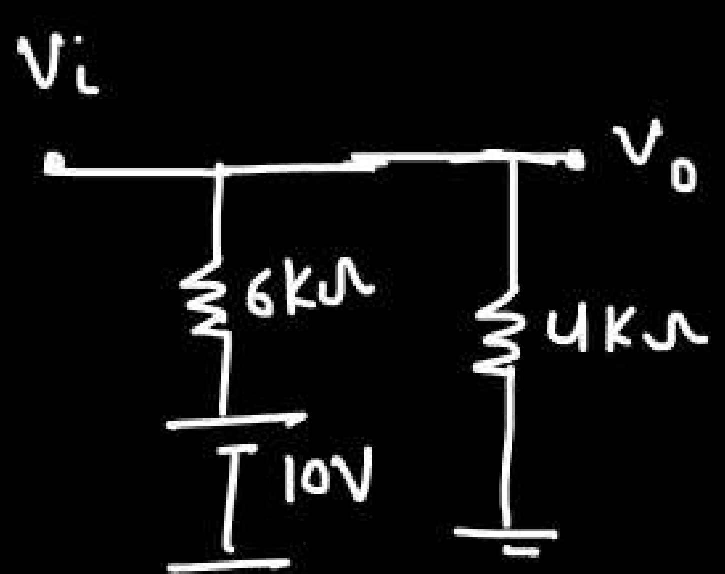
$V_{D_1} > 1V \; \{ V_i > 5V \}$

$\Rightarrow V_{D_1} > V_{D_2}$

$\Rightarrow$ first D_1 will turn ON and then we will decide the cond^n of D_2



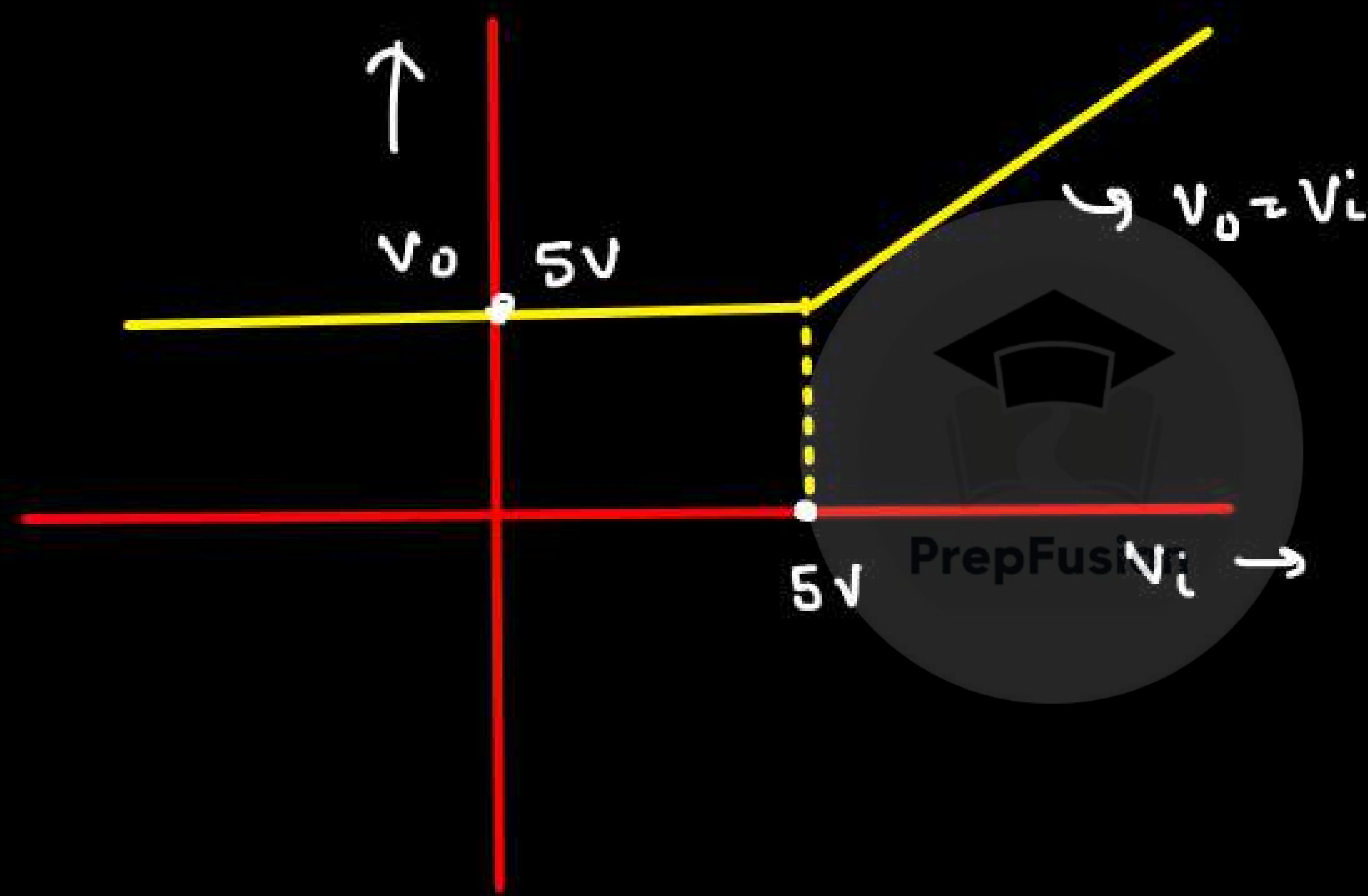
$\Rightarrow$ diode D_2 off



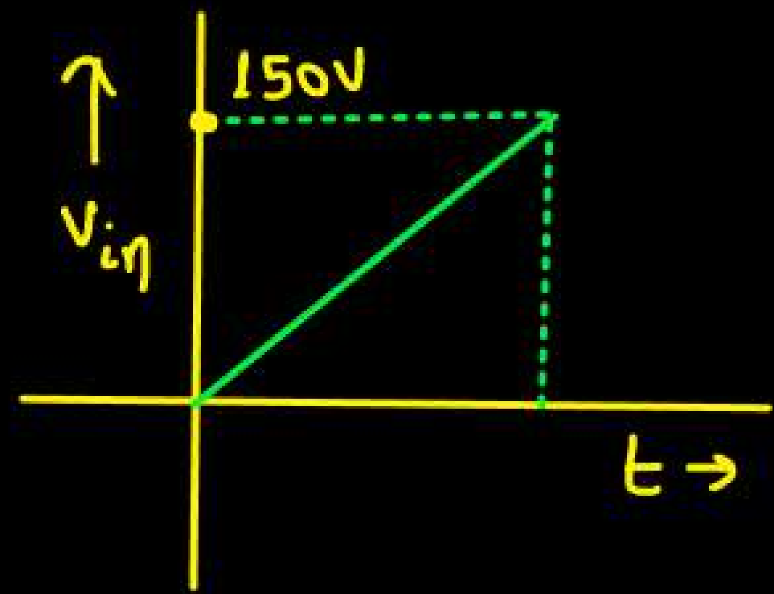
$$\boxed{V_0 = V_i}$$

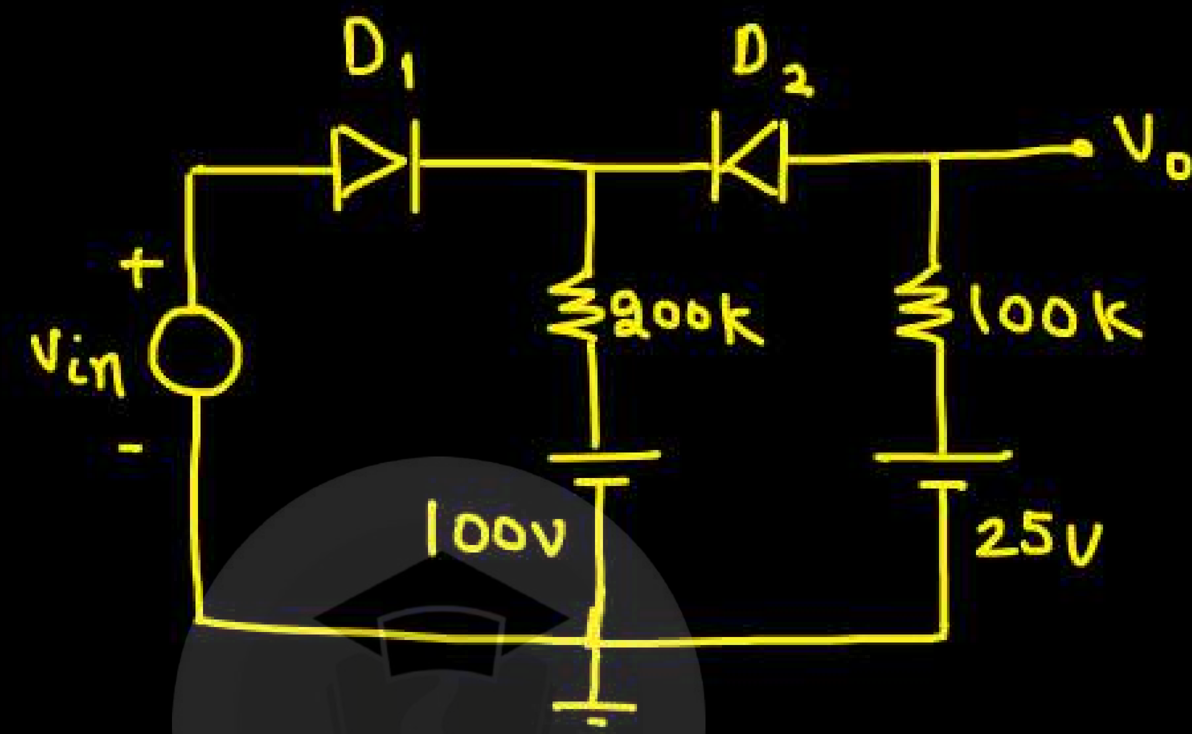
$V_i < 5V \Rightarrow V_0 = 5V$

$V_i > 5V \Rightarrow V_0 = V_i$



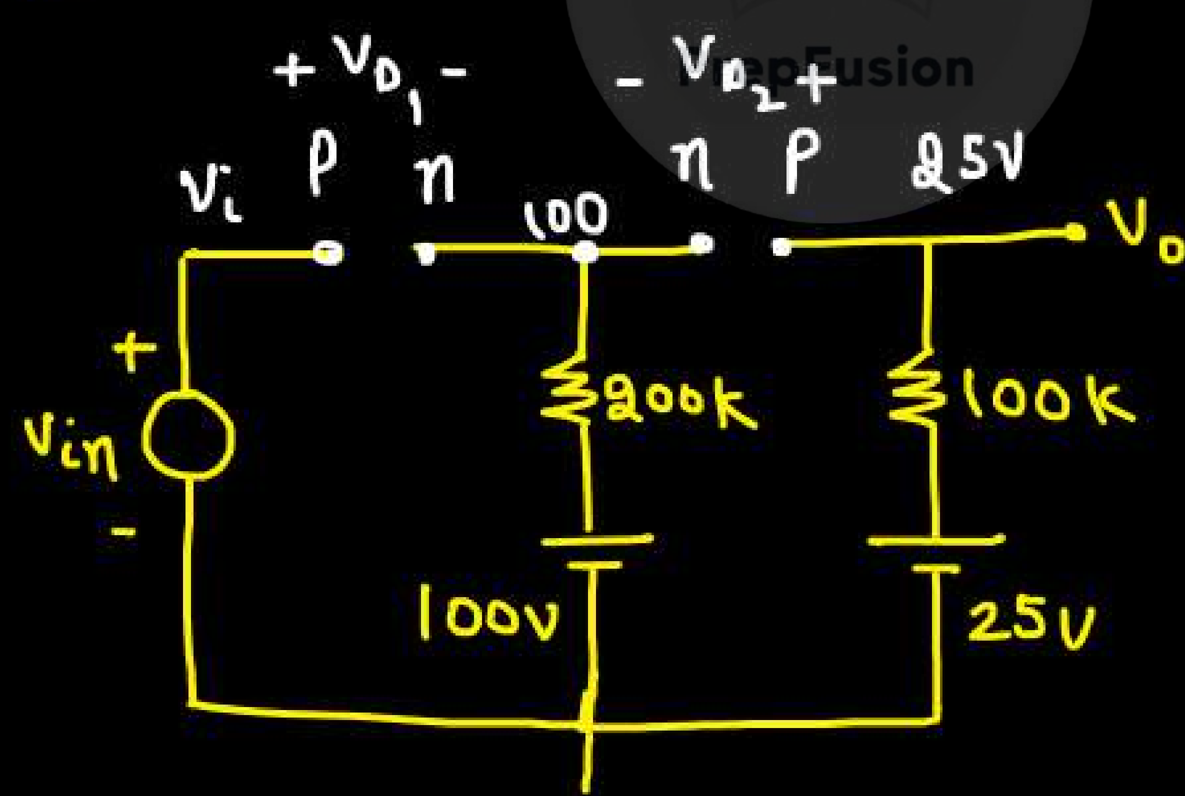
Q.





Draw VTC.

→ O.C. Test



(i) $\boxed{V_i < 100V}$

$V_{D_1} = V_i - 100$

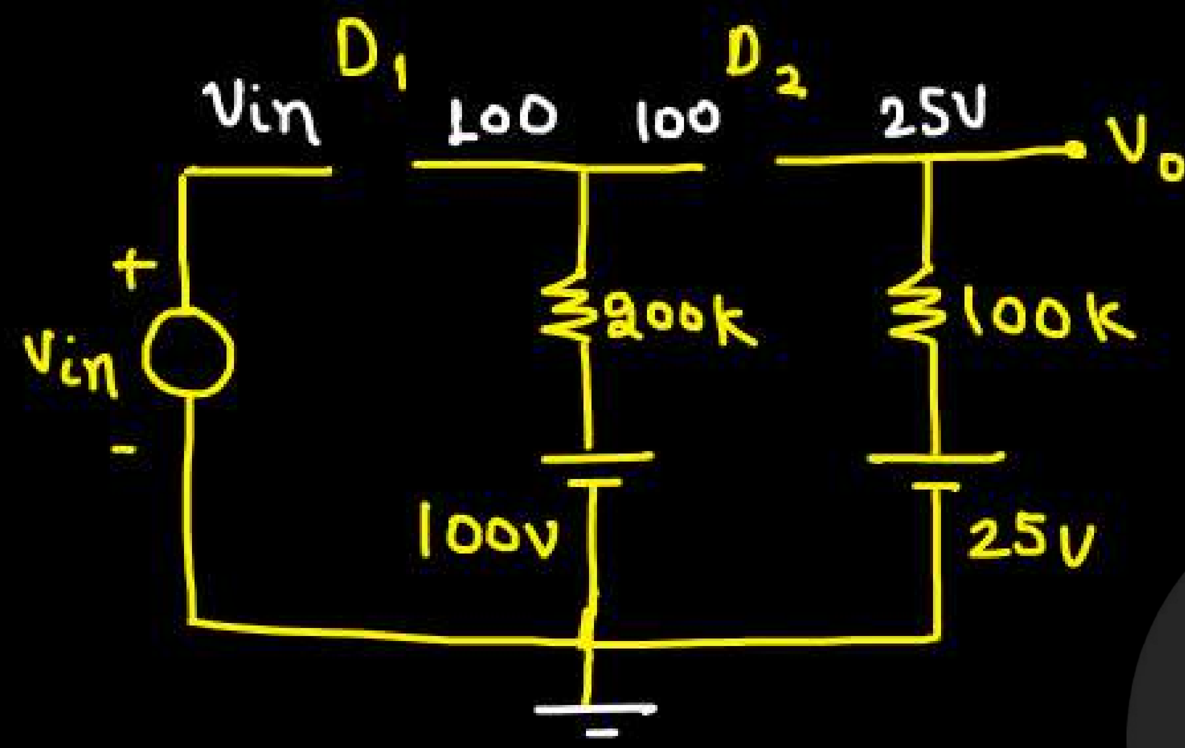
$V_{D_2} = -75V$

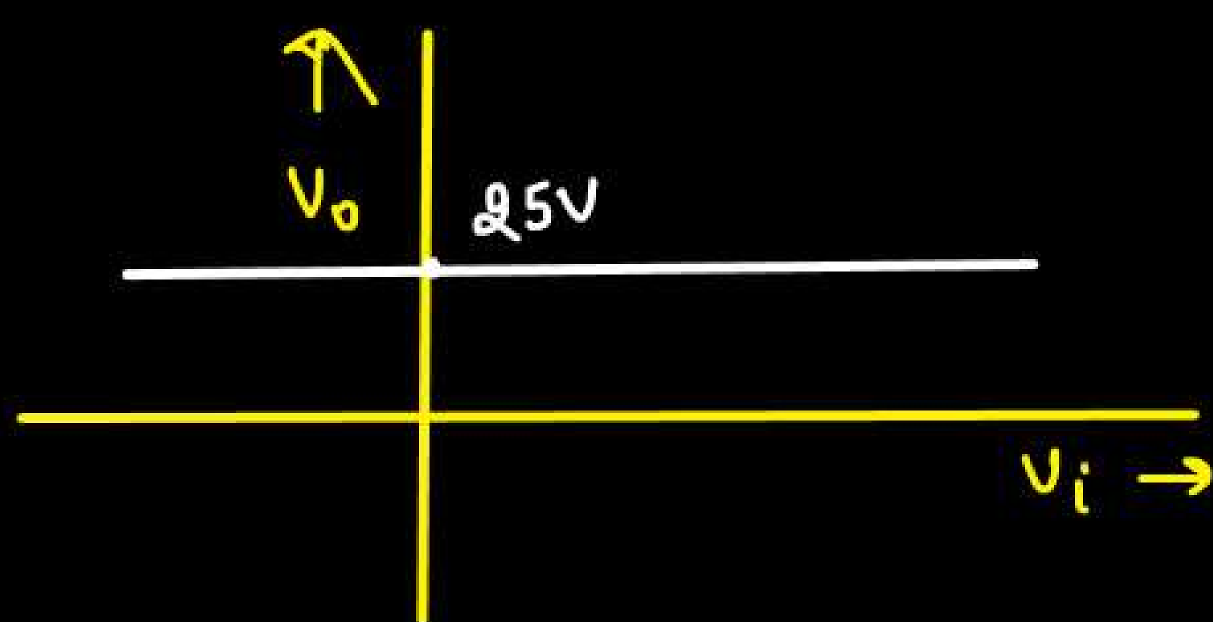
$\Rightarrow D_2$ is off

D_1 is off

$\Rightarrow \boxed{V_o = 25V}$

(ii) $V_i > 100V$



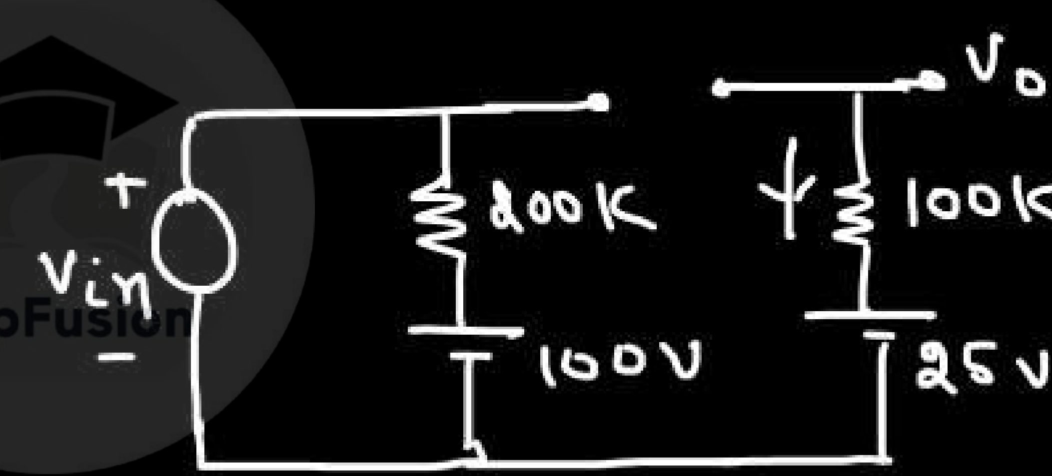


$V_{D_2} = -75V \rightarrow D_2$ off

$V_{D_1} = V_{in} - 100$

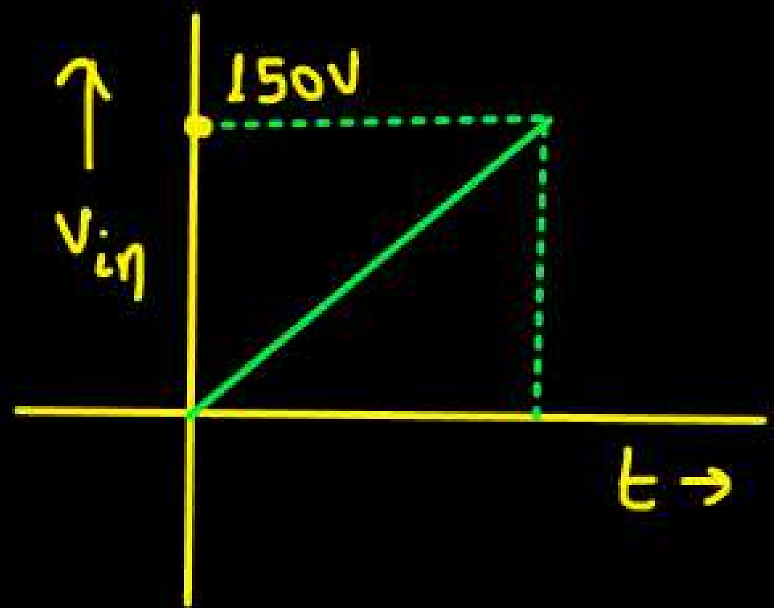
$\Downarrow$

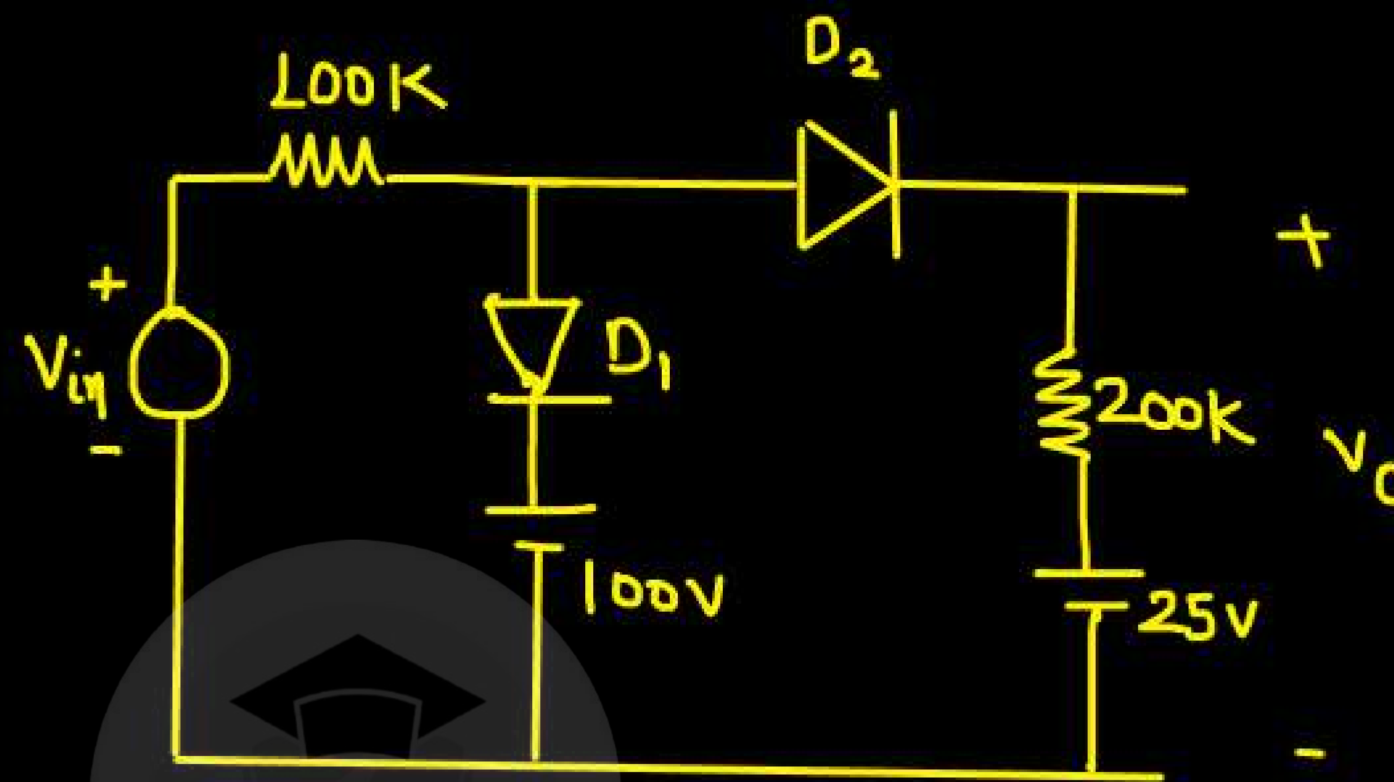
D_1 ON



$\boxed{V_0 = 25V}$

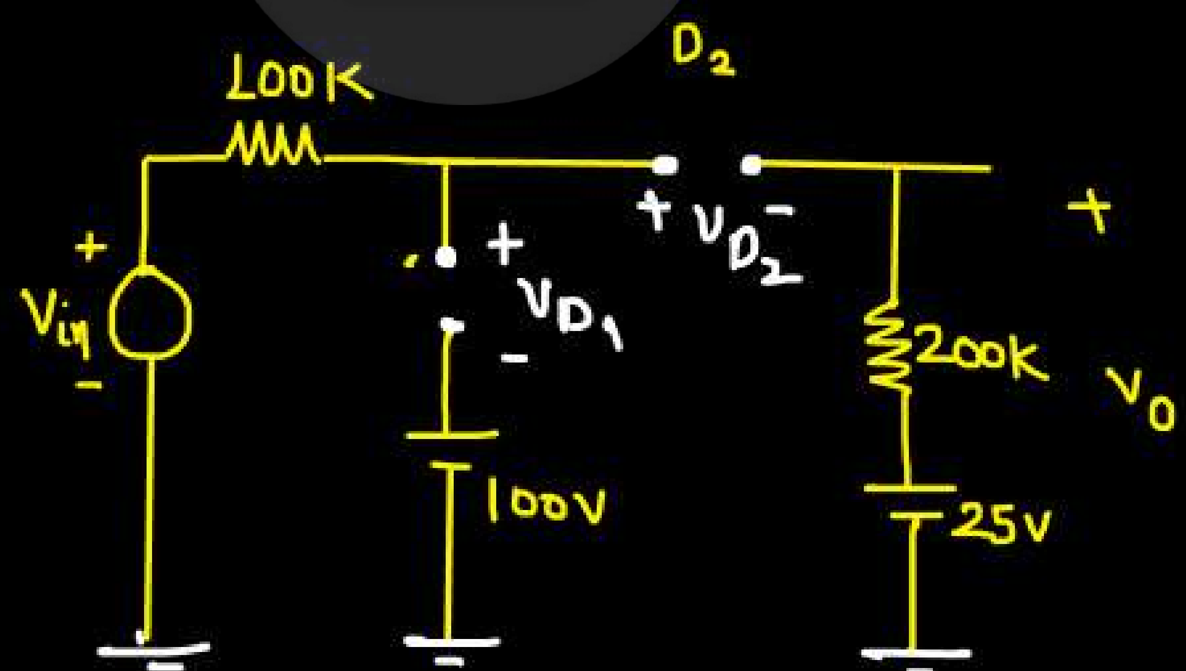
Q.





Draw VTC.

→ Apply O.C. Test



(i) $V_i < 25V$

$V_{D_1} = V_i - 100$

$V_{D_2} = V_i - 25$

$\Rightarrow D_1$ and D_2 off

$\boxed{V_o = 25V}$

(ii) $25 < v_i < 100V$

$v_{D_1} = V_{in} - 100V$

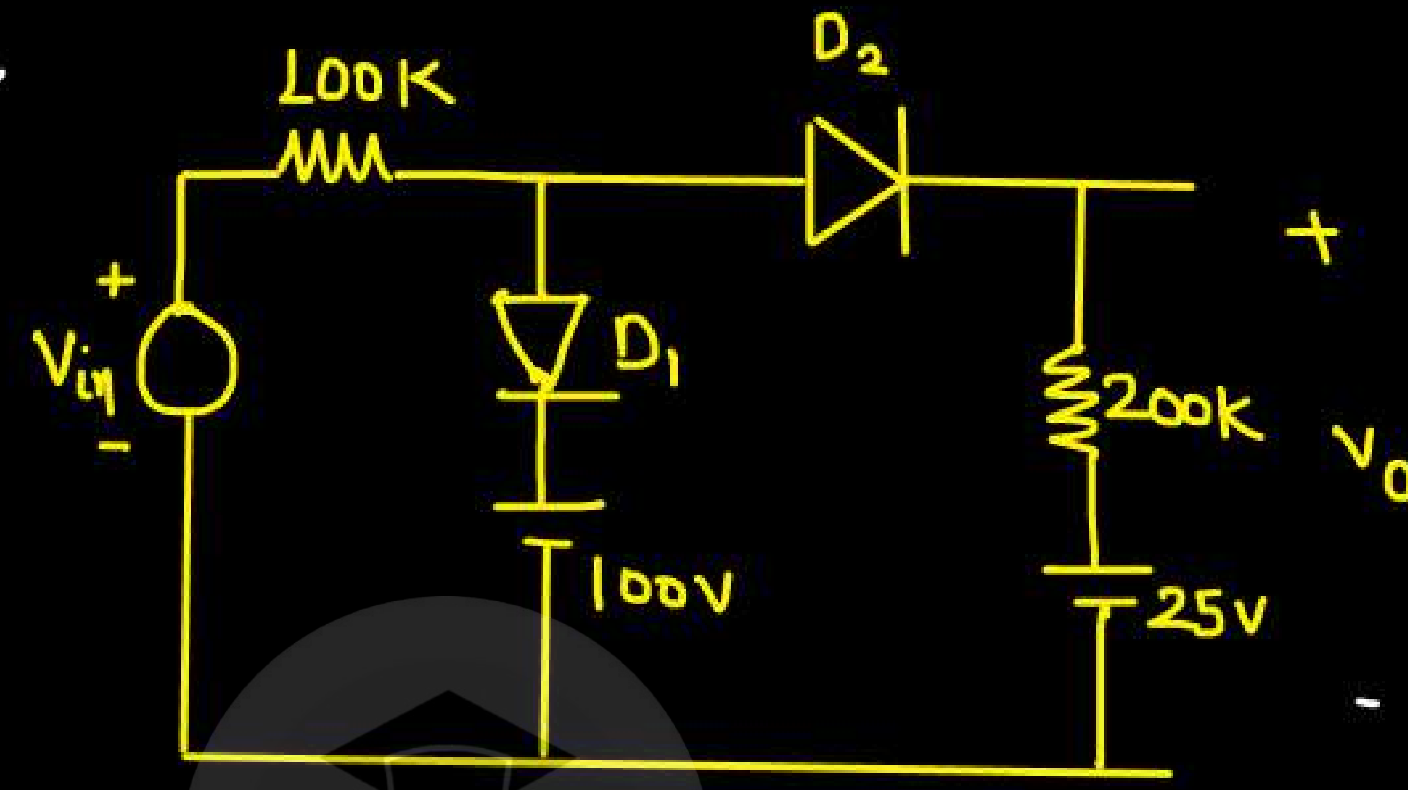
$v_{D_2} = V_{in} - 25V$

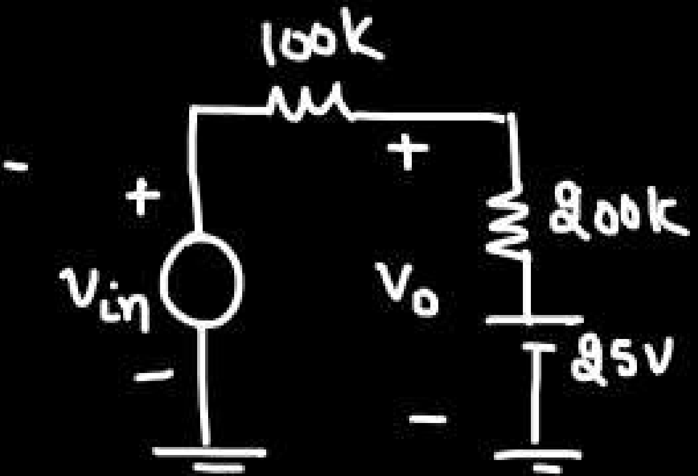
$\Downarrow$

D_2 turns ON

D_1 turns off

$$\boxed{V_o = \frac{2V_{in} + 25}{3}}$$



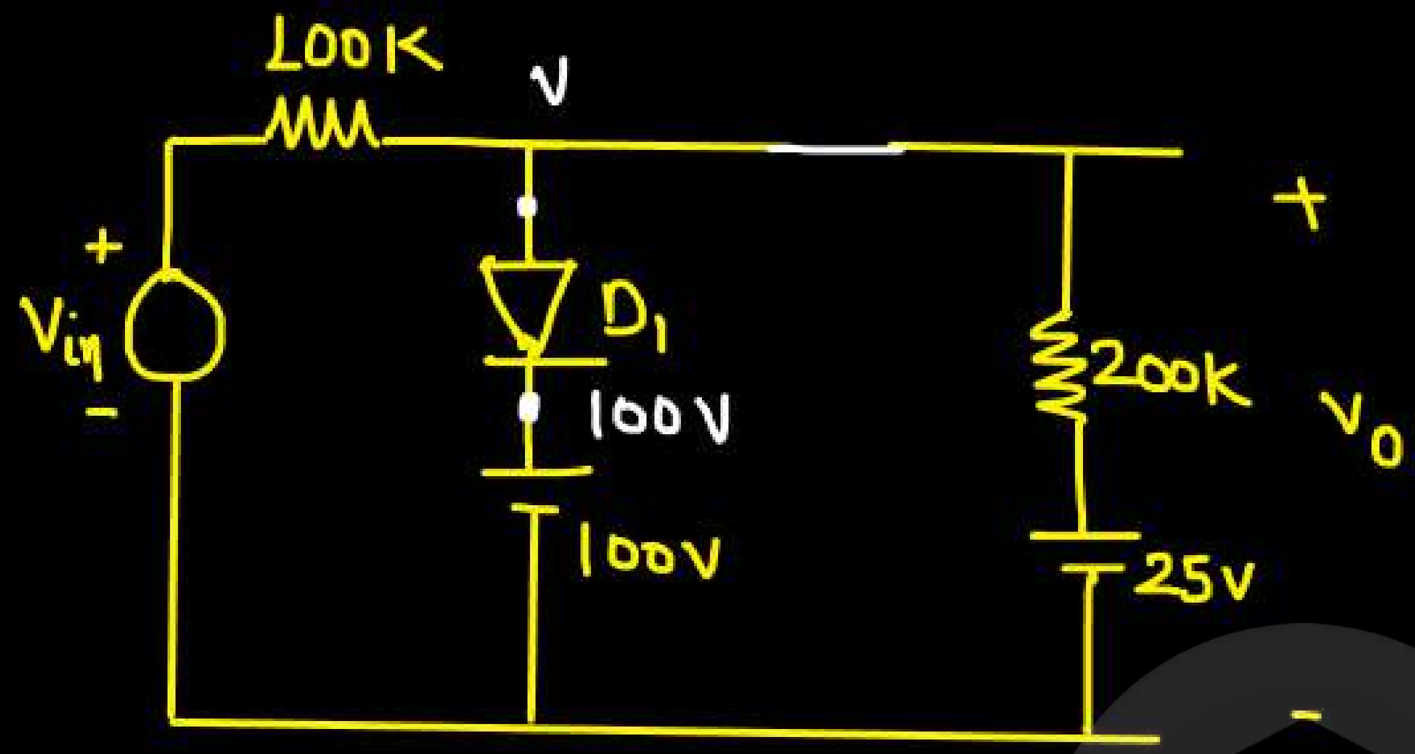


(iii) $V_i > 100V$

$v_{D_1} = V_{in} - 100 \Rightarrow +ve$

$v_{D_2} = V_{in} - 25 \Rightarrow +ve$

$\Rightarrow$ Here $v_{D_2} > v_{D_1} \Rightarrow$ So, first D_2 turns on, then we will decide about D_1.



$$\frac{V-25}{200k} + \frac{V-V_{in}}{100k} = 0$$

$$3V - 25 = 2V_{in}$$

$$\boxed{V = \frac{2V_{in}+25}{3}}$$

$$V_{0_1} = \frac{2V_{in}+25}{3} - 100$$

if $V_{0_1} > 0 \Rightarrow$ then only D_1 turns ON

$$\frac{2V_{in}+25}{3} > 100 \Rightarrow \boxed{V_{in} > 137.5V}$$

(iii) $100V < V_{in} < 137.5V$

$\Rightarrow$ D_1 is off

D_2 is ON

$$\Rightarrow \boxed{V_o = \frac{2V_{in} + 25}{3}}$$

(iv) $V_{in} > 137.5V$

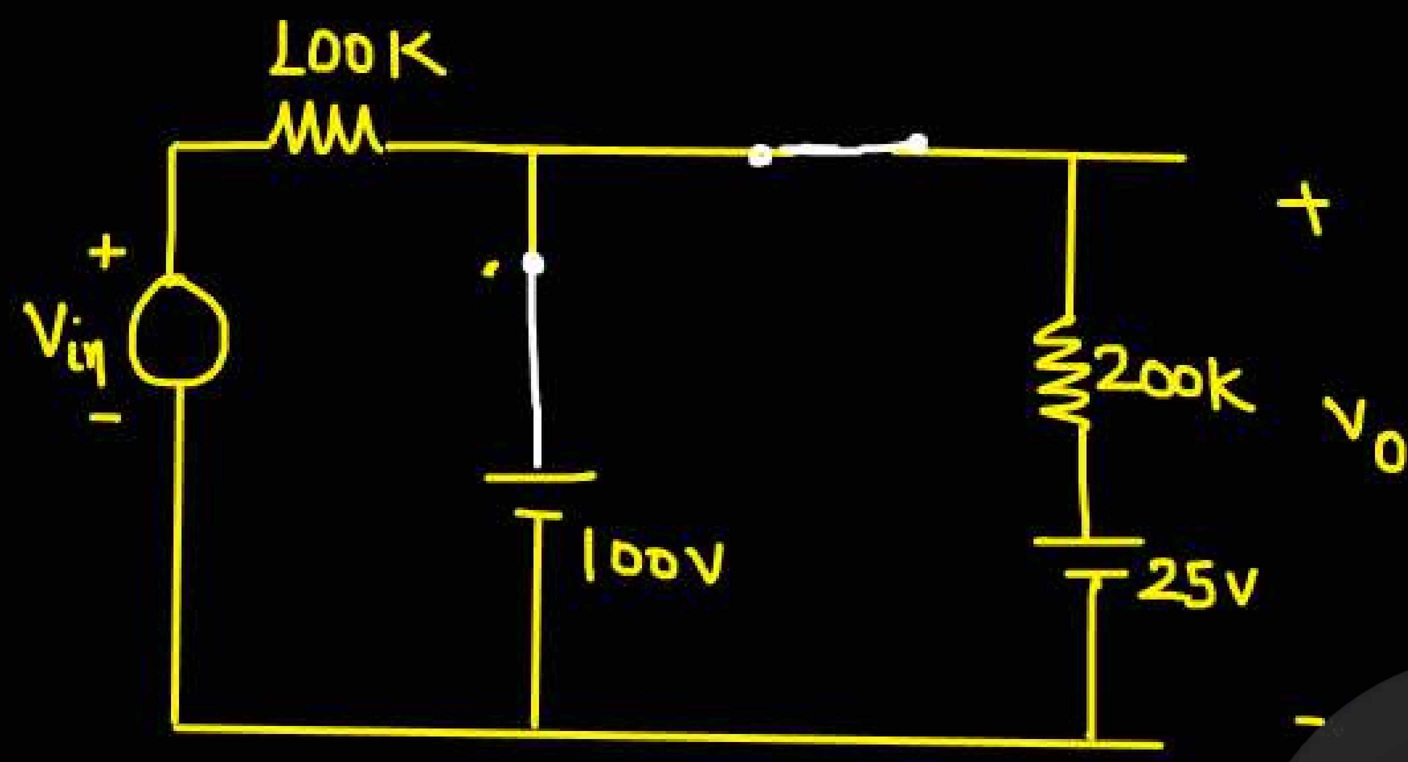
o.c. Test

$V_{D_1} = V_{in} - 100V$

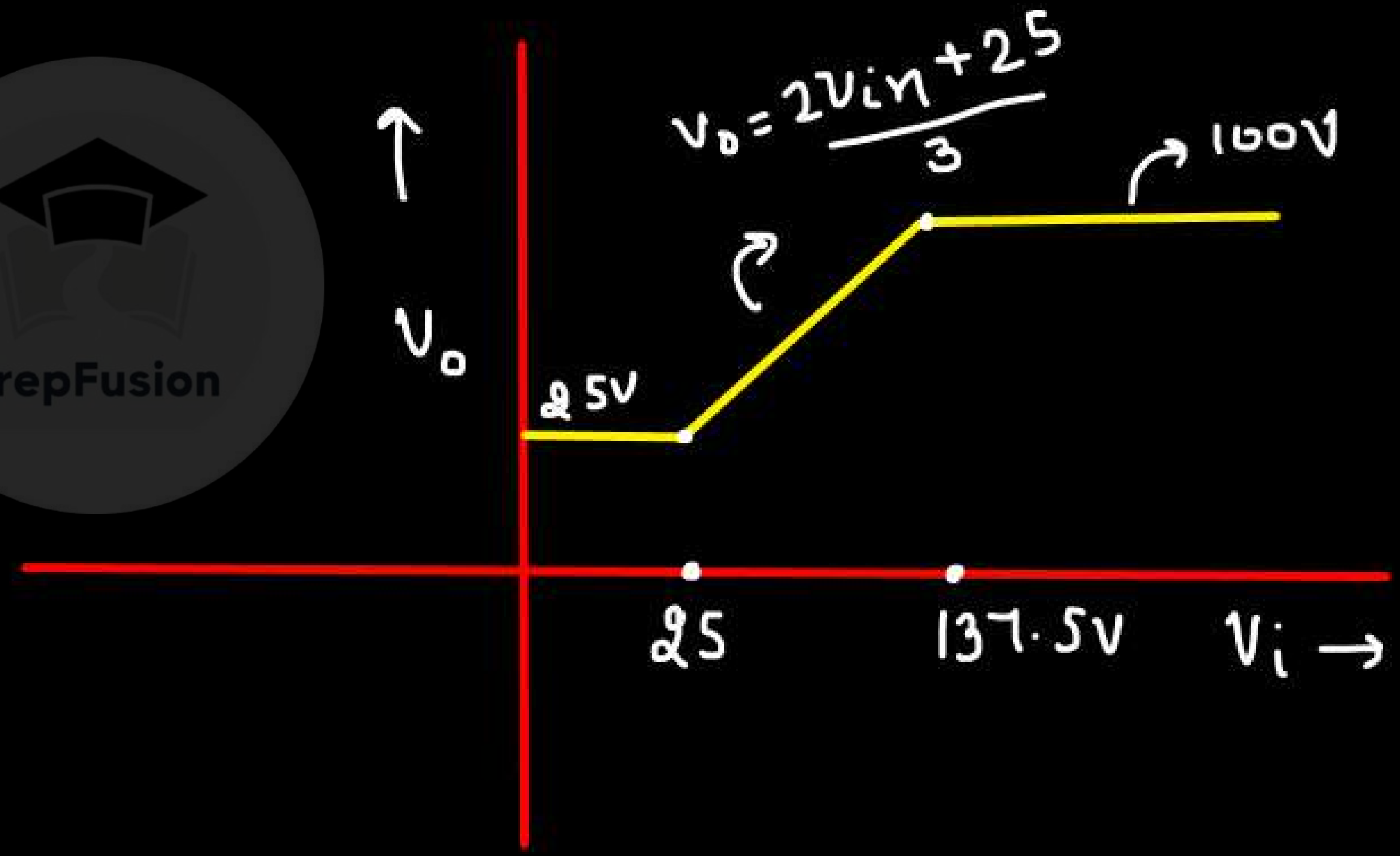
$V_{D_2} = V_{in} - 25V$

$\Rightarrow$ Here, again D_2 will decide the cond^n of D_1.

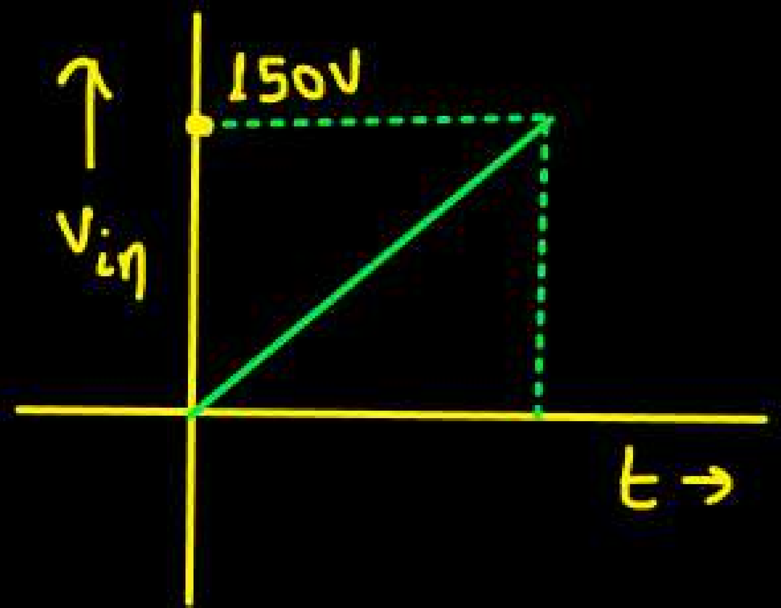
But from previous analysis, we know that D_1 turns ON when $V_i > 137.5V$

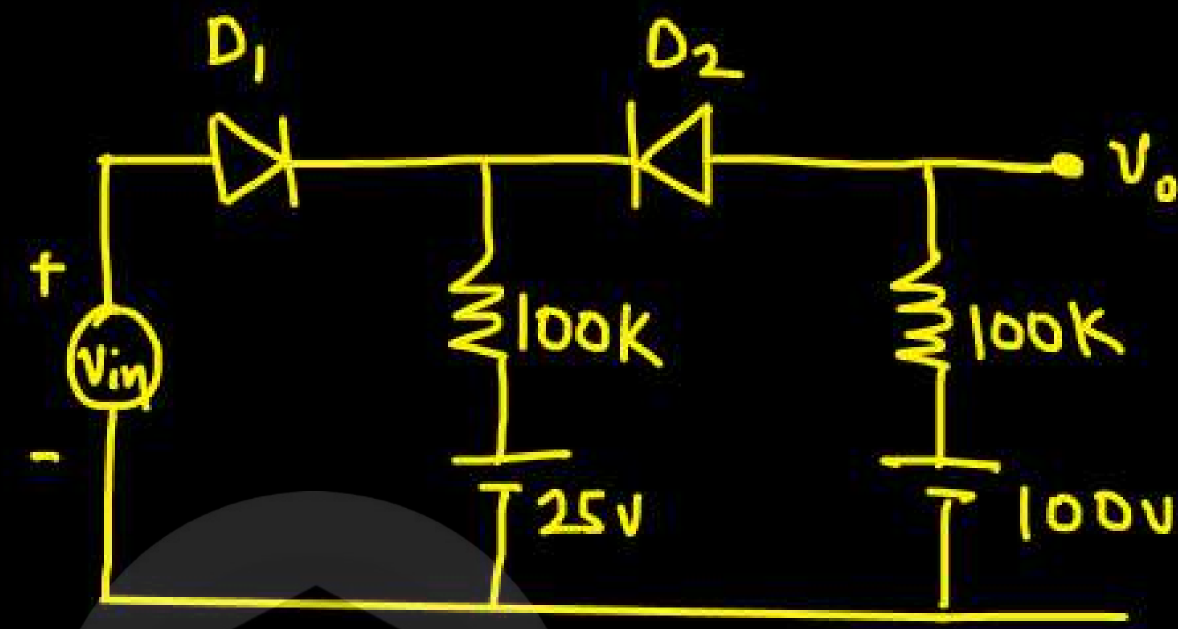


$$\boxed{V_0 = 100V}$$



Q.





Draw VTC.

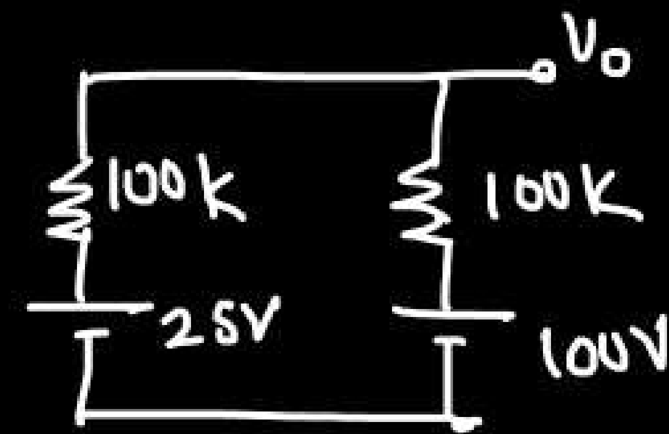
→ O.C. Test. →

(i) $V_{in} < 25V$

$V_{D_1} = V_{in} - 25$

$V_{D_2} = 75V$

⇒ D_1 is off, D_2 is ON ⇒



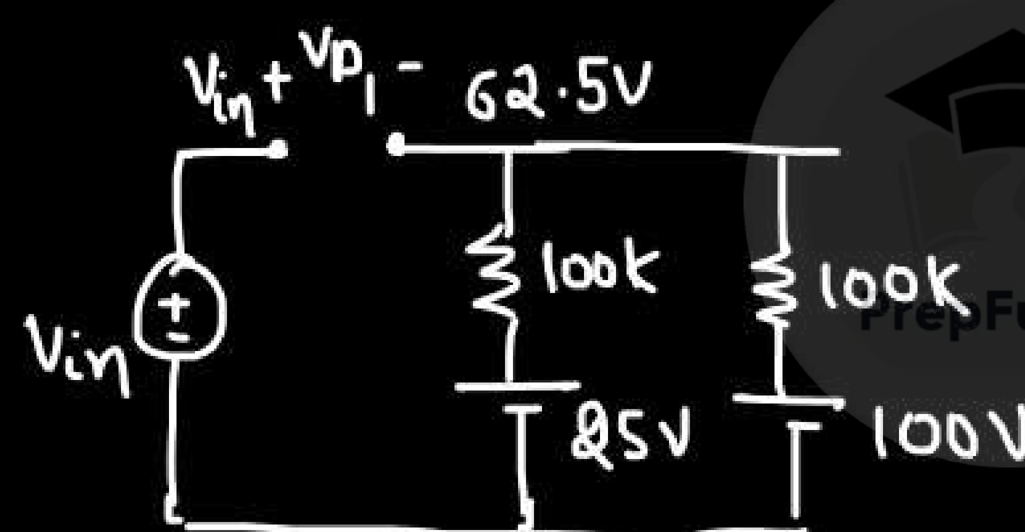
$\boxed{V_0 = 62.5V}$

(iii) $25V < v_i < 62.5V$

$V_{D_1} = v_i - 25V$

$V_{D_2} = 75V$

$\Rightarrow$ Here $V_{D_2} > V_{D_1}$ $\Rightarrow$ first D_2 will turn ON and decide the condⁿ of D_1



$V_{D_1} = V_{in} - 62.5V$

$\Rightarrow V_{in} < 62.5V \Rightarrow D_1$ is off, D_2 is ON $\Rightarrow$ $\boxed{V_0 = 62.5V}$

(iv) $100V > V_i > 62.5V$

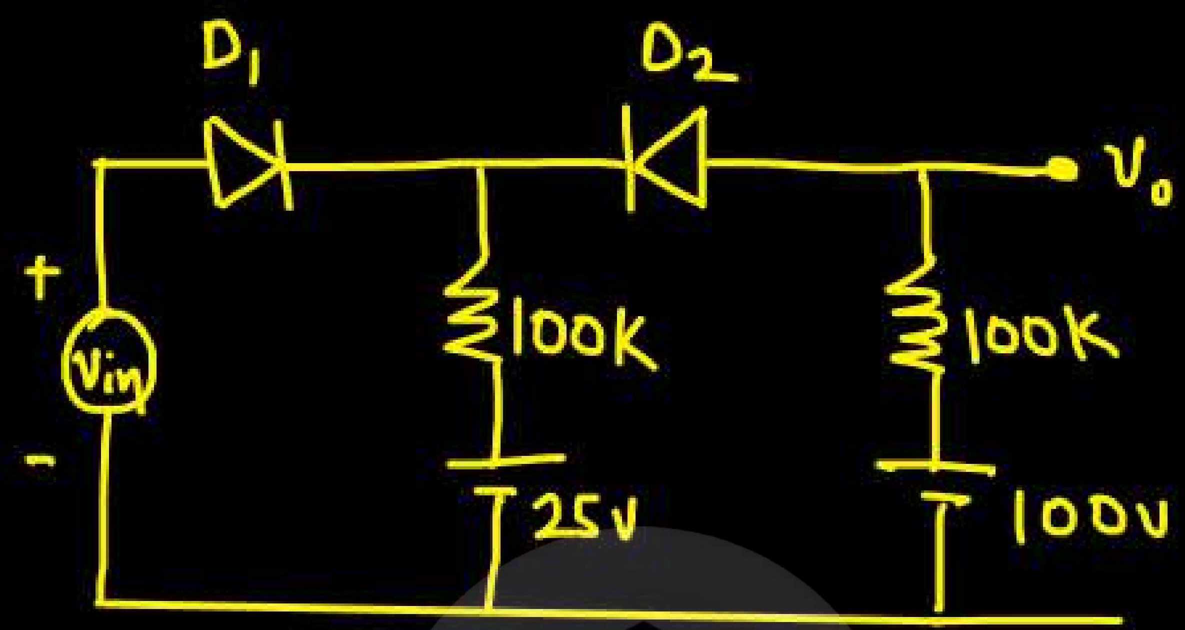
$V_{D_1} = V_{in} - 25$

$V_{D_2} = 75V$

$\Downarrow$

First D_2 turns ON

↳ decide D_1 condn



↳ from prev. analysis, we know D_1 is ON for $V_i > 62.5V$

D_1 and D_2 are ON

$$\boxed{V_o = V_{in}}$$

when D_1 is ON, the o.c. potential across D_2 changes.

$V_{D_2} = V_{in} - 100V$

and if $V_{in} > 100V \Rightarrow D_2$ will be off

(v) $V_{in} > 100V$

$V_{D_1} = V_{in} - 25V$

$V_{D_2} = 75V$

if $V_{in} > 100V \Rightarrow D_1$ will turn ON first and then we will decide the working cond^n of D_2.

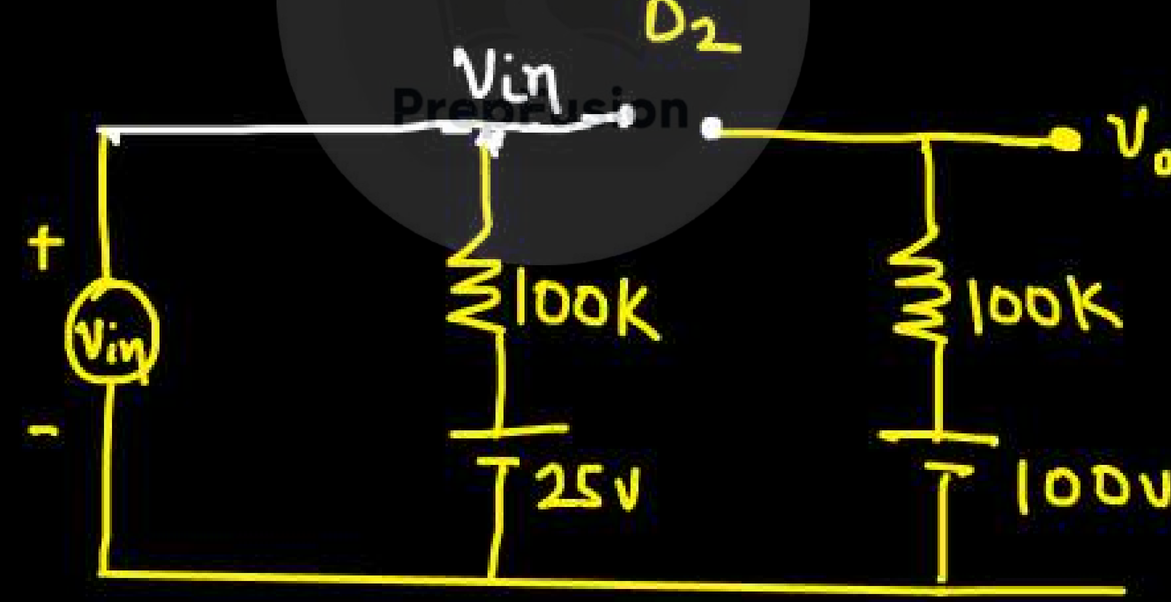
if D_1 turns ON $\Rightarrow$

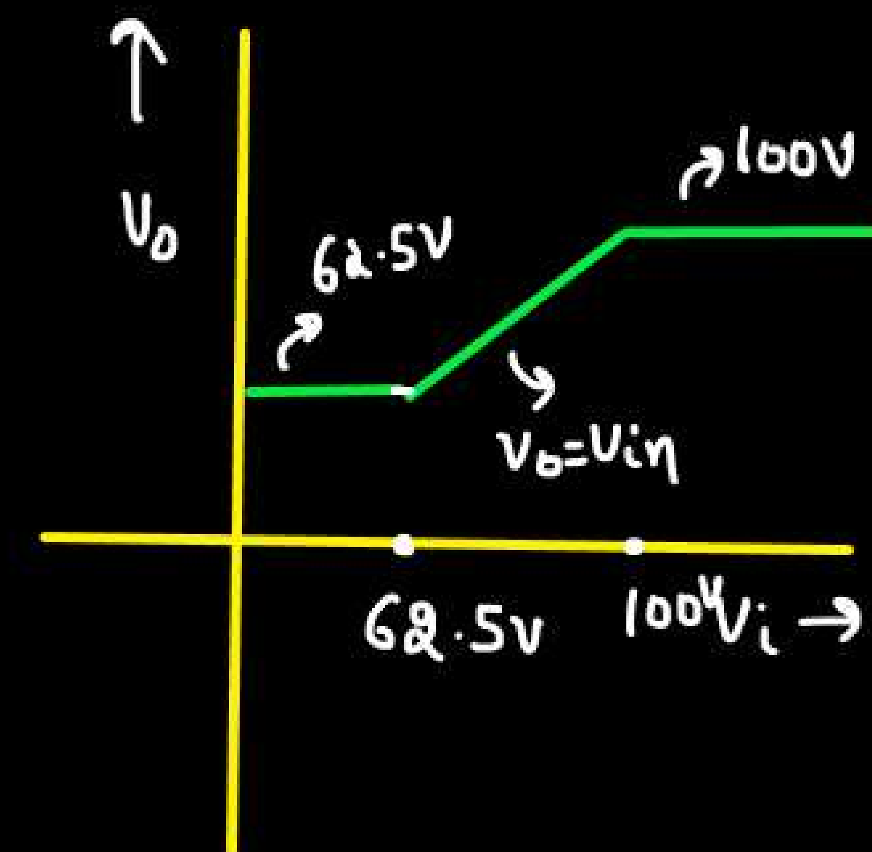
$V_{D_2} = V_{in} - 100$

and for $V_{in} > 100$

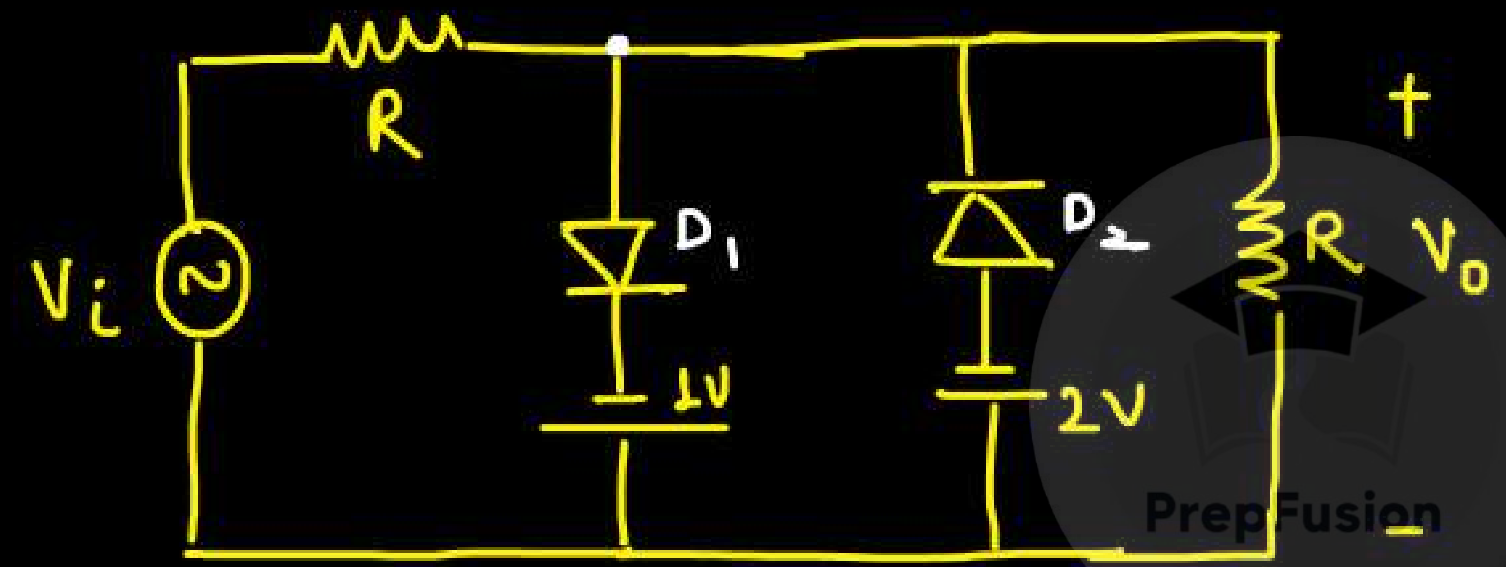
D_2 is off

$\boxed{V_0 = 100V}$



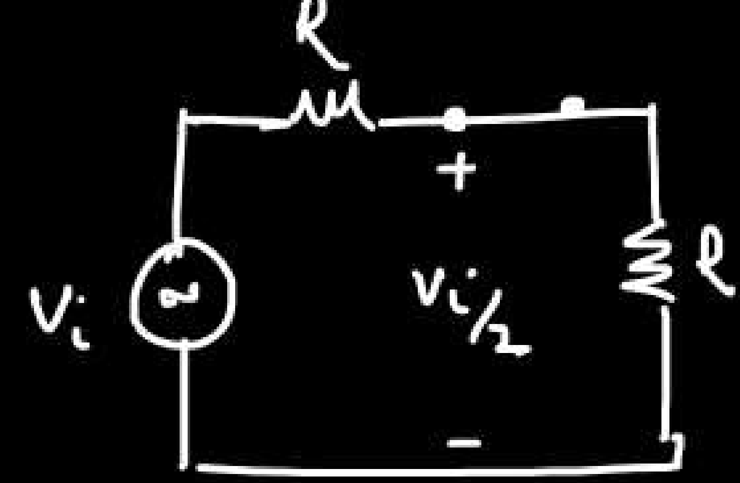


Q. For o/p to be clipped, the i/p V_i should lie out of what range?



→ $V_{D_1} = V_i/_2 + 1$

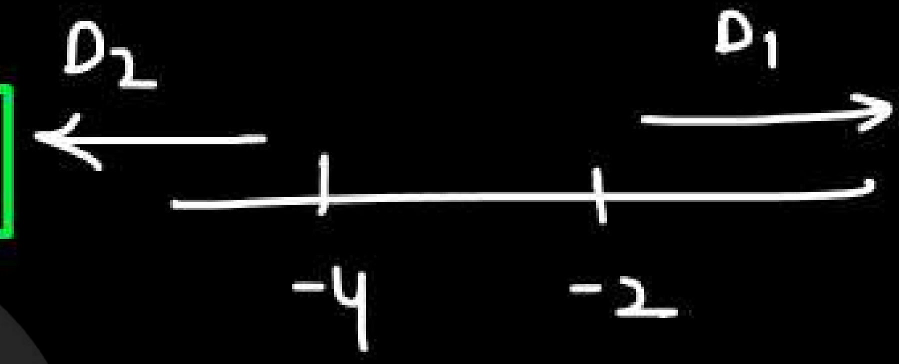
$V_{D_2} = -2 - V_{in}/_2$



$$V_{D_1} = \frac{V_{in}}{2} + 1$$

$$V_{D_2} = -2 - V_{in}/2$$

$$\Rightarrow \frac{V_{in}}{2} + 1 > 0 \Rightarrow \underline{\underline{V_{in} > -2}} \Rightarrow \boxed{V_0 = -1V}$$



$\Downarrow$

D_1 turns ON

D_2 turns off

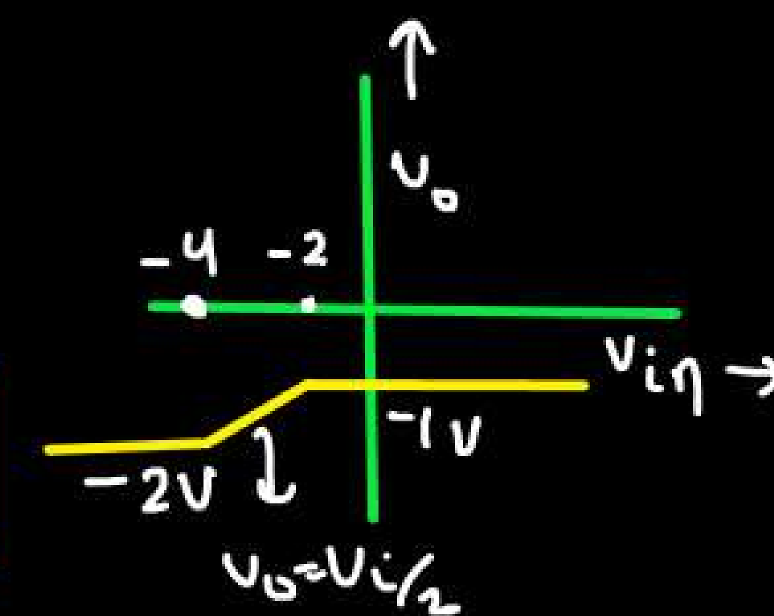
$$\Rightarrow -2 - \frac{V_{in}}{2} > 0 \Rightarrow \frac{V_{in}}{2} < -2 \Rightarrow \underline{\underline{V_{in} < -4}} \Rightarrow \boxed{V_0 = -2V}$$

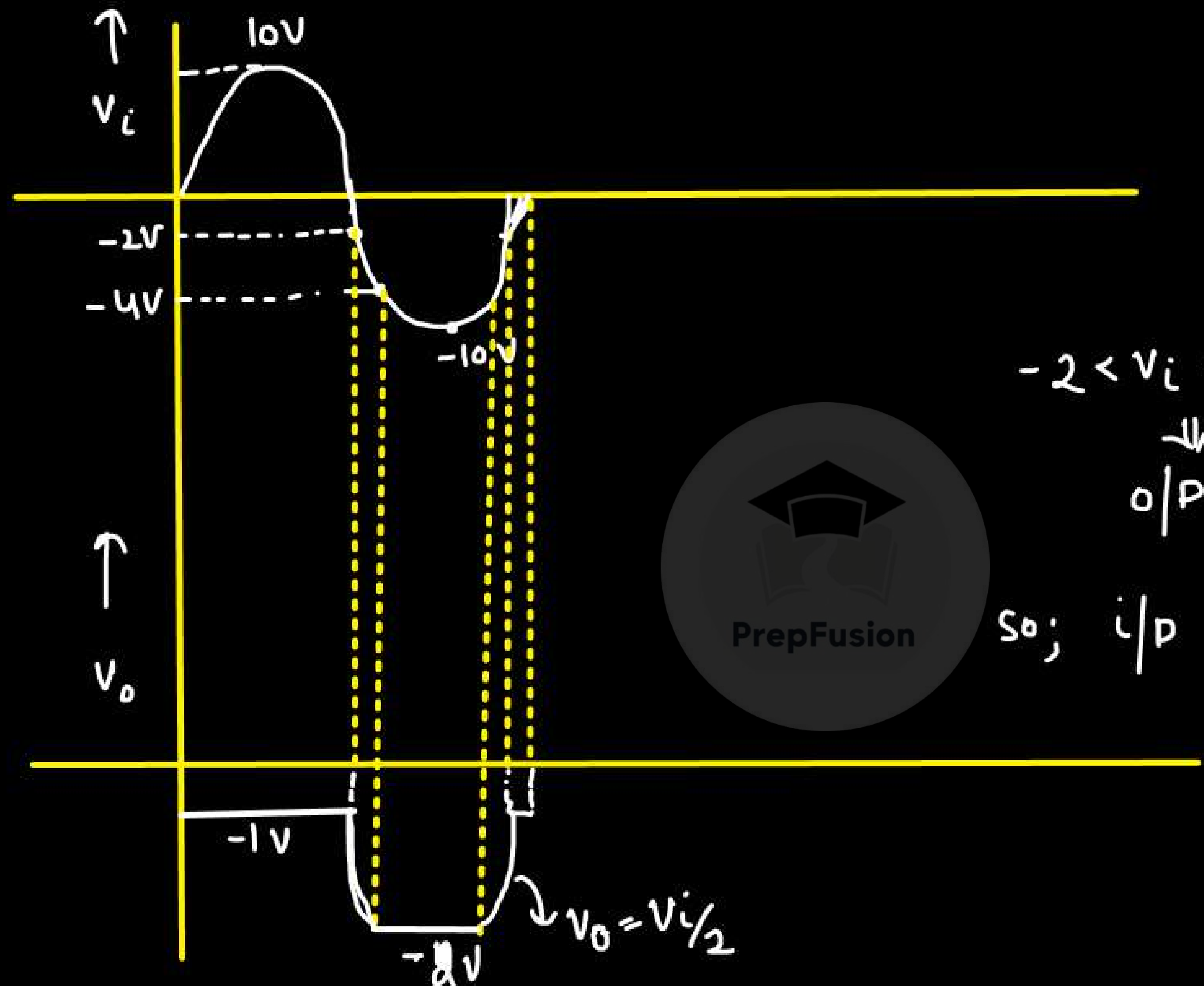
$\Downarrow$

D_2 turns on

D_1 turns off

$$\Rightarrow -2 < V_{in} < -4 \Rightarrow D_1 \text{ and } D_2 \text{ off} \Rightarrow \boxed{V_0 = V_i/2}$$





$-2 < v_i < -4$

$\Downarrow$

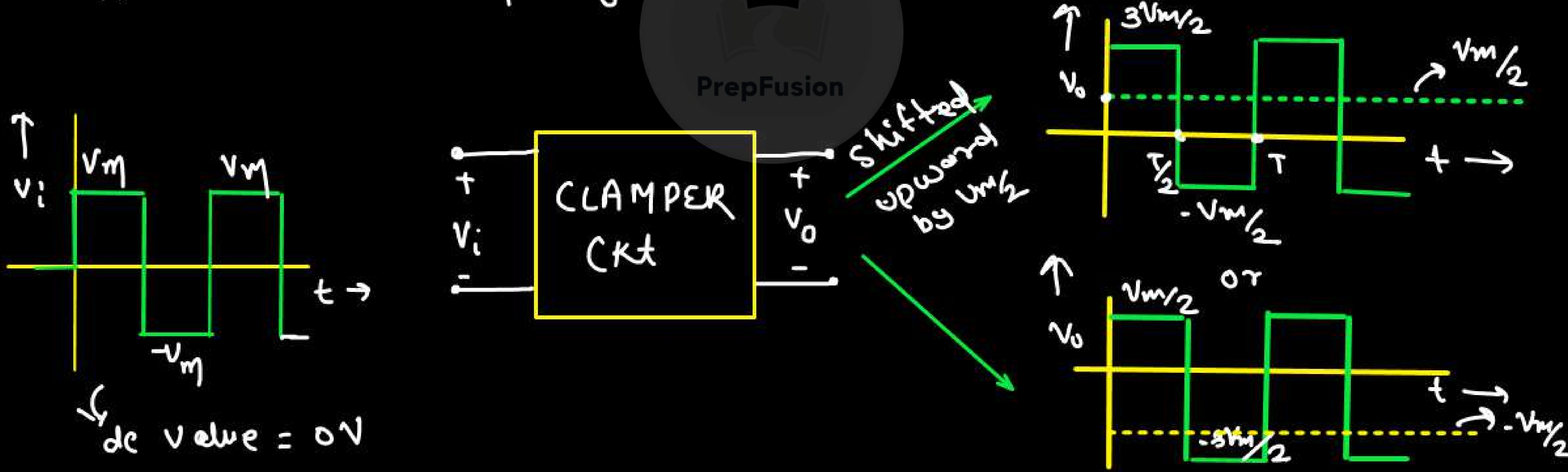
o/p is not clipped.

so; i/p should lie out of the range -2 to -4V if it wants to be clipped.

CLAMPER CIRCUIT

Definition :-

Circuit that shift the waveform of input signal to a desired reference dc level without changing the actual appearance of the i/p signal.



Classification

Positive clamper

↓ shifts the waveform upward

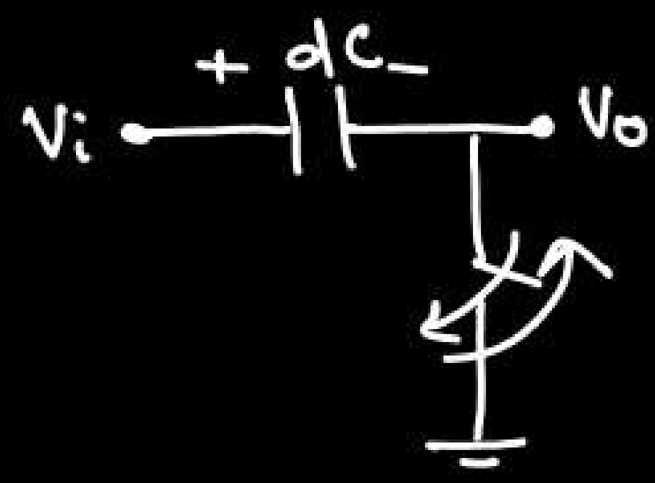
Negative clamper

↳ shifts the waveform downward

Clamper ckt with some bias

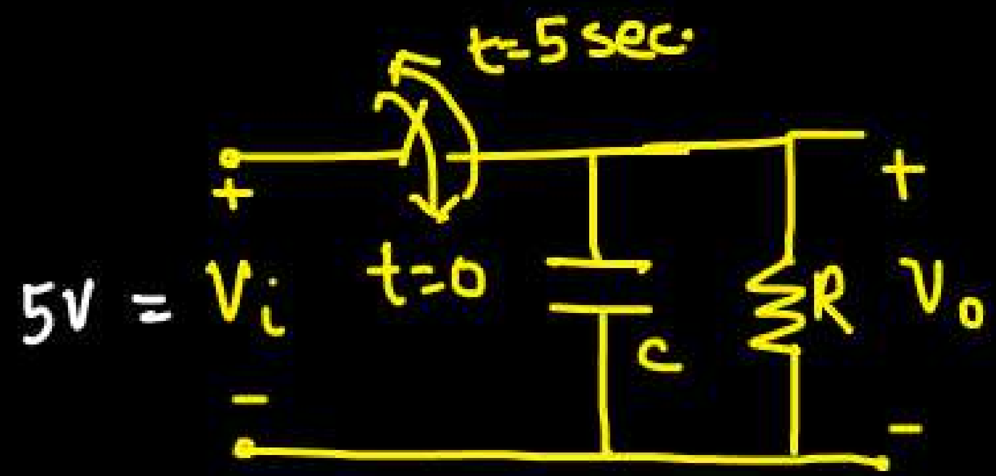
↳ Think of the ckt?

$V_o = V_i + \text{dc value}$



$\Rightarrow$ diode

✯ Revision Question :-

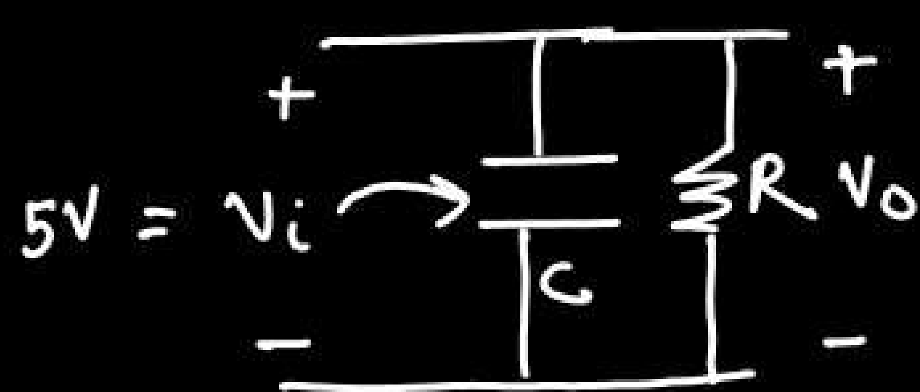


Find V_o at $t = 0^+$ sec., 1 sec., 5^- sec., 10 sec., 20 sec., 5^+ sec.

$RC = 50K$ sec.

switch is first closed @ t=0 and opened again @ t= 5 sec.

→ $0 < t < 5$ sec.

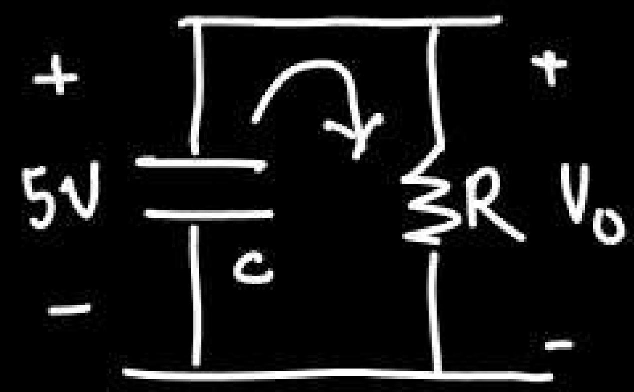


$V_o(t = 0^+) = 5V$

$V_o(t = 1) = 5V$

$V_o(t = 5^-) = 5V$

$t > \underline{\underline{5}}\ \text{sec.}$



$$v_o(t) = 5e^{-t/RC}$$

$RC = 50K$ sec.

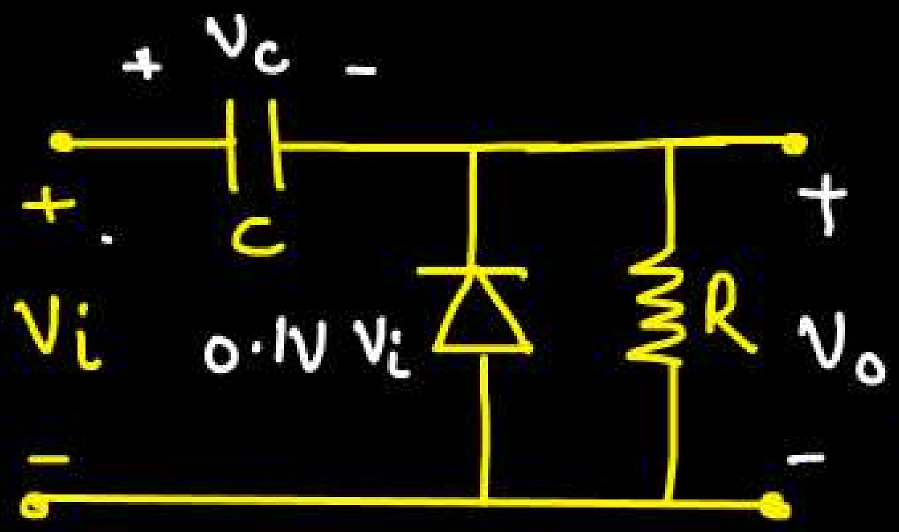
$= 50 \times 10^3$ sec.

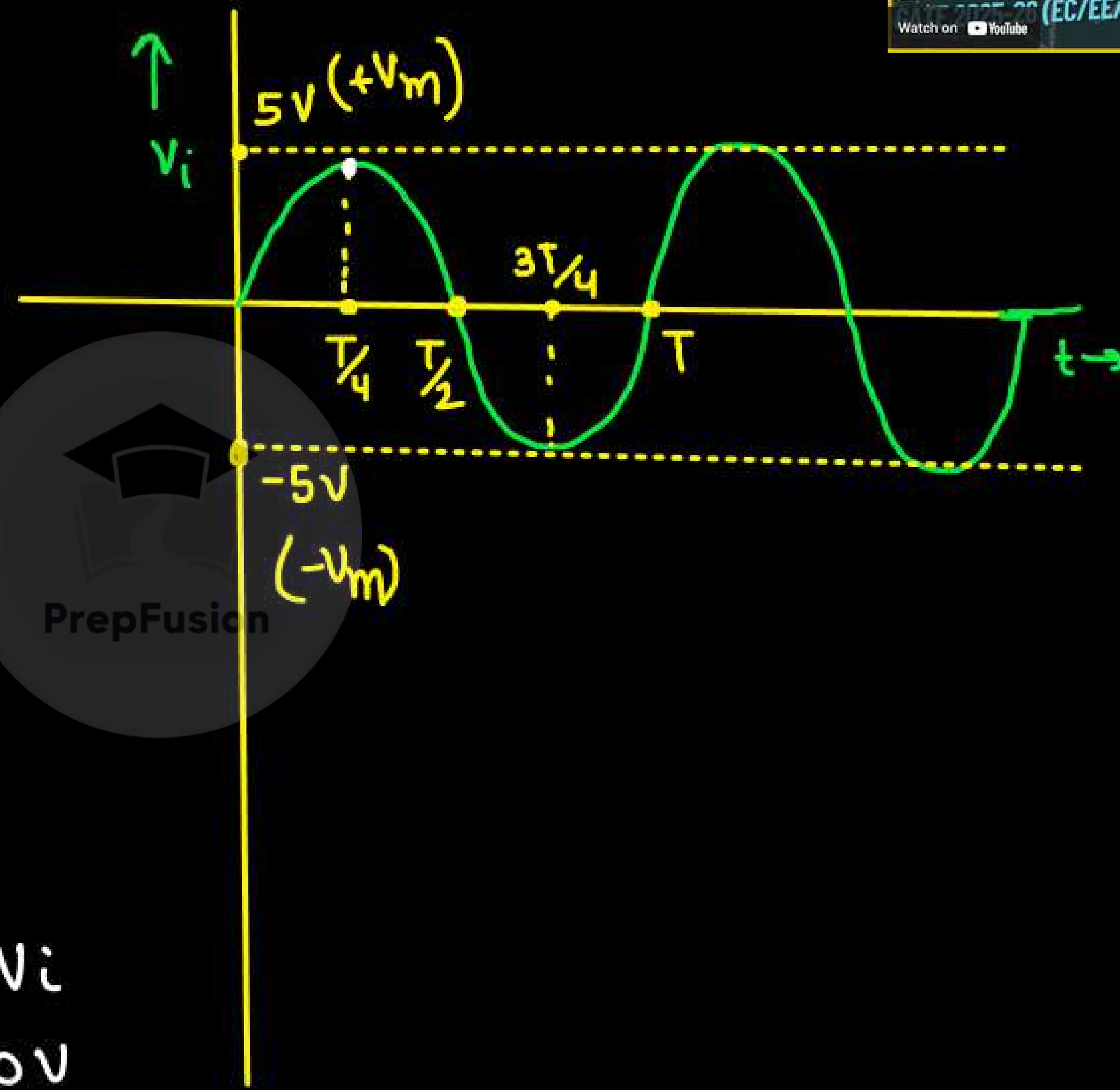
↳ very large

since RC is very large, cap. will not discharge very quickly and remain @ 5V for a very long time.

$$v_o(t=5^+) = v_o(t=10) = v_o(t=15) = v_o(t=20\ \text{sec}) = \underline{\underline{5V}}$$

1. Positive clamper ckt :-



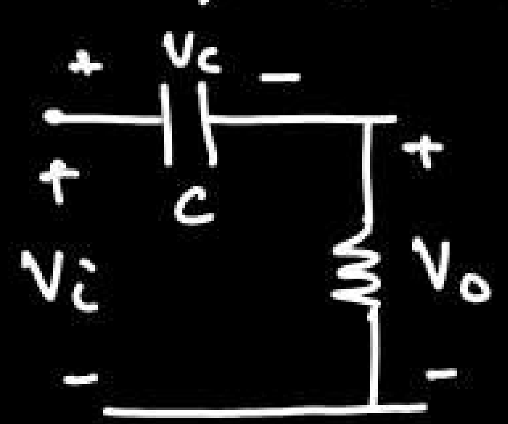


RC → very large

@ $t=0$, $V_c(0^+) = 0V$

$0 < t < T/2$

For $V_i > 0V \Rightarrow$ diode $\Rightarrow$ off



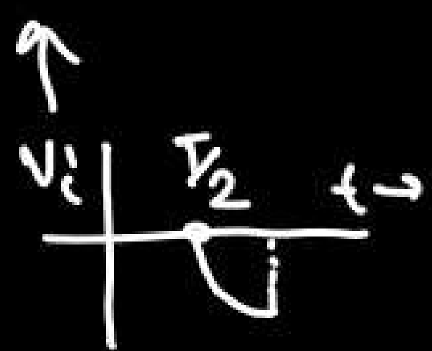
$\Rightarrow V_o = V_i$

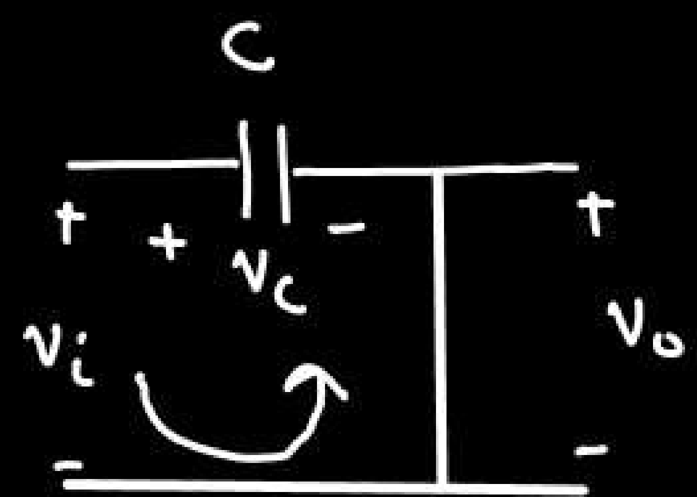
$V_c = 0V$

For $t \Rightarrow T/2$ to $3T/4$

$$3T/4 > t > T/2$$

@ $t = T/2^{+} \Rightarrow$ diode turns ON





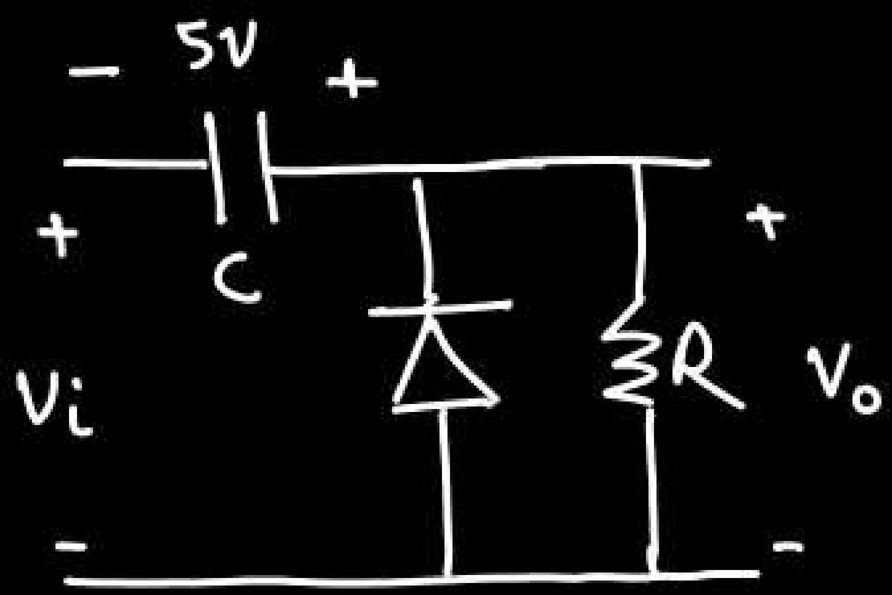
$$v_c = v_i$$

$$v_o = 0V$$

$$v_c(3T/4) = -V_m$$

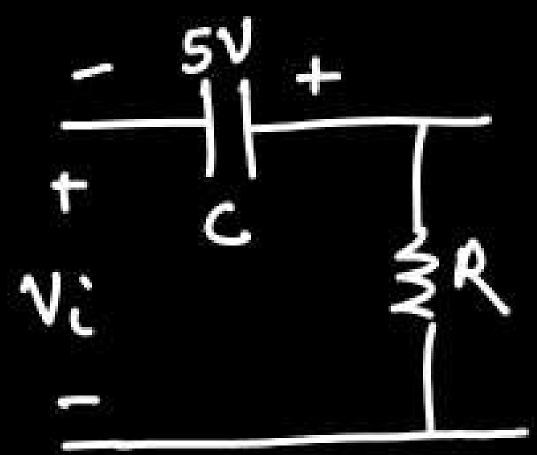
$$v_o(3T/4) = 0V$$

@ $t = 3T/4^{+}$ let $V_m = 5V$



$v_i(3T/4^{+}) = -4.9V$ (het)

Diode turns off



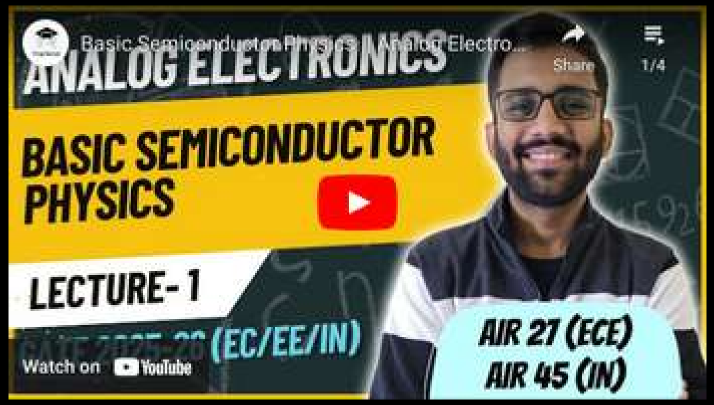
→ since RC is very large, cap. can neither charge nor discharge.

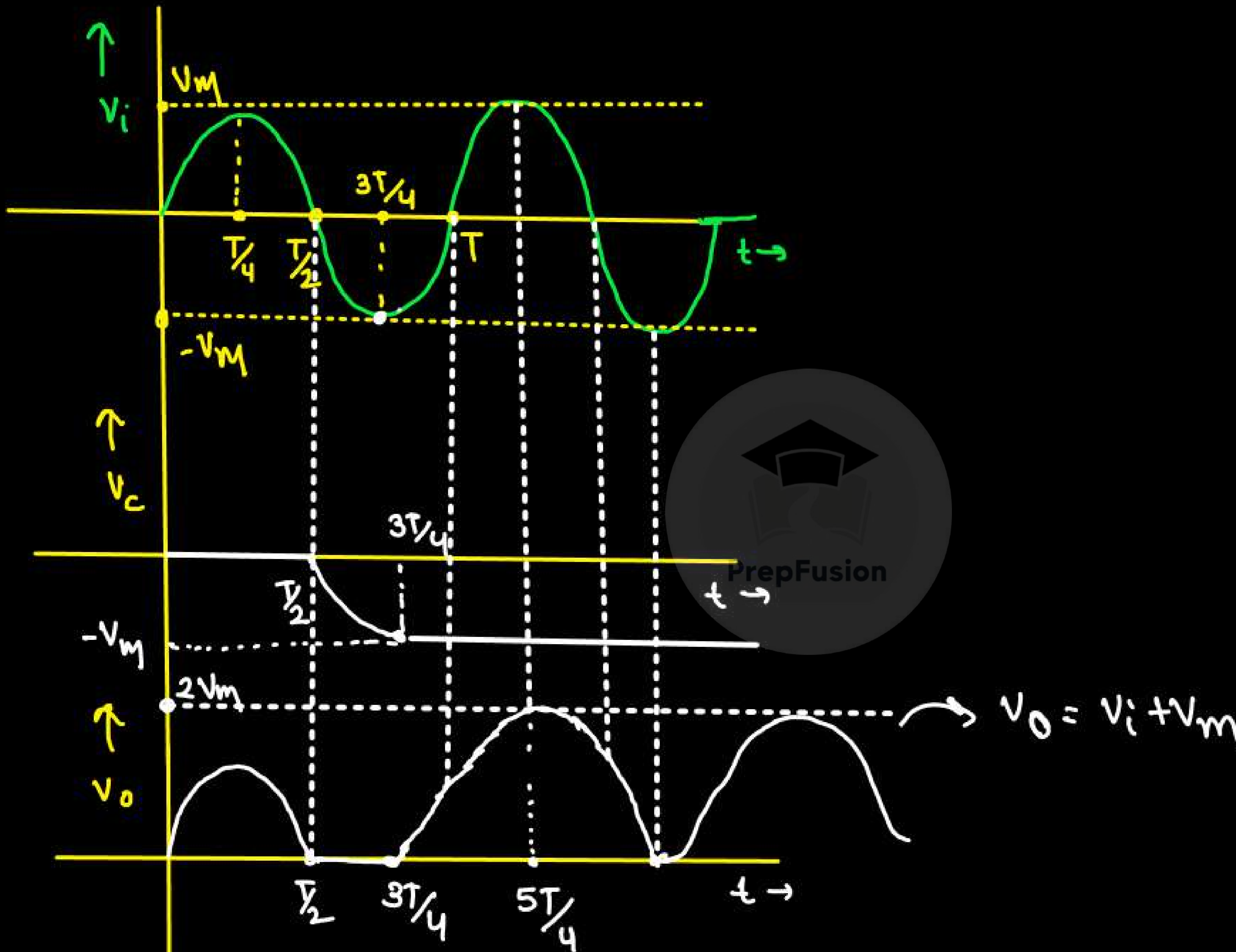
To turn on the diode $V_i + 5 < 0 \Rightarrow V_i < -5V$

↳ NOT possible

$\Rightarrow \boxed{V_c = -5V}$ (always)

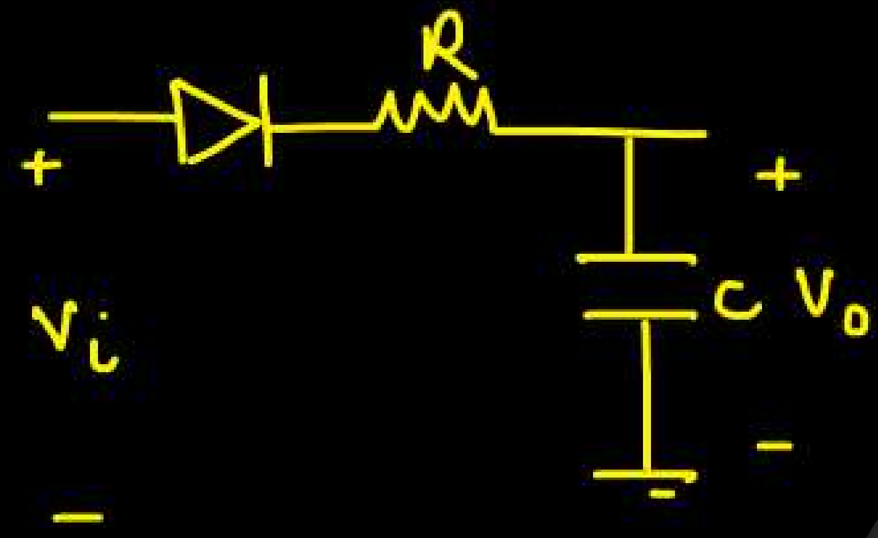
$\boxed{V_0 = V_i + 5V}$




Vm
v_i
-Vm
T/4
T/2
3T/4
T
t →
v_c
3T/4
T/2
-Vm
t →
2Vm
v_o
T/2
3T/4
5T/4
t →
$v_o = v_i + V_m$
PrepFusion

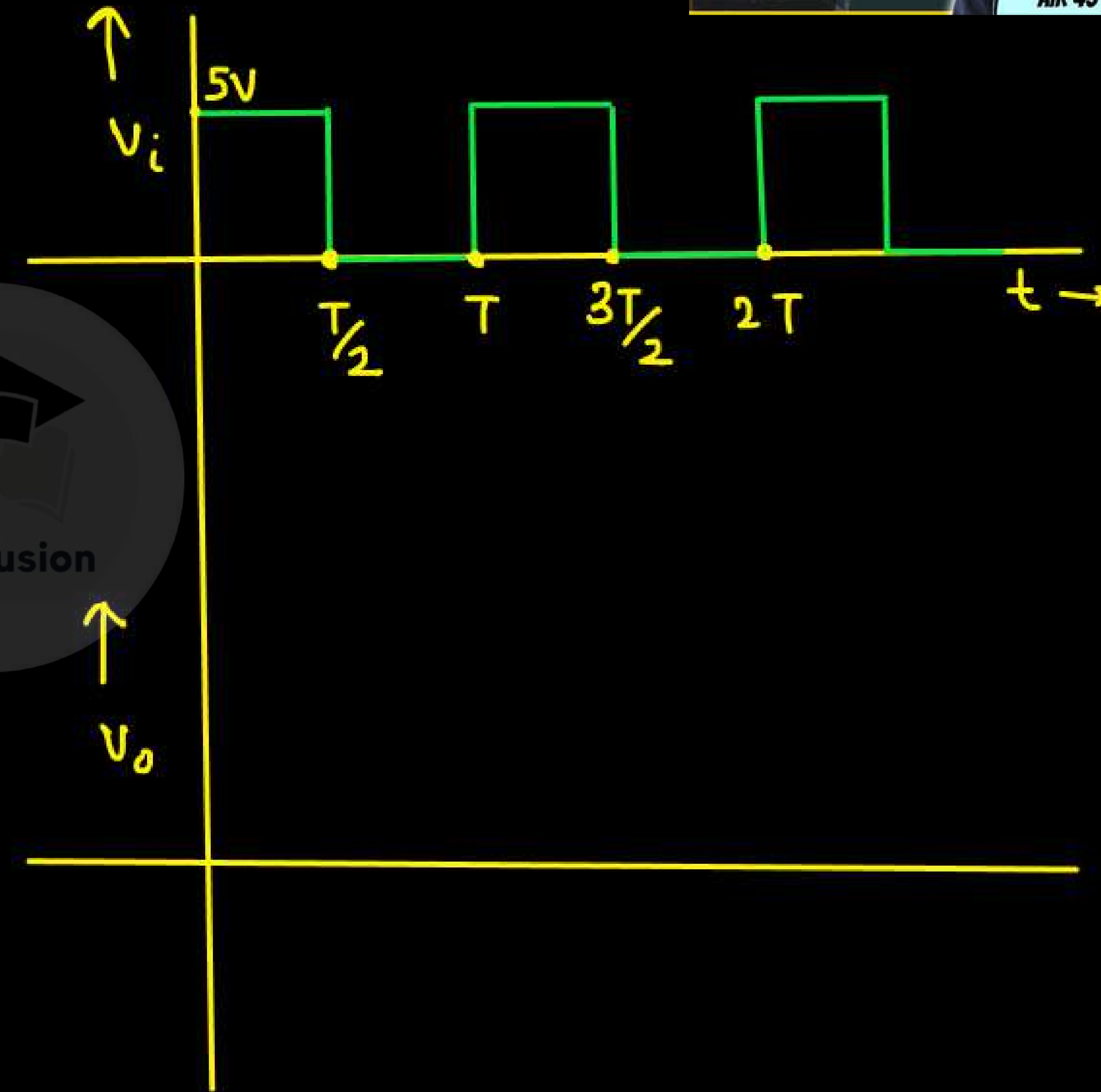

ANALOG ELECTRONICS
BASIC SEMICONDUCTOR PHYSICS
LECTURE-1
(EC/EE/IN)
AIR 27 (ECE)
AIR 45 (IN)
Watch on YouTube

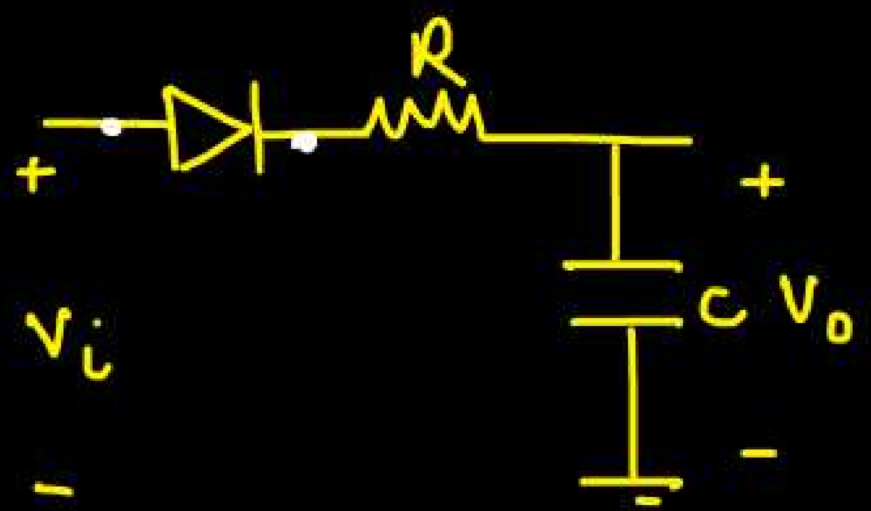
Q. Draw o/p waveform.

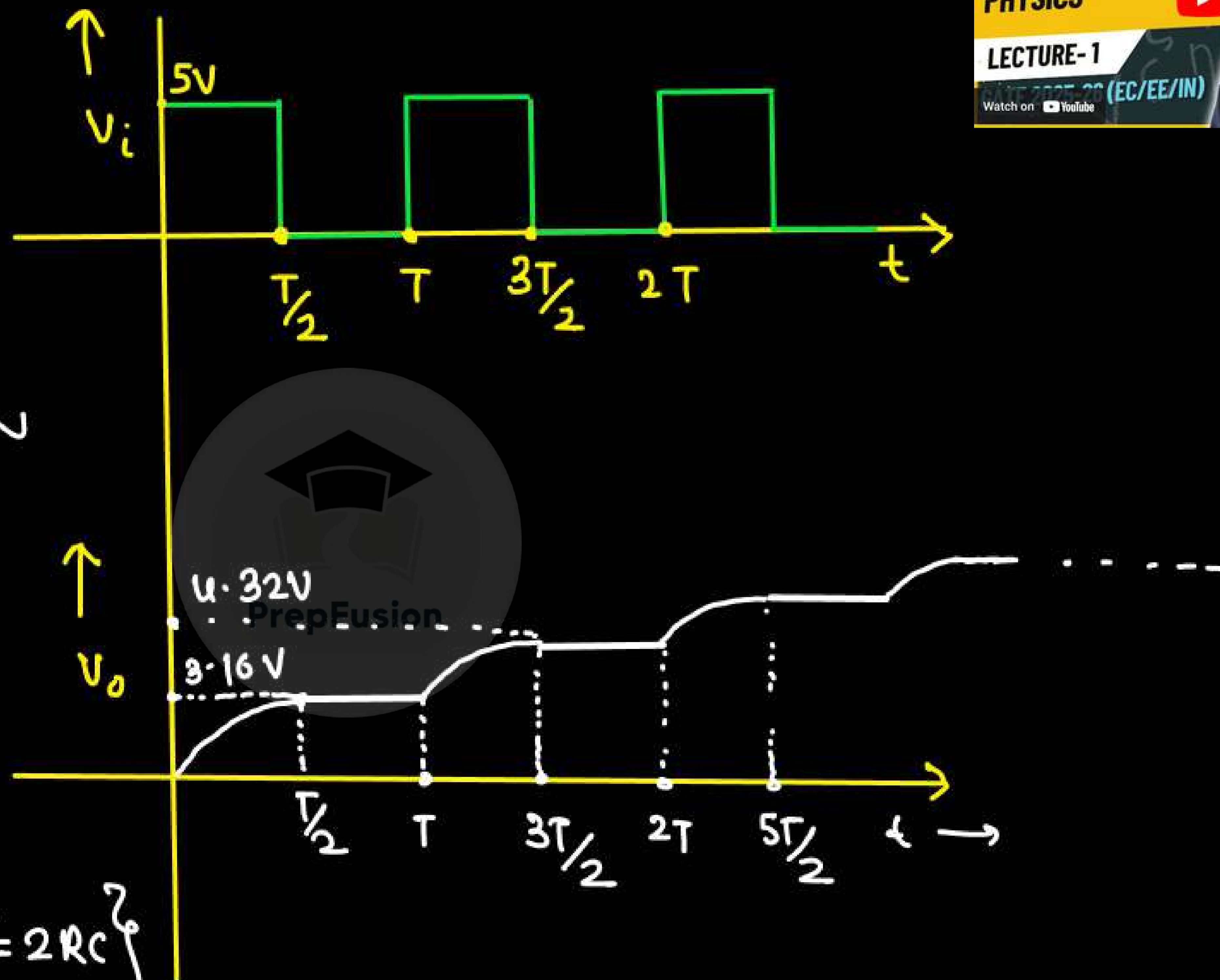


Given $\underline{\underline{T = 2RC}}$

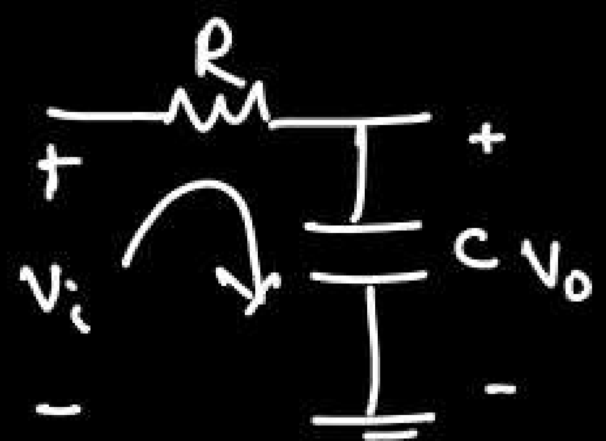
Also, find the time (in terms of T) in which o/p reaches to 4.32V ?







@ $t=0 \Rightarrow$ diode turns ON

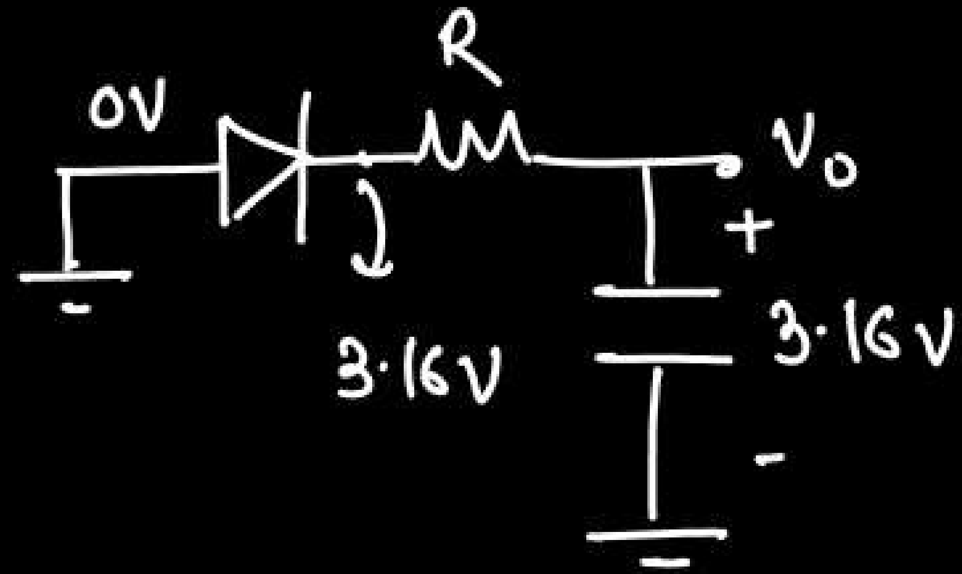


$$V_o = 5\left(1 - e^{-t/RC}\right)$$

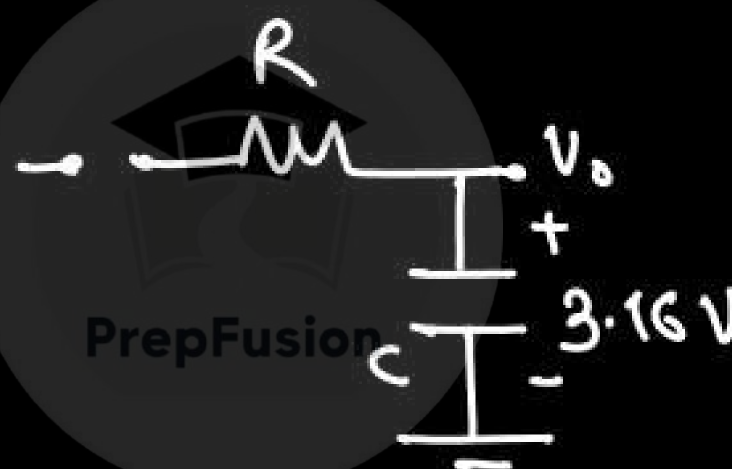
$$= 5\left(1 - e^{-T/2RC}\right) \quad \{T = 2RC\}$$

$$= 5\left(1 - e^{-1}\right) = 3.16\text{V}$$

@ $t = T/2^{+}$

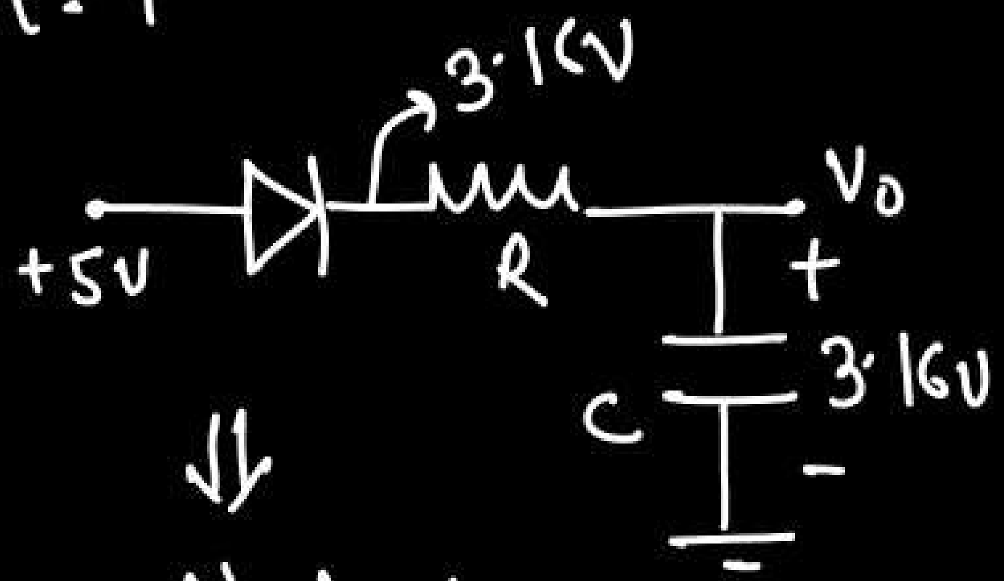


diode turns off $\Rightarrow$



$T/2 < t < T \Rightarrow$ diode off $\Rightarrow V_0 = 3.16V$

@ $t = T^{+}$



$\Downarrow$

diode turns ON

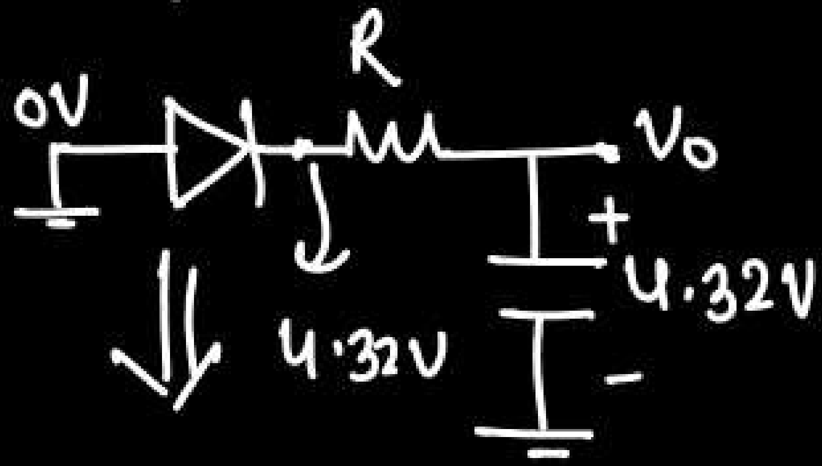
$$V_0 = 5 + (3.16 - 5)\, e^{-(t-T)/RC}$$

$$V_0\left(\tfrac{3T}{2}\right) = 5 - 1.84\, e^{-T/2RC} \qquad \{T = 2RC\}$$

$$\boxed{V_0\left(\tfrac{3T}{2}\right) = 4.32\text{ V}}$$

For $3T/2 < t < T$

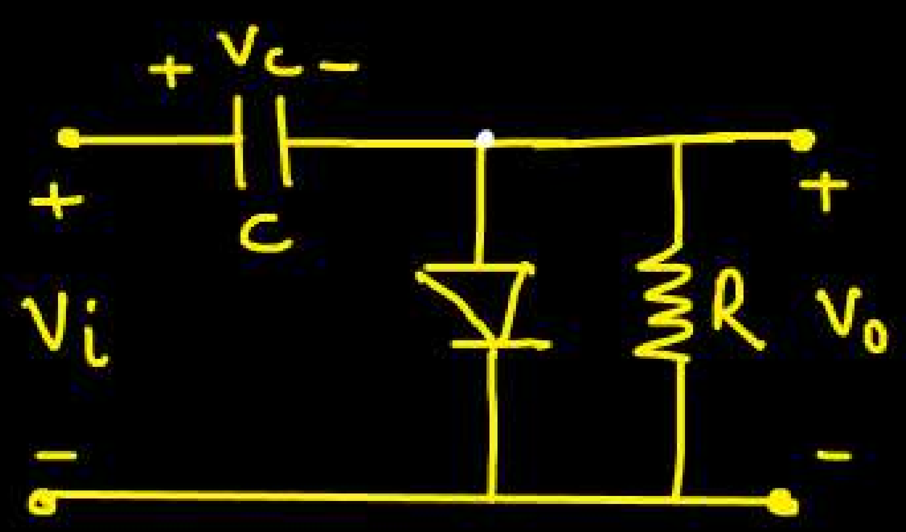
$V_i = 0$

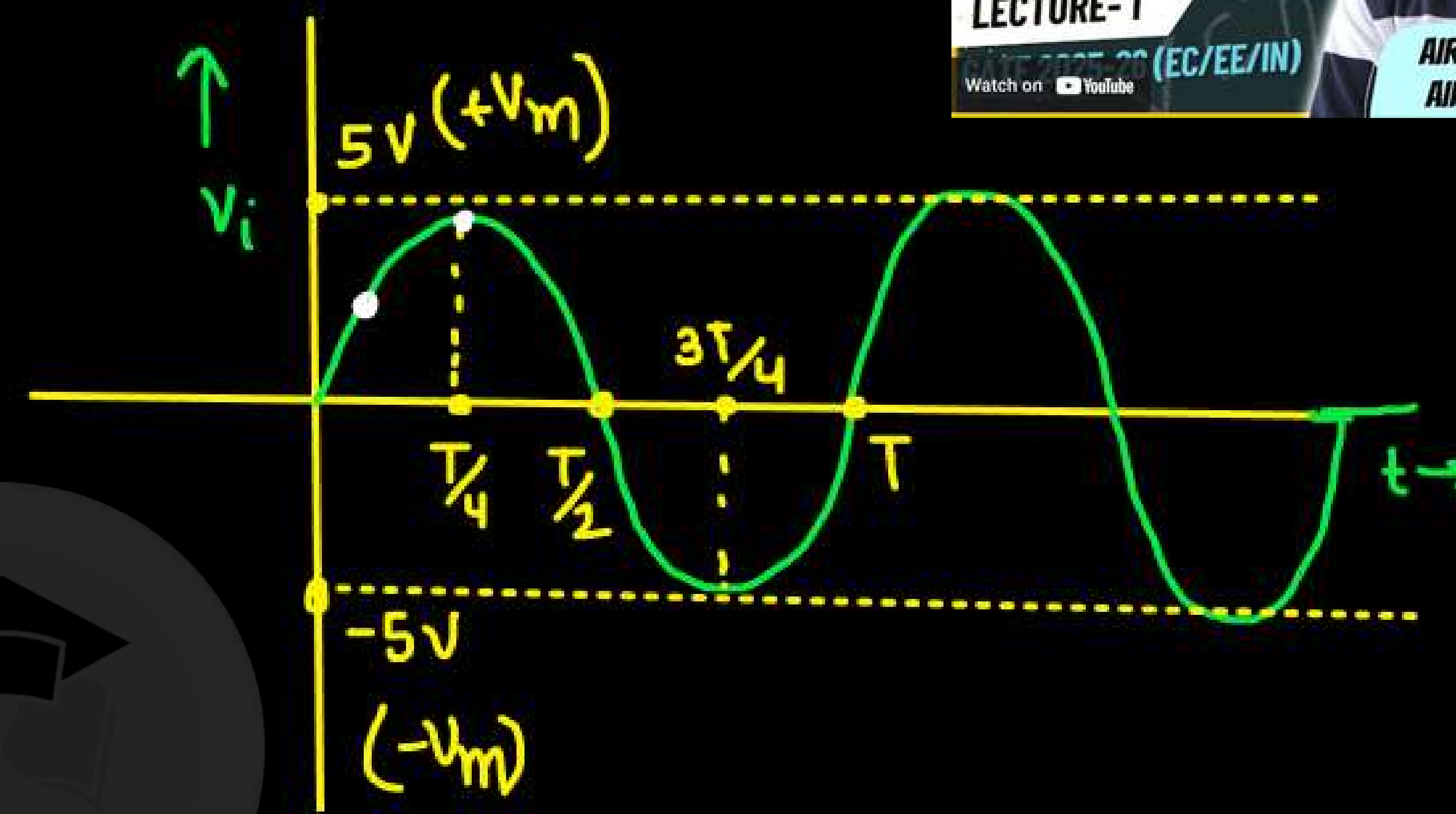


diode off

$V_o = 4.32V$

2. <u>Negative clamper ckt</u> :-

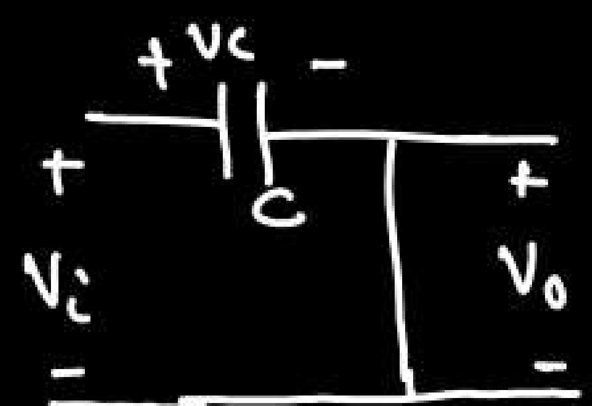




@ $t = 0^+$

$V_i > 0V$, $V_c(0^+) = 0V$

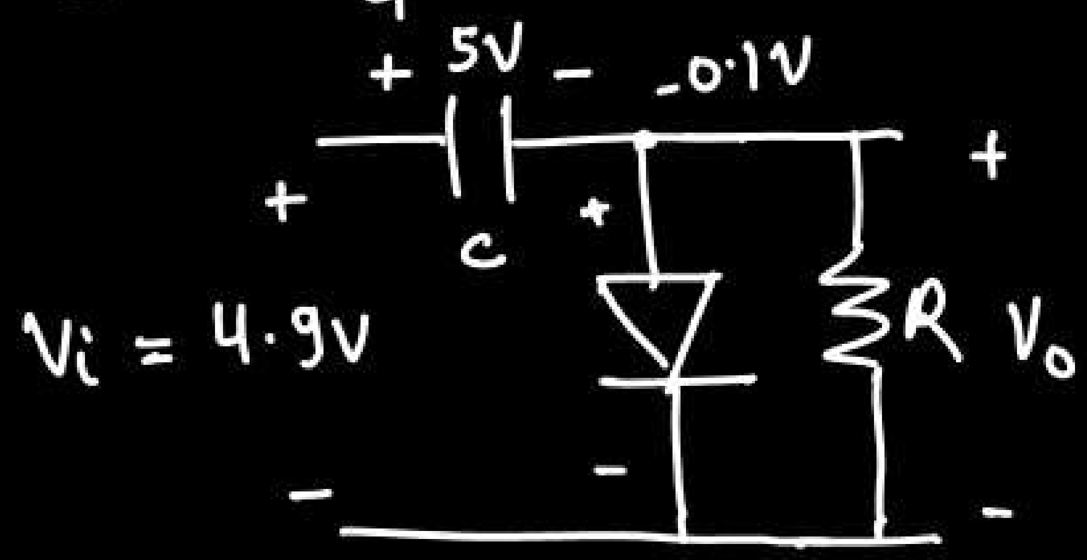
$\Rightarrow$ diode turns ON



$0 < t < T/4 \Rightarrow V_o = 0V$

$V_c = V_i$

@ $t = T/4^+$



Diode turns off ⇒ cap. can neither charge nor discharge.
(RC → very large)

For turning ON the diode;

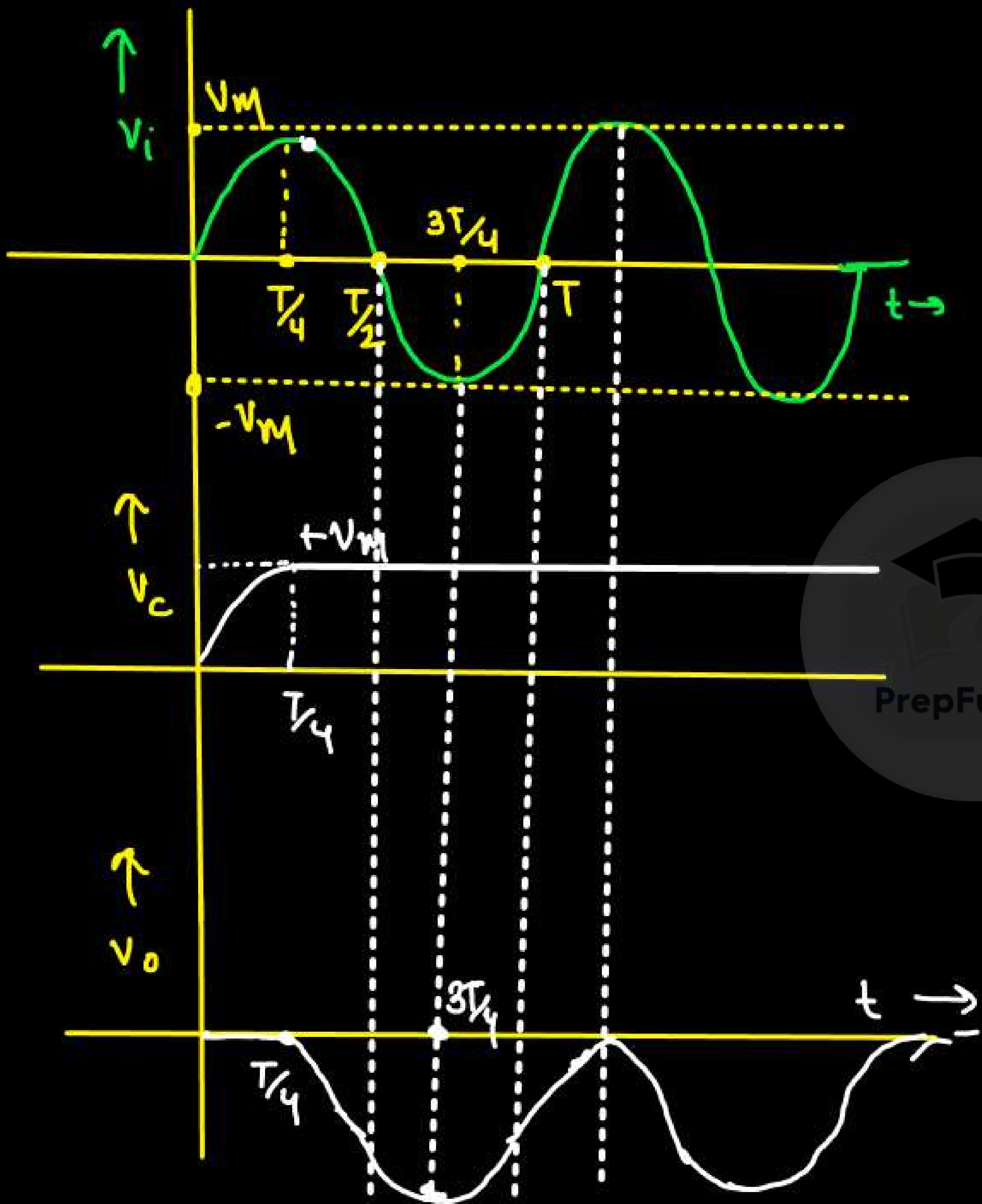
$$V_i - 5V > 0 \Rightarrow V_i > 5V \Rightarrow \text{NOT Possible}$$

⇓

diode can never turn ON

$V_c = 5V$ (always)

$$\boxed{V_o = V_i - 5V}$$



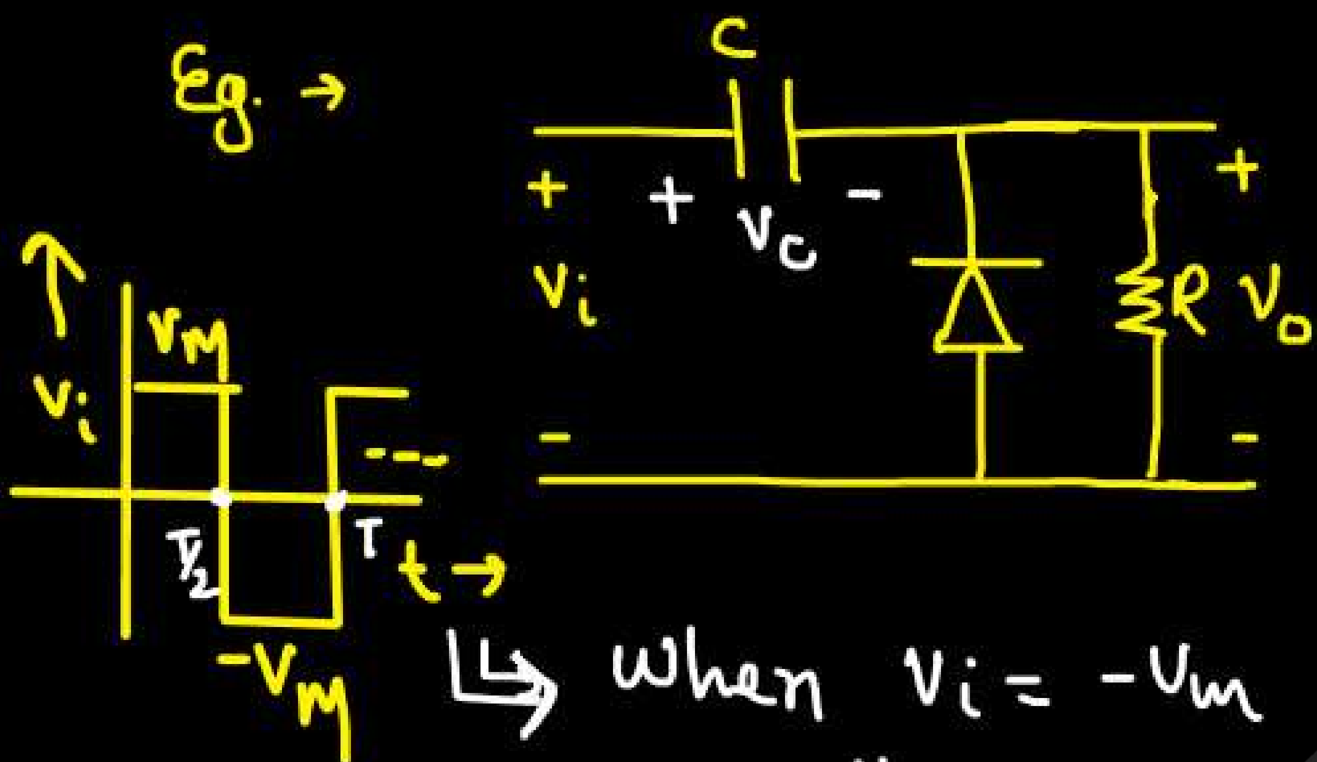
$$\boxed{v_o = v_i - v_m}$$

★ How to solve clamper ckt in one step:-

i) Turn on the diode nearest to the supply with desired max/min i/p voltage.

(ii) Find the cap. voltage (That will be its steady state voltage). Now you can write your steady state o/p.

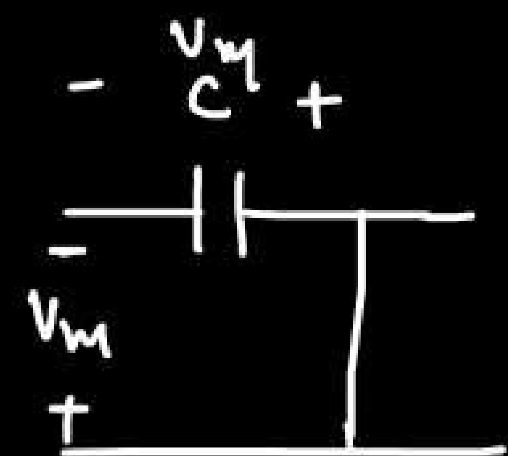
Eg. →



Steady state V_o ?

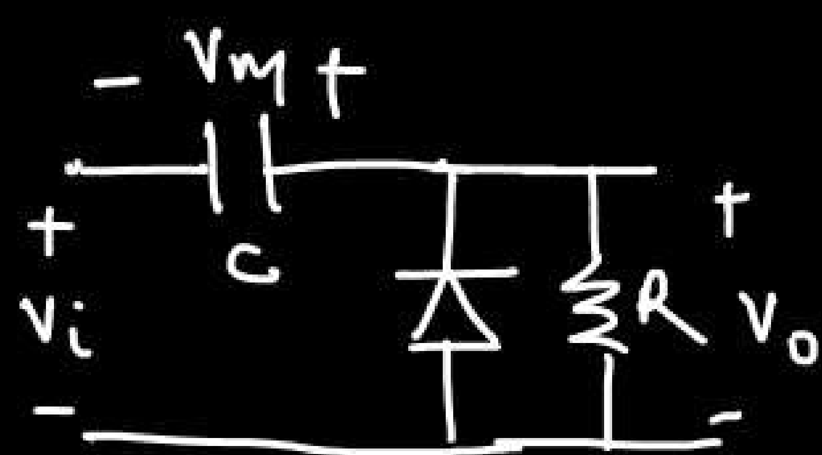
RC → very large

↳ when $V_i = -V_m$ ⇒ diode turns ON



$\underline{\underline{V_c = -V_M}}$ ↷ steady state cap. voltage

⇒

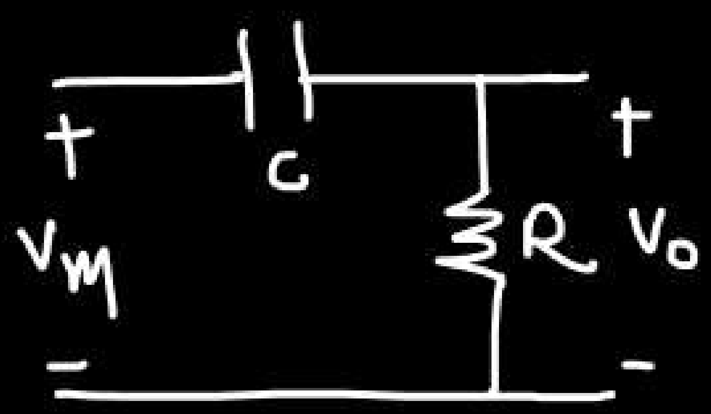


$$\boxed{V_o = V_i + V_M}$$

Exact Analysis:-

$0 < t < T/2$

$v_i = v_m \Rightarrow$ diode off

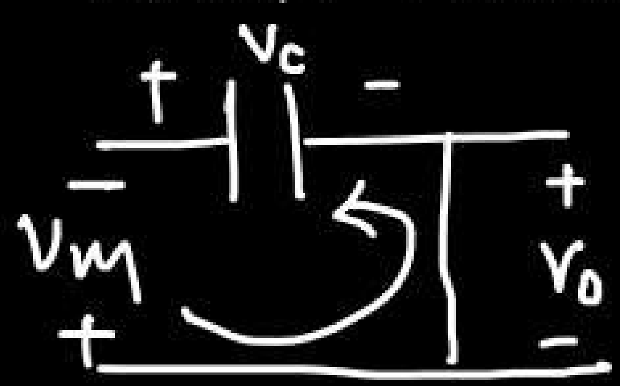


$v_c = 0\,V$

$v_o = v_m$

$T/2 < t < T$

$v_i = -v_m \Rightarrow$ diode turns on

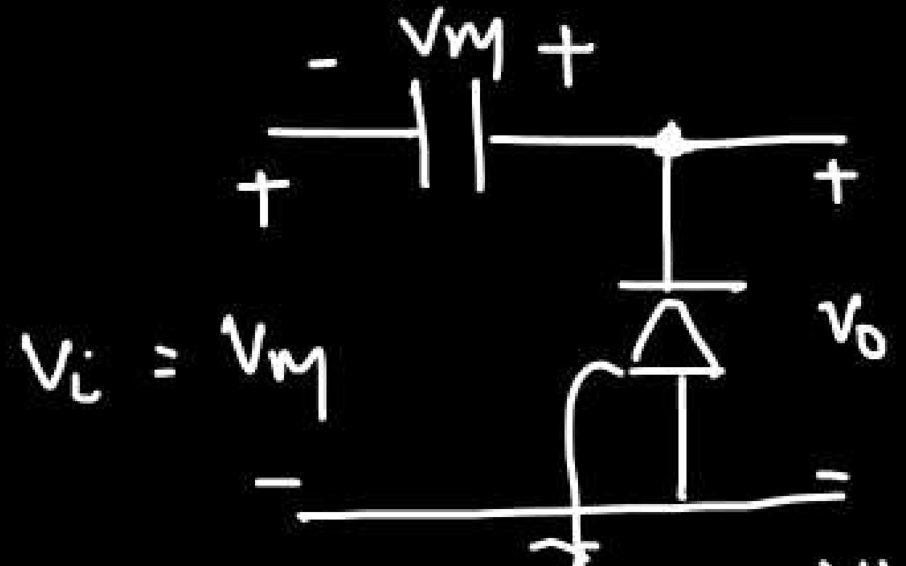


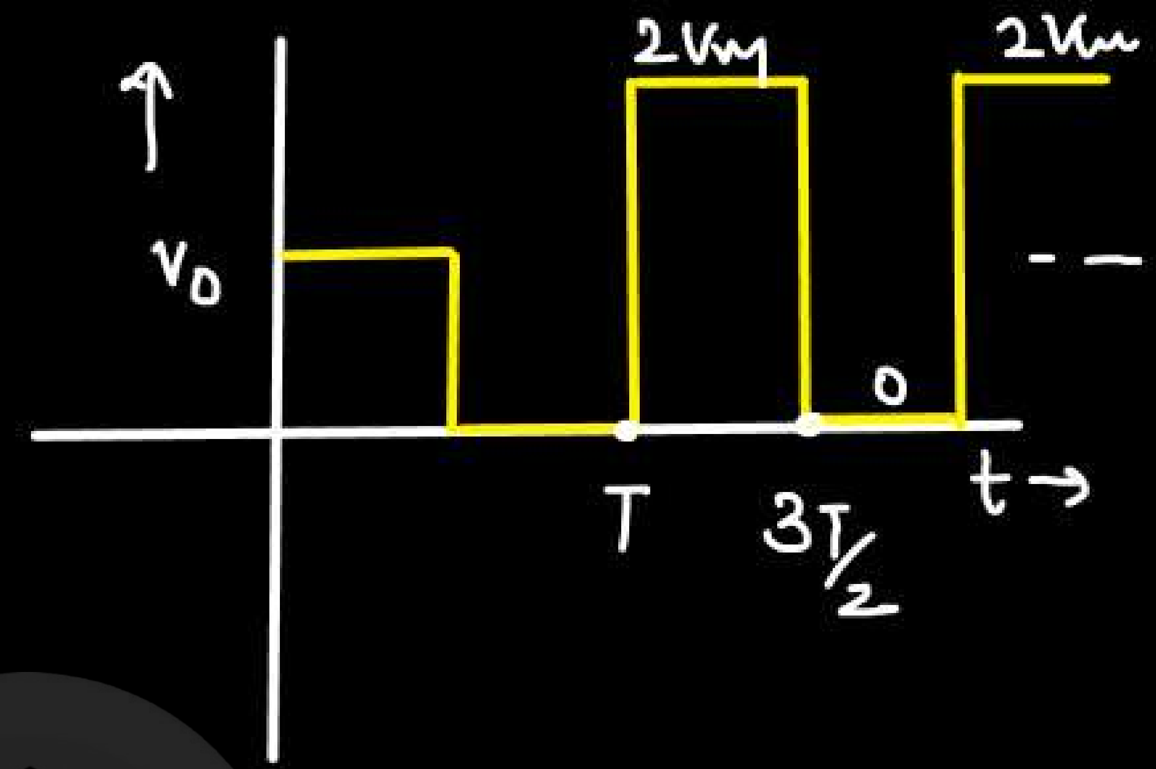
$\Rightarrow v_o = 0\,V$

$v_c = -v_m$

$T < t < 3T/2$

$v_i = +v_m$





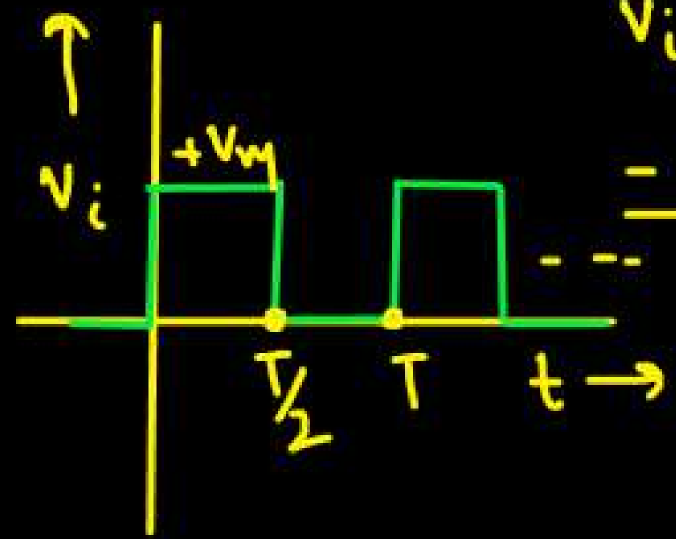
diode will be off

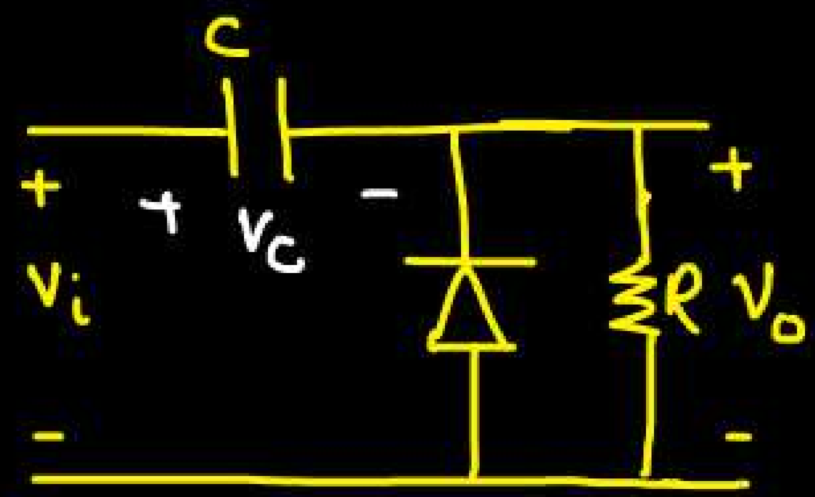
To turn on the diode $v_i + v_m < 0 \Rightarrow v_i < -v_m \Rightarrow$ NOT Possible

diode will be always be off

$$\Rightarrow \boxed{v_o = v_i + v_m}$$

Eg. →

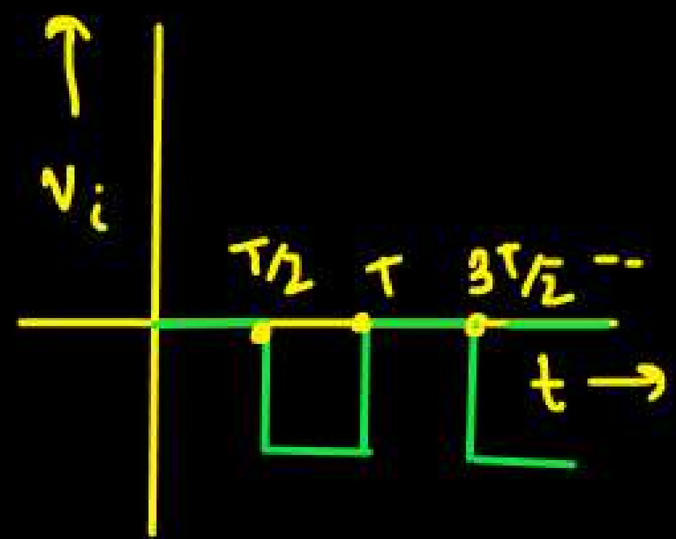


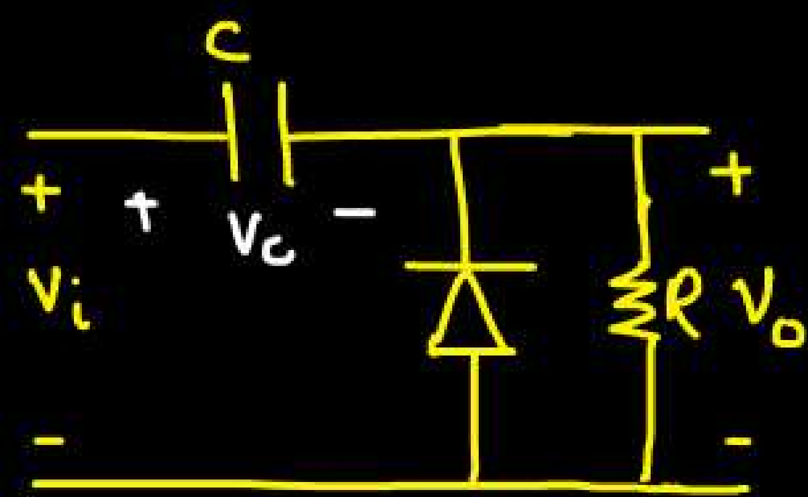


V_c (steady state) $= 0V$

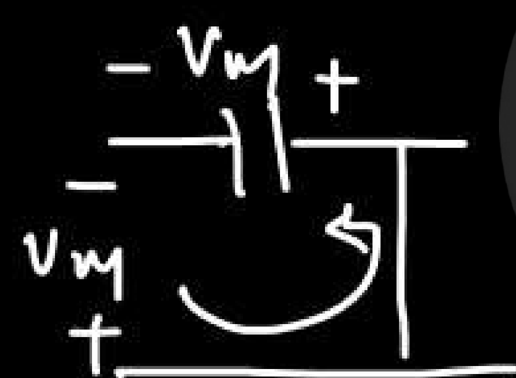
$$\boxed{V_0 = V_i}$$

Eg. →



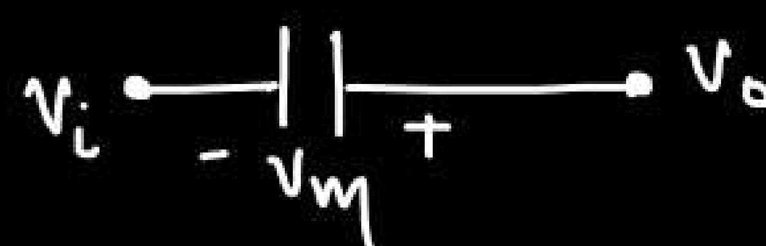


when $V_i = -V_m \Rightarrow$ diode turns on



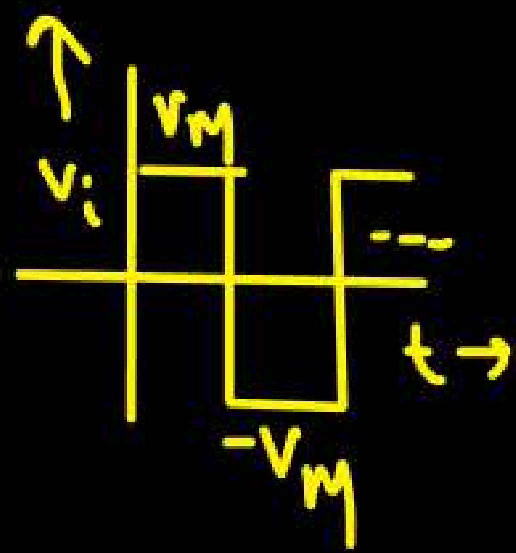
$V_c(s.s.) = -V_m$

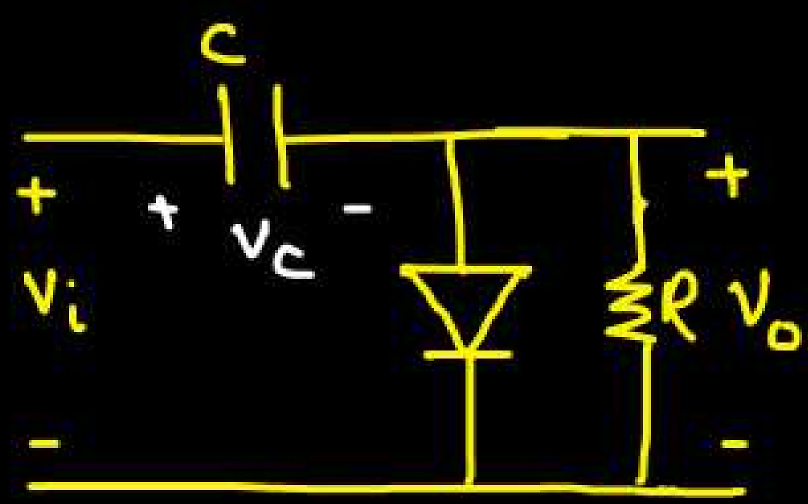
⇒



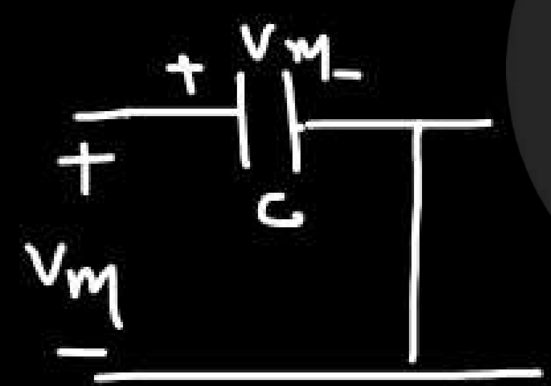
$\Rightarrow \boxed{V_o = V_i + V_m}$ → steady state o/p

Eg. →



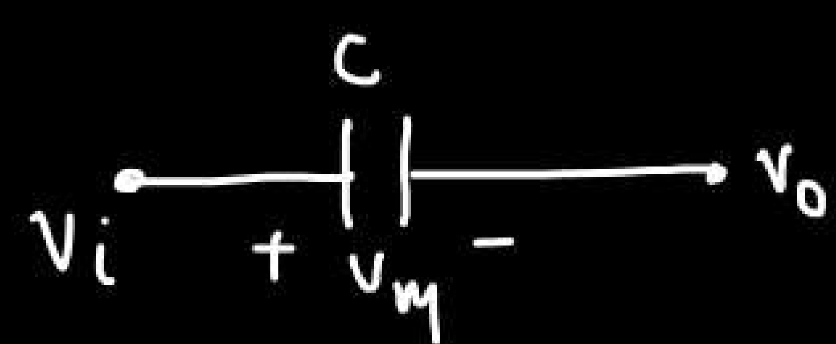


$V_i = V_m \Rightarrow$ diode turns ON



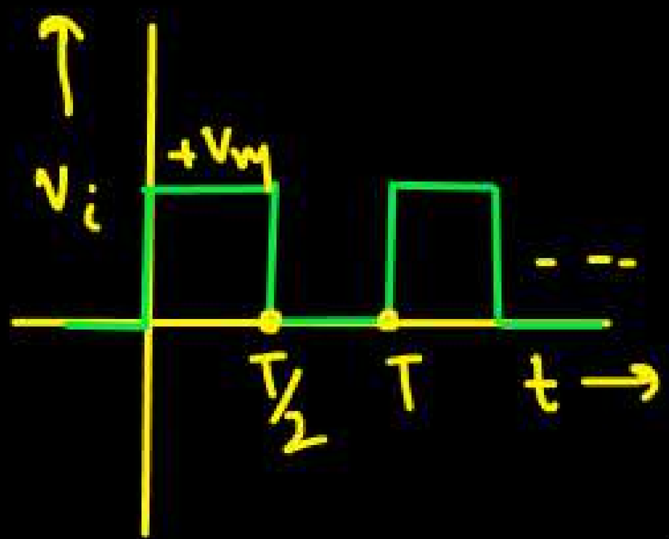
$V_c(s.s.) = +V_m$

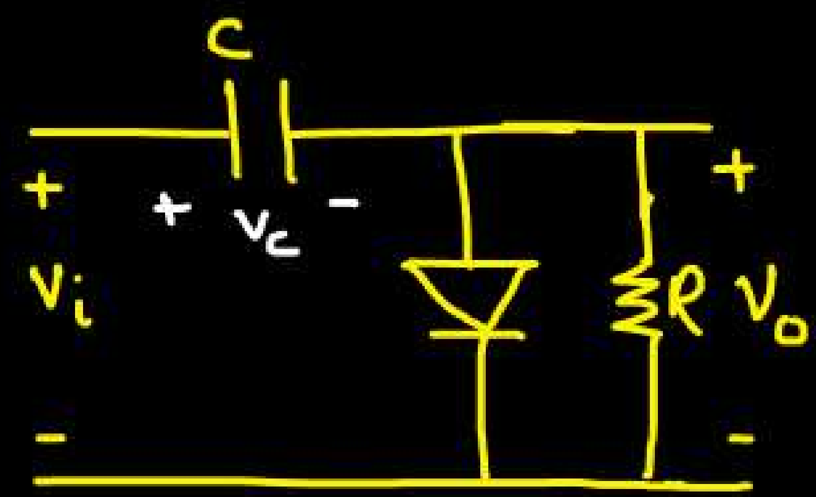
$\Rightarrow$



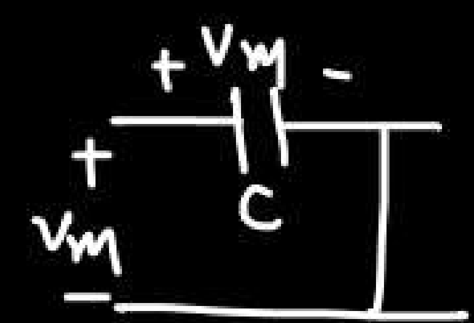
$$\boxed{v_{o(ss)} = V_i - V_m}$$

Eg. →



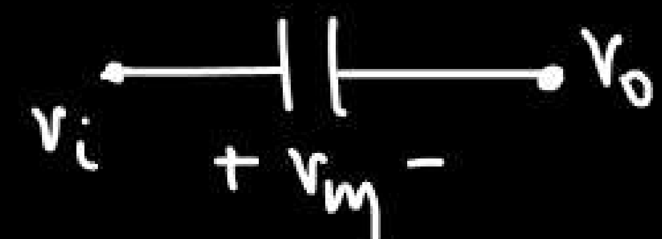


$\Rightarrow v_i = V_m \Rightarrow$ diode turns on



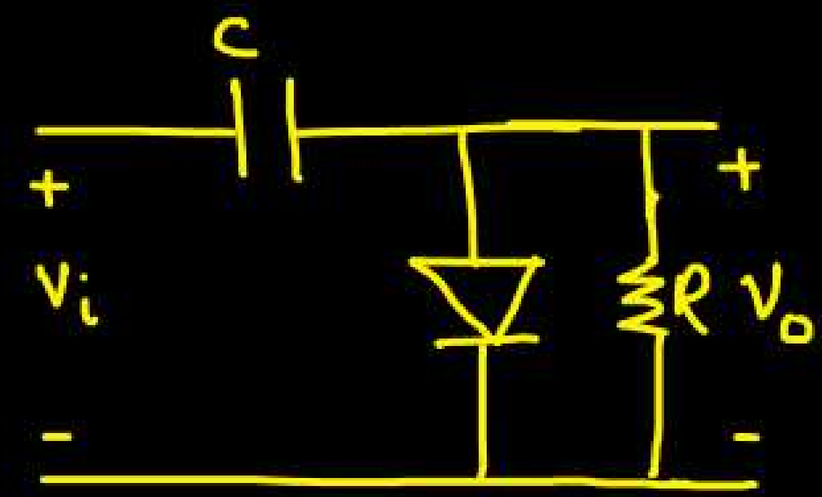
$V_c = V_m$

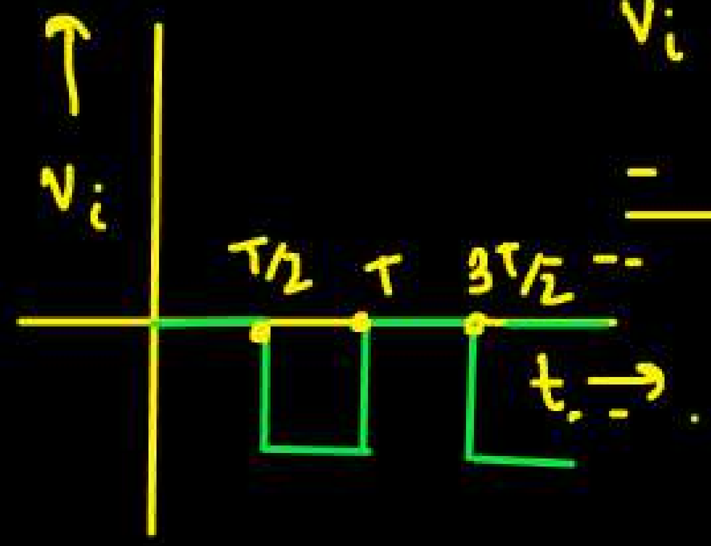
$\Rightarrow$



$\boxed{v_o = v_i - v_m}$

Eg. →





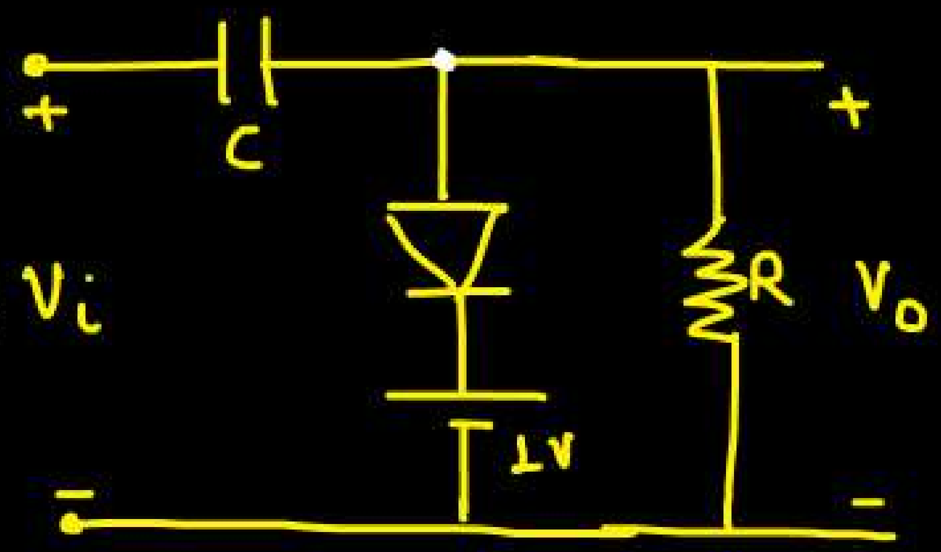
$V_c(s.s.) = 0V$

$\boxed{V_o(s.s.) = V_i}$

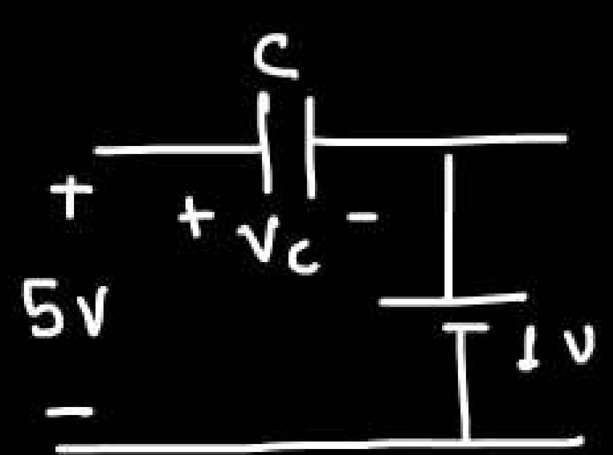
★ Clamper circuit with the bias :-

Eg. 1 →

5 sinωt = V_i



↳ when $v_i = +5v$ (max^m positive supply) ⇒ diode is ON



$$\boxed{V_c (s.s.) = 5 - 1 = 4V}$$

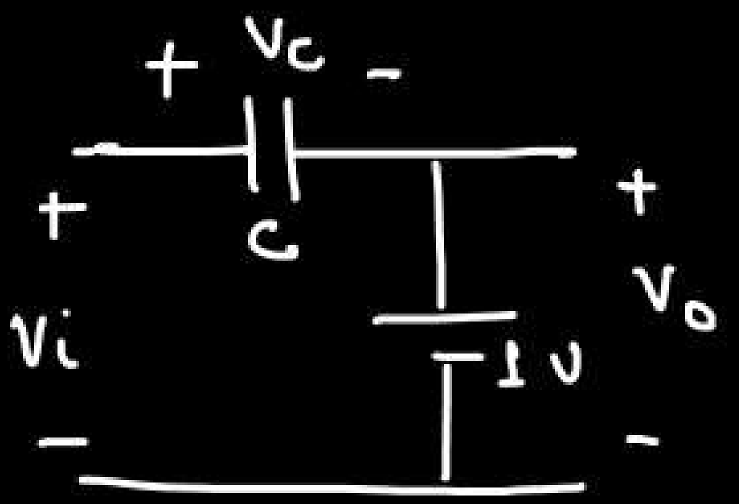
⇒

⇒ $$\boxed{V_0 (s.s.) = V_i - 4}$$

Exact Analysis:-

@ $t = 0^+$

$v_i > 0 \Rightarrow$ diode turns ON



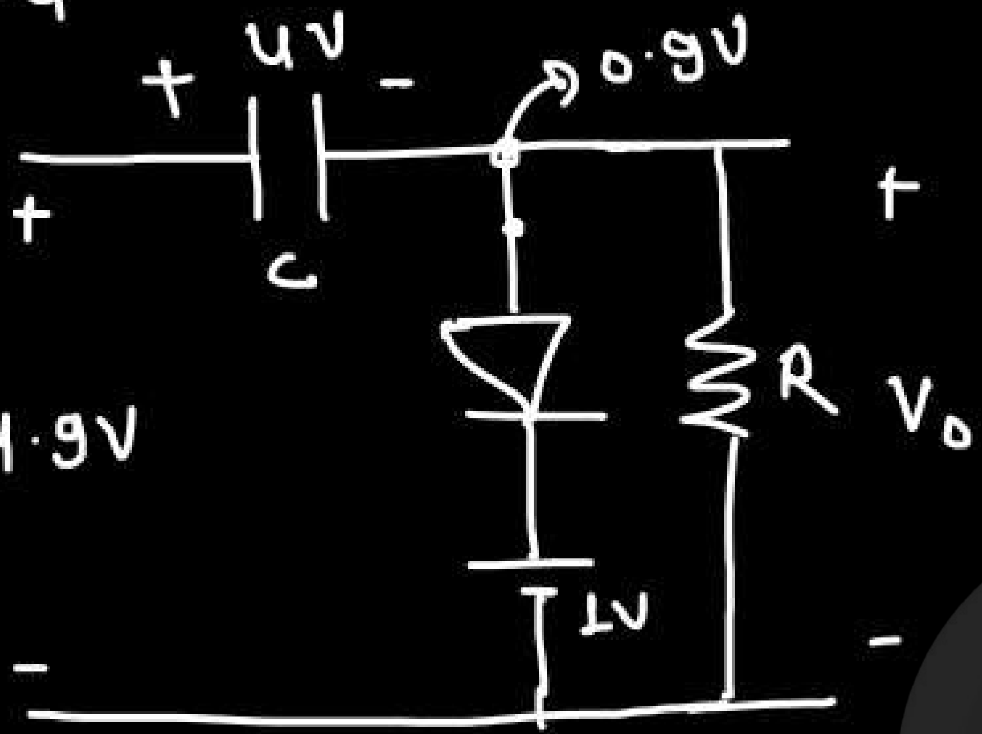
$0 < t < T/4 \Rightarrow$ diode remain turned ON

$$V_i\left(\frac{T}{4}\right) = 5V$$

$$V_c\left(\frac{T}{4}\right) = 4V$$

$$V_o\left(0 < t < \frac{T}{4}\right) = 1V$$

@ $t = T/4^+$



$V_i = 4.9V$

$V_i(T/4^+) = 4.9V$ {let}

$\Downarrow$

diode turns off

$\Downarrow$ $\boxed{V_0 = V_i - 4V}$

To turn it on

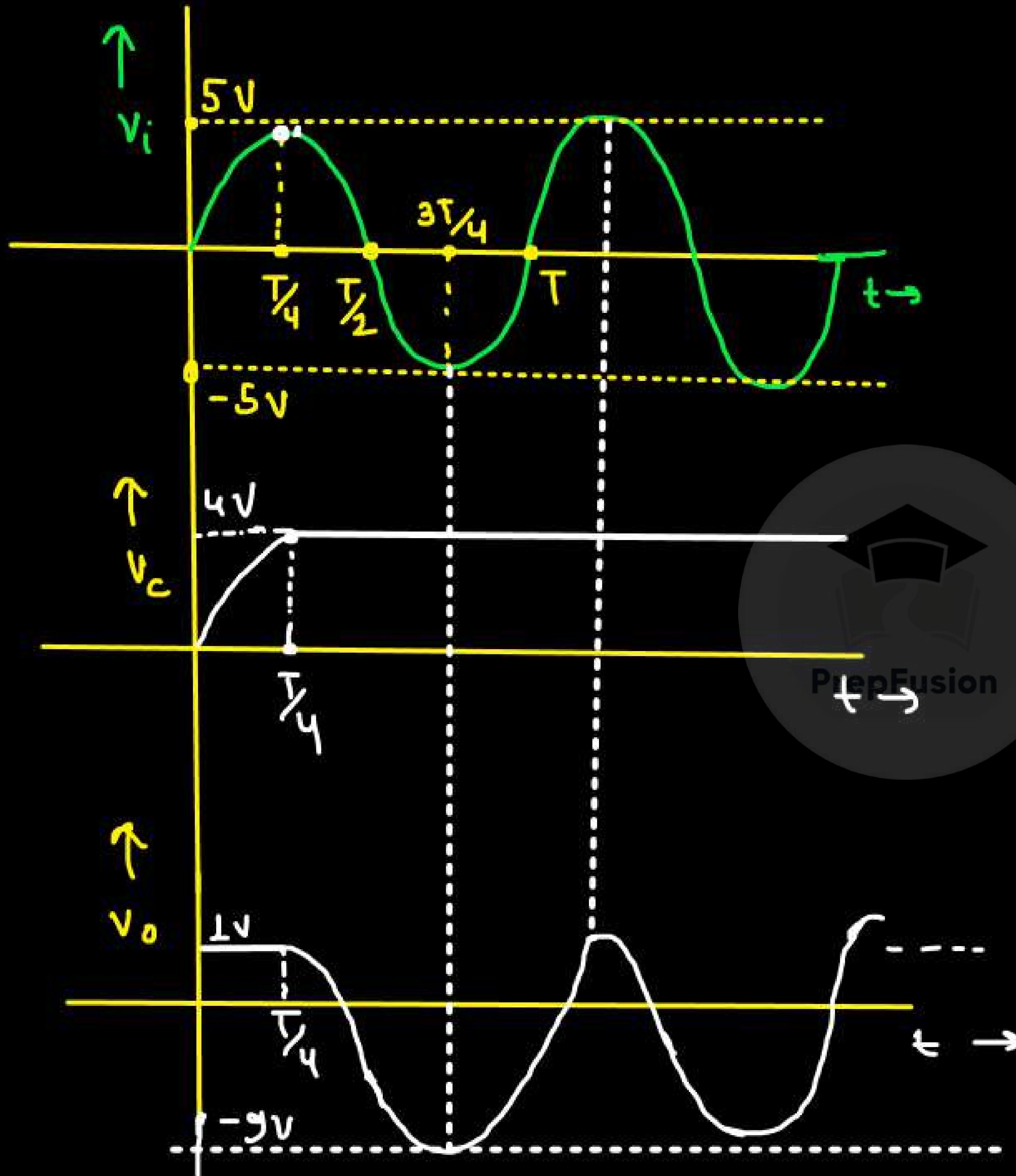
$V_i - 4 > 1$

$V_i > 5$

$\Downarrow$

NOT possible

$\Rightarrow$ diode will always be off.



v_i
5 V
-5 V
T/4
T/2
3T/4
T
t →
v_c
4 V
T/4
t →
v_o
1 V
T/4
-9 V
t →

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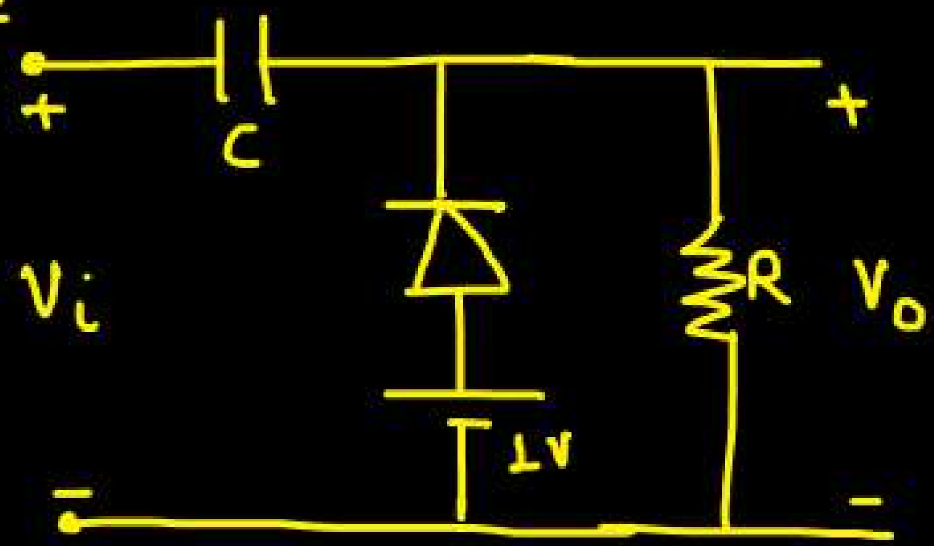
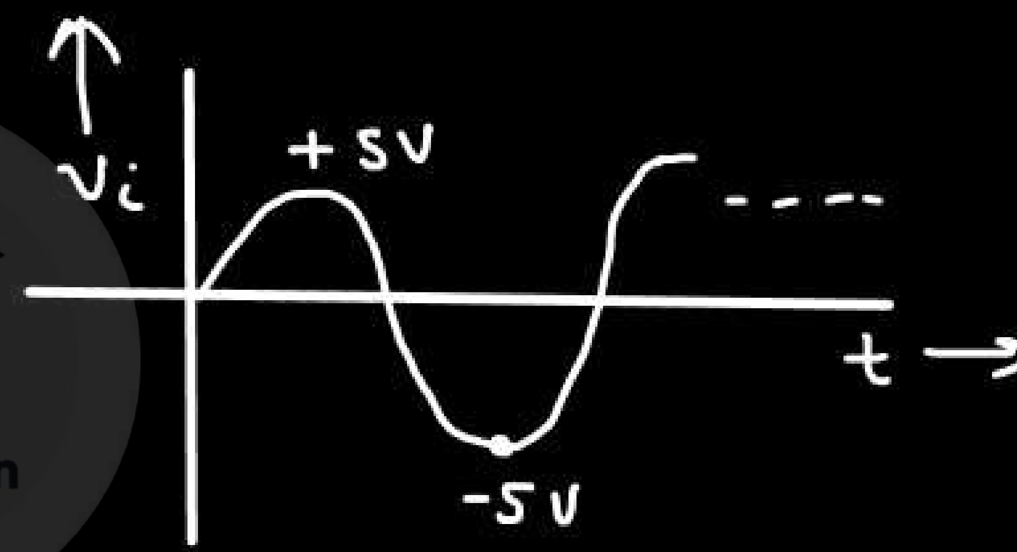
Eg. 2 →

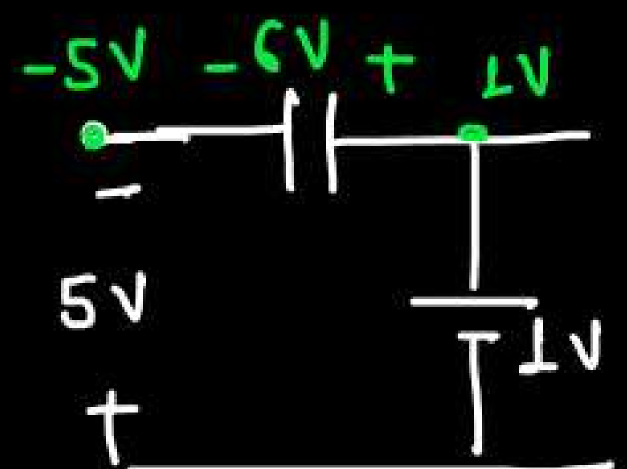


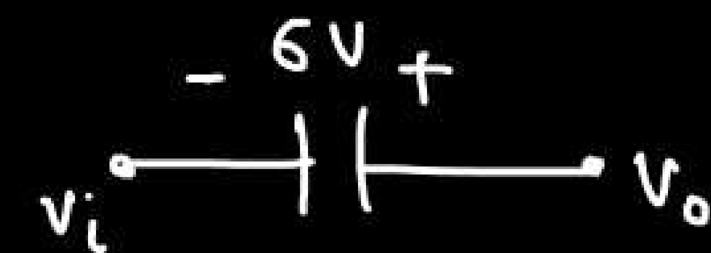
Find steady state V_o?

$V_i = 5\sin\omega t$



↳ $V_i = -5V \Rightarrow$ diode is ON

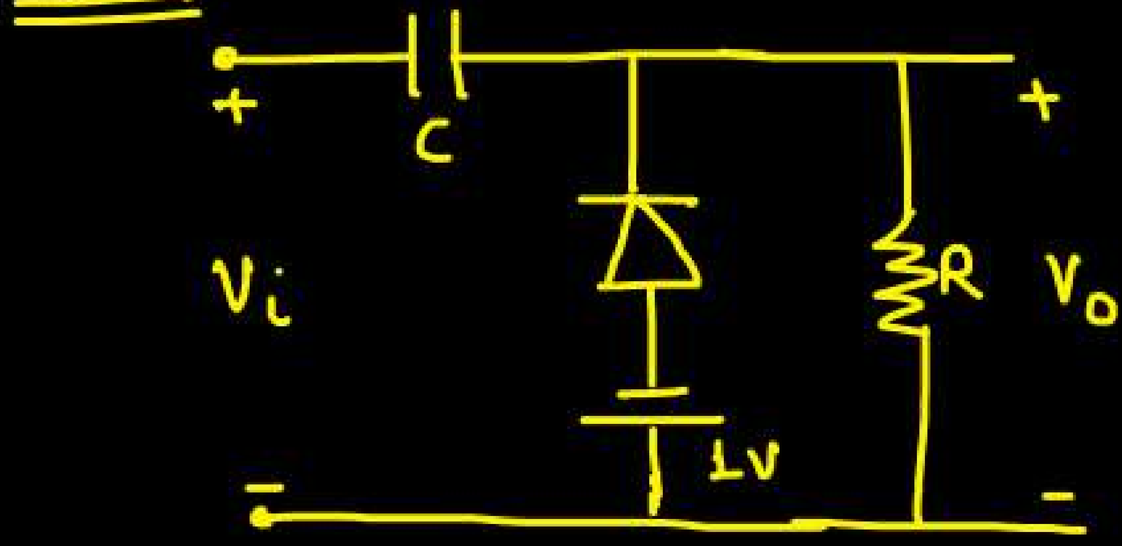


↳ 

$\Rightarrow \boxed{V_o = V_i + 6}$

$$\boxed{V_{o(s.s)} = 5\sin\omega t + 6}$$

Eg. 3 →

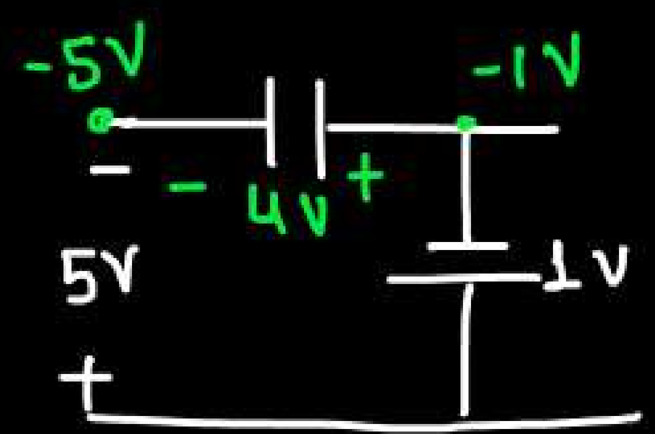


Find steady state V_o?

$V_i = 5\sin\omega t$

→

$V_i = -5V \Rightarrow$ diode is ON



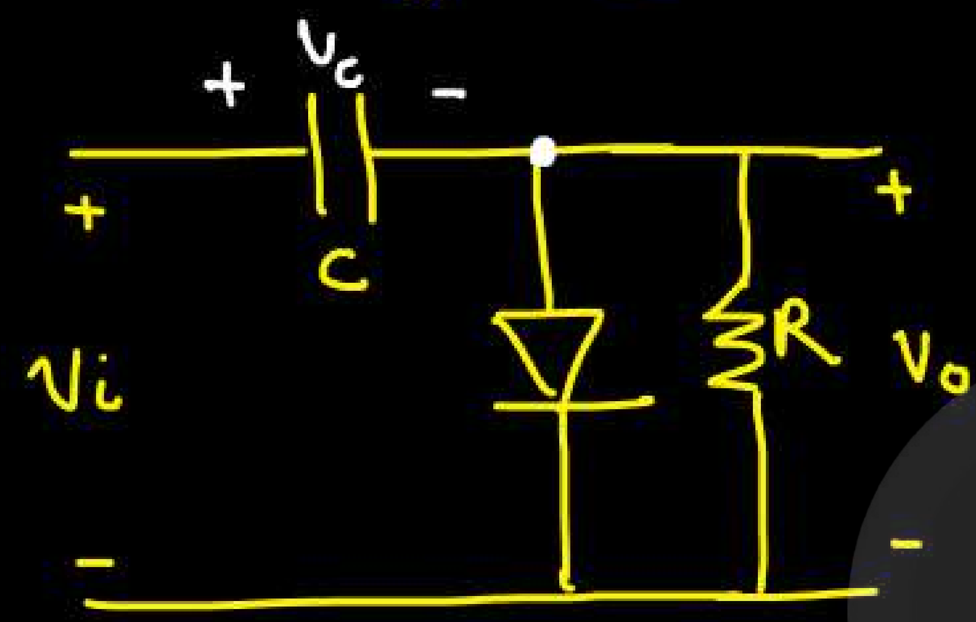
↳

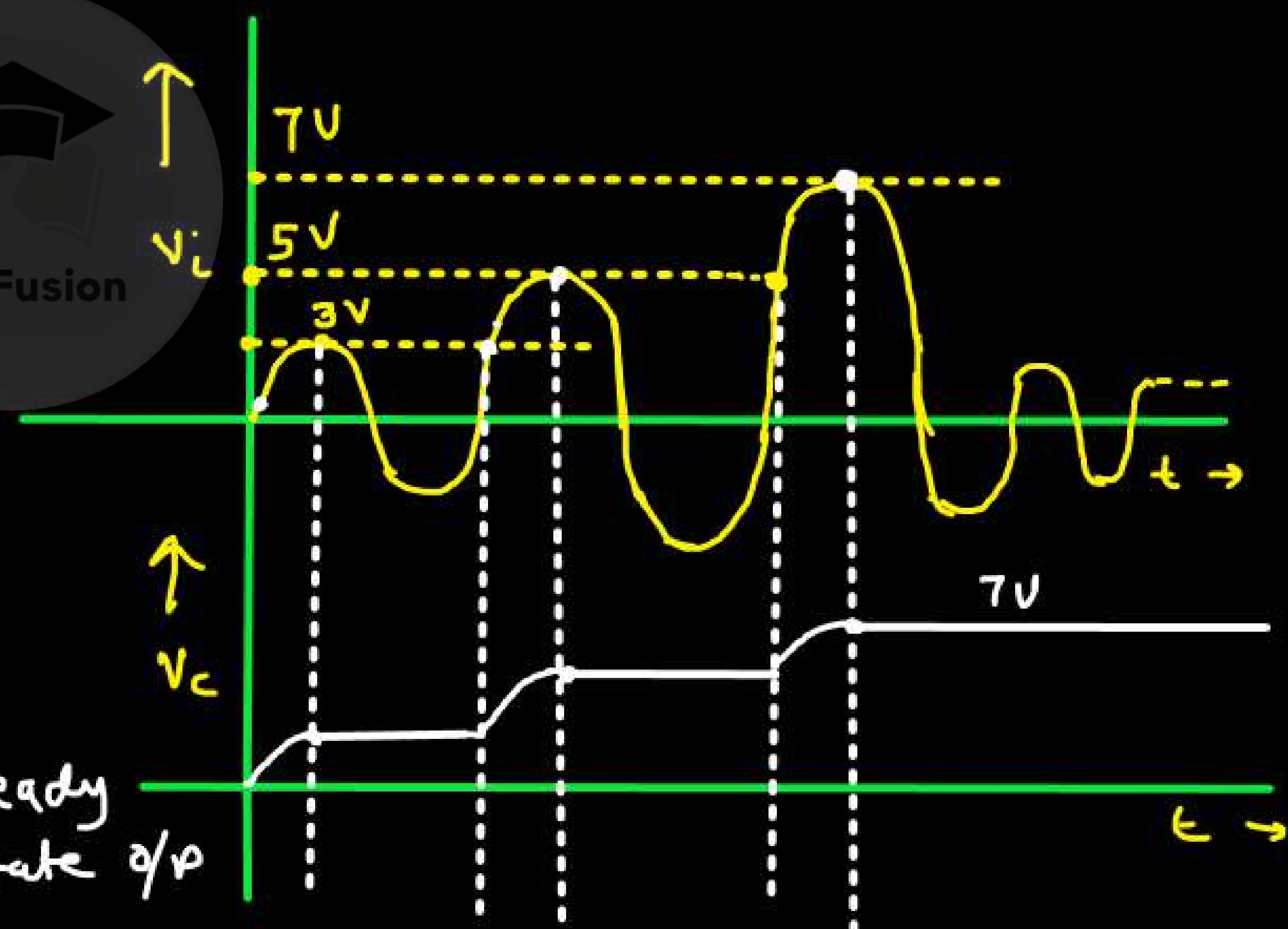
$V_o = V_i + 4V$

$$\boxed{V_o = 5\sin\omega t + 4}$$

Q. Find steady state o/p. Draw V_c waveform.

RC → very large

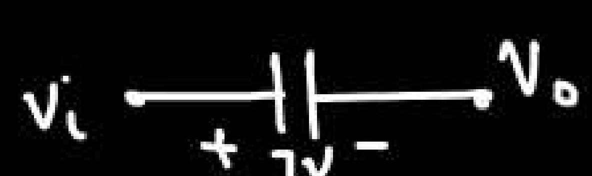




→ $V_i = 7V$ (max^m positive supply)

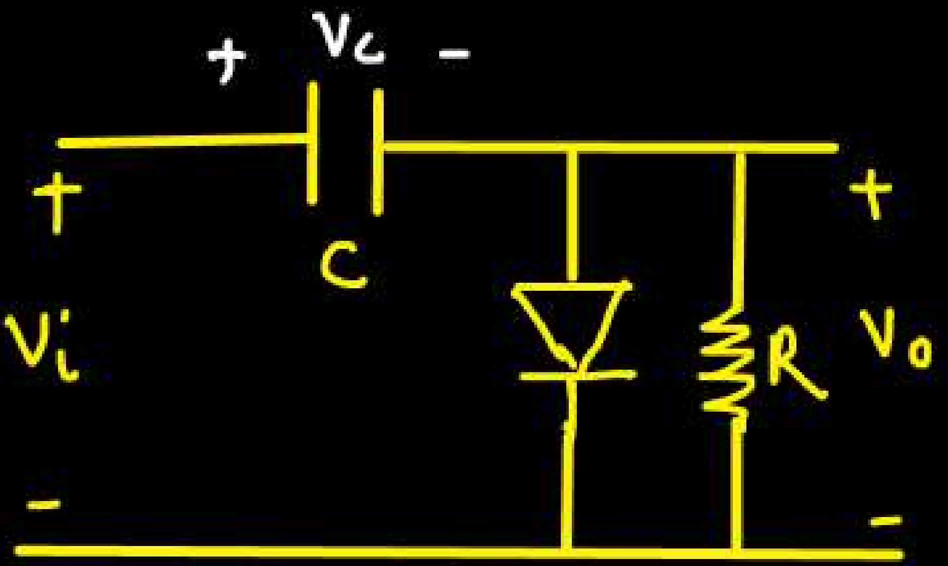
⇓

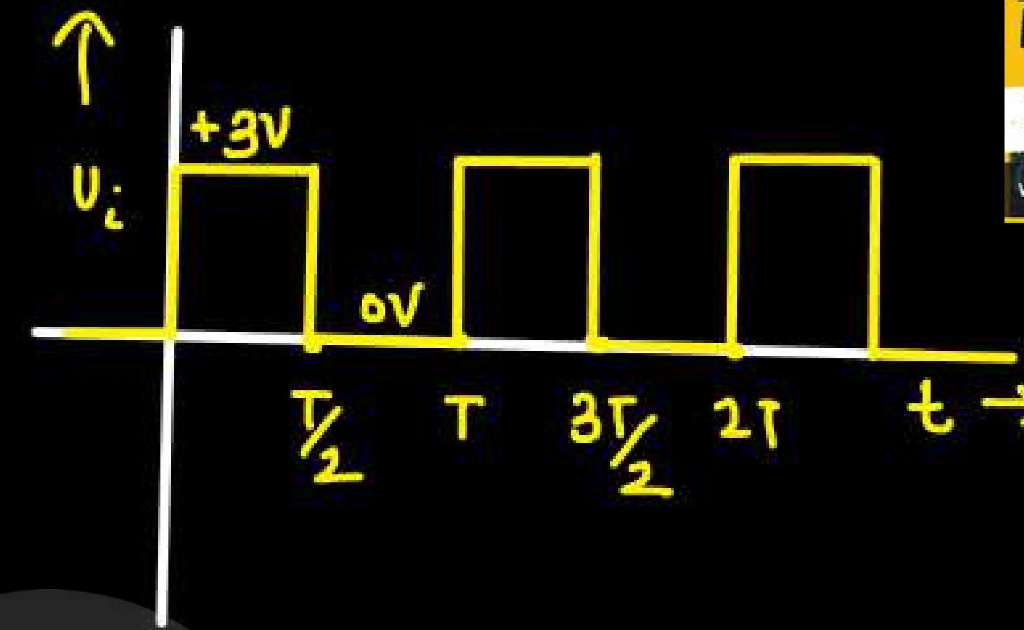
diode is ON

↳ 

$$\boxed{V_o = V_i - 7V}$$ → steady state o/p

Q.





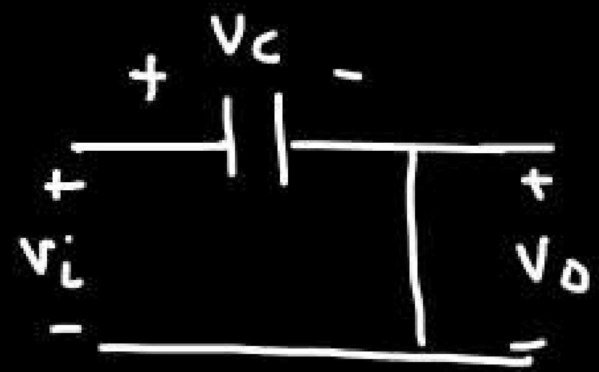
Given, $T = 2RC$

Find V_0 @ $t = \frac{43T}{4}$

→ $0 < t < T/2$

⇒ $V_i = 3V$ ⇒ diode turns ON

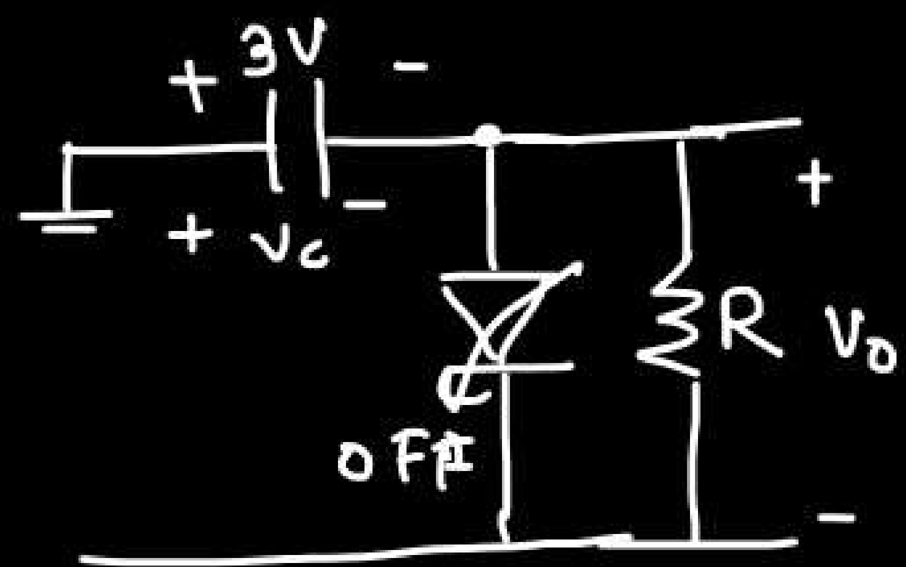
$V_c = 3V$, $V_0 = 0V$



$@\ t = \frac{T}{2}^{+}$

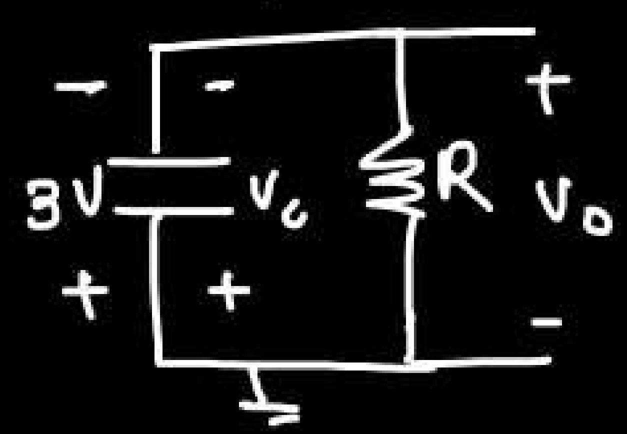
$\frac{T}{2} < t < T$

$V_i = 0V$



$\Rightarrow$ Diode turns ON

$V_o\left(\frac{T}{2}^{+}\right) = -3V$



$V_o = -V_C$

$V_o = -3e^{-\left(t-\frac{T}{2}\right)/RC}$

$V_o(T) = -3e^{-T/2RC} \quad \{T = 2RC\}$

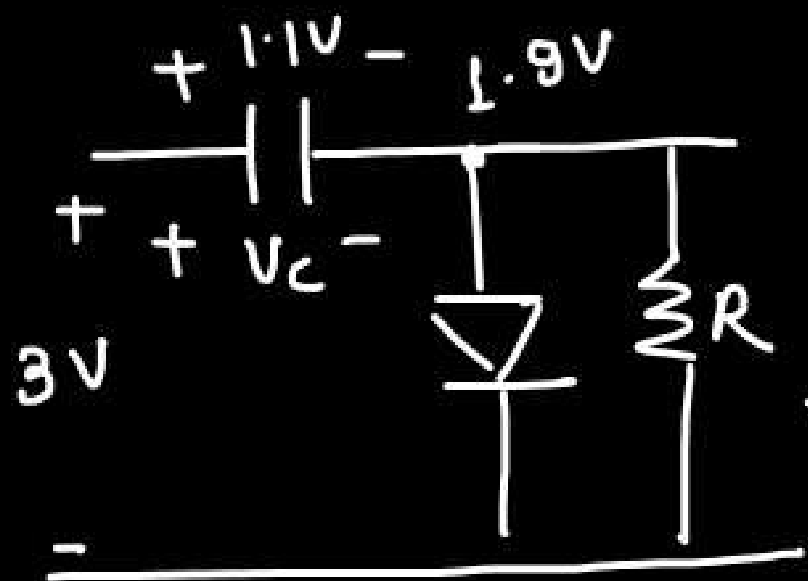
$= -3e^{-1} = -1.1V$

$$v_o(T) = -1.1V$$

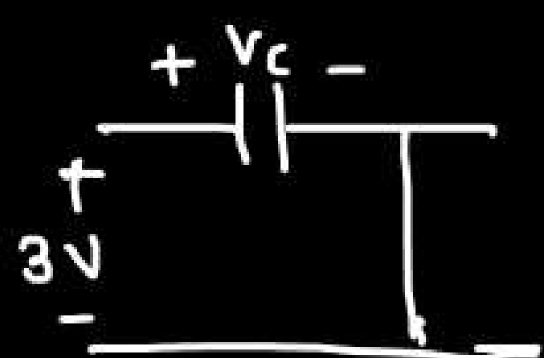
$$v_c(T) = 1.1V$$

@ $t = T^+$

$V_i = 3V$



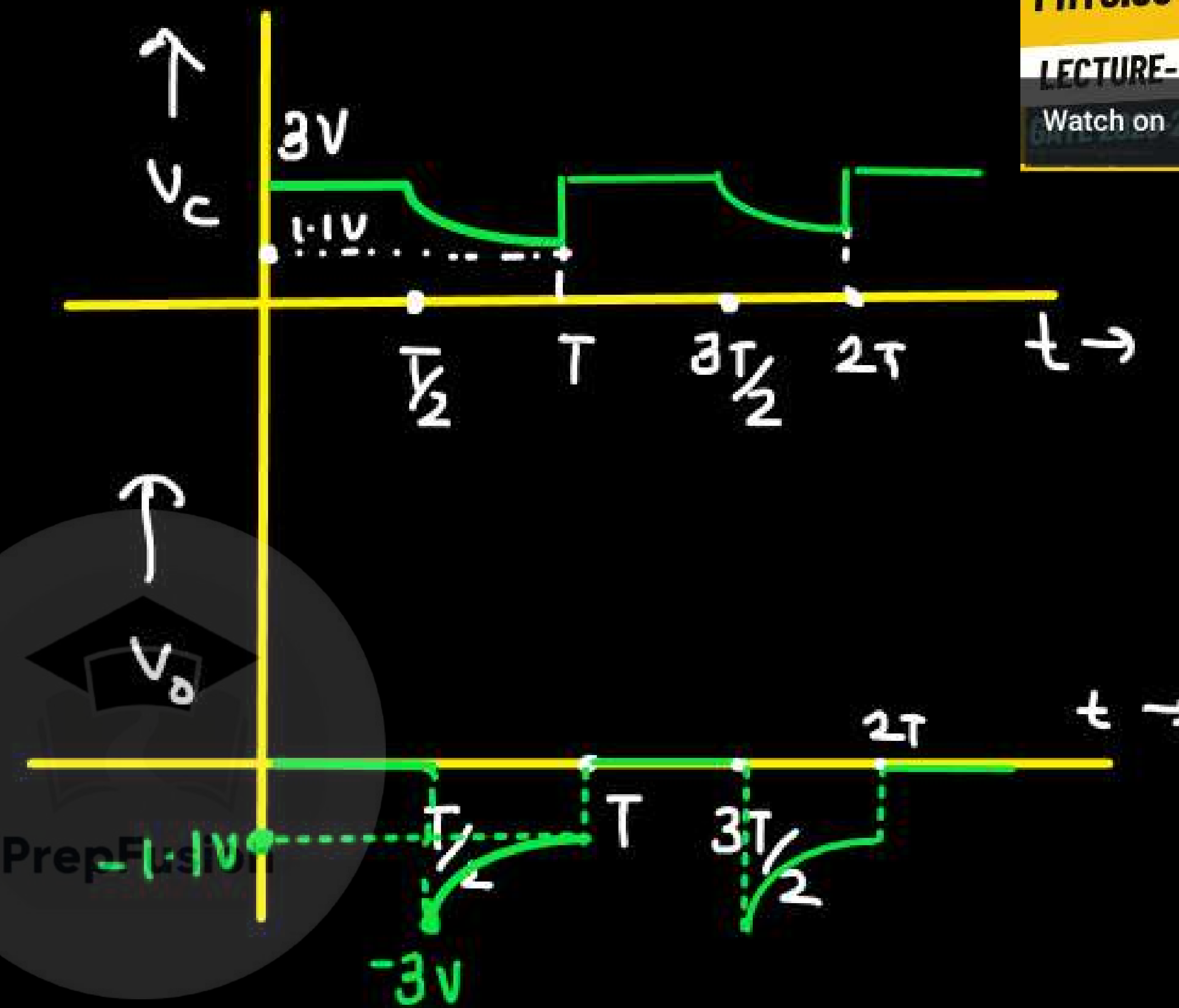
⇒ diode Turns ON



$T < t < 3T/2$

$V_c = 3V$

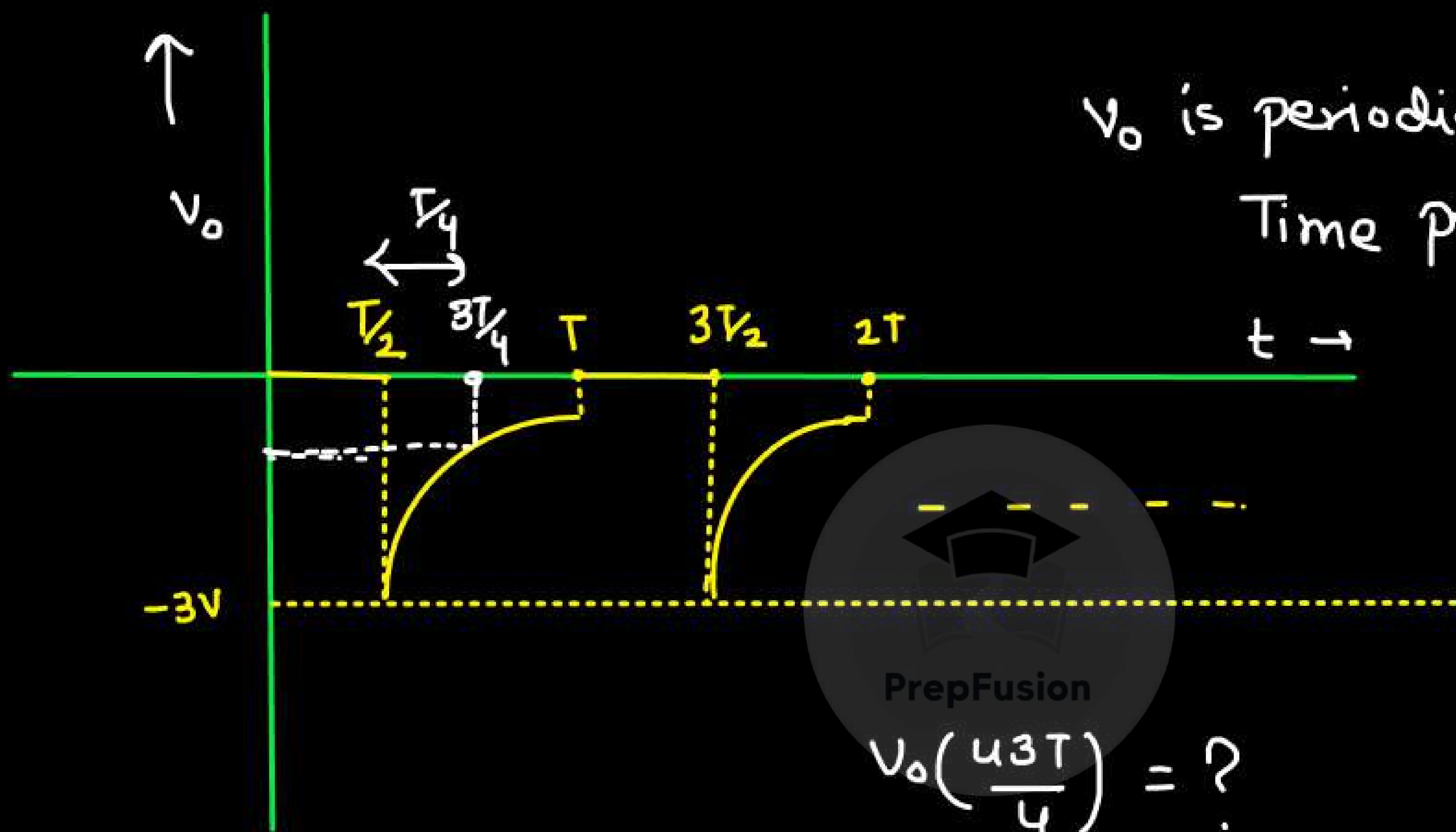
$V_o = 0V$



@ $t = 3T/2^+$ ⇒ diode off

⇓

cap discharges



V_o is periodic by Time period T

$$V_o\left(\frac{43T}{4}\right) = ?$$

$$V_o\left[\frac{43T}{4}\right] = V_o\left[10T + \frac{3T}{4}\right] = V_o\left[\frac{3T}{4}\right]$$

$$v_o(t) = -3e^{-(t - T/2)/RC}$$

$$v_o\left(\frac{3T}{4}\right) = -3e^{-\left(\frac{3T}{4}-\frac{T}{2}\right)/RC}$$

$$= -3e^{-T/4RC} \qquad T = 2RC$$

$$= -3e^{-2RC/4RC}$$

$$= -3e^{-1/2}$$

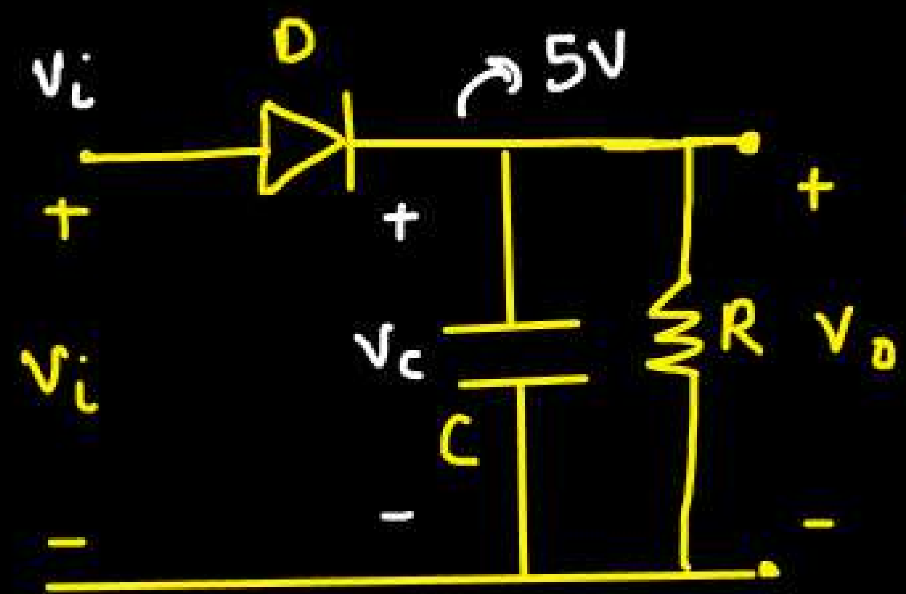
$$v_o\left(\frac{3T}{4}\right) = -1.8V = v_o\left(\frac{43T}{4}\right)$$

$$\boxed{v_o\left(\frac{43T}{4}\right) = -1.8V}$$

Peak detector circuits:-

↳ Detects either the +ve peak or -ve peak

★ Positive peak detector circuit



$\boxed{RC = High}$

For $t = 0^+ \Rightarrow V_i > 0V$

$\Rightarrow$ Diode will be ON

$V_c = V_i \quad \{0 < t < T/4\}$

@ $t = T/4^+$

$V_i = 4.9V$ {let}, $V_c = 5V$

$\Rightarrow$ diode will be OFF $\Rightarrow \boxed{V_c = 5V}$

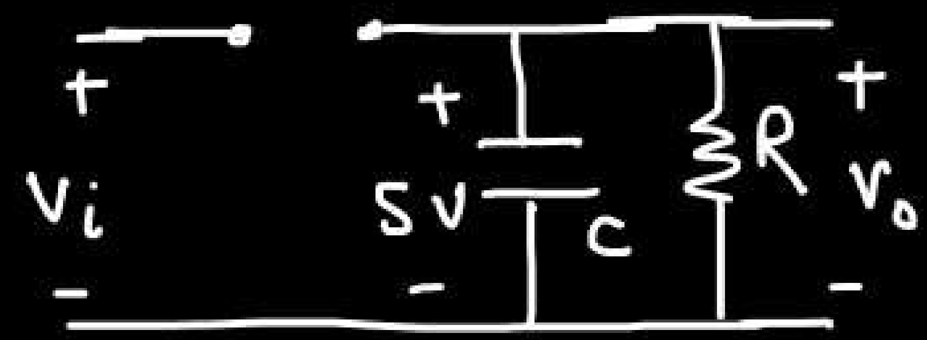
To turn on the diode,

$V_i > 5V \Rightarrow$ NOT possible

$\Rightarrow$ Diode will always be OFF

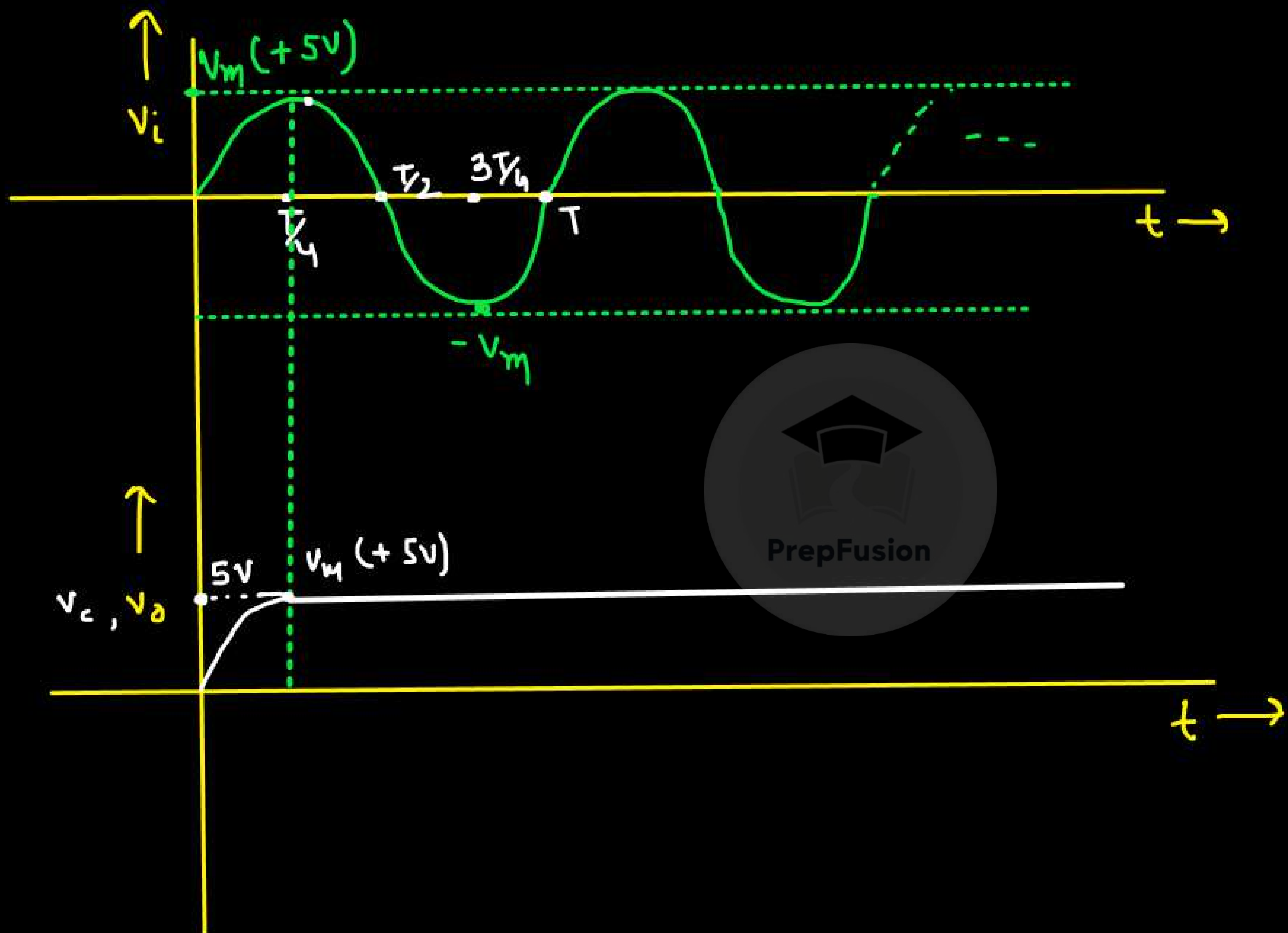
@ $t = T/4^+$

diode is off



The cap. will not discharge because RC value is very large

$$\boxed{V_c\,(s.s.) = 5V}$$



Vm (+5V)
Vi
T/4
T/2
3T/4
T
-Vm
t →
5V
Vm (+5V)
Vc , Vo
t →
PrepFusion

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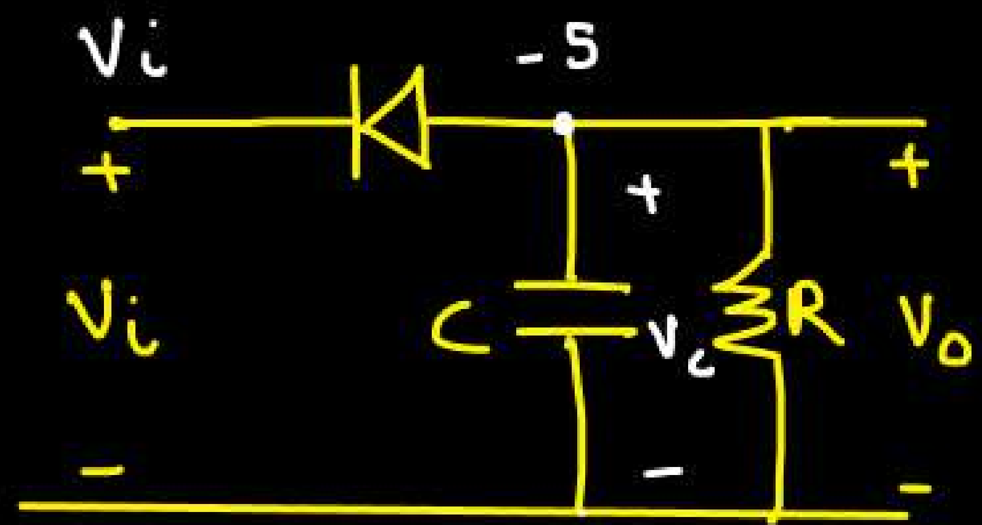
★ Negative Peak Detector Circuit:-



For $0 < t < T/2 \Rightarrow V_i = +ve \Rightarrow$ diode is off

$$V_o = V_c = 0V \quad \forall \; \{0 < t < T/2\}$$

@ $t = T/2^{+} \Rightarrow V_i < 0 \Rightarrow$ diode will turn ON

$$V_c = V_i \quad \{T/2 < t < 3T/4\}$$

@ $t = 3T/4^{+}$

$V_i = -4.9V$ {Let} , $V_c = -5V$

$\Rightarrow$ diode is off

To turn on the diode, $V_i < -5V$

$\Downarrow$

NOT Possible

$\Downarrow$

diode will always be off

$\boxed{V_c = -5V}$ → steady state

{since RC is very large, the cap. can't discharge further}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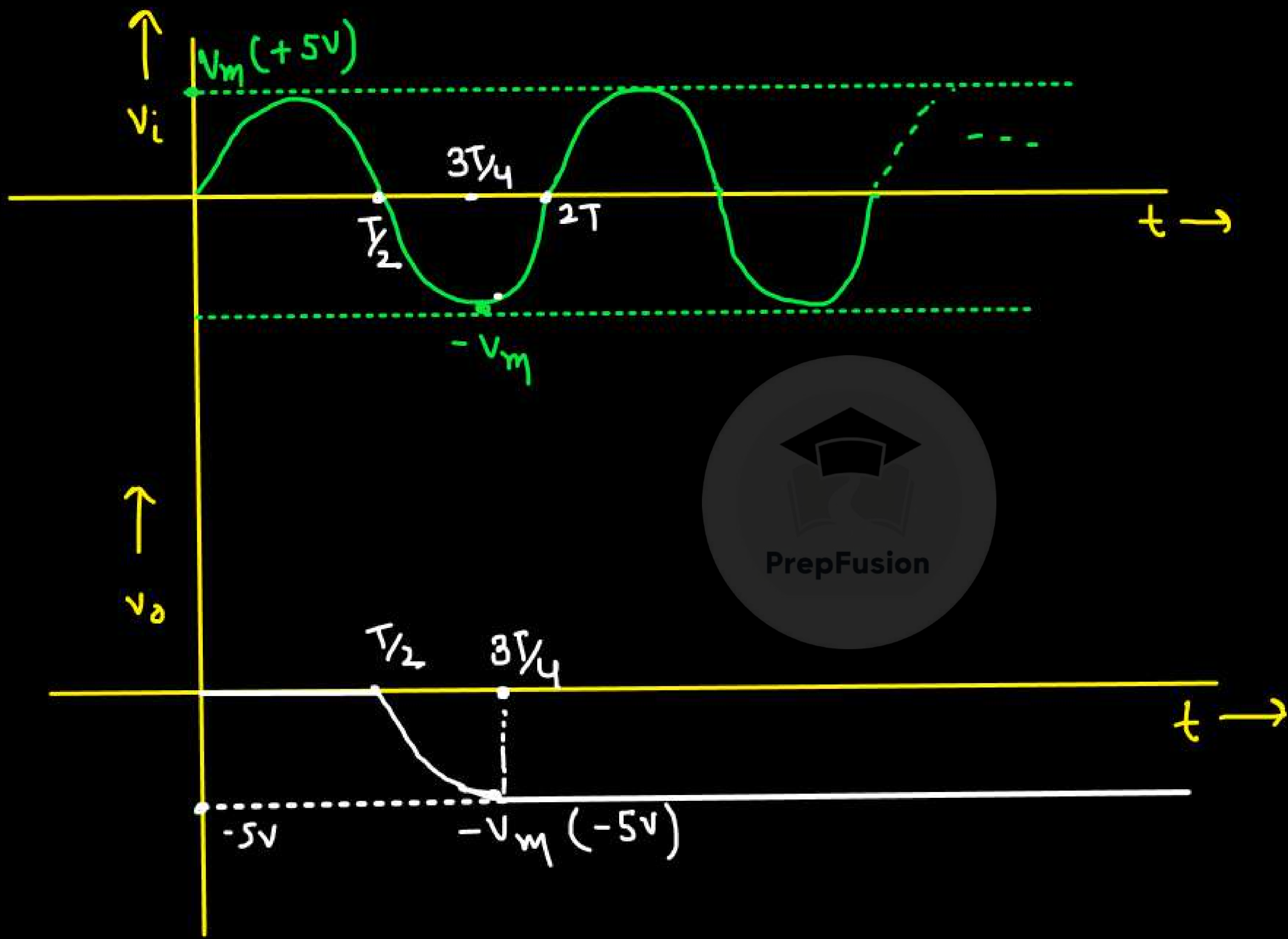
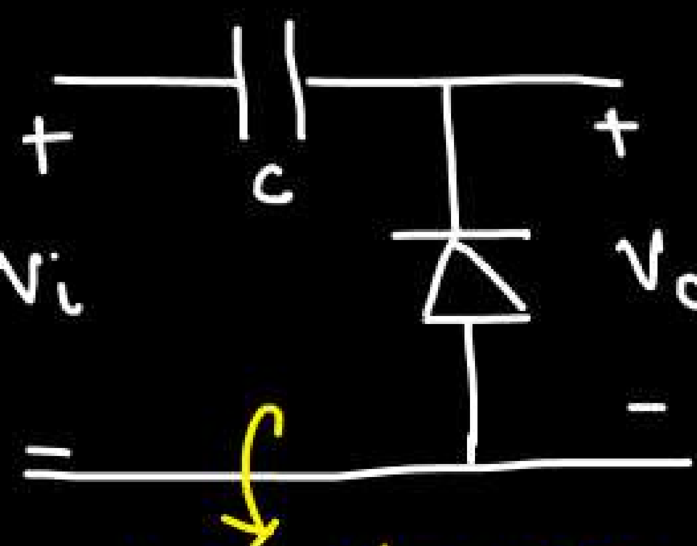

Vm (+5V)
vi
3T/4
T/2
2T
t
-Vm
v0
T/2
3T/4
t
-5V
-Vm (-5V)

Given $v_i = V_m \sin\omega t$

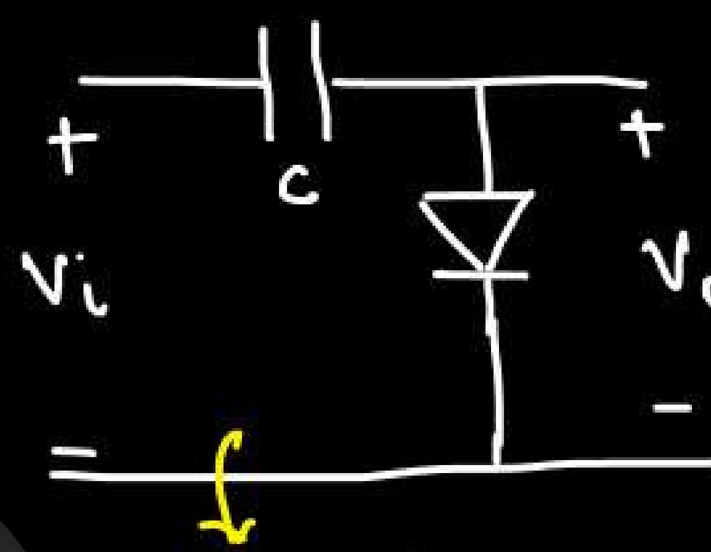
(a)



$V_o = V_i + V_m$

+ve clamper

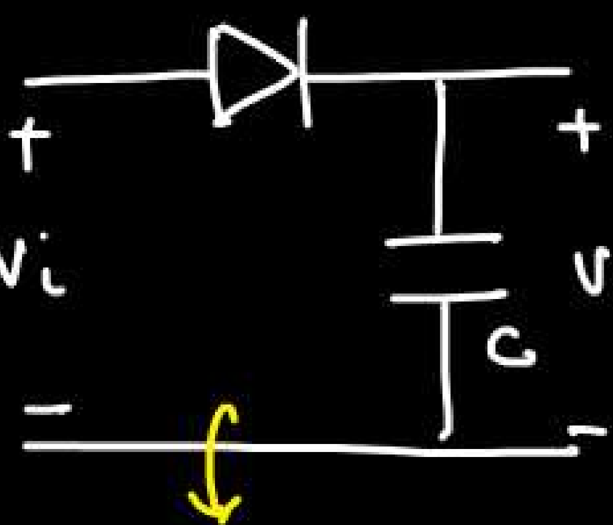
(b)



$V_o = V_i - V_m$

-ve clampler

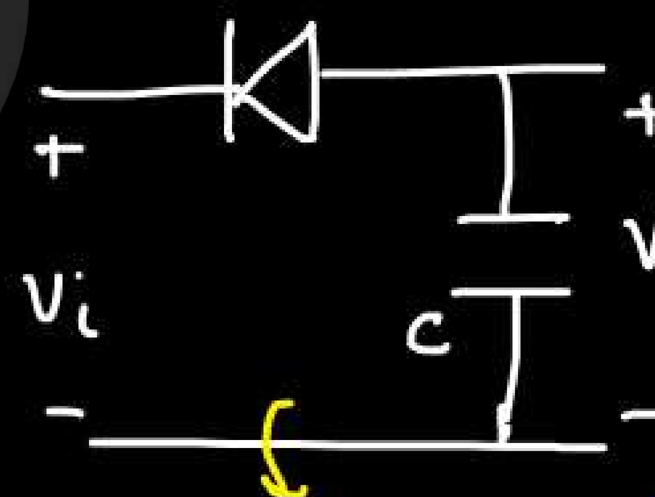
(c)



$V_o = +V_m$

+ve peak detector

(d)

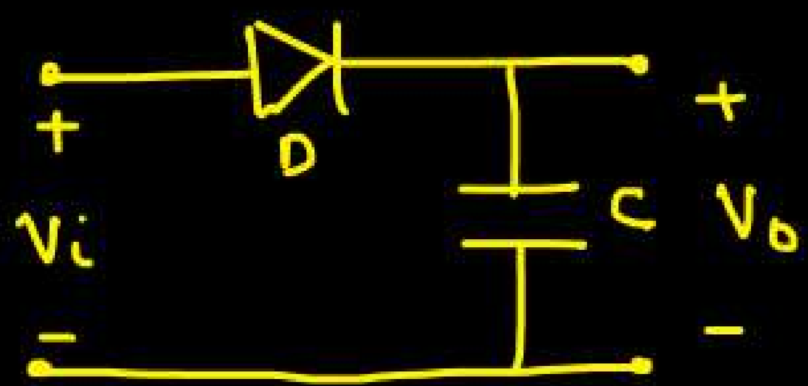


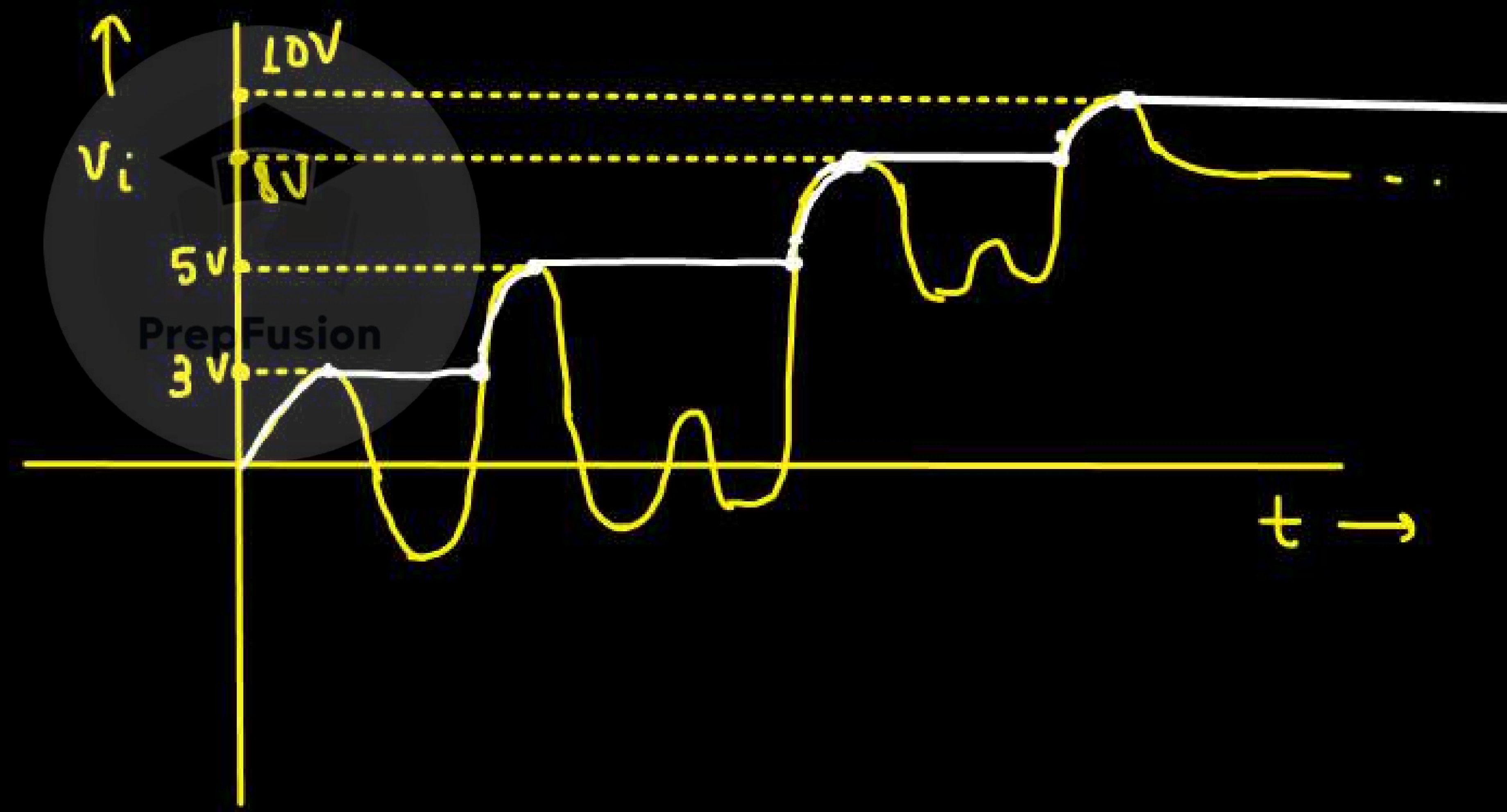
$V_o = -V_m$

-ve peak detector

Q. Find the steady state o/p.

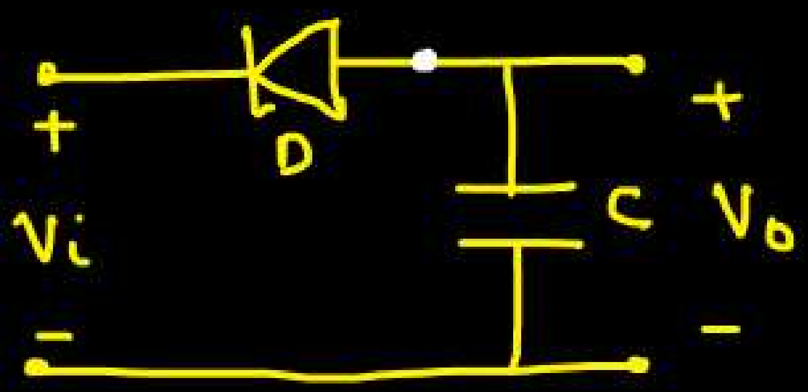
Draw V_o waveform.

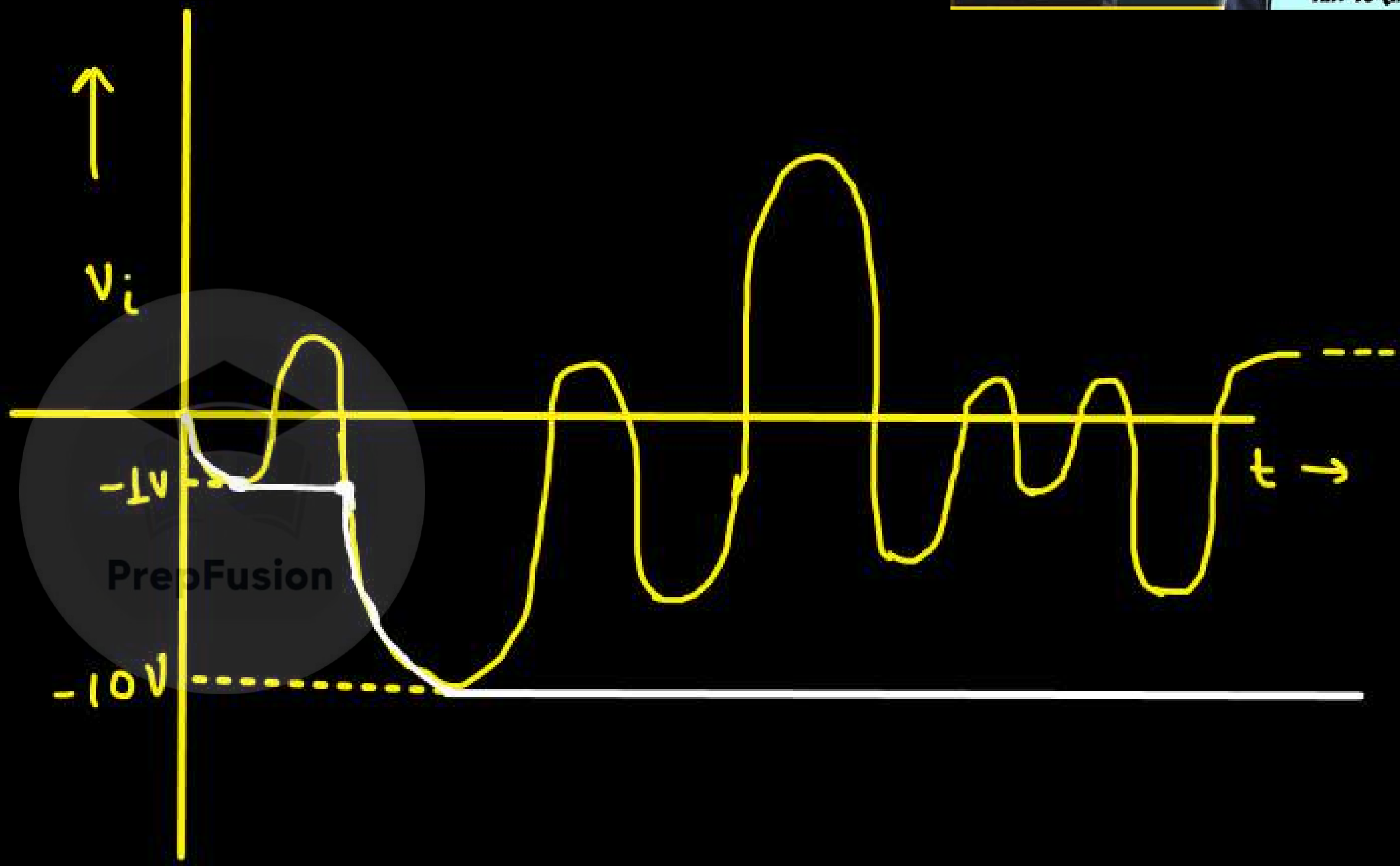




Q. Find the steady state o/p.

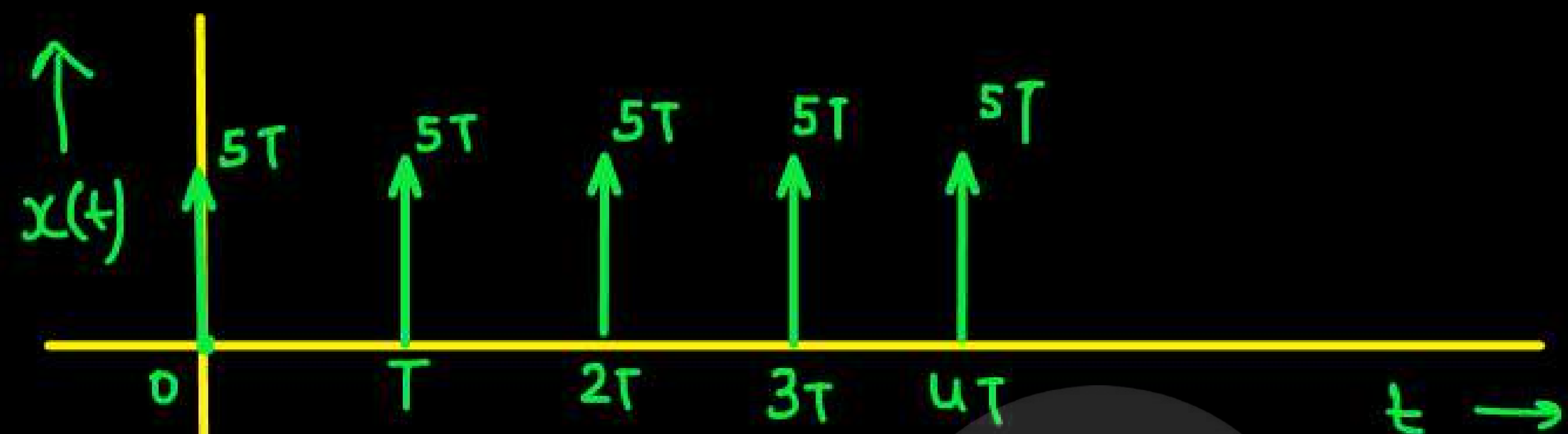
Draw V_o waveform.





$$\boxed{V_o\,(S.S.) = -10V}$$

Q. Find the average of the given signal.

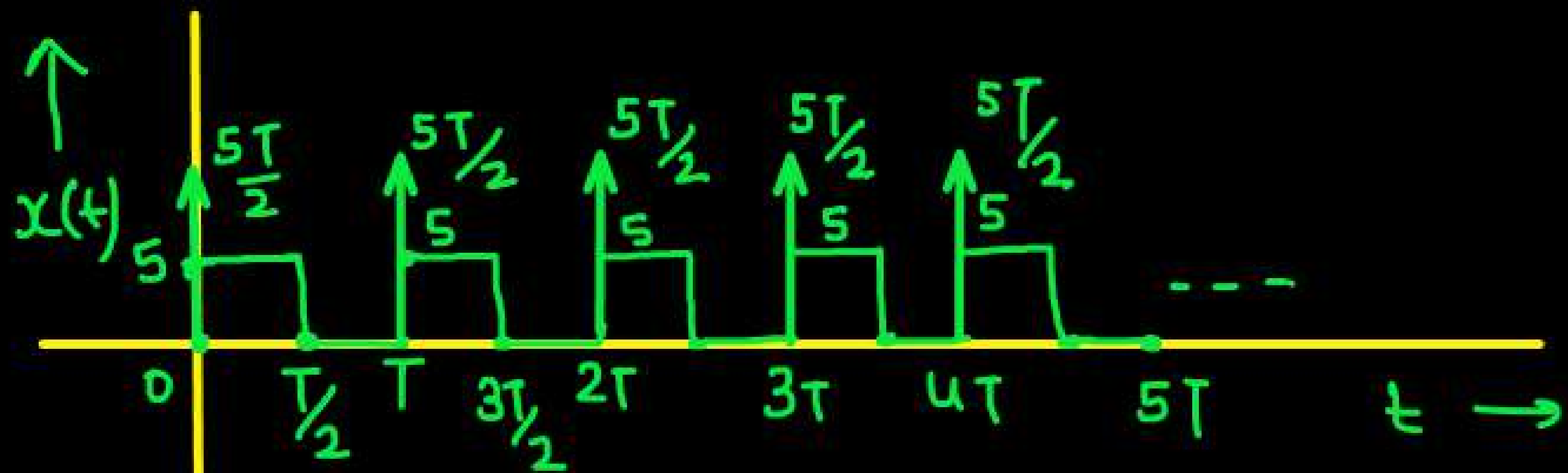


(a)

$$\Rightarrow \quad \text{avg.} = \frac{\text{Area of one Time period}}{\text{Time period}}$$

$$= \frac{5T}{T} = \underline{\underline{5}}$$

$$\boxed{\text{avg.} = 5}$$



(b)

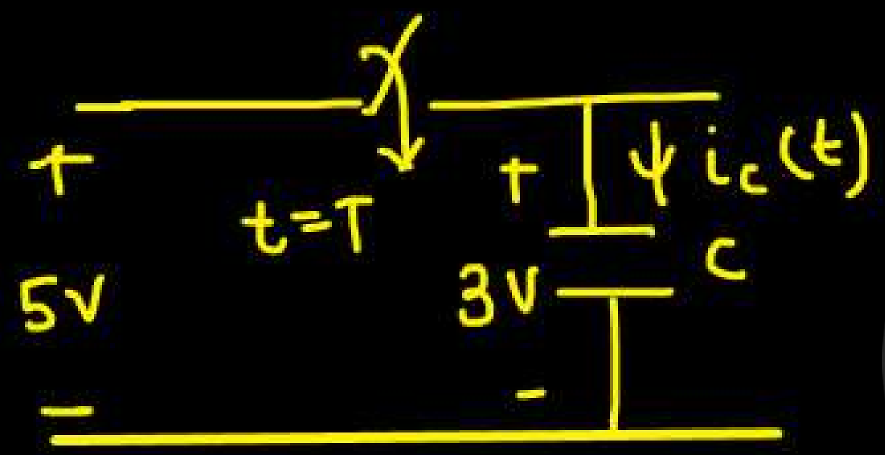
$$\text{Avg} = \frac{\frac{5T}{2} + \frac{5T}{2}}{T} = \frac{5T}{T} = 5$$

$$\boxed{\text{Avg} = 5}$$

Q. Cap. is initially charged to 3V.

The switch is closed @ $t = T$.

Find $i_c(T) = ?$



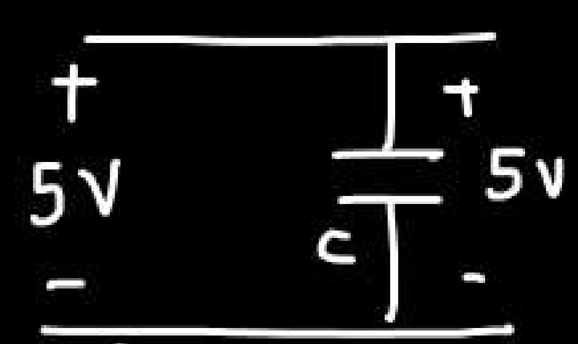
$$v_c(T^-) = 3V$$
$$v_c(T^+) = 5V$$

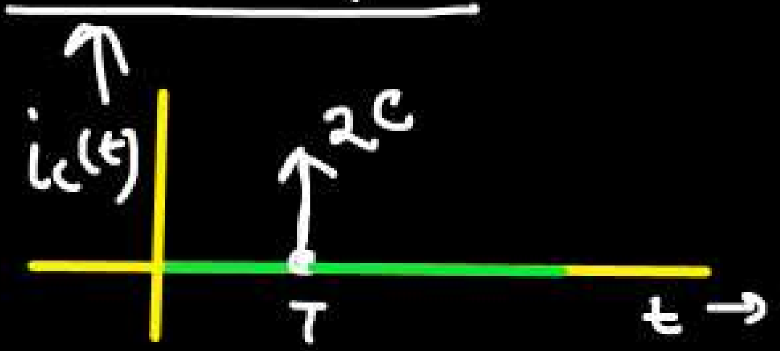
$$i_c(t) = C\frac{dv_c(t)}{dt}$$

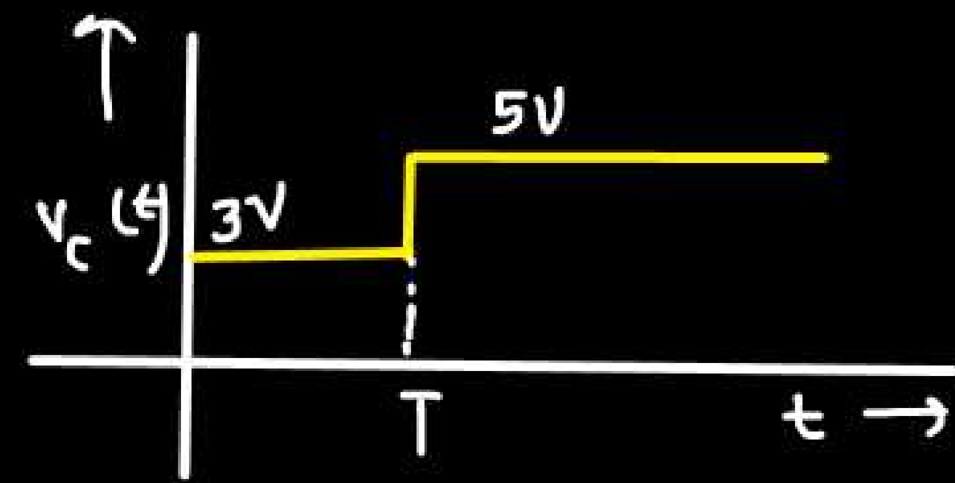
$$i_c(t) = \frac{C[5-3]}{0}$$

$$\boxed{i_c(t) = 2C\,\delta(t-T)}$$

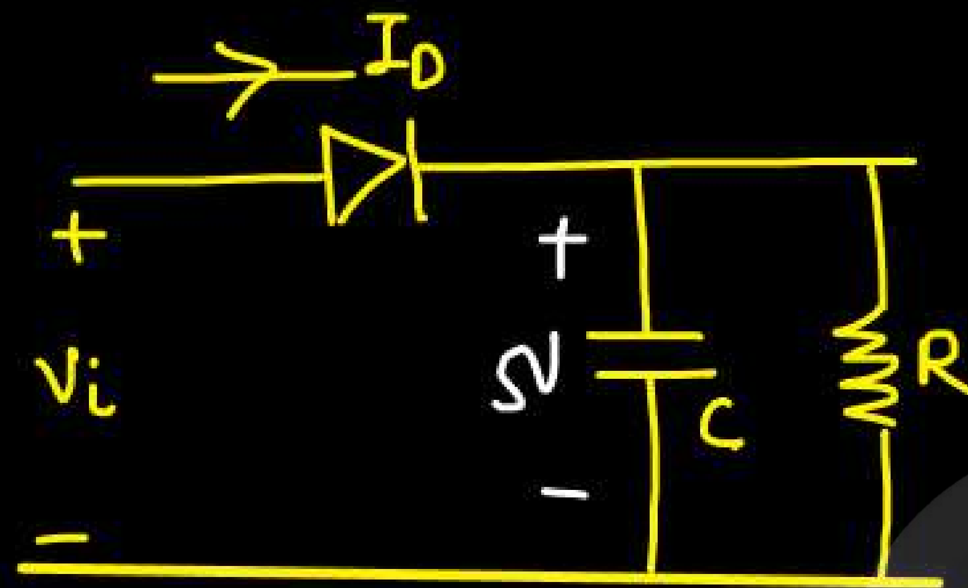
→

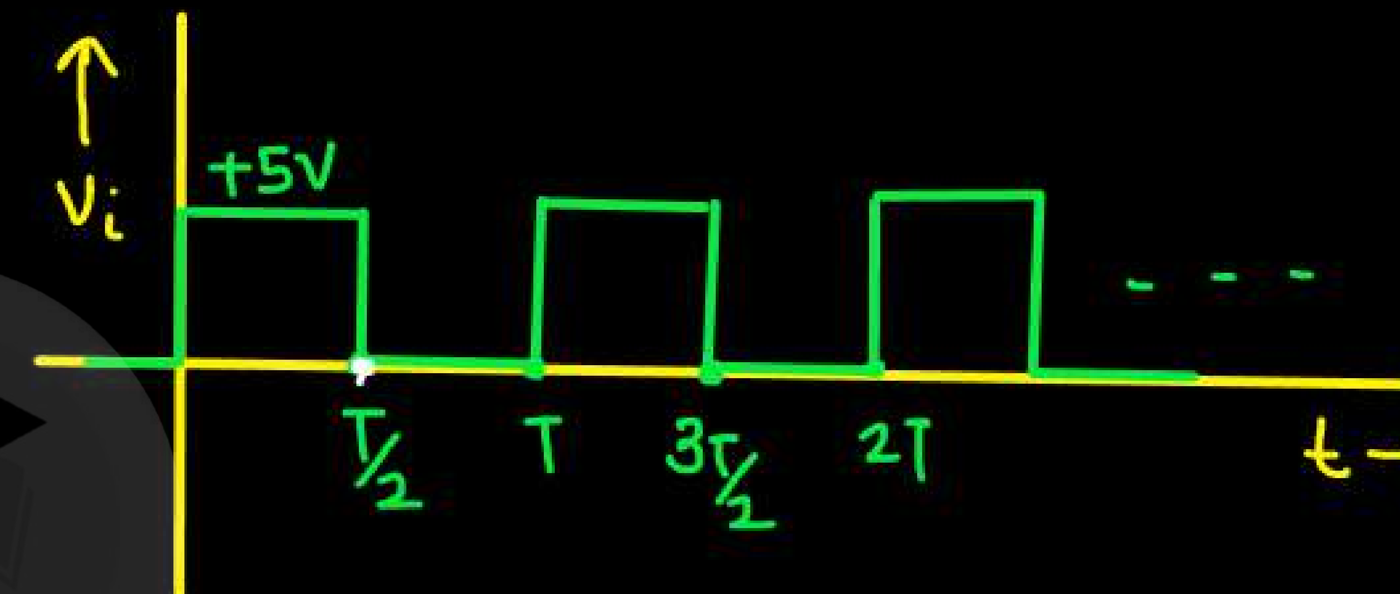






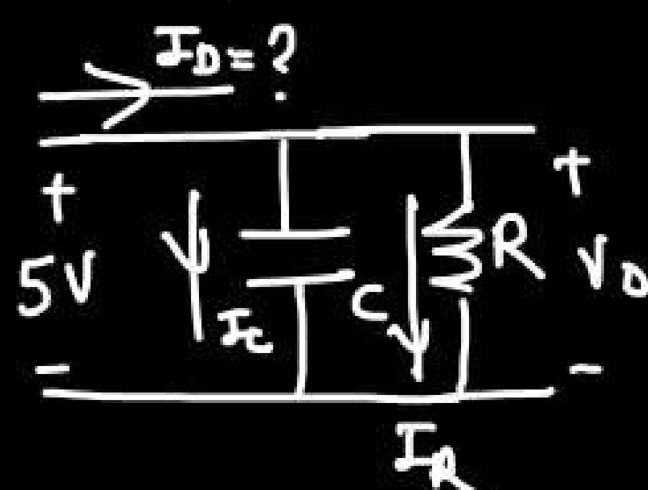
Q. Find $(I_D)_{avg}$ at steady state.





Given $RC = 20T$

→ $0 < t < T/2 \Rightarrow V_i = 5V \Rightarrow$ diode is ON



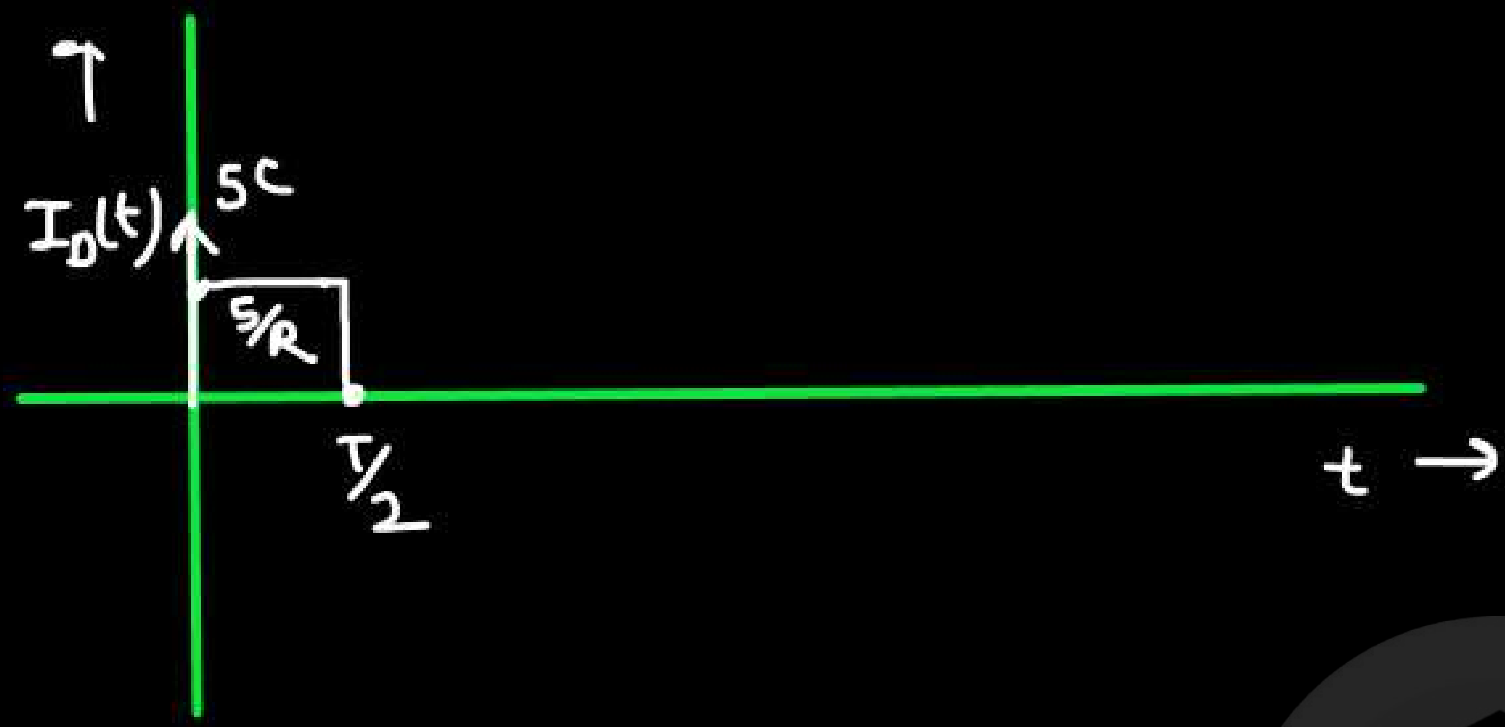
$V_o = 5\,V$

$0 < t < T/2$

$I_D(t) = I_C(t) + I_R(t)$

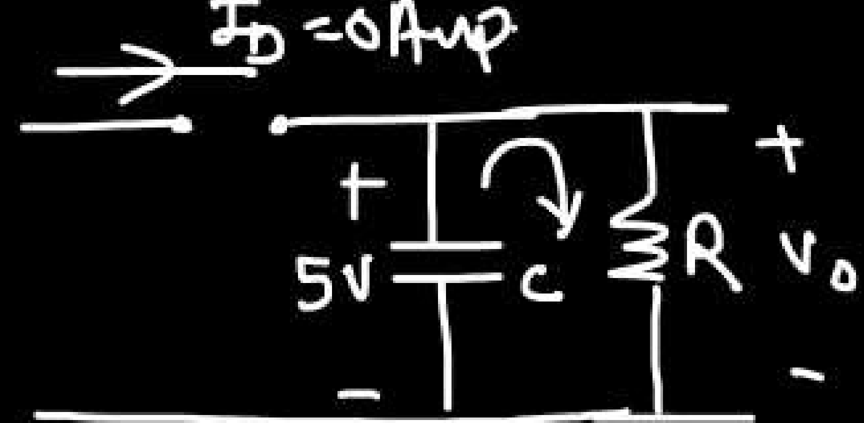
$= 5C\,\delta(t) + 5/R$

$$\boxed{e^{-x} = 1 - x}$$



For $T/2 < t < T$

$v_i = 0\,V \Rightarrow$ diode turns off

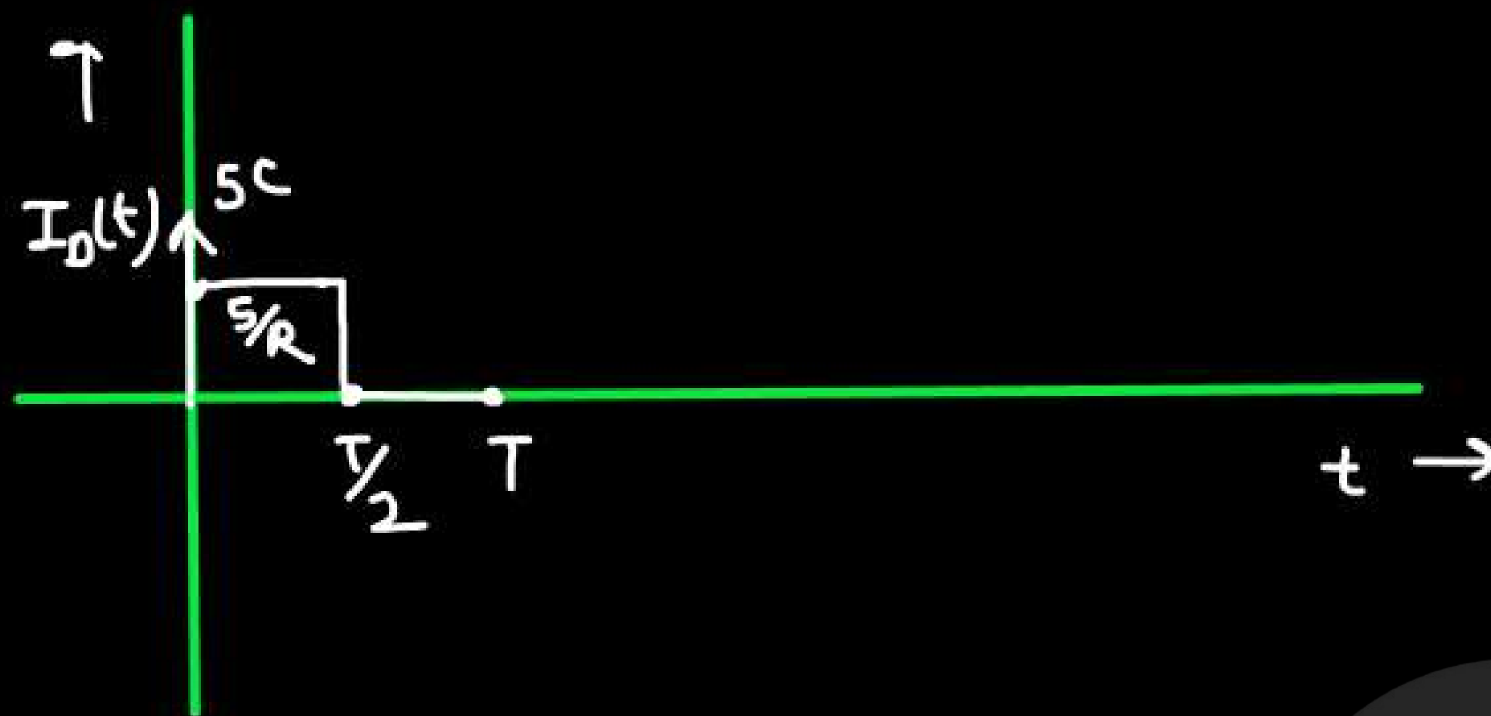


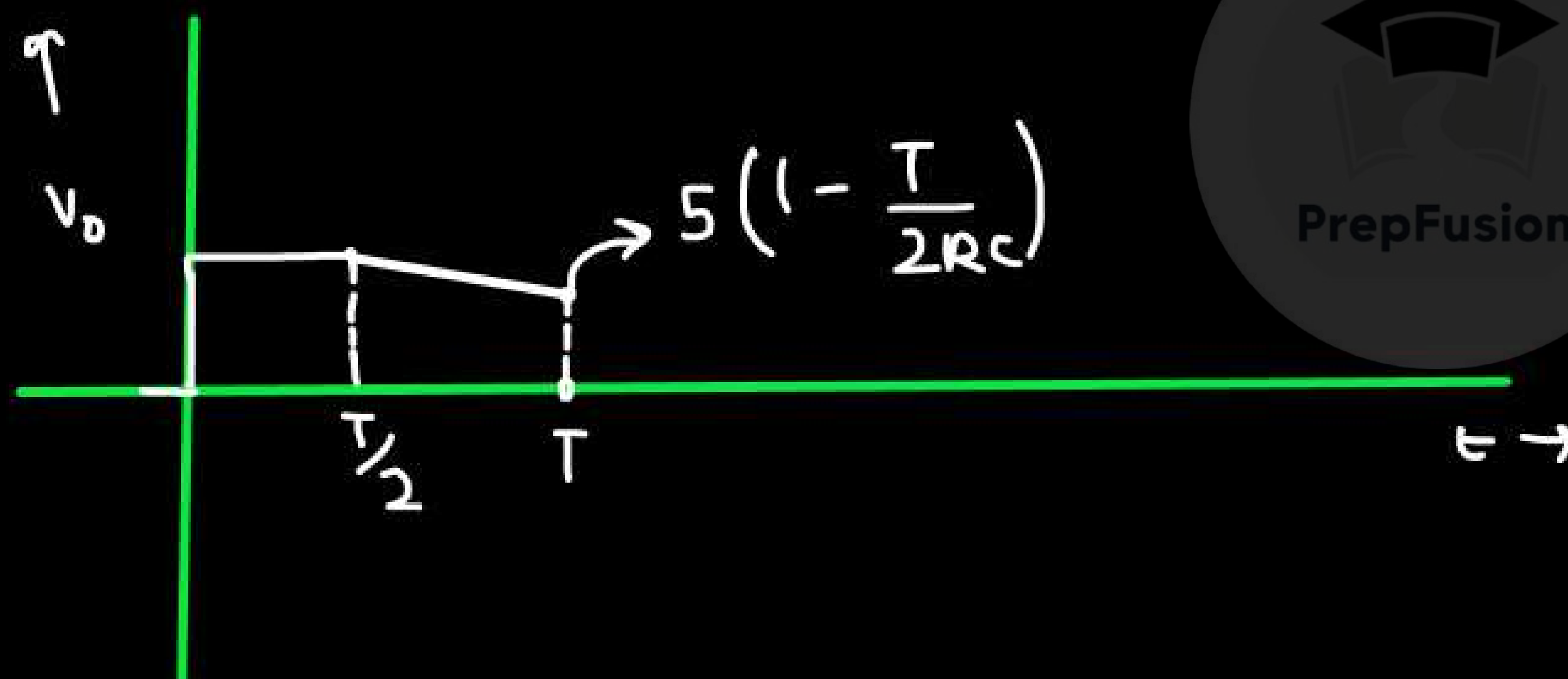
$$\boxed{I_D = 0 \text{ Amp}}$$

$$v_o(t) = 5e^{-(t-T/2)/RC}$$

$$v_o(t) = 5\left[1 - \frac{(t - T/2)}{RC}\right]$$

$$v_o(T) = 5\left[1 - \frac{T}{2RC}\right] \Leftarrow$$


$I_D(t)$
5C
5/R
T/2
T
t →


V_0
$5\left(1-\frac{T}{2RC}\right)$
T/2
T
t →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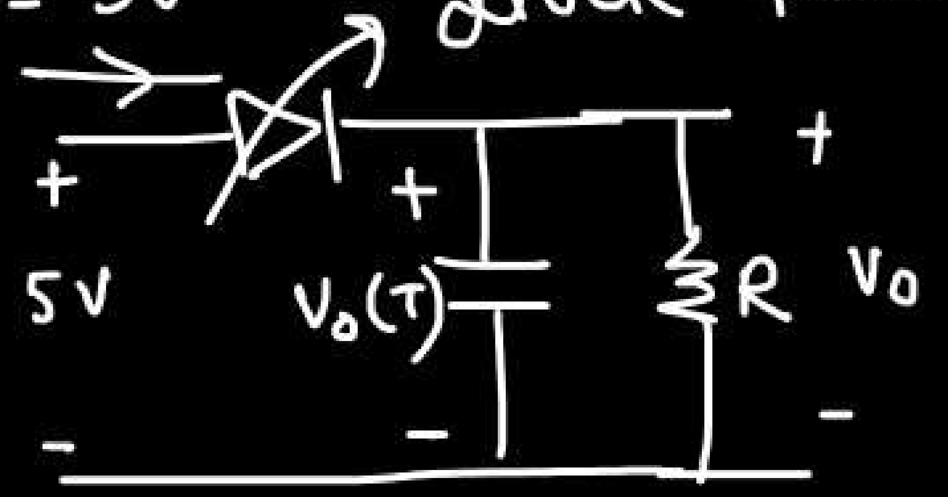
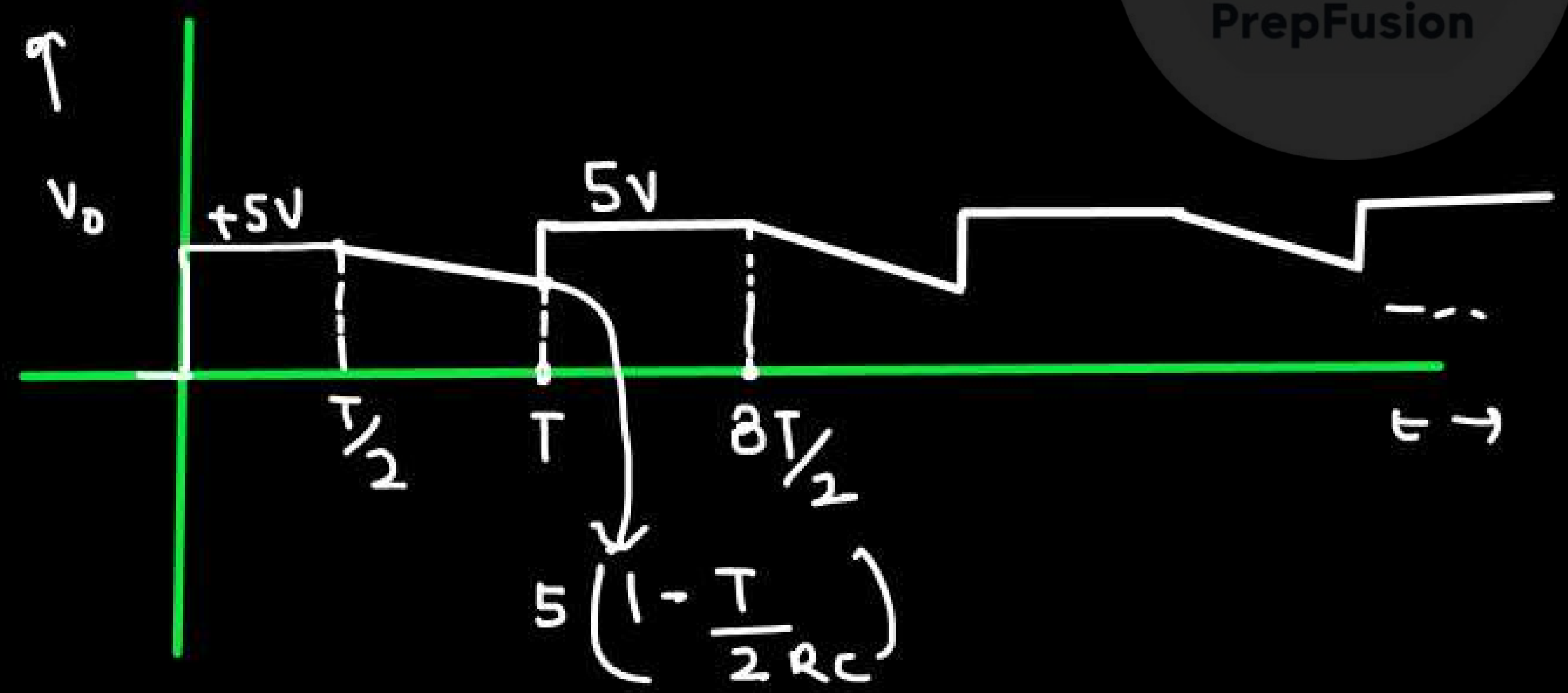
$\Rightarrow T < t < 3T/2$

$V_i = 5V$ diode turns on

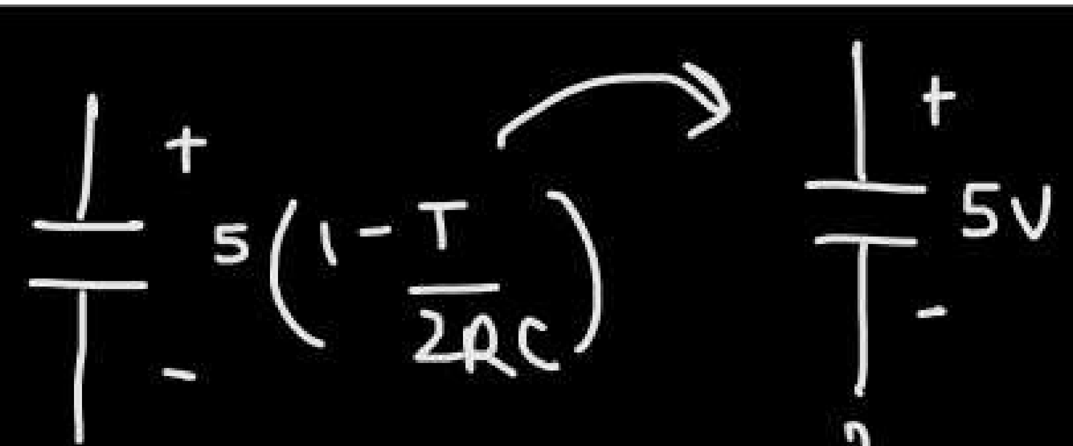


$V_0(T^+) = 5V$



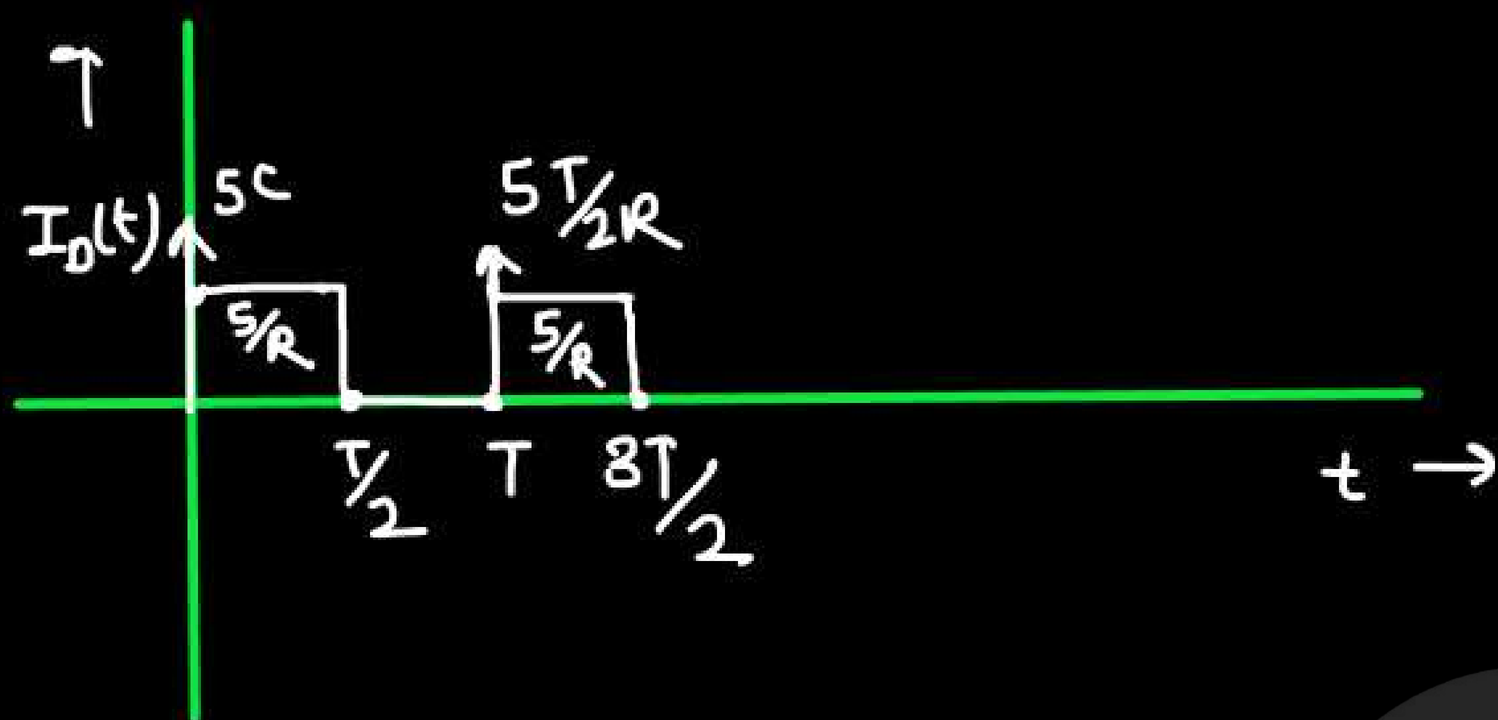
resistor current

$$\boxed{I_D(t) = \frac{5}{R} + \frac{5T}{2R}\delta(t-T)}$$



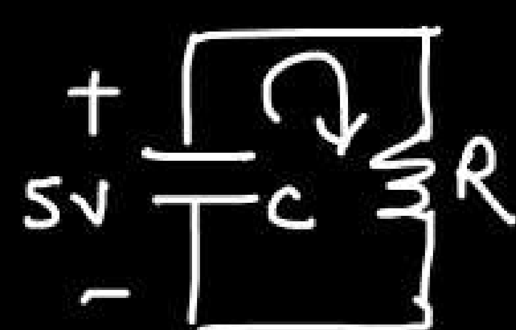
$$C\left\{5 - \left[5 - \frac{5T}{2RC}\right]\right\}\delta(t)$$

$$= \frac{5C}{2RC}T\,\delta(t) = \frac{5T}{2R}\delta(t)$$

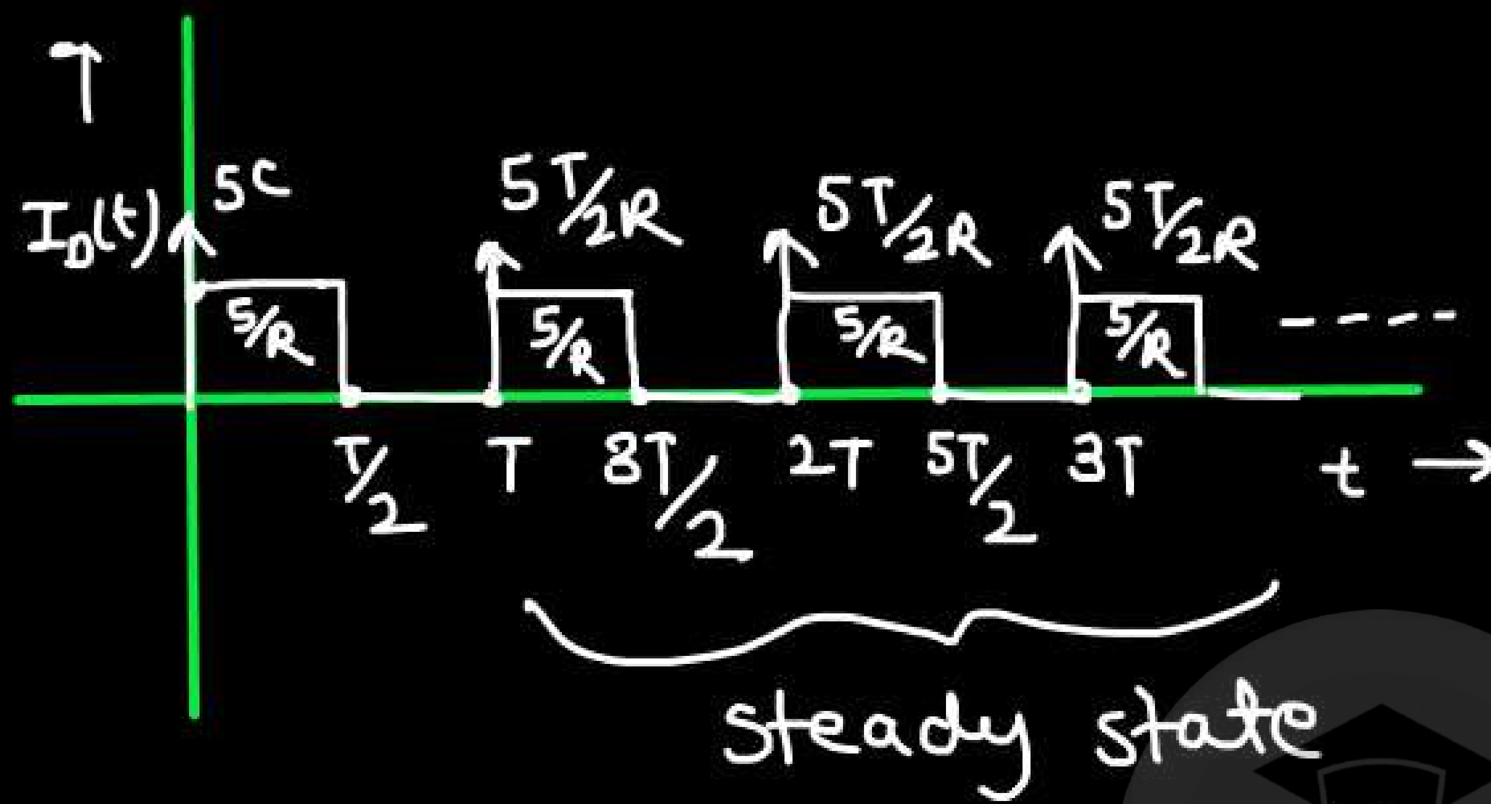


For $3T/2 < t < 2T$

$V_i = 0V$, $V_0 = +5V \Rightarrow$ diode will be off $I_D = 0$ Avg.



→ it will discharge in the same manner as $T/2 < t < T$

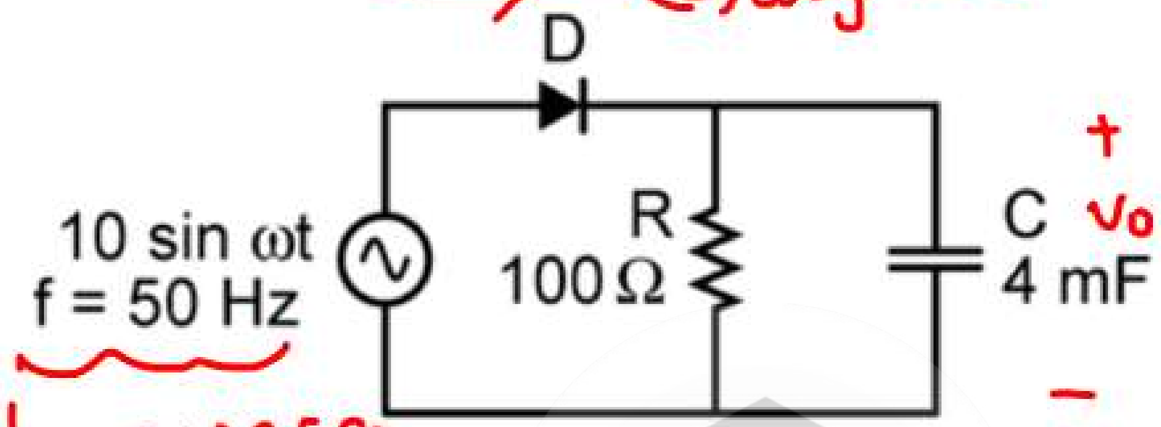


$$\left[I_D(t)_{avg}\right]_{S.S.} = \frac{\frac{5}{R}\left[\frac{3T}{2} - T\right] + \frac{5T}{2R}}{T} = \frac{\frac{5T}{2R} + \frac{5T}{2R}}{T}$$

$$\boxed{(I_D)_{avg.} = \frac{5}{R}}$$

Q. The figure shows a half-wave rectifier. The diode D is ideal. The average steady-state current (in Amperes) through the diode is approximately ____________.

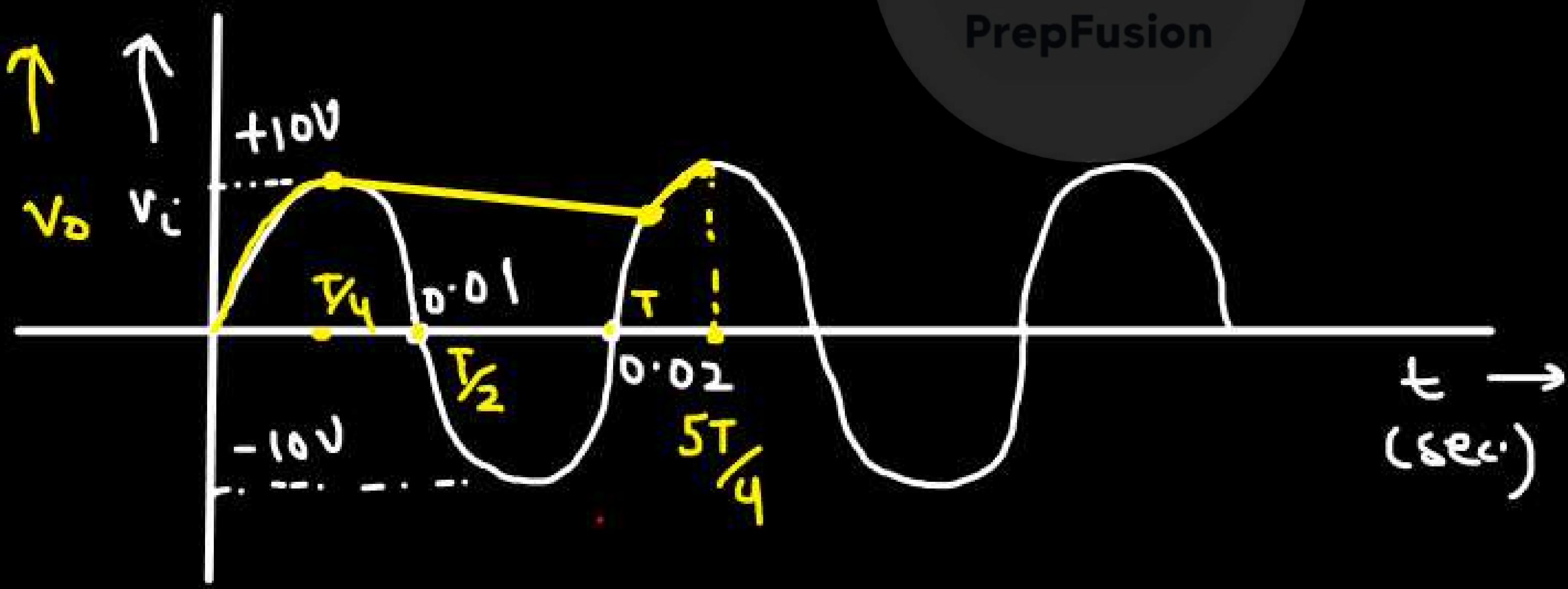
$\rightarrow (I_D)_{avg.}$ (s.s.)



$RC = 400\,m\,sec.$

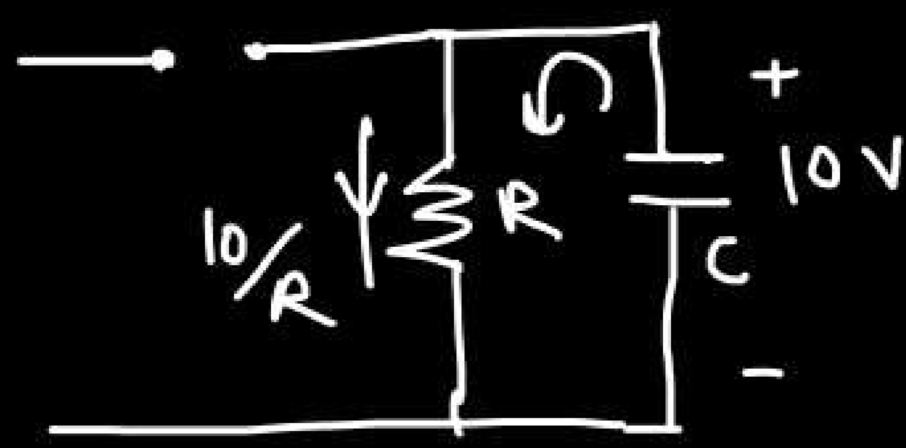
$= 0.4\,sec.$

$T = \frac{1}{50} = 0.02\,sec.$



@ $t = T/2^{+}$

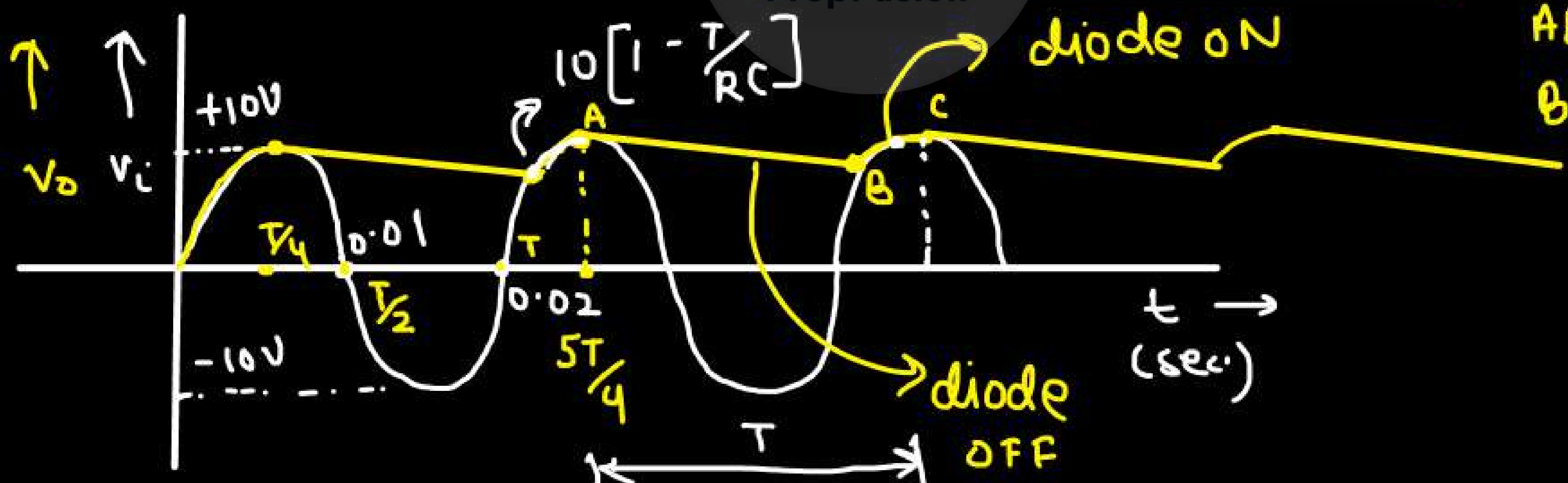
diode is off



$$V_0(t) = 10\, e^{-(t - T/4)/RC}$$

$$V_0(t) = 10\left[1 - \frac{(t - T/4)}{RC}\right] \qquad \{e^{-x} = 1 - x\}$$

$$\boxed{V_0\left(\frac{5T^-}{4}\right) = 10\left[1 - \frac{T}{RC}\right]} \approx 9.99\,V$$

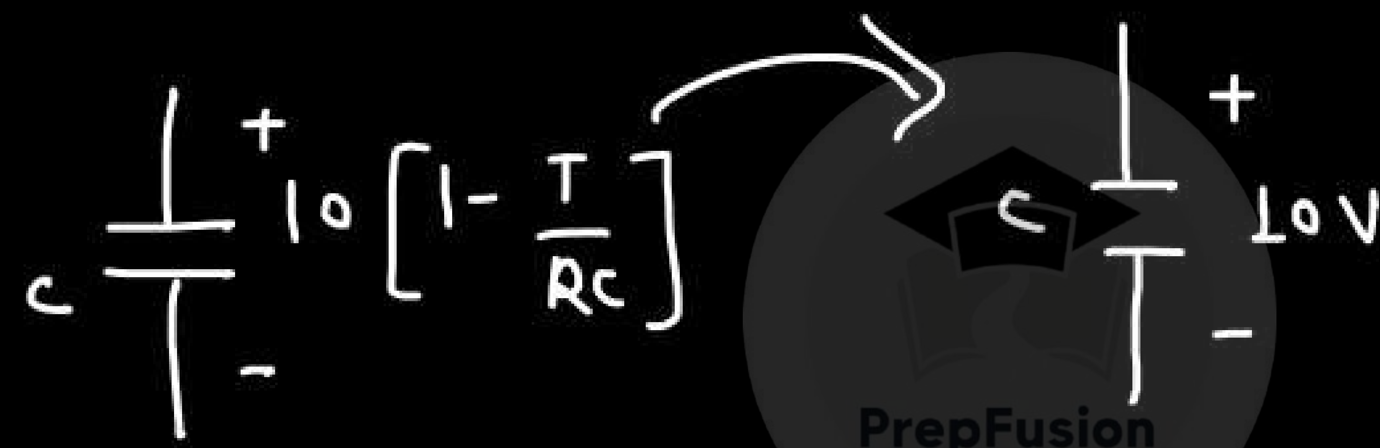


AB → diode off

BC → diode ON

$$V_0\left(\frac{5T^+}{4}\right) = 10\,V$$

$$V_0\left(\frac{5T^-}{4}\right) = 10\left[1 - \frac{T}{RC}\right]V$$



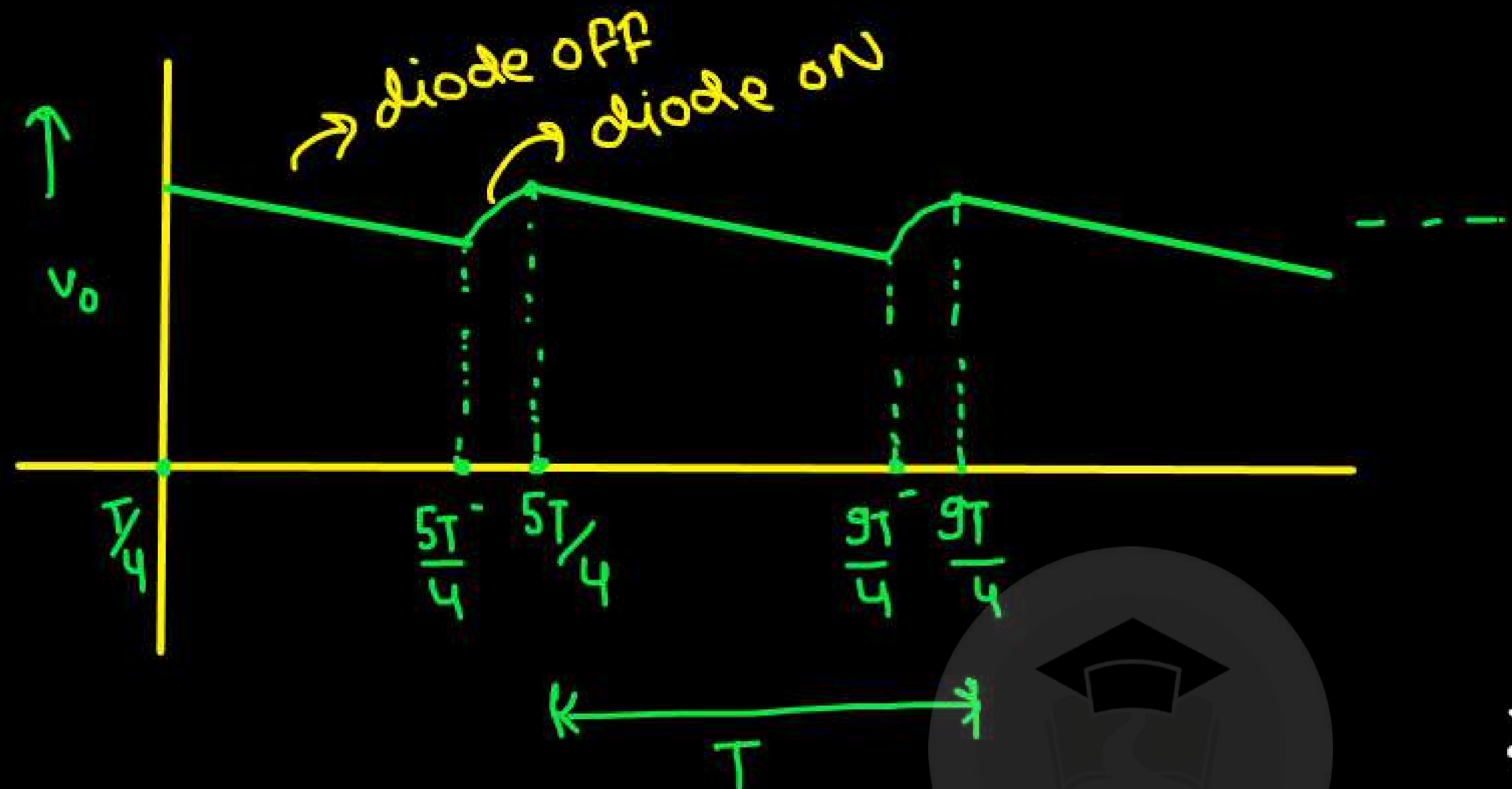
$$\Rightarrow C\left[10 - \left[10 - \frac{10T}{RC}\right]\right]$$

$$= \frac{10T}{RC} \times C\,\delta\left(t - \frac{5T}{4}\right)$$

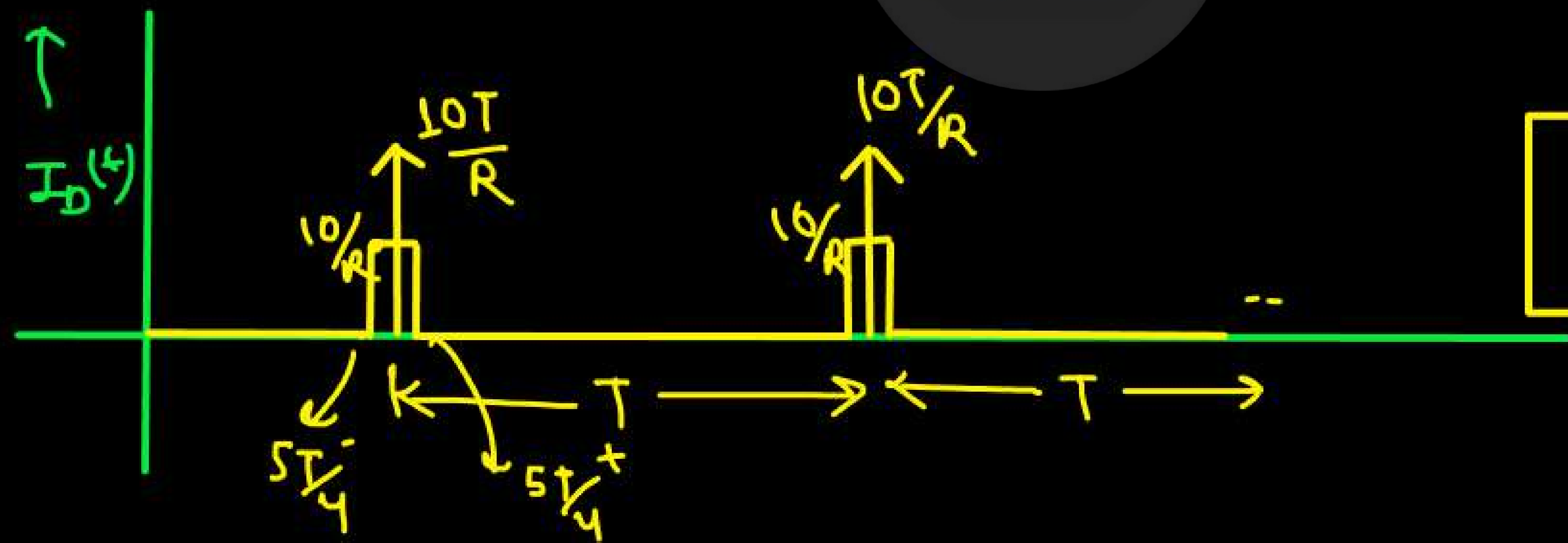
$$= \frac{10T}{R}\,\delta\left(t - \frac{5T}{4}\right)$$

$$I_D(t) = I_R(t) + I_C(t)$$

$$= \frac{10}{R} + \frac{10T}{R}\,\delta\left(t - \frac{5T}{4}\right)$$



$$I_{D\,Avg} = \frac{\frac{10T}{R} + \frac{10}{R}[0]}{T}$$



$$\boxed{(I_D)_{avg} = \frac{10}{R}}$$

$$= \frac{10}{100}$$

$$= 0.1 \text{ Amp.}$$

Voltage Multiplier :-

Produces dc voltage greater than its max^m input voltage.

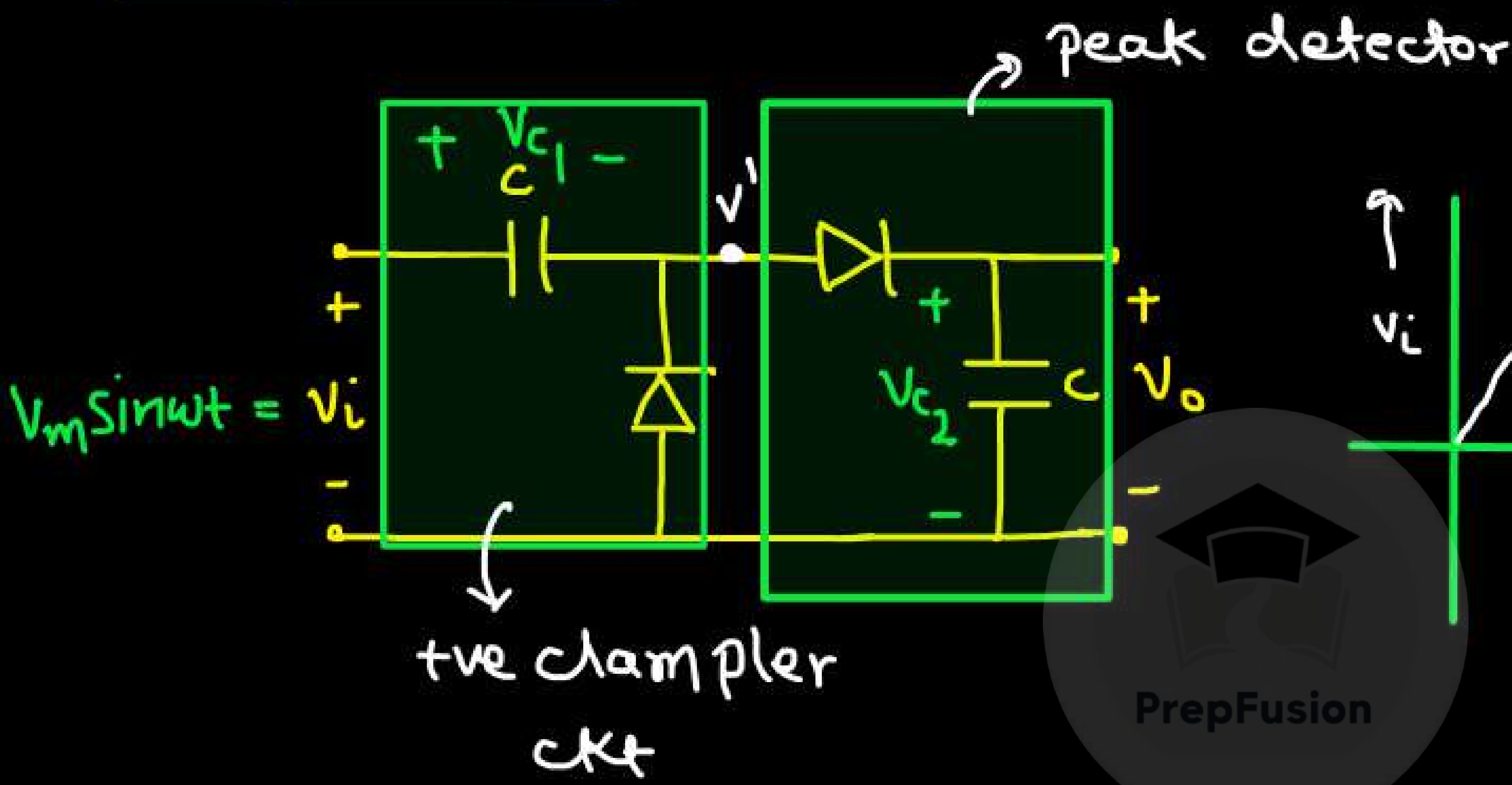
$K=1 \Rightarrow V_o = V_m \Rightarrow$ Positive peak detector

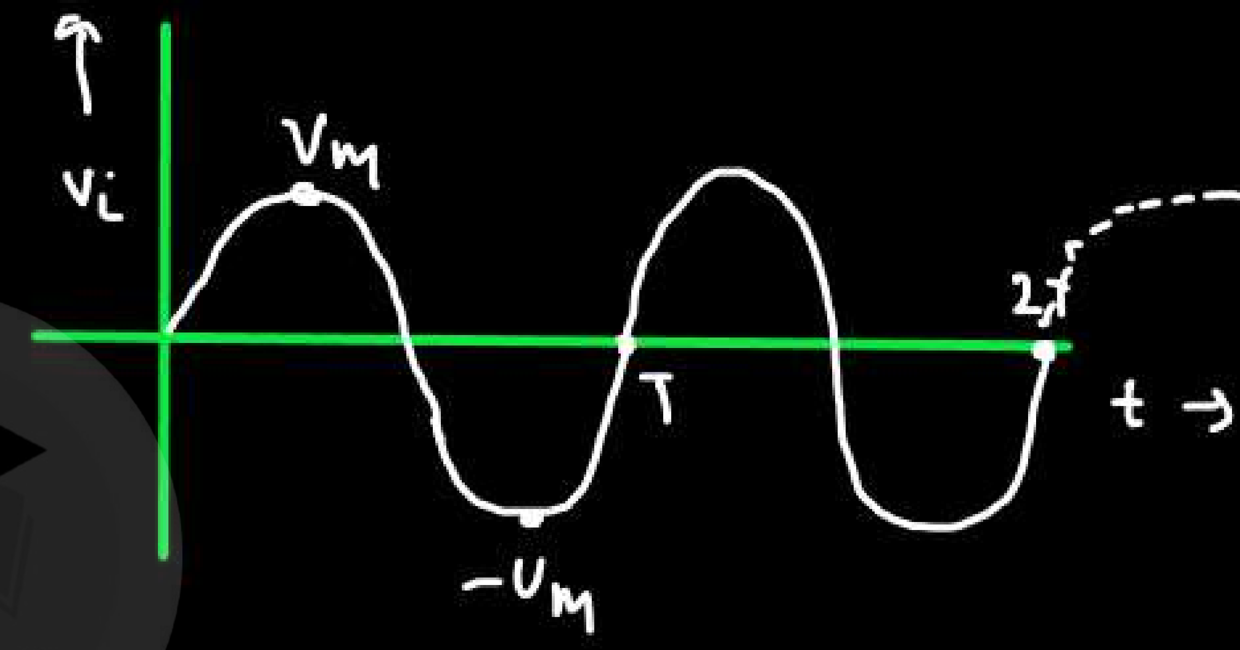
$K=2 \Rightarrow V_o = 2V_m \Rightarrow$ Voltage double

$K=3 \Rightarrow V_o = 3V_m \Rightarrow$ Voltage Tripler

$K=4 \Rightarrow V_o = 4V_m \Rightarrow$ voltage Quadrupler

★ Voltage doubler :-



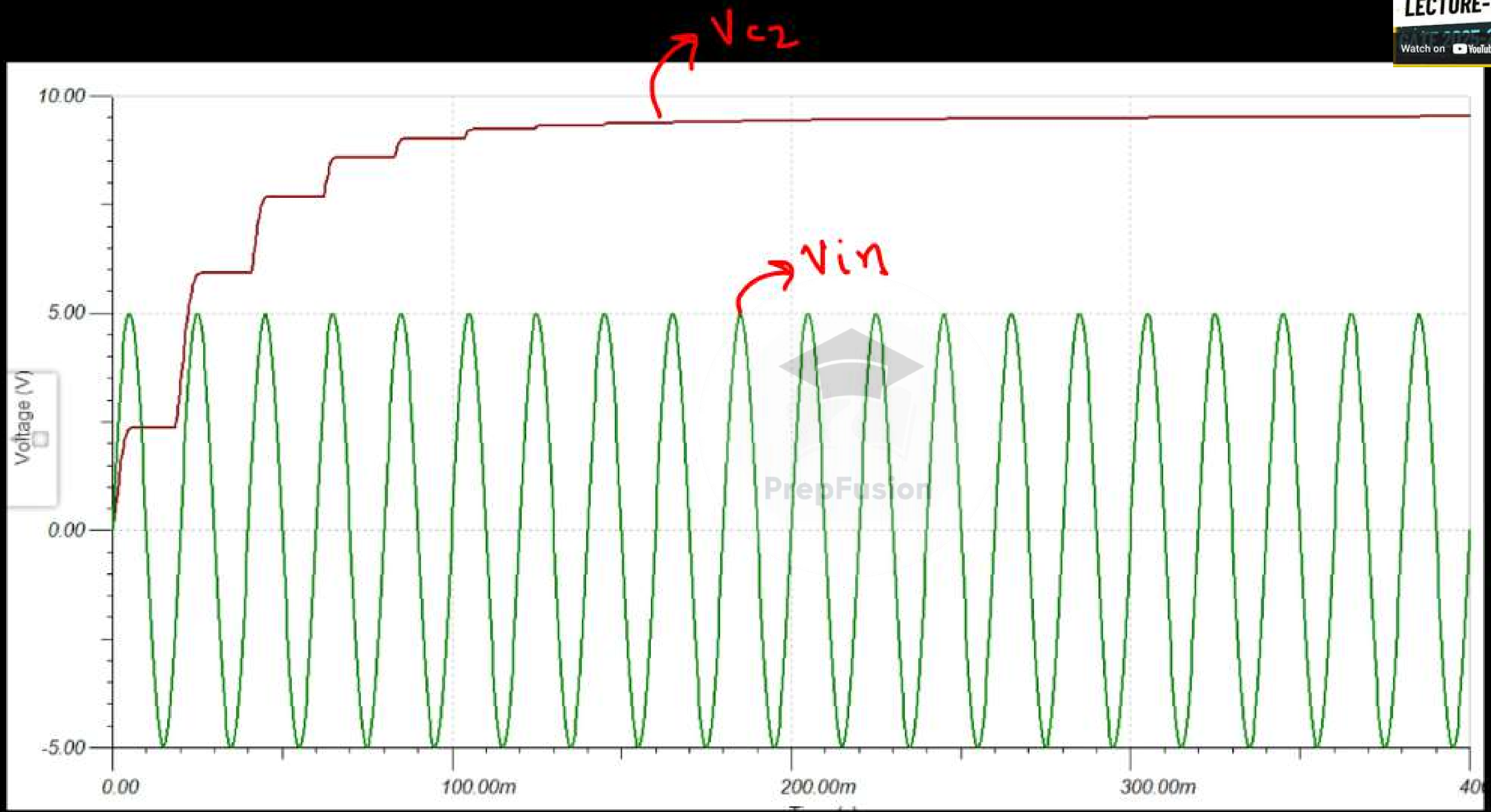


$$\left.\begin{aligned} V_{C_1}(t=T) &= -V_m \\ V_{C_2}(t=T) &= 2V_m \end{aligned}\right\} X$$

$$v' = v_i + V_m \Rightarrow \text{steady state}$$

$$V_{C_1} = -V_m \Rightarrow \text{steady state}$$

$$V_o = 2V_m \Rightarrow \text{steady state}$$



Vc2
Vin
10.00
5.00
0.00
-5.00
Voltage (V)
0.00
100.00m
200.00m
300.00m
PrepFusion

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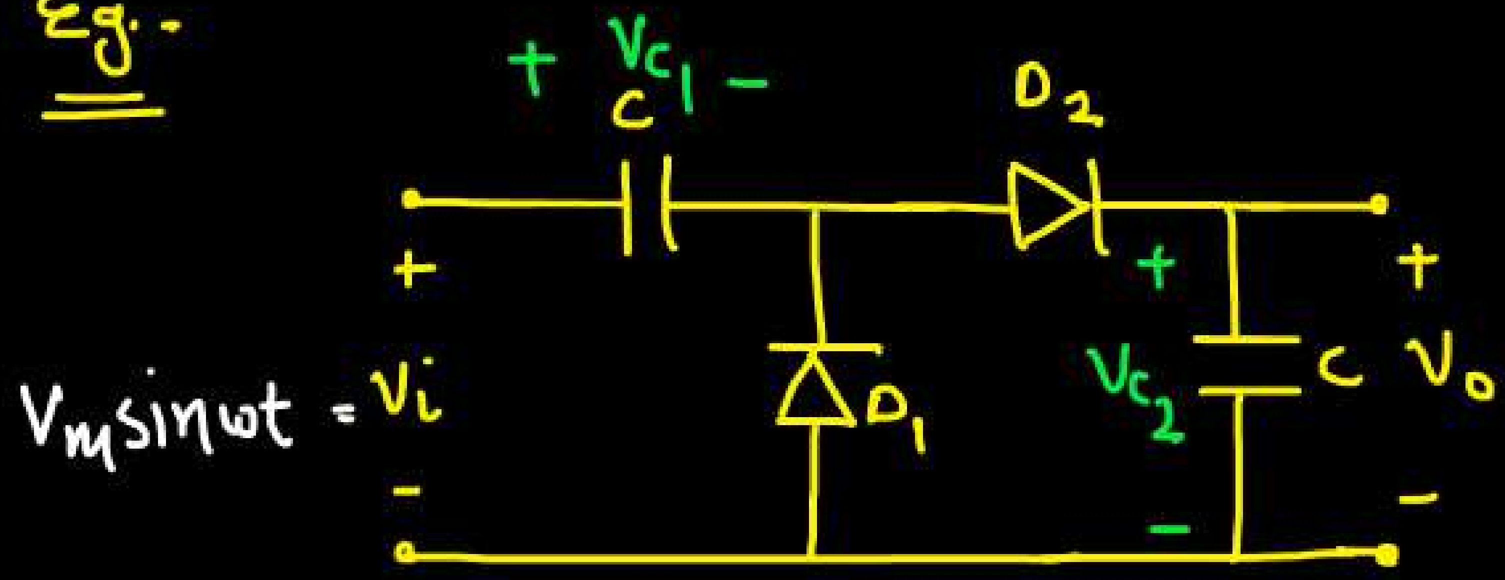
☆ Another Method to Solve Voltage Multipliers:-

↳ Turn on the diode nearest to the supply with peak voltage. Find steady state cap. voltage value. Repeat the same with other diode and find steady state cap voltage value of other cap.

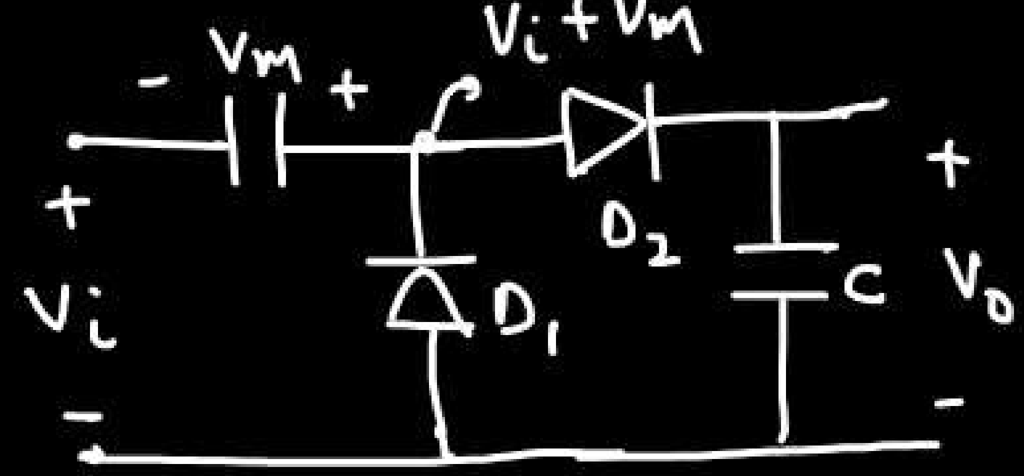
Eg.-



→ Need to turn ON D_1

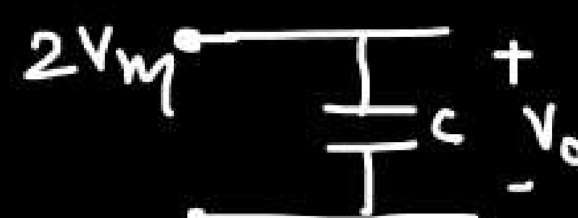
when $V_i = -V_m$; D_1 will turn ON

$V_{C_1} = -V_m \Rightarrow$ steady state voltage



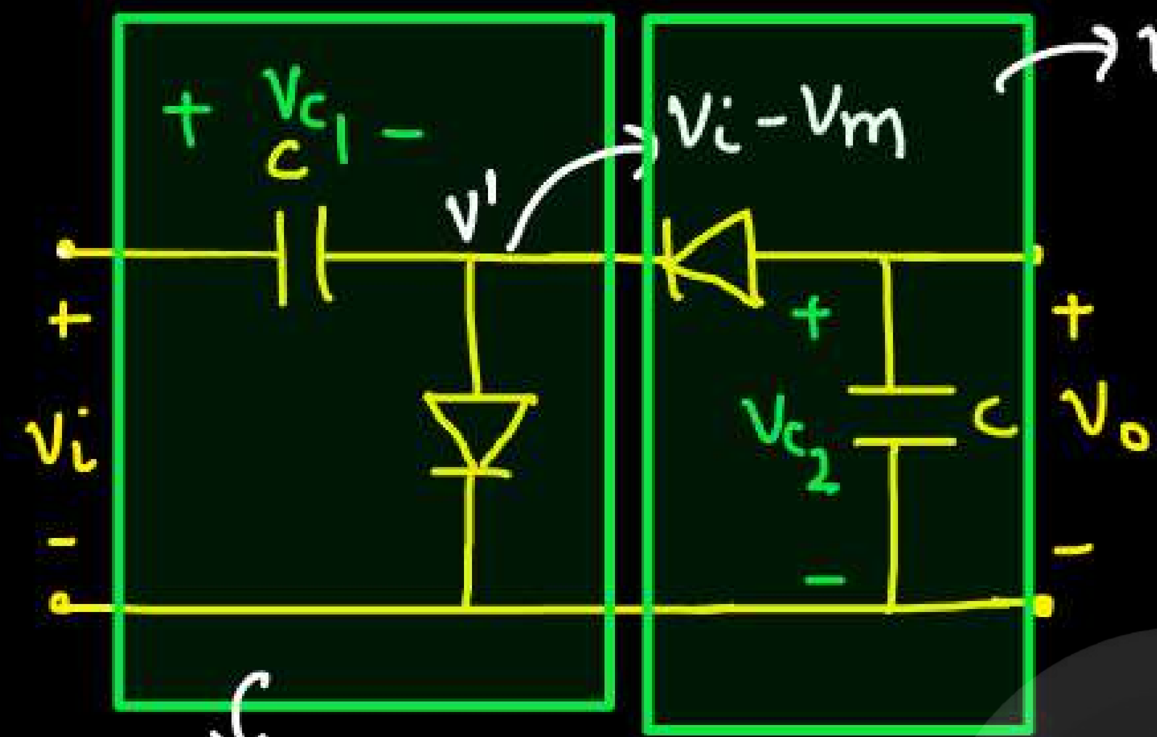
$\Rightarrow$ need to turn ON D_2

when $V_i = +V_m \Rightarrow D_2$ is ON



$$\boxed{V_o = 2V_m}$$

Eg. 2



→ negative peak detector

negative clampler

$$v' = V_i - V_m$$

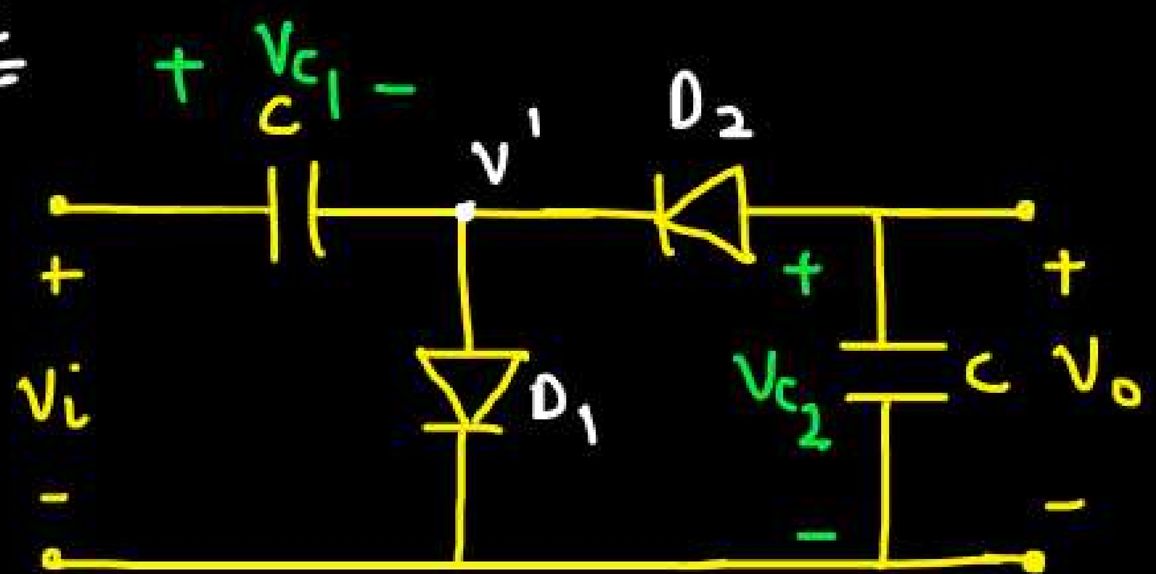
$$v' = \underbrace{V_m \sin\omega t - V_m}$$

↳ negative peak is $-2V_m$

$$\boxed{(V_o)_{s.s.} = -2V_m}$$

$$\boxed{(V_{c_1})_{s.s.} = +V_m}$$

M-II

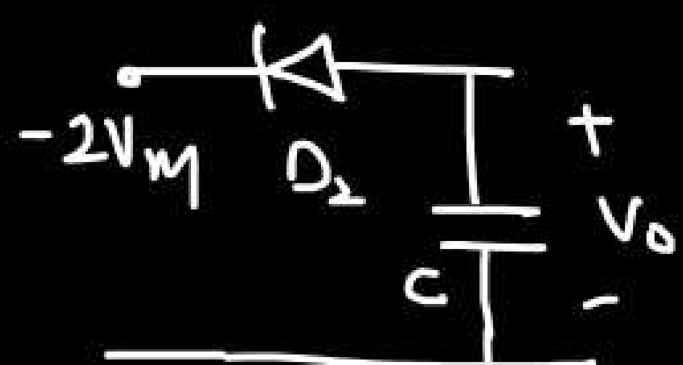


$V_i = V_m \Rightarrow$ diode D_1 turns ON

$$\boxed{V_{c_1} = +V_m}$$

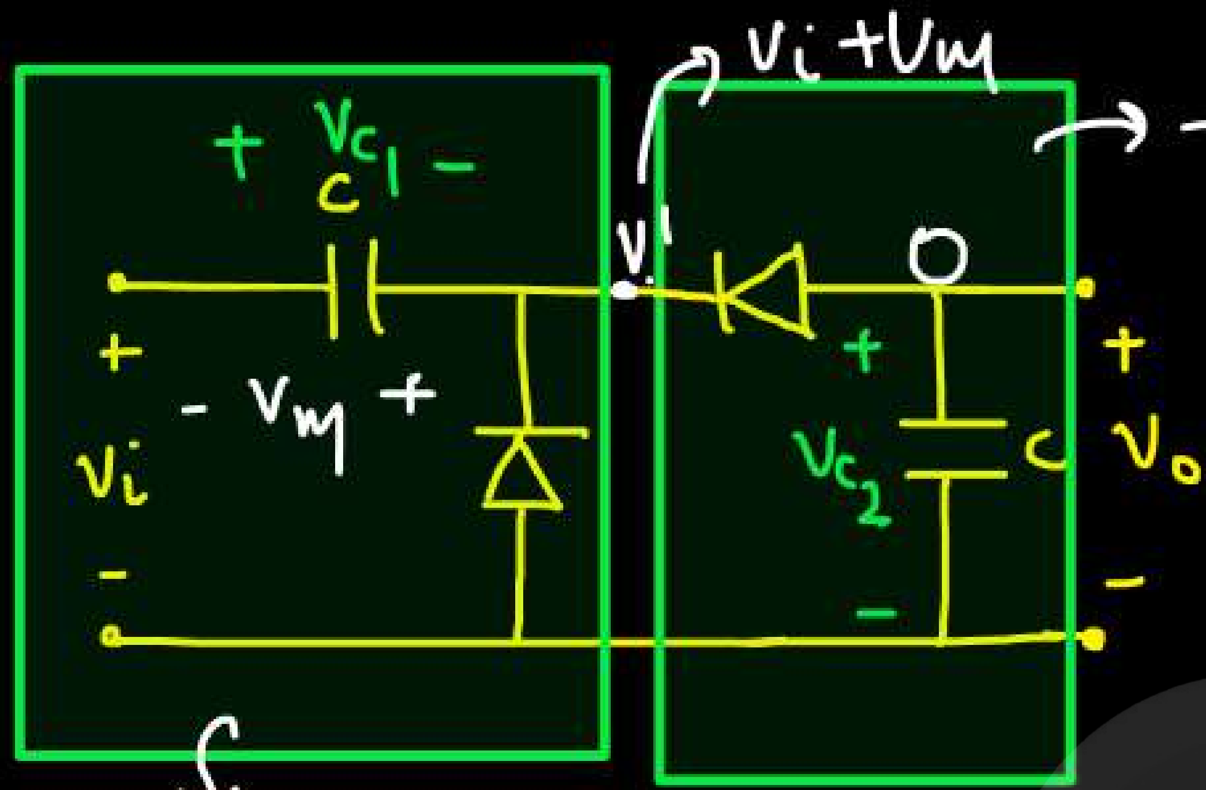
$v' = v_i - V_m$

when $v_i = -V_m \Rightarrow$ diode D_2 is ON



$$\boxed{(V_o)_{S.S.} = -2V_m} = V_{c_2}$$

Eg. 3



→ -ve peak detector

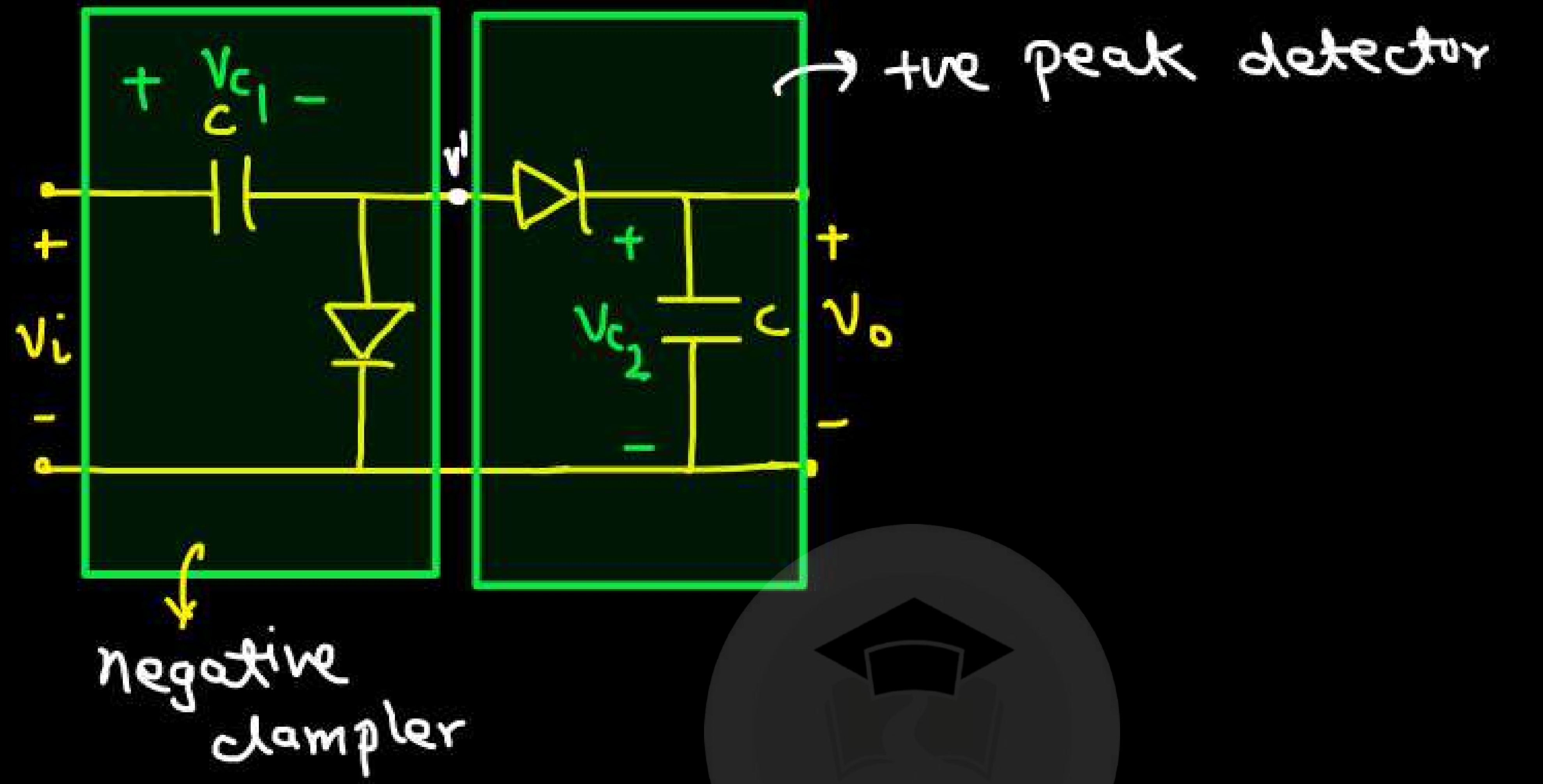
+ve clampler

$$V' = V_i + V_m$$

$$V' = V_m \sin\omega t + V_m \Rightarrow \text{min value} = 0V$$

$\boxed{(V_0)_{s.s.} = 0V}$ & $\boxed{(V_{c_1})_{s.s.} = -V_m}$

Eg 4

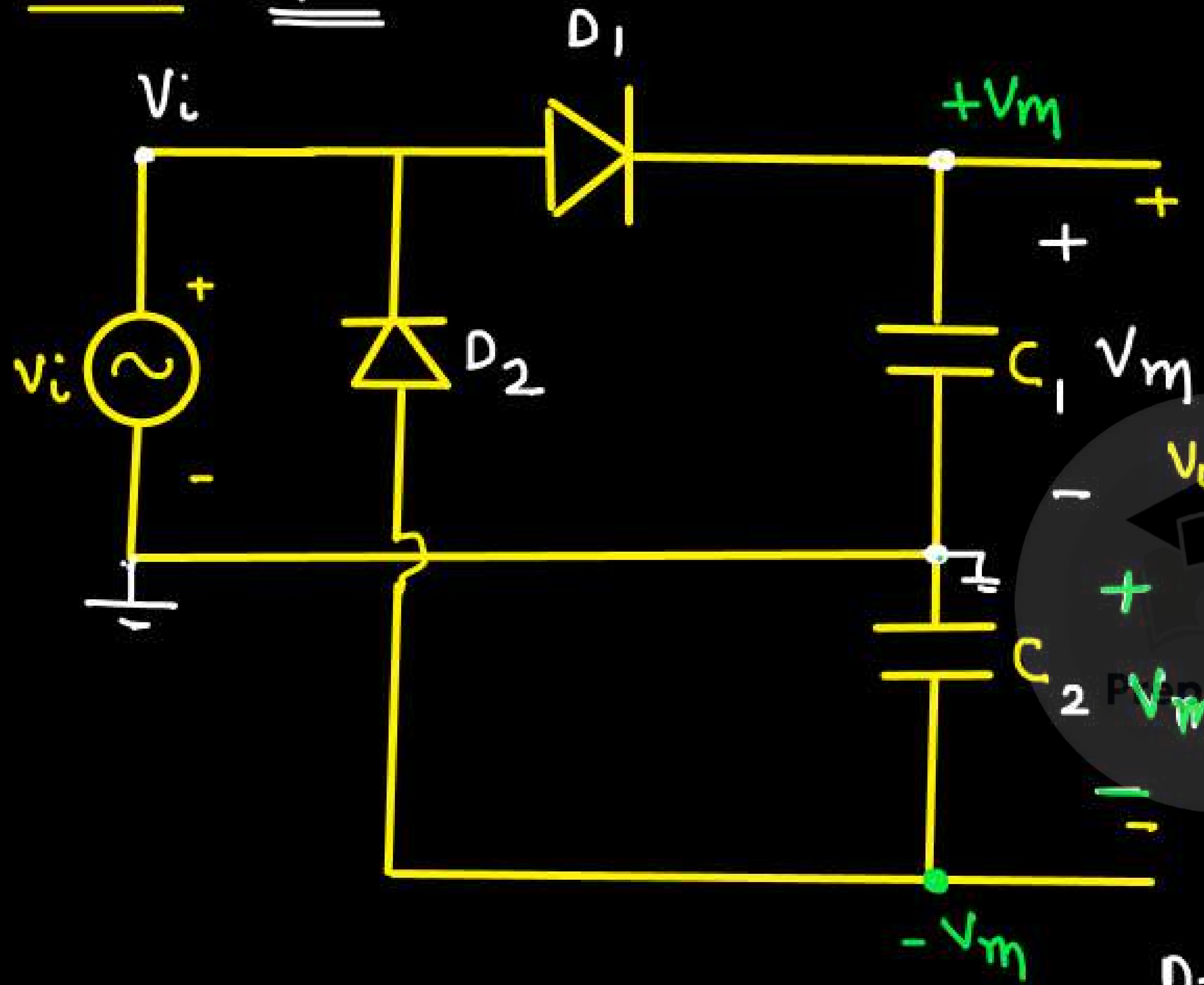


$$V' = V_i - V_m = V_m \sin\omega t - V_m \Rightarrow \text{max value} = 0$$

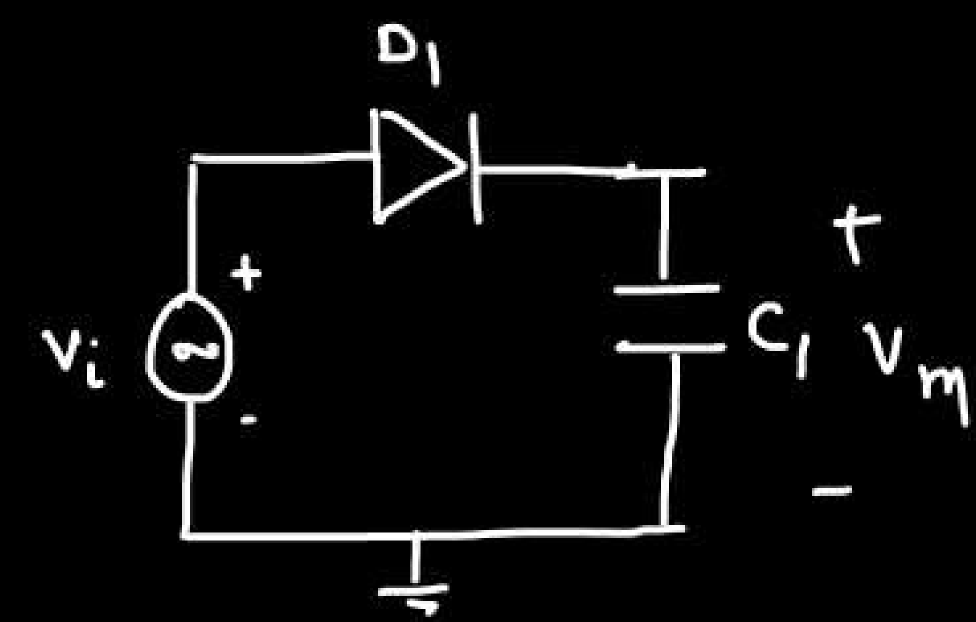
$$\Rightarrow \boxed{V_o = 0V} \qquad \boxed{V_{C_1} = V_m}$$

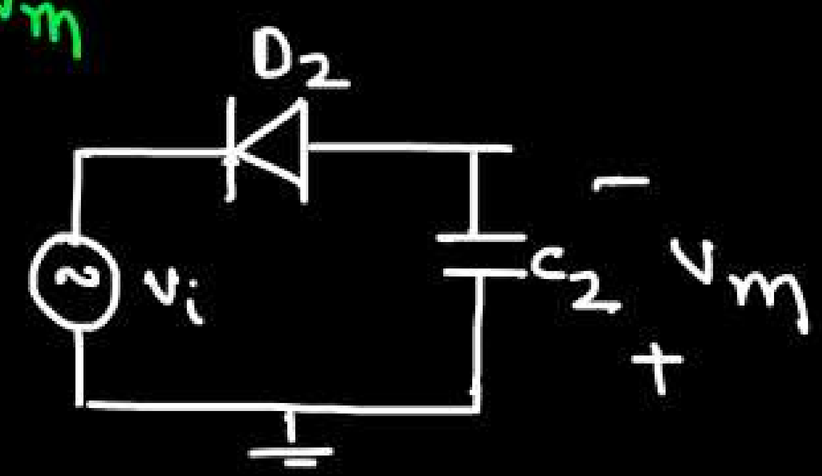
Eg. 5

M-I



$v_i = V_m \sin\omega t$

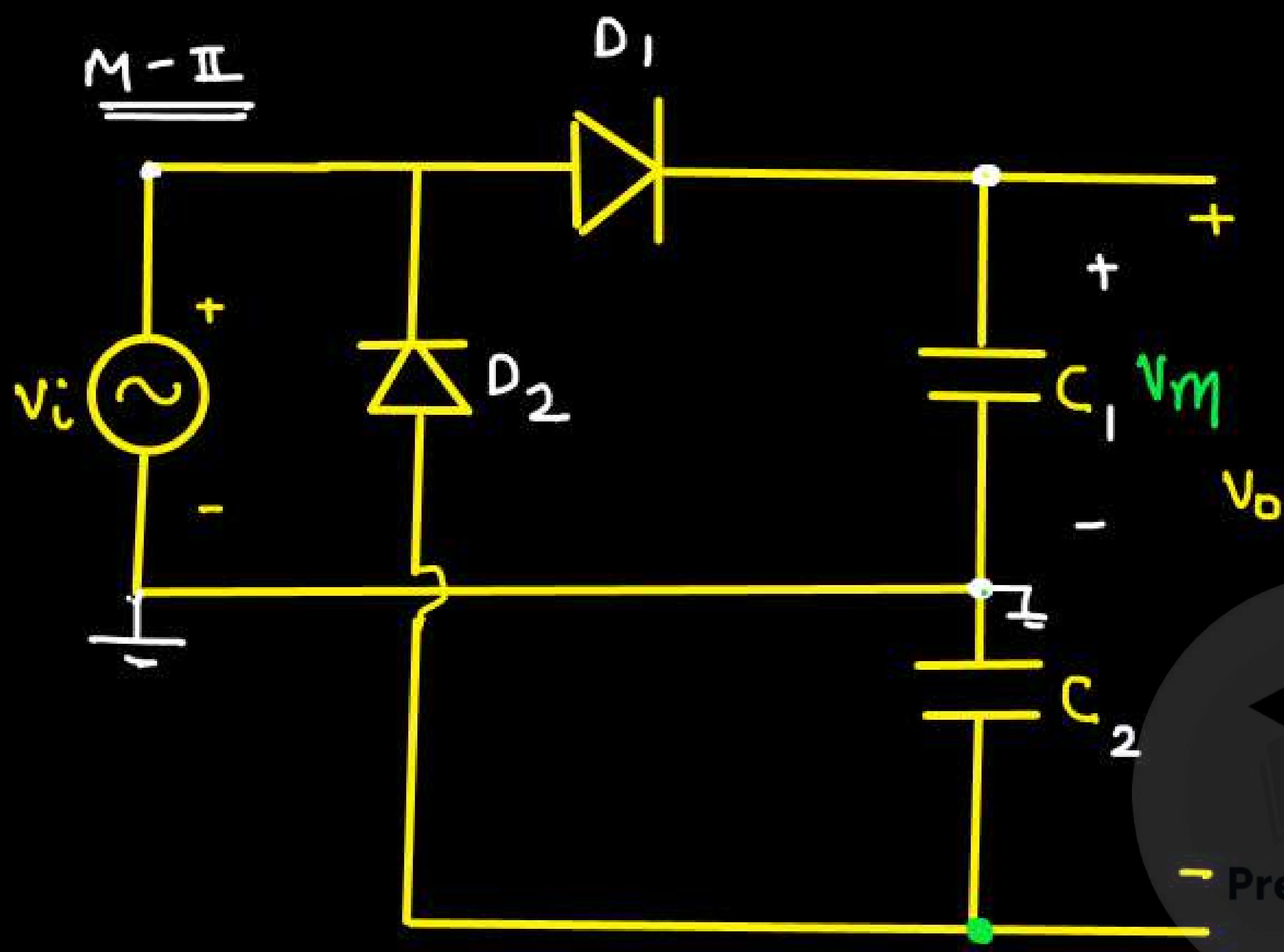




$V_o = V_m - (-V_m)$

$\boxed{V_o = 2V_m}$

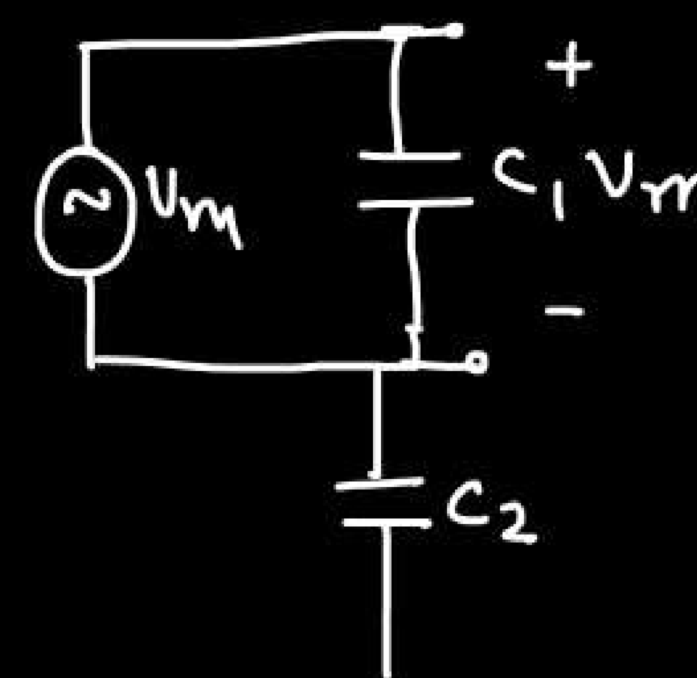
M - II



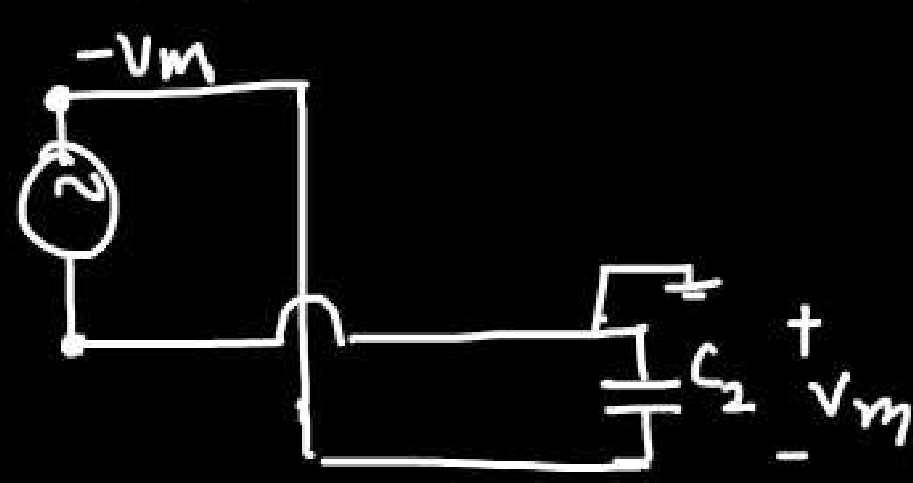
$V_i = +V_m$

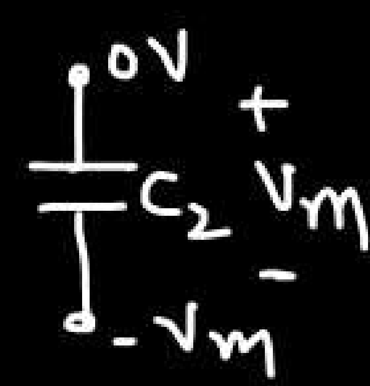
$\Rightarrow D_1$ is ON

D_2 is OFF



$V_i = -V_m \Rightarrow D_1$ is off, D_2 is ON



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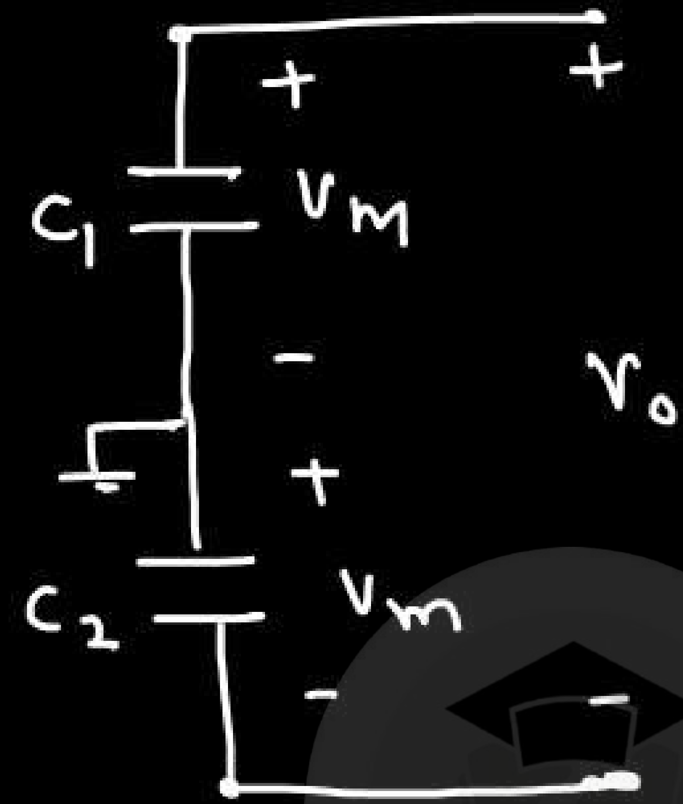
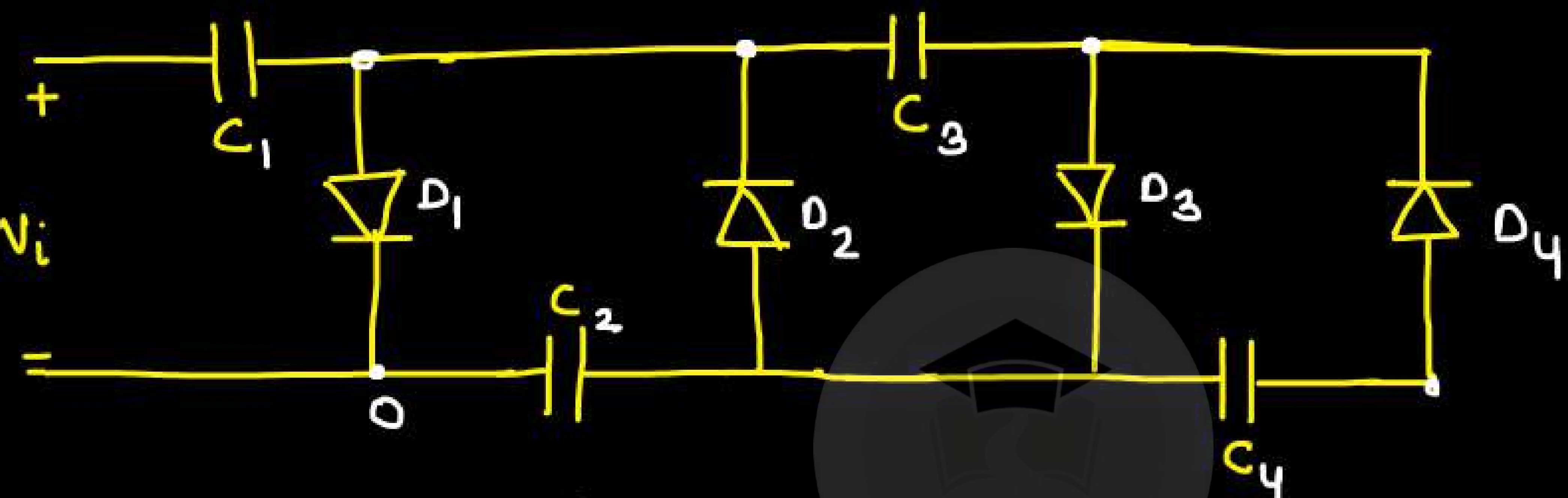

C_1
V_m
V_0
C_2
V_m
+
−

$$\boxed{V_0 = 2V_m}$$

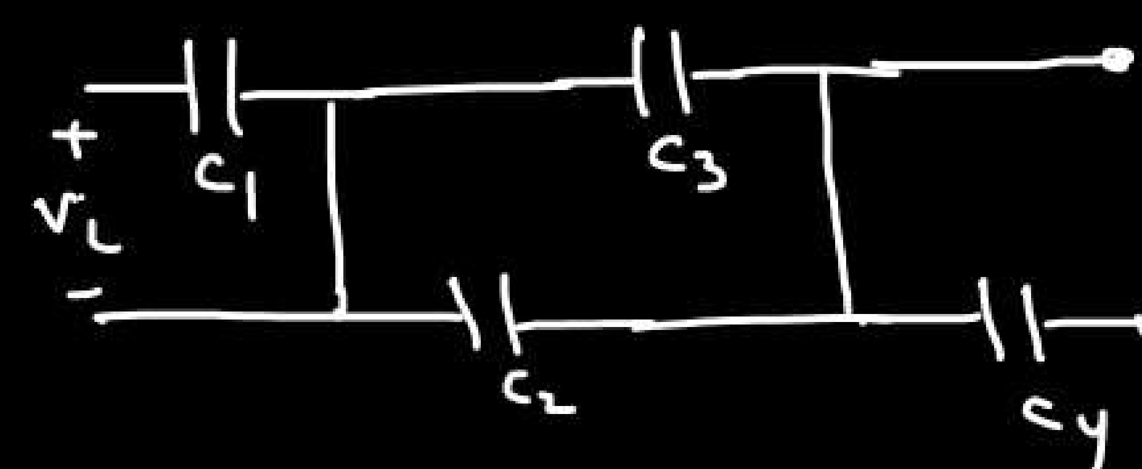
★ Voltage Tripler and Quadrupler :-

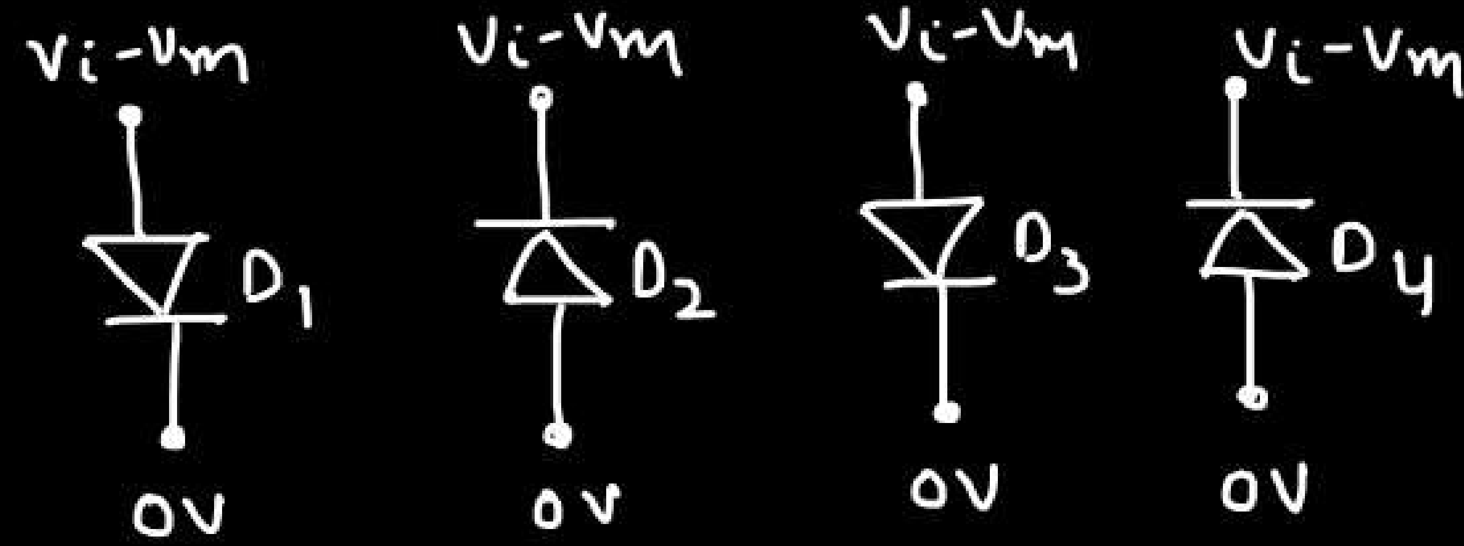


$\Rightarrow V_i = +V_m \Rightarrow D_1$ is ON, D_3 is ON, D_2 and D_4 is OFF

$\Rightarrow C_1$ charges to V_m

$$\boxed{V_{C_1} = +V_m}$$

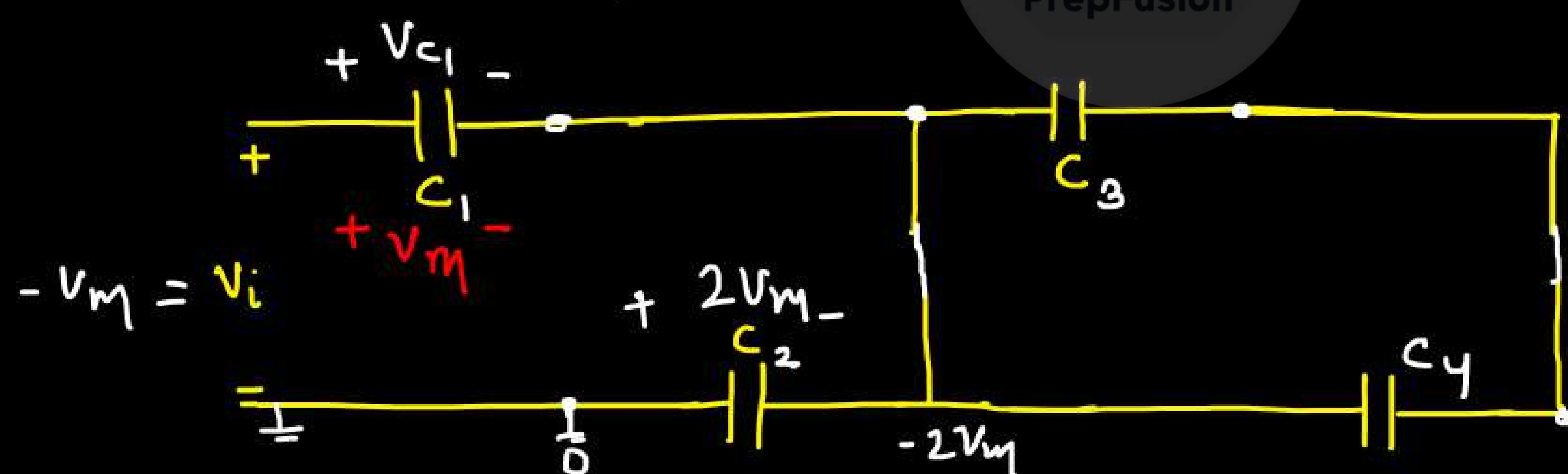


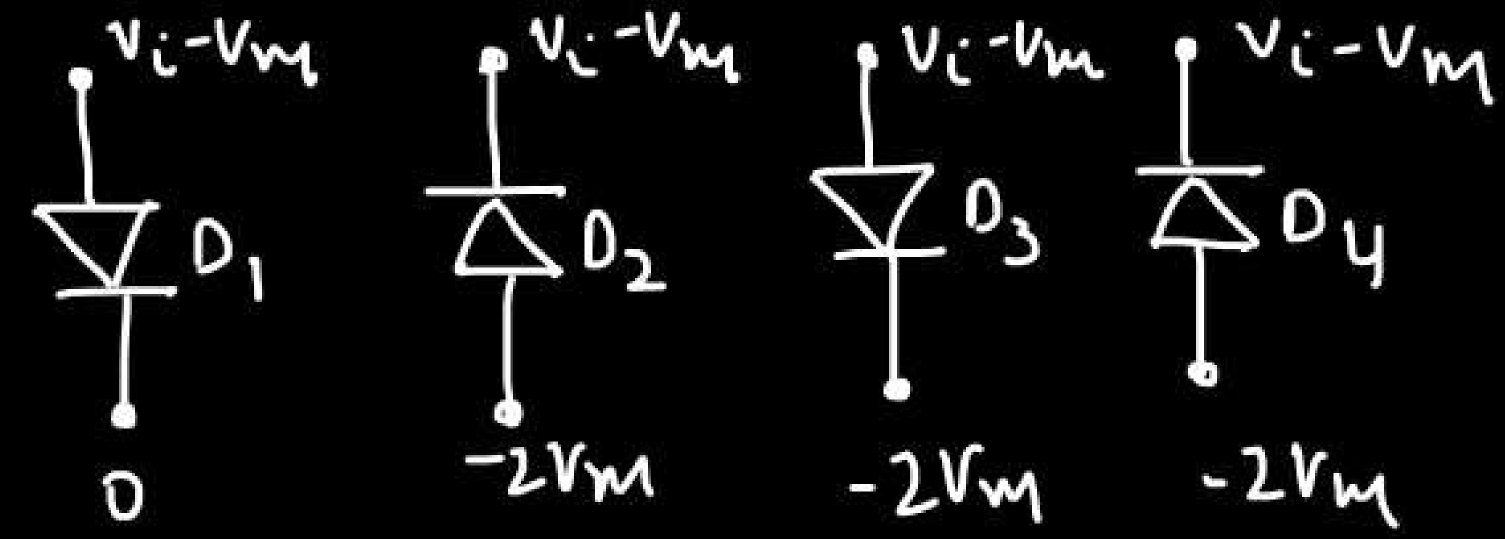


(ii) $V_i = -V_m$

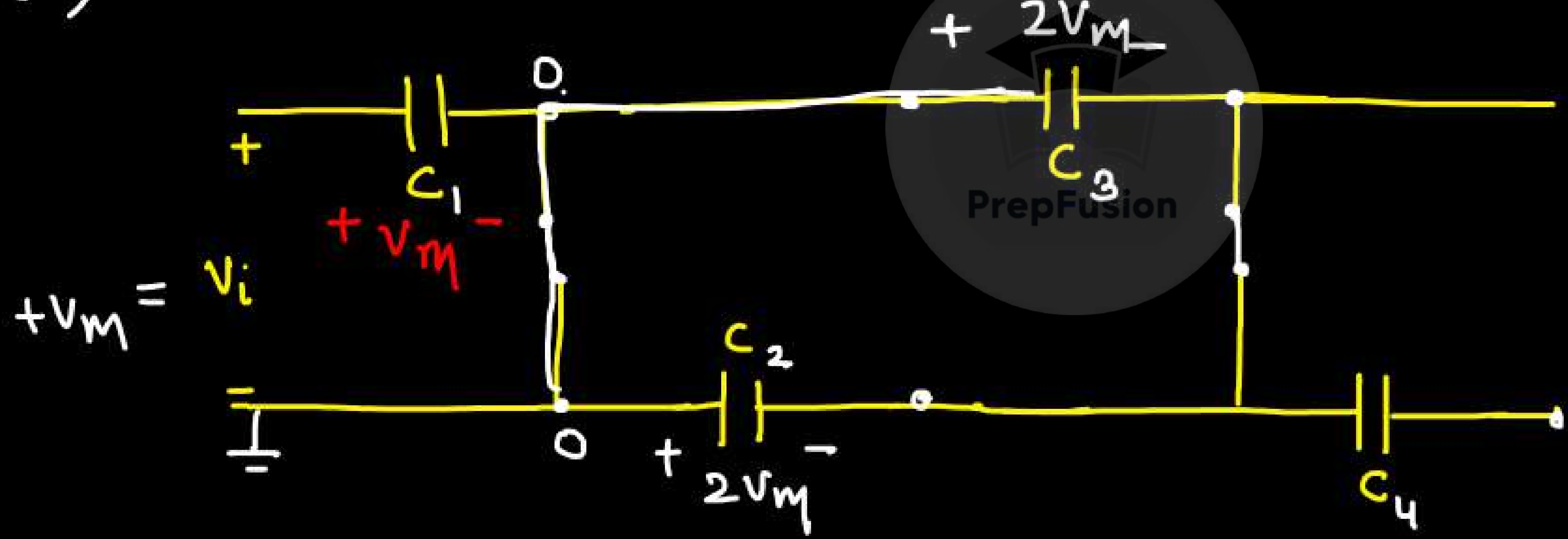
D_1 and D_3 are off

D_2 and D_4 are ON

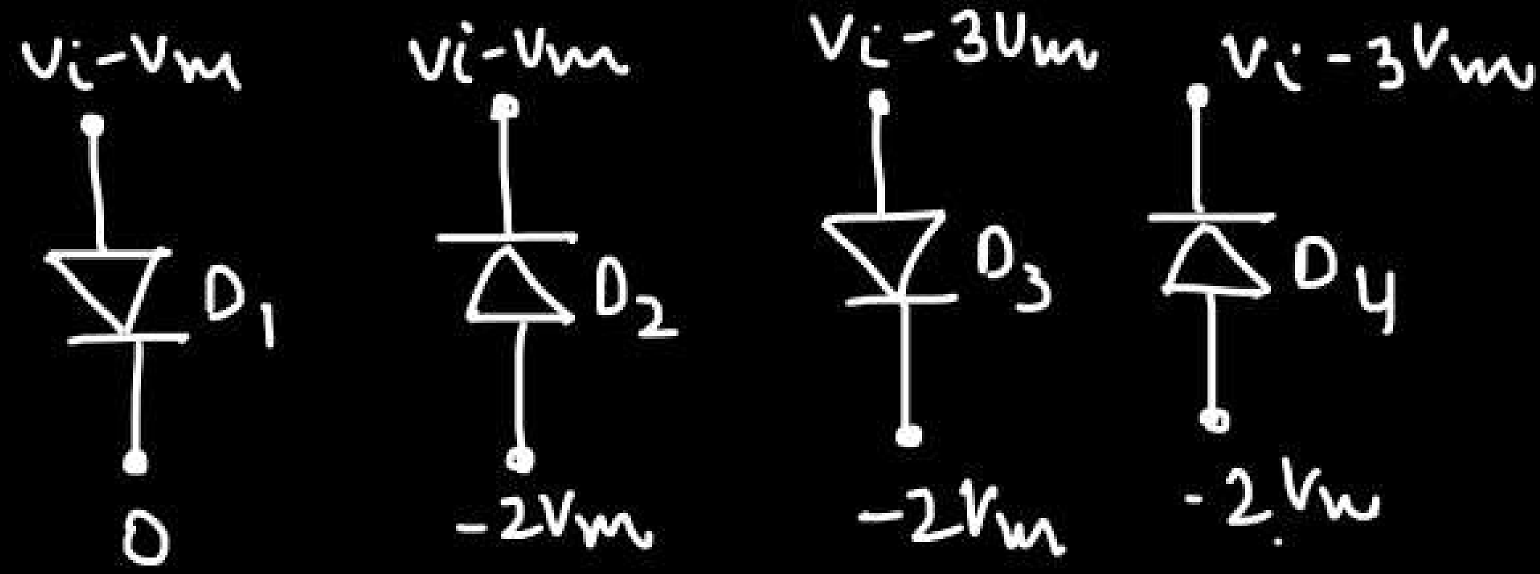




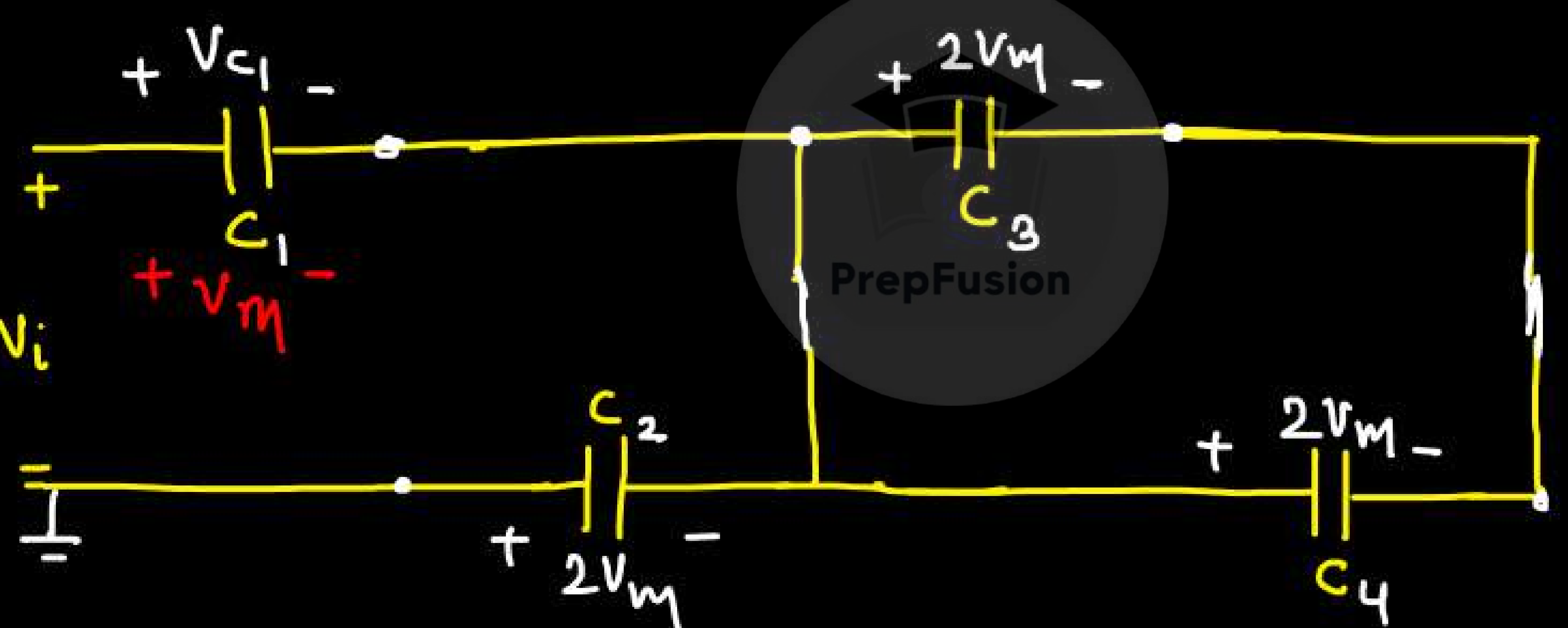
(iii)



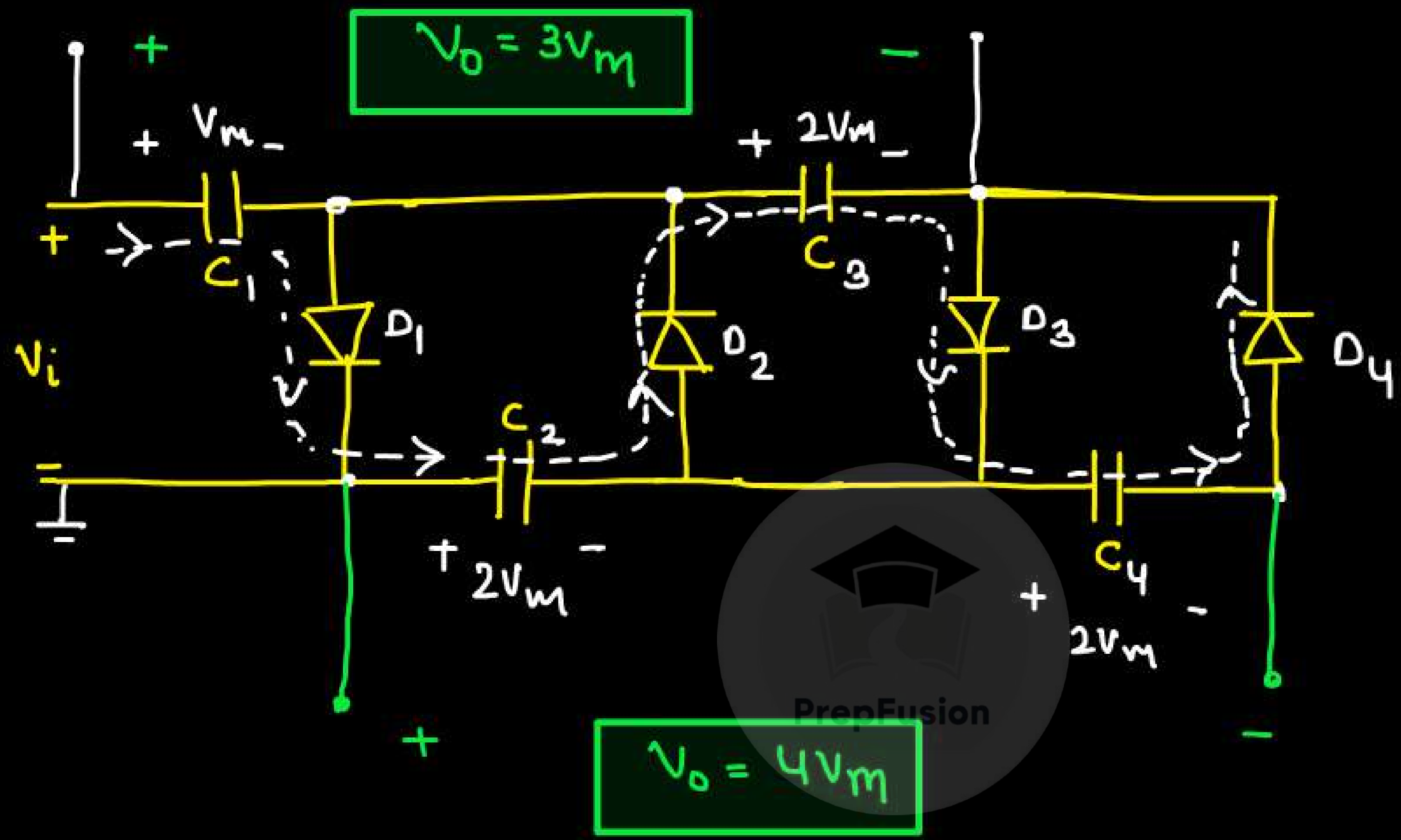
$V_i = +V_m \Rightarrow D_1$ and D_3 are ON, D_4 and D_2 are off



(iv)



$V_i = -V_m \Rightarrow D_1, D_3$ are off ; D_2, D_4 are ON



$V_o = 3V_m$
+
−
+ V_m −
+ $2V_m$ −
C_1
C_3
D_1
D_2
D_3
D_4
V_i
+
−
C_2
+ $2V_m$ −
C_4
+ $2V_m$ −
+
−
$V_o = 4V_m$

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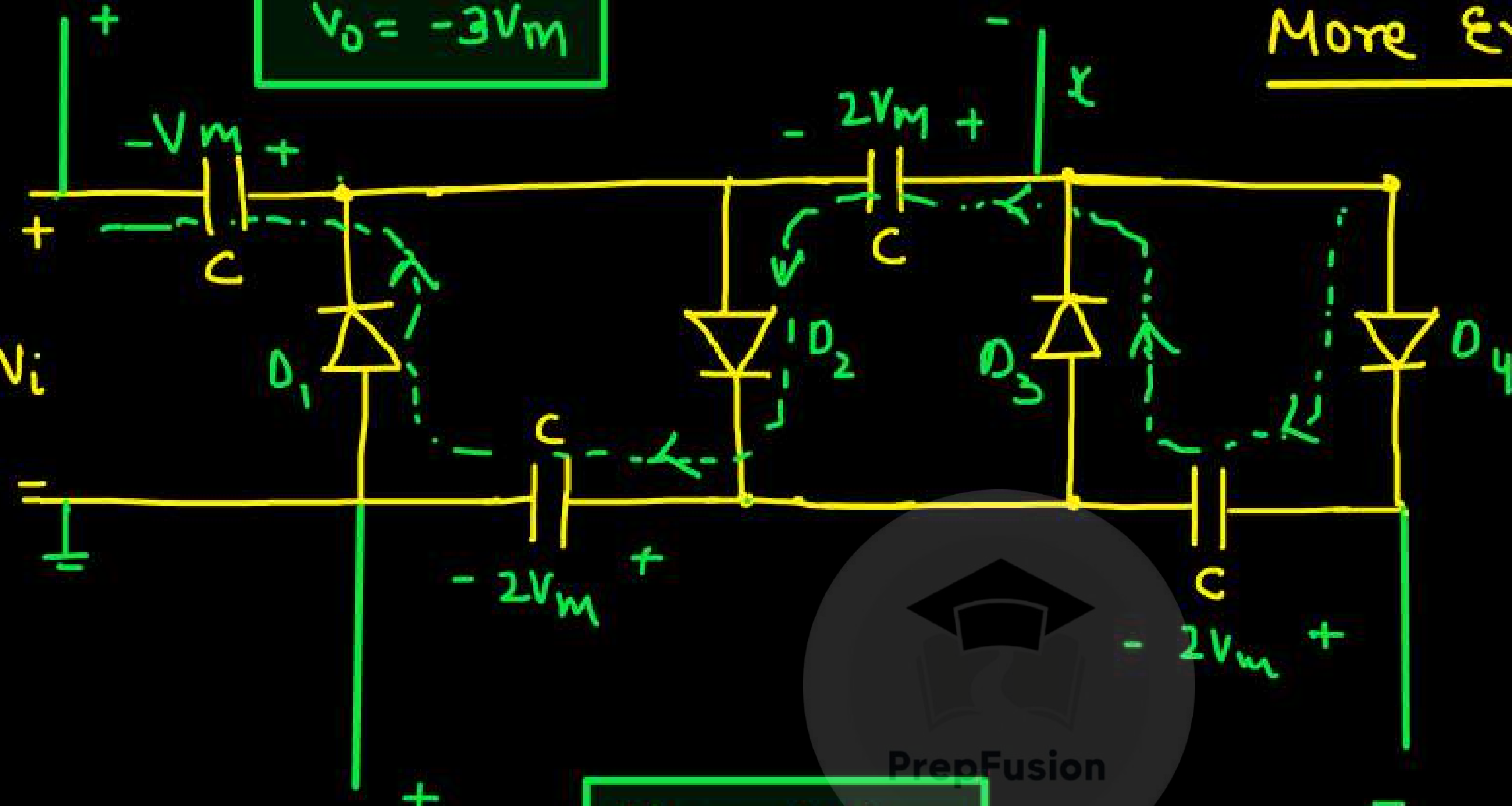
More Examples

eg.1

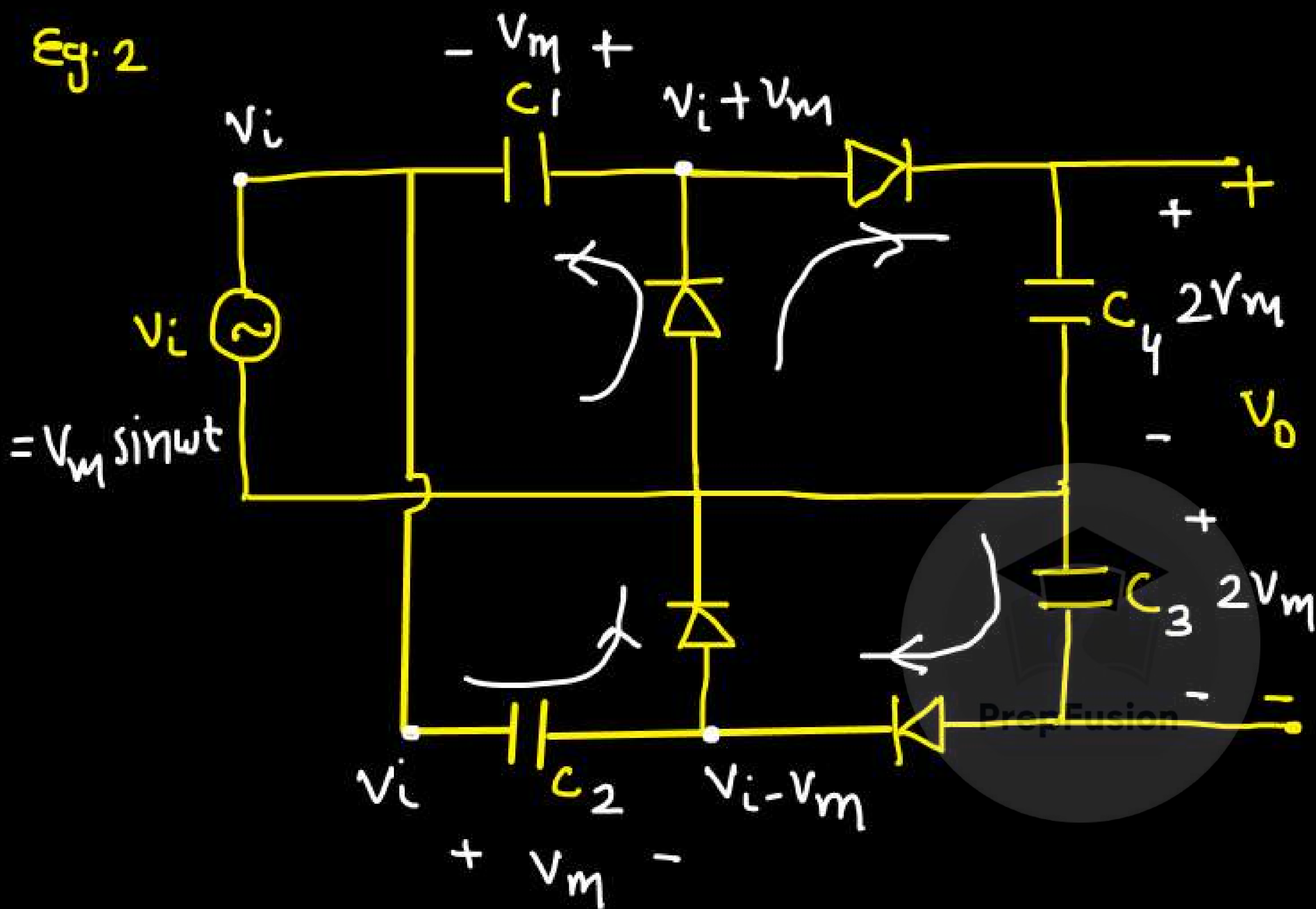
$\boxed{V_o = -3V_m}$

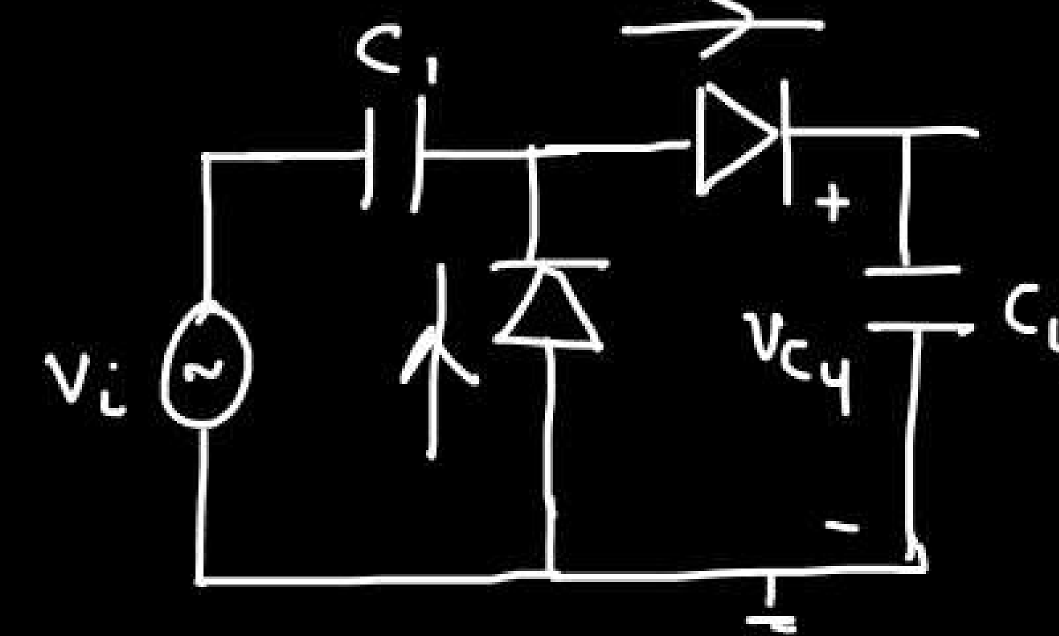


$\boxed{V_o = -4V_m}$

$\boxed{V_o = 4V_m}$

Eg. 2



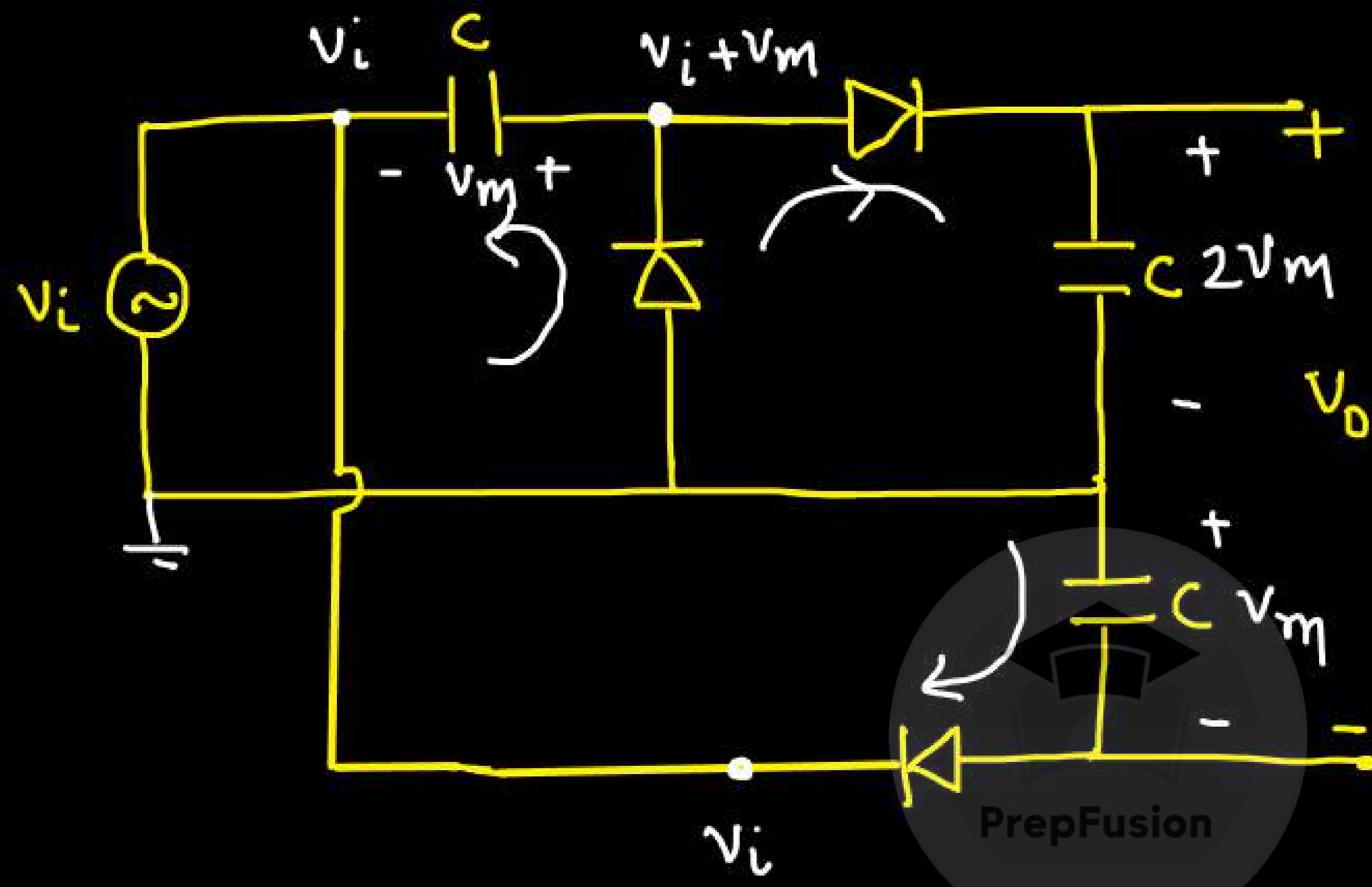


$$V_o = 2V_m + 2V_m$$

$$\boxed{V_o = 4V_m}$$

$$V_{C4} = 2V_m$$

Eg.3

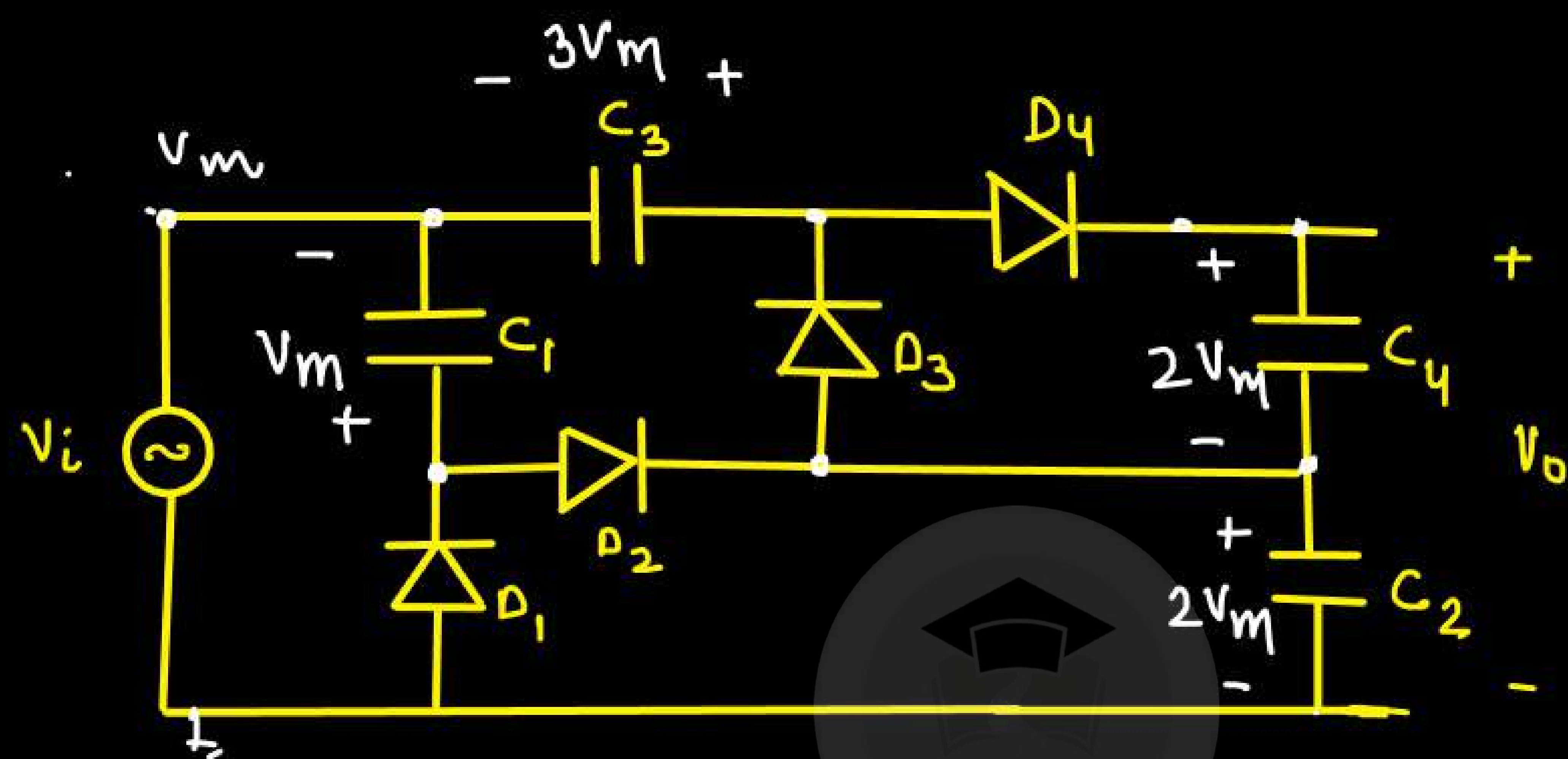


$= -V_m$

$V_o = 2V_m + V_m$

$$\boxed{V_o = 3V_m}$$

Eg.4



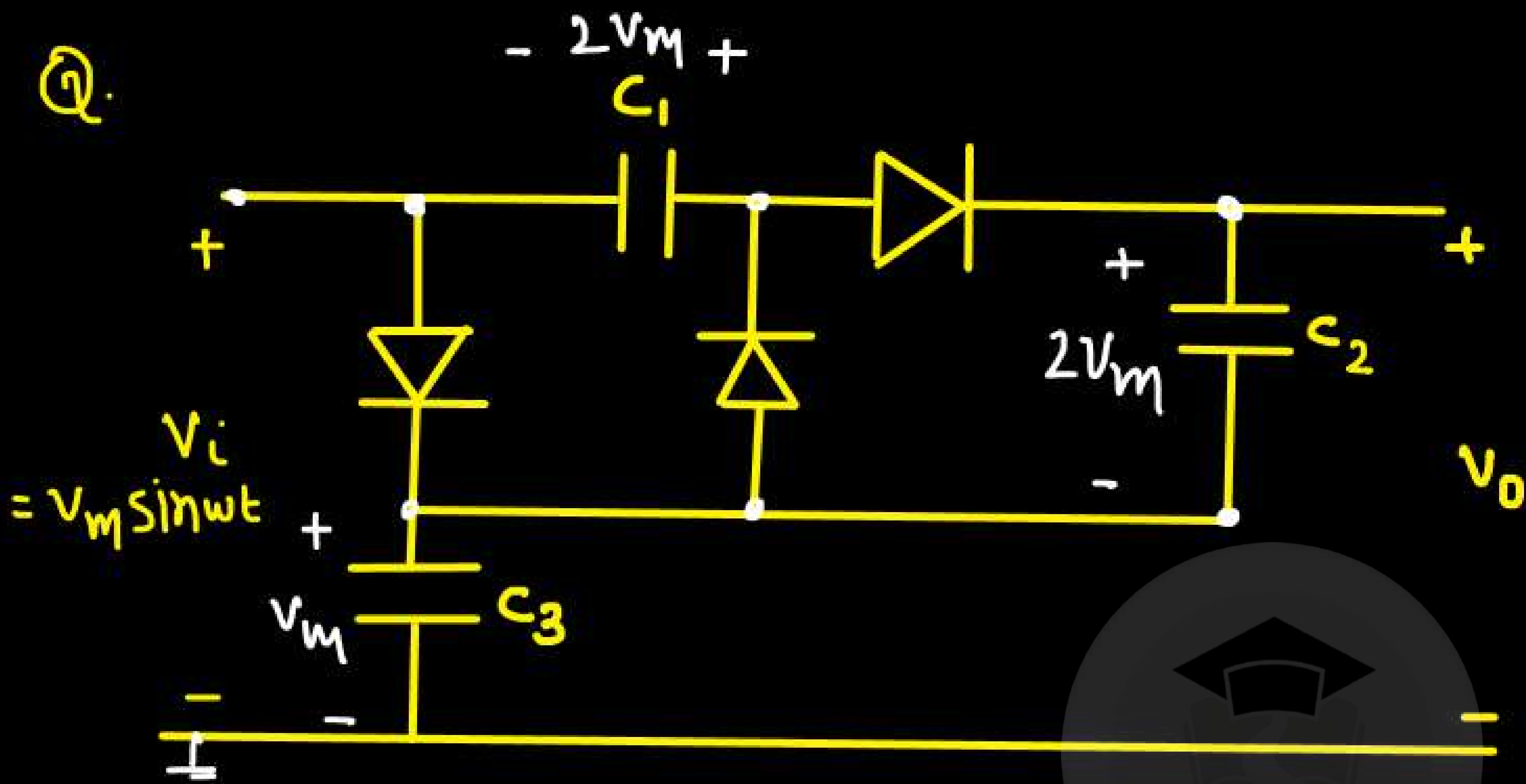
NEVER CROSS DIODE

1. $V_i = -V_m$
2. $V_i = +V_m$
3. $V_i = -V_m$
4. $V_i = +V_m$

$$V_o = 2V_m + 2V_m$$

$$\boxed{V_o = 4V_m}$$

Q.



(1) $V_i = +V_m$

(2) $V_i = -V_m$

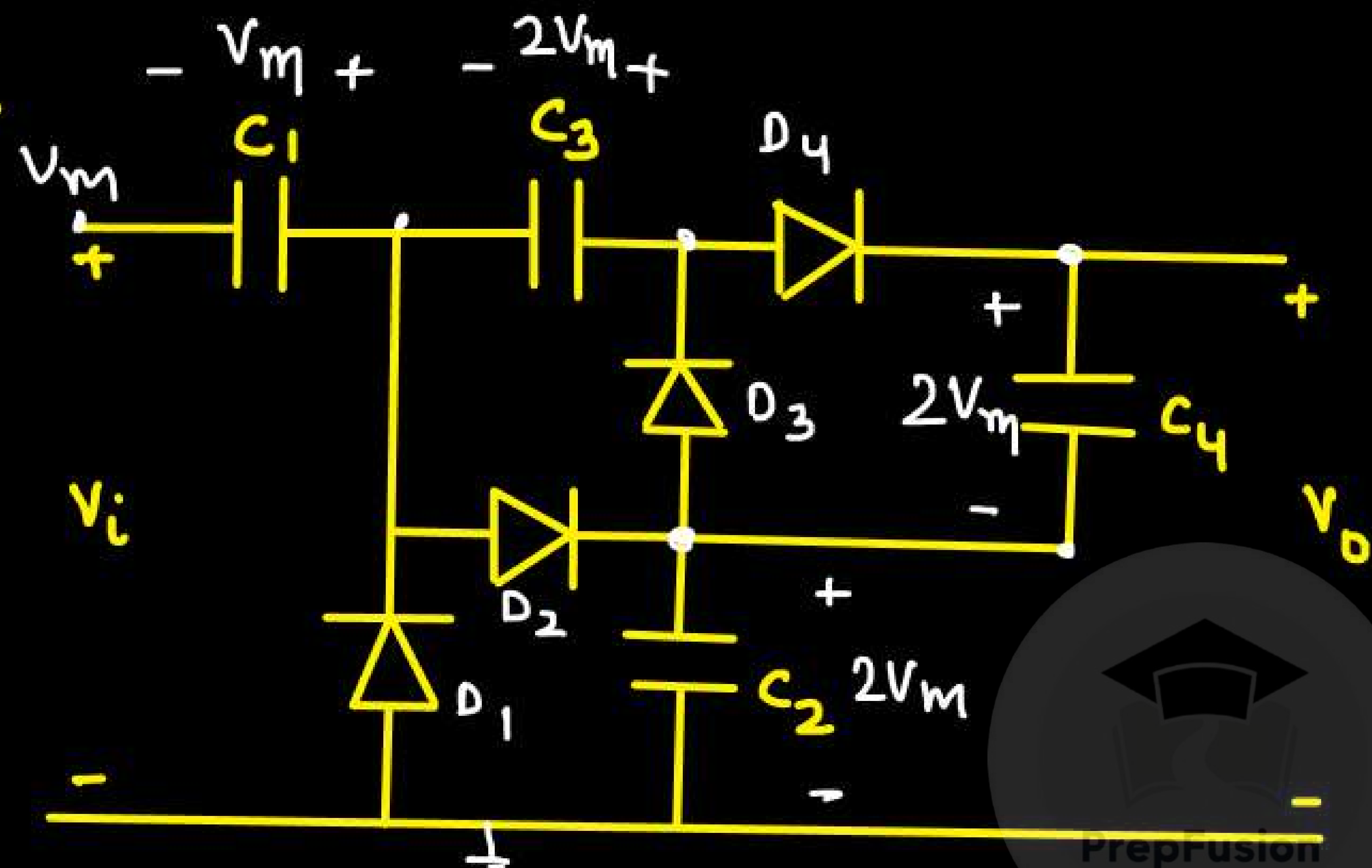
(3) $V_i = +V_m$

$$V_o = V_{C_2} + V_{C_3}$$

$$V_o = 2V_m + V_m$$

$$\boxed{V_o = 3V_m}$$

Q.



① $V_i = -V_m$

② $V_i = +V_m$

③ $V_i = -V_m$

④ $V_i = +V_m$

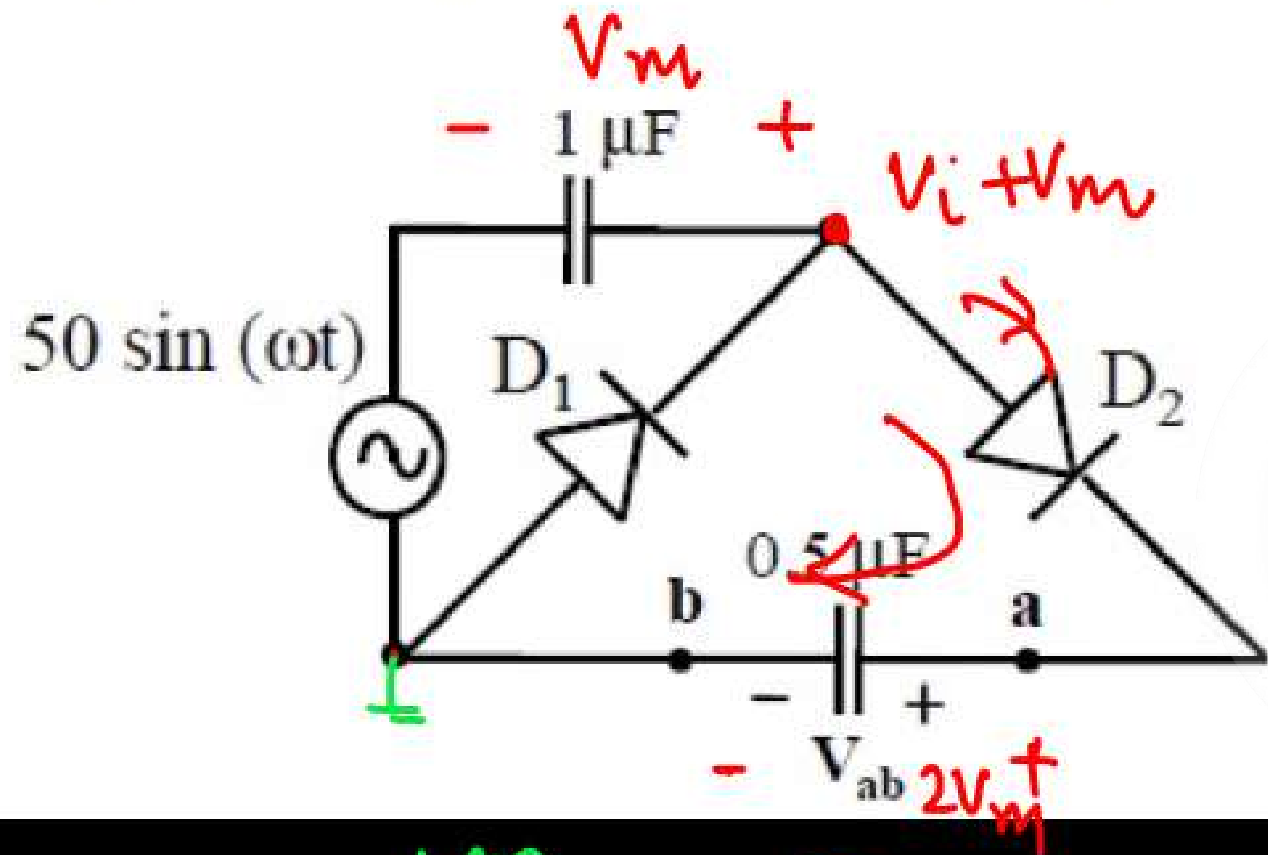
$$V_o = V_{C_4} + V_{C_2}$$

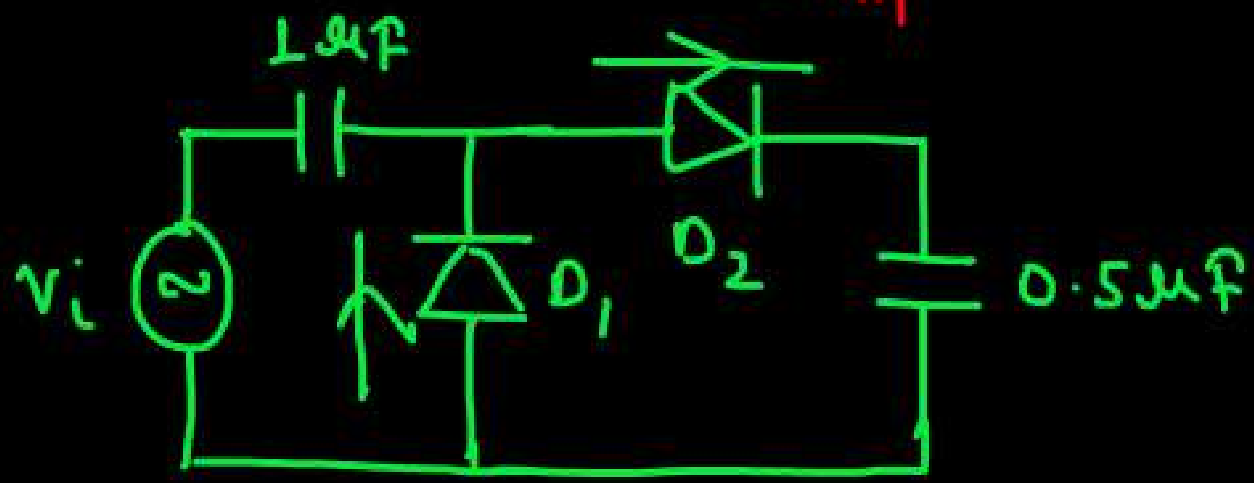
$$V_o = 2V_m + 2V_m$$

$$\boxed{V_o = 4V_m}$$

Assignment - 3

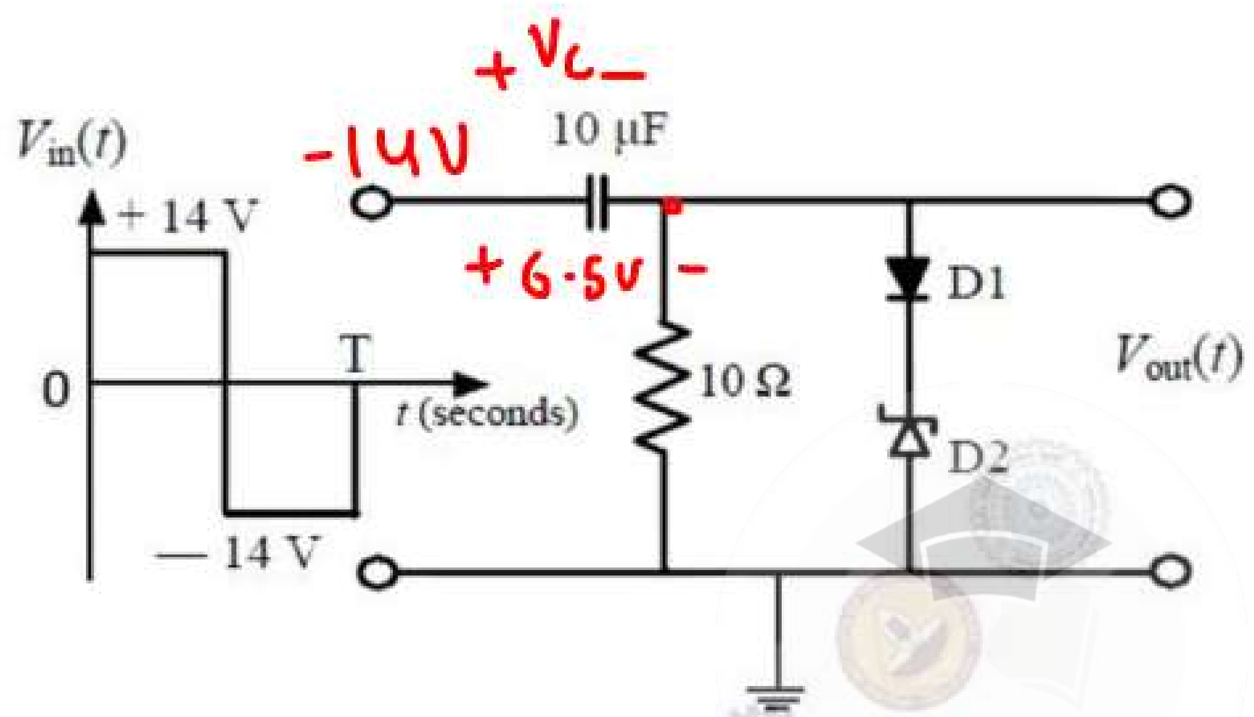
In the circuit shown, assume that diodes D_1 and D_2 are ideal. In the steady state condition, the average voltage V_{ab} (in Volts) across the 0.5 µF capacitor is ______.





$+$ $2V_m$ $-$ $= 2 \times 50 = 100V$

In the figure, D1 is a real silicon *pn* junction diode with a drop of 0.7 V under forward bias condition and D2 is a Zener diode with breakdown voltage of − 6.8 V. The input $V_{in}(t)$ is a periodic square wave of period T, whose one period is shown in the figure.



Assuming 10τ << T, where τ is the time constant of the circuit, the maximum and minimum values of the output waveform are respectively,

(A) 7.5 V and −20.5 V

(B) 6.1 V and −21.9 V

(C) 7.5 V and −21.2 V

(D) 6.1 V and −22.6 V

@ t=0

$V_{in}=14$, $V_c=0$

D_1 turns ON

D_2 goes into B.D.