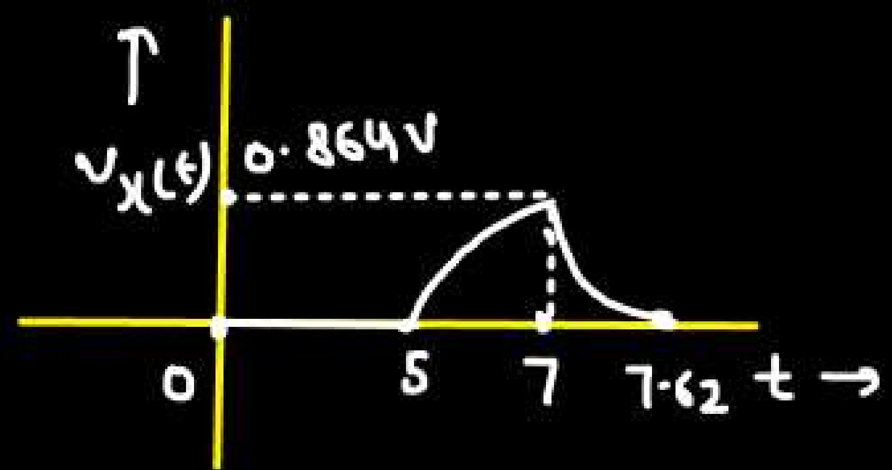
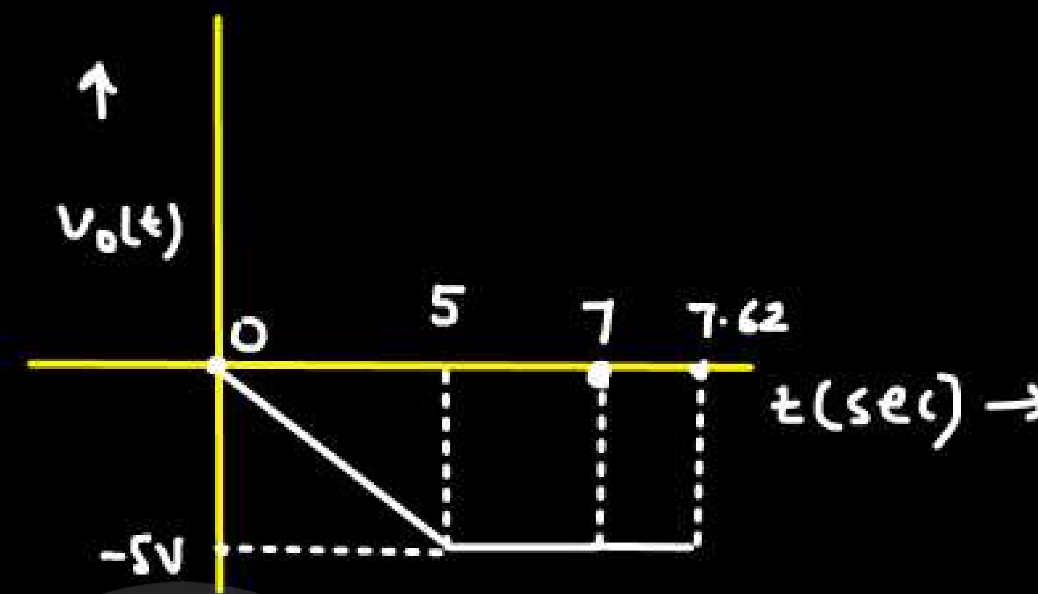
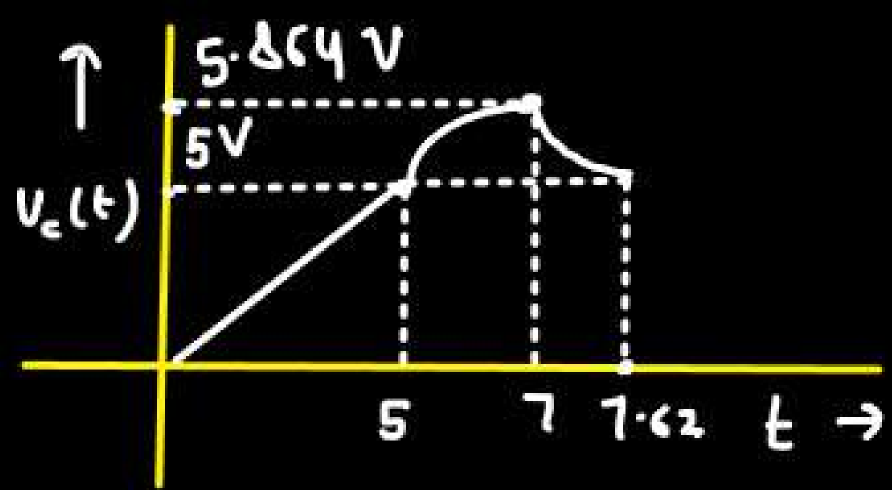
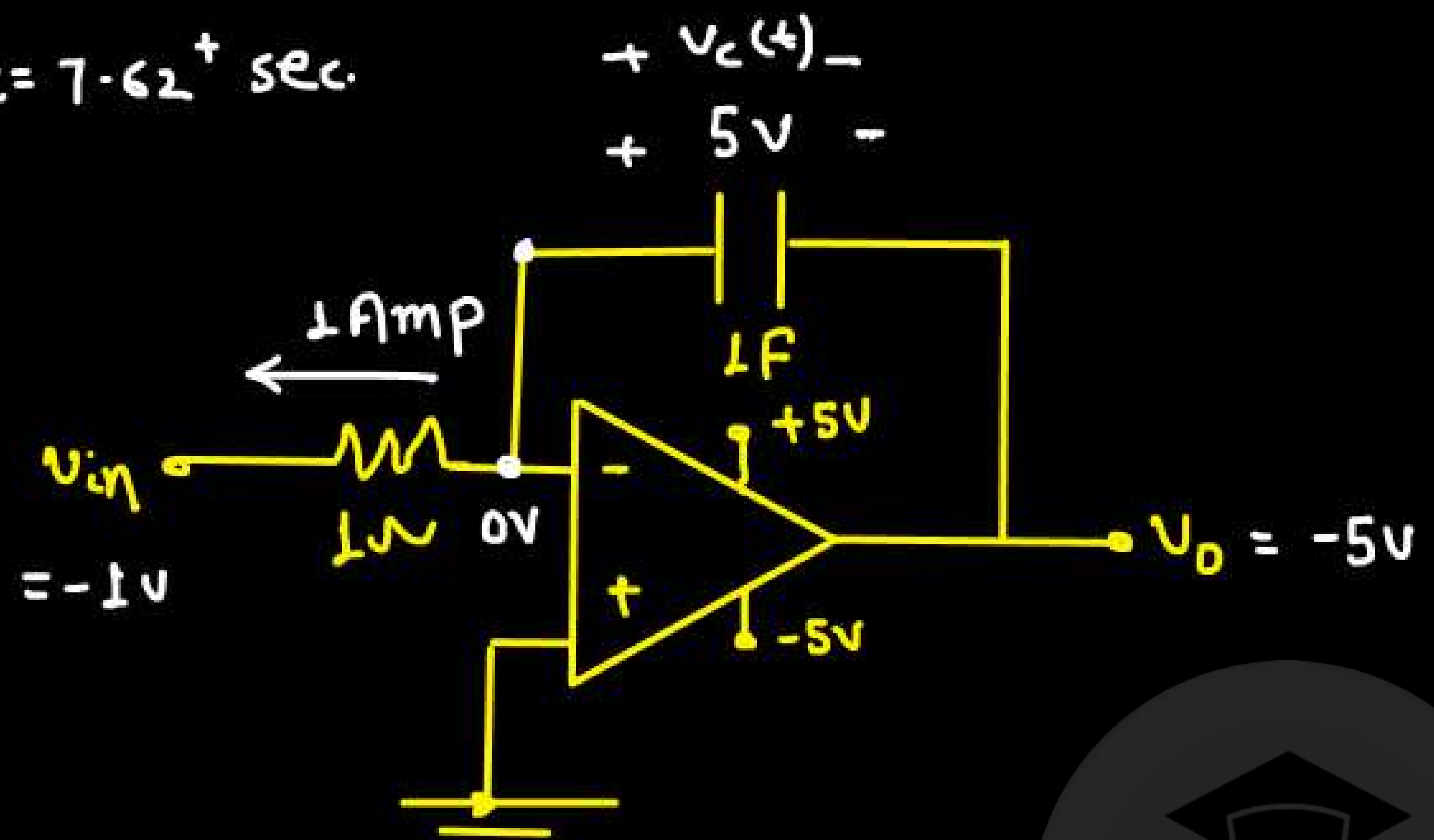

$v_x(t)$
0.864V
0
5
7
7.62
t →


$v_o(t)$
0
5
7
7.62
t(sec) →
-5V


5.864 V
5V
$v_c(t)$
5
7
7.62
t →

at $t = 7.62^{+}$ sec.



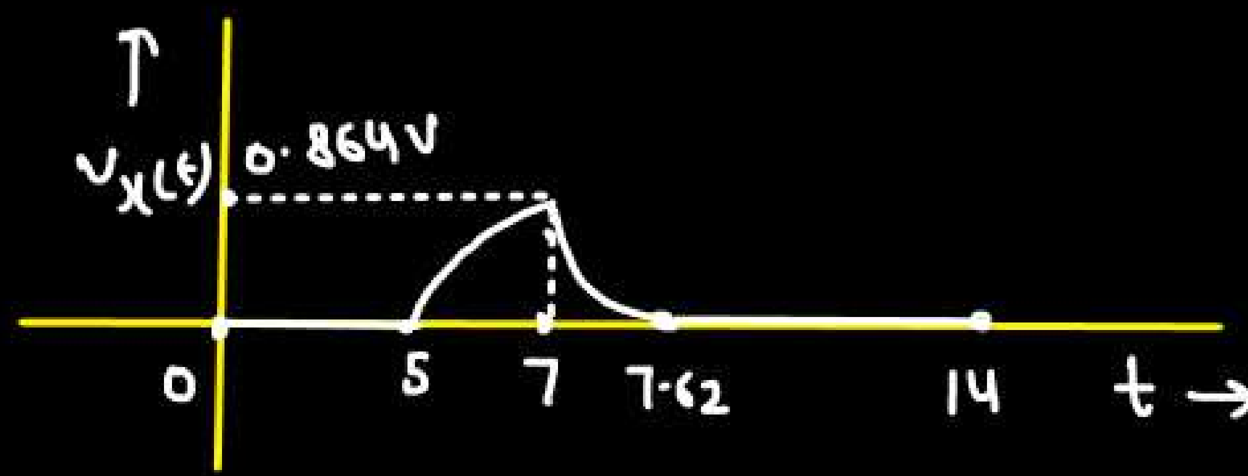
$$v_c(t) = 5 - \frac{1}{c}(1)(t - 7.62)$$

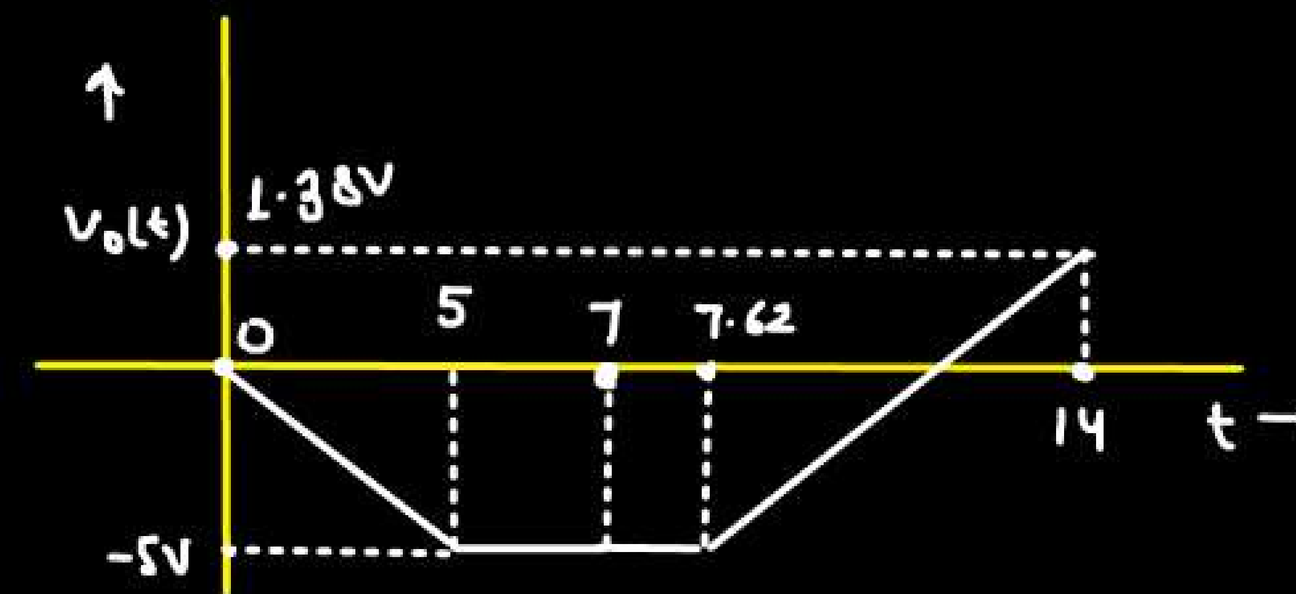
$$v_c(t) = 5 - (t - 7.62)$$

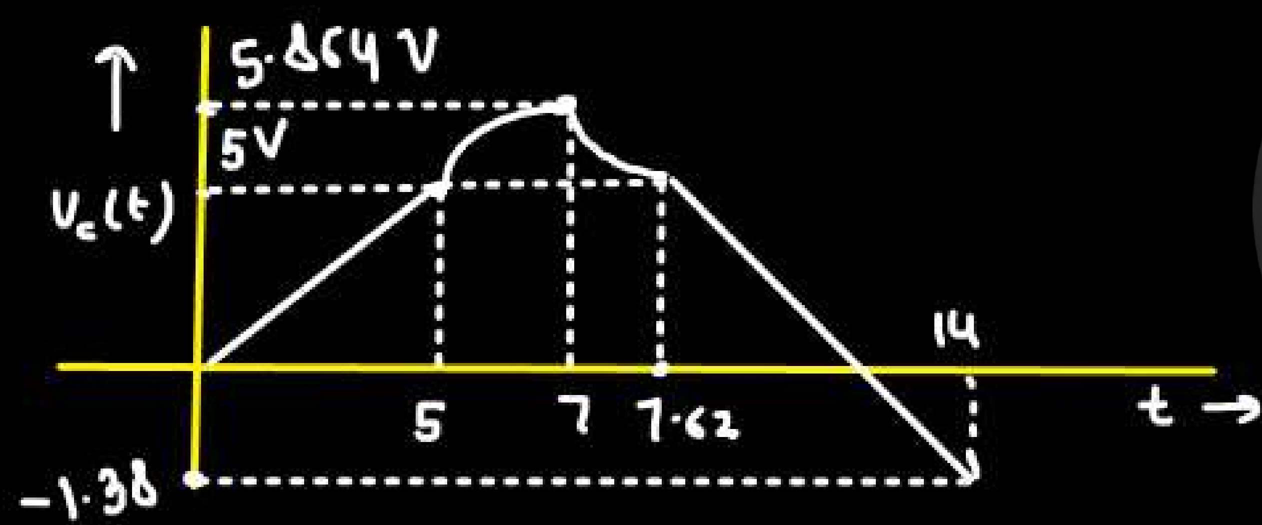
$$v_c(14\,sec.) = 5 - (14 - 7.62) = -1.38V$$

$$V_o(t) = (t - 7.62) - 5$$

$$v_o(t) = 1.38V$$





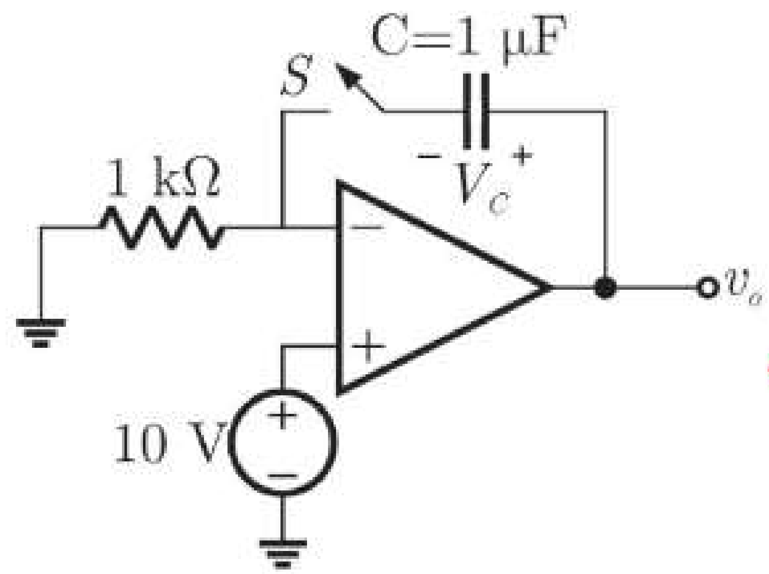


$$V_0(10\,sec) = (10-7.62)-5$$

$$= -2.62\,V$$ Ans.

For the circuit shown in the following figure, the capacitor C is initially uncharged. At $t = 0$, the switch S is closed. The voltage V_C across the capacitor at $t = 1$ millisecond is:

(GATE-2006)



In the figure shown above, the OP-AMP is supplied with ±15V

(A) 0 Volt

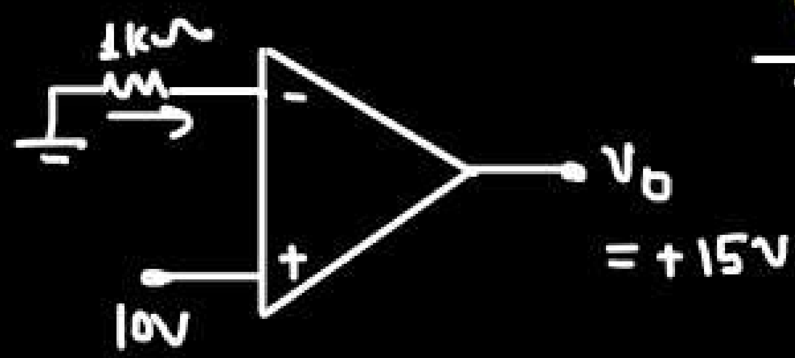
(B) 6.3 Volts

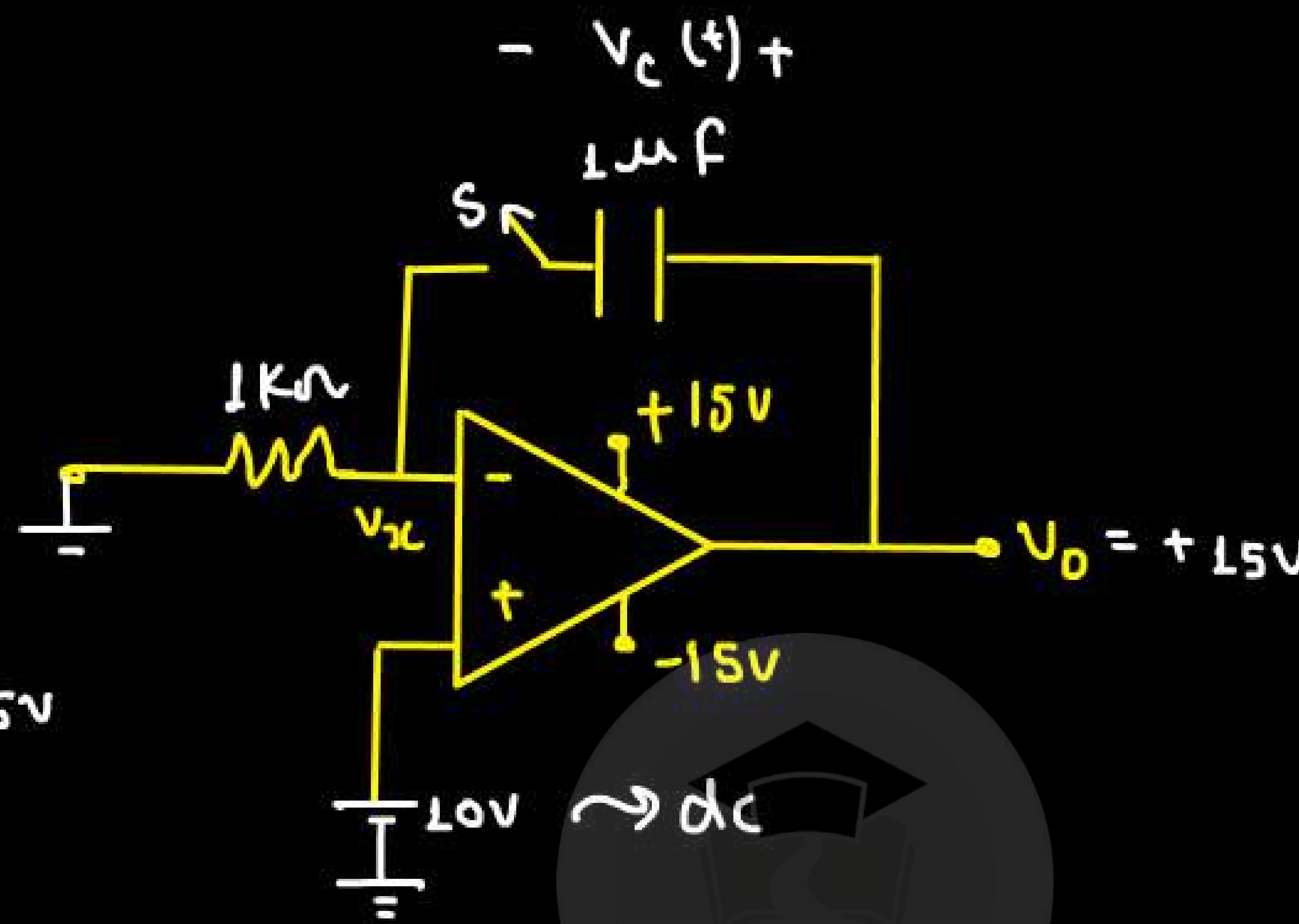
(C) 9.45 Volts

(D) 10 Volts

(E) 8.93V

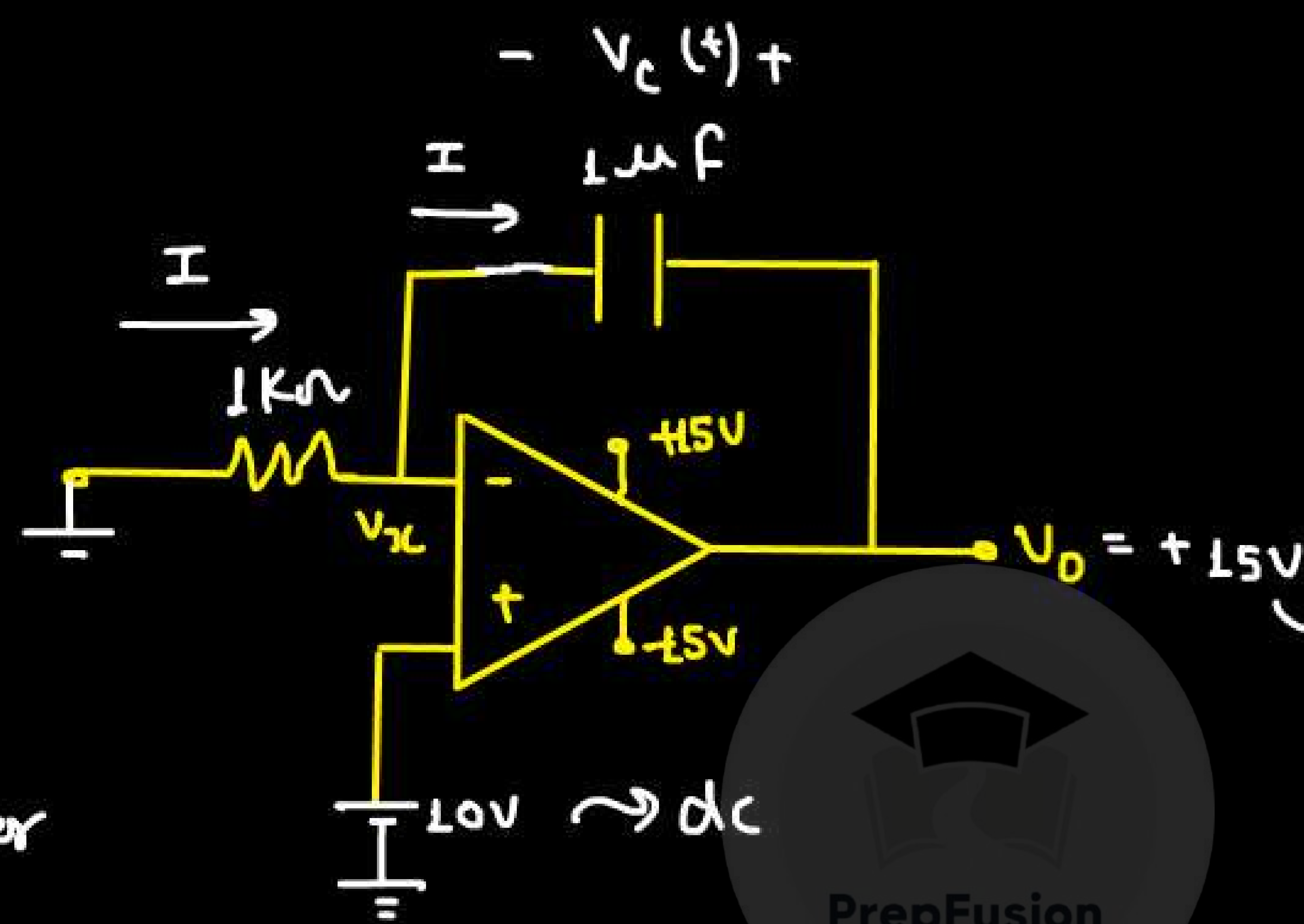
For $t<0$





$$V_0(t<0) = +15V$$

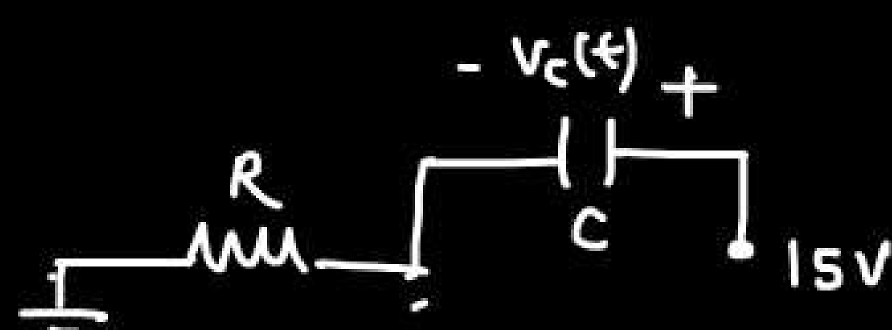
For t>0:-



~> −15V ~> +15V

What Q.P. setter Thought

O/P saturated ⇒ Virtual short NOT valid ⇒



$V_c(0^+) = 0V$

$V_c(\infty) = 15V$

$V_c(t) = 15\left(1 - e^{-t/1m}\right)$

$$V_c(1ms) = 15\left(1 - e^{-1m/1m}\right)$$

$$\boxed{V_c(1ms) = 9.48V}$$

$v_x(0^+) = 15V$

$v_x(\infty) = 0V$

$$\boxed{v_x(t) = 15e^{-t/1m}}$$

at $t = 0^+$

$V_- = 15V, \quad V_+ = 10V \Rightarrow V_0(0^+) = -15V$

now

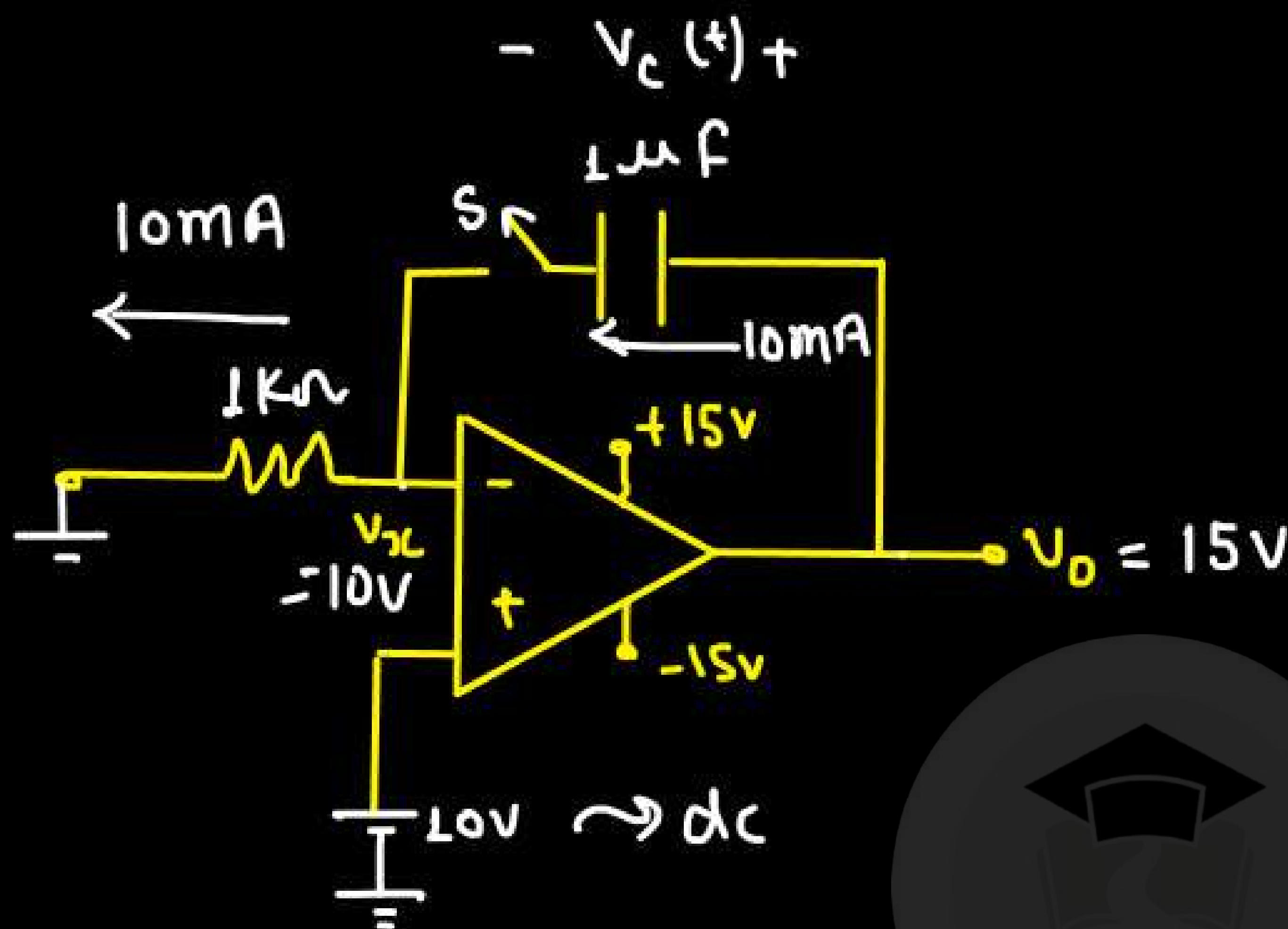
$v_x(0^+) = -15V$

$\Rightarrow v_- = -15V, \quad v_+ = 10V \Rightarrow v_0(0^+) = +15V$

*

$$\boxed{\Rightarrow v_0 \text{ is toggling b/w } +15V \text{ and } -15V \text{, only @ } t=0^+ \Rightarrow \text{The ckt will not work}}$$

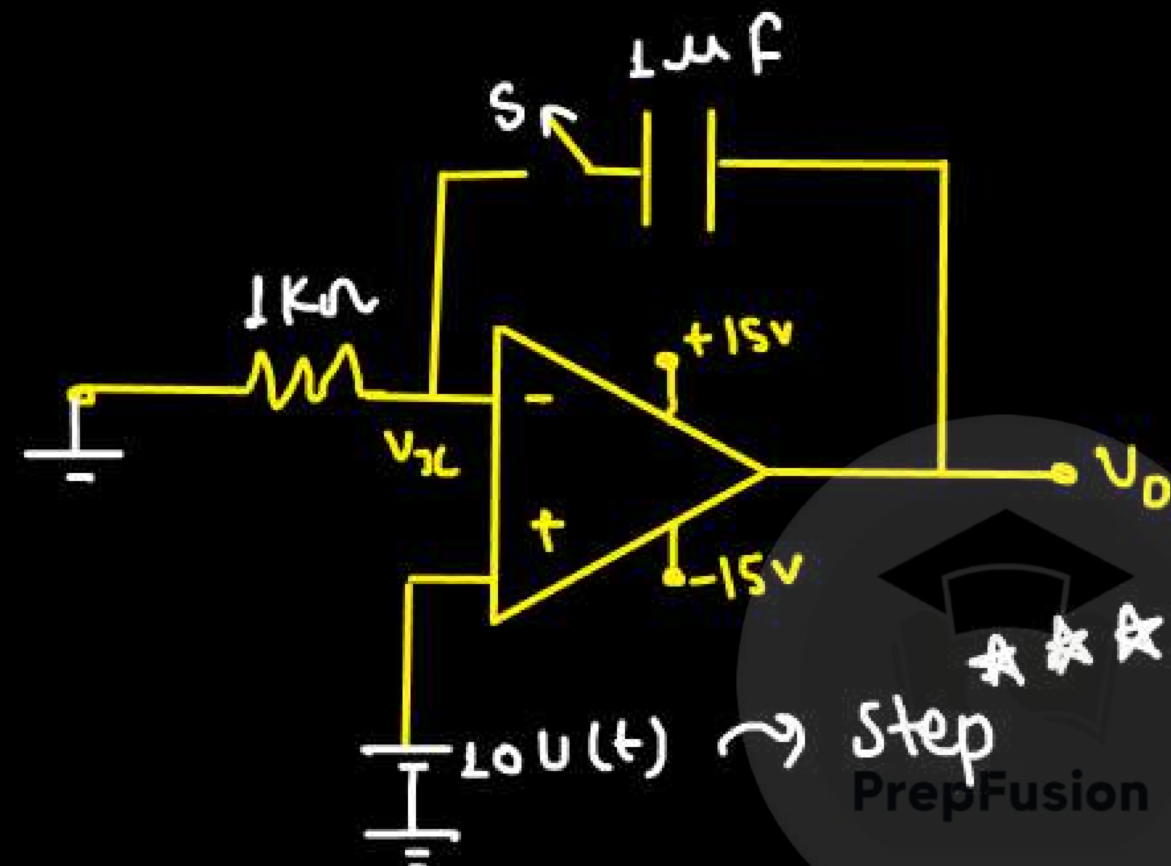
$t > 0$



$V_c(0^-) = 0V$

$V_c(0^+) = 5V$

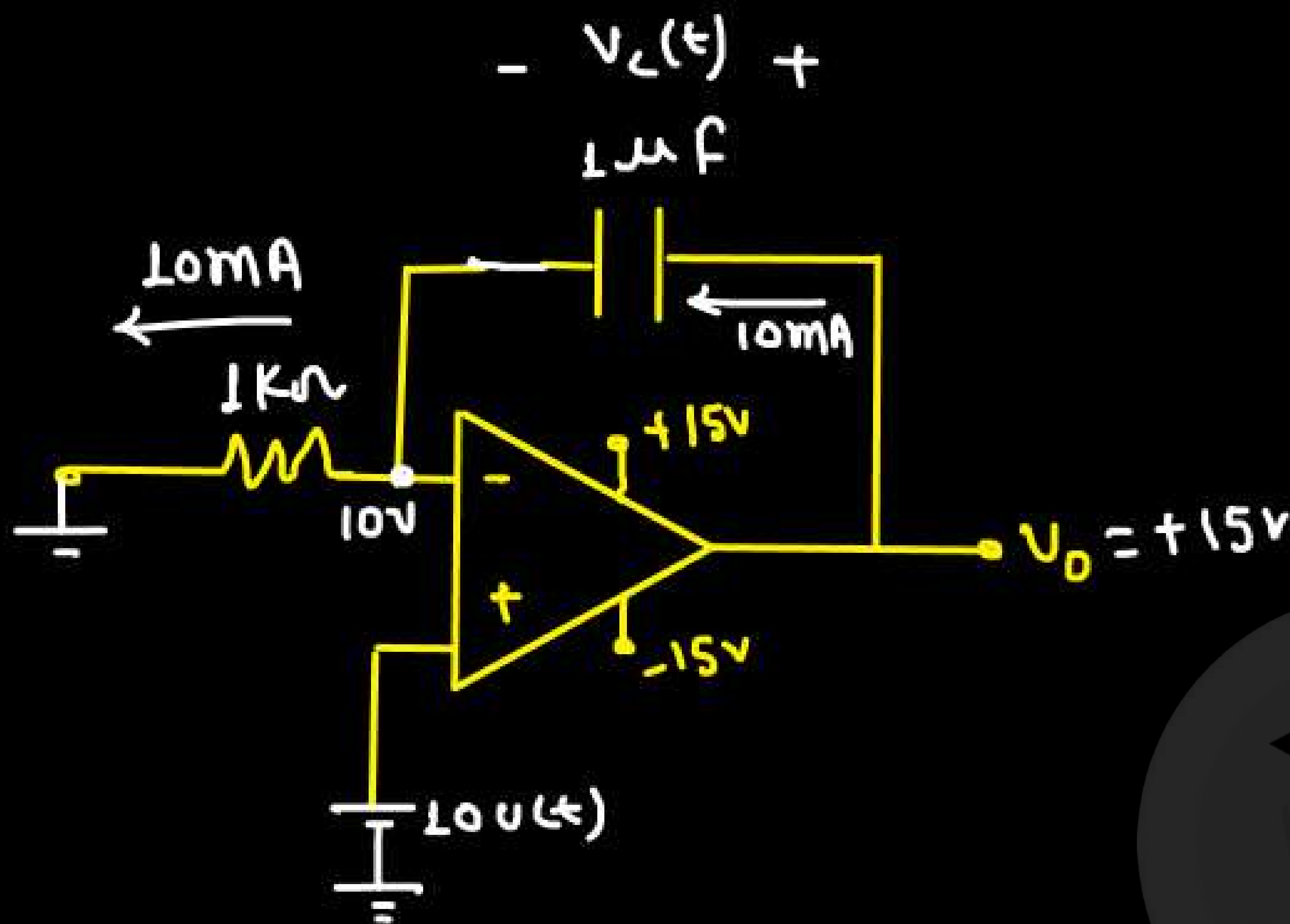
Correct Question :-



Q. The switch is closed @ $t=0$. Find v_c at $t = 1ms$

→ @ $t=0^+$

o/p is not saturated + Negative f/b is +nt $\Rightarrow$ virtual short valid



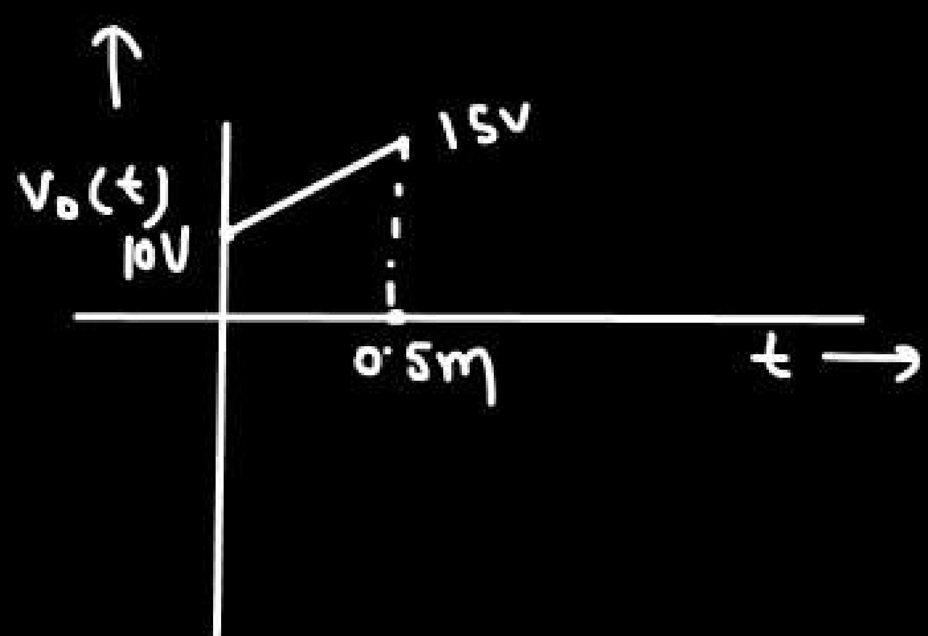
$$V_c(t) = \frac{1}{1\mu f}\int_0^t 10mA\, dt$$

$$V_c(t) = 10t \times 10^3$$

$$V_0(t) = 10 + V_c(t)$$

$$V_0(t) = 10 + 10^4 t \text{ volt}$$

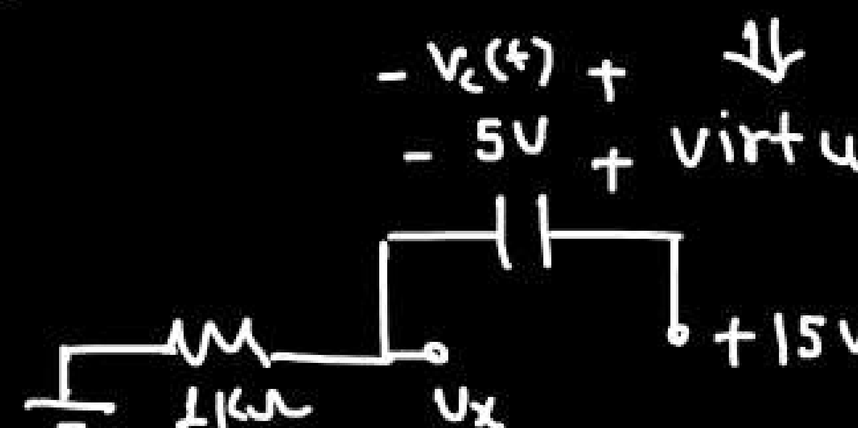
$$V_0(0.5m) = 15 \text{ volt}$$



@ $t = 0.5$ msec. ⇒ o/p is saturated.

⇓

virtual short NOT valid



$$v_c(0.5m^+) = 5V, \quad v_c(\infty) = 15V$$

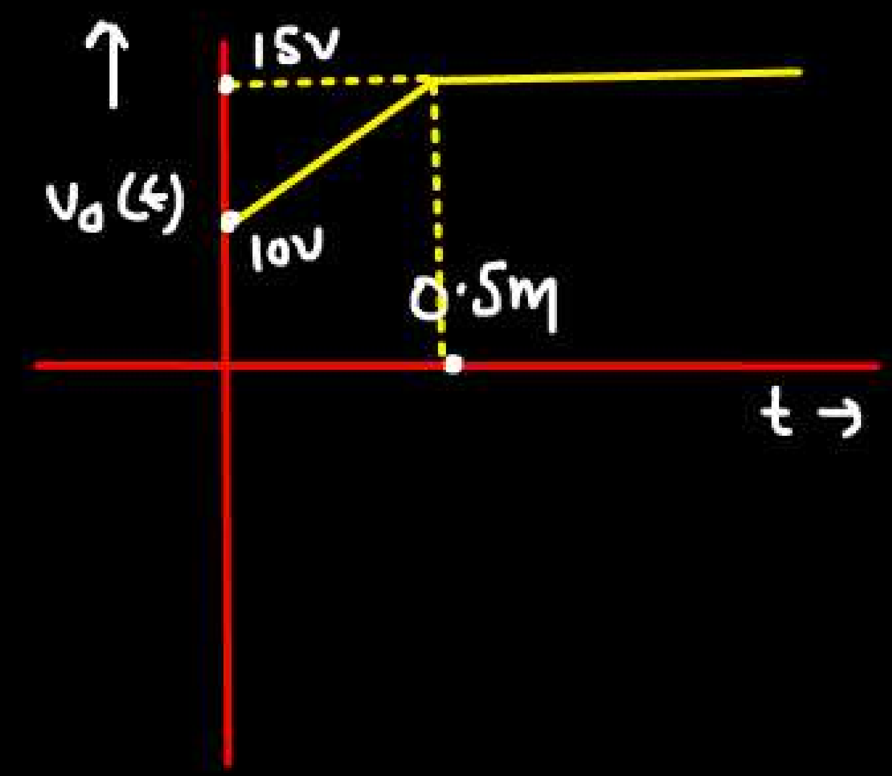
$$v_c(t) = 15 - 10e^{-(t-0.5m)/1m}$$

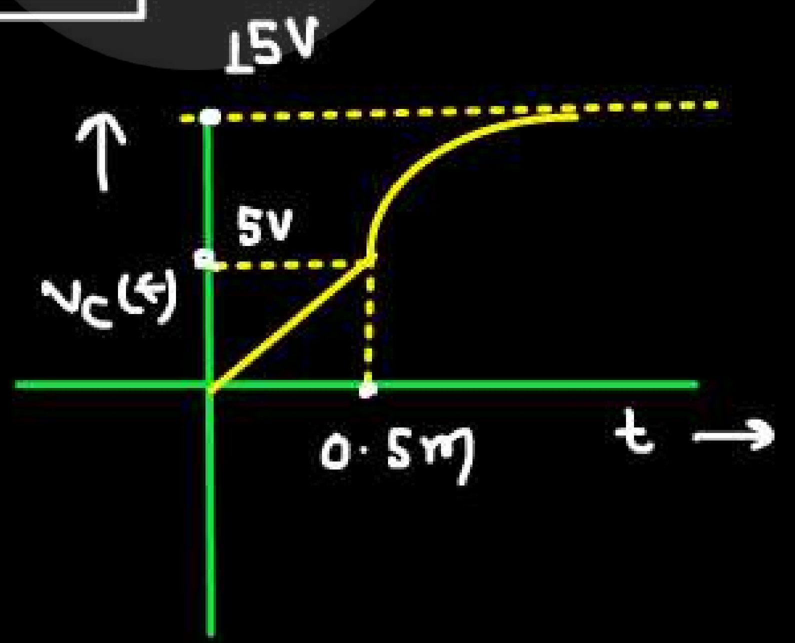
$$v_1(0.5m^+) = 10V, \quad v_1(\infty) = 0V$$

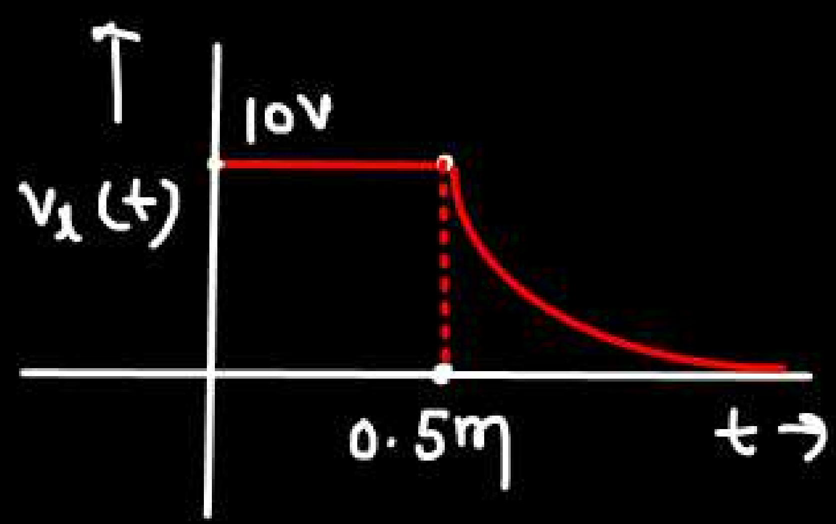
$$v_1(t) = 10e^{-(t-0.5m)/1m}$$

$$v_c(1ms) = 15 - 10e^{-(0.5m)/1m}$$

$$\boxed{v_c(1ms) = 8.93V}$$

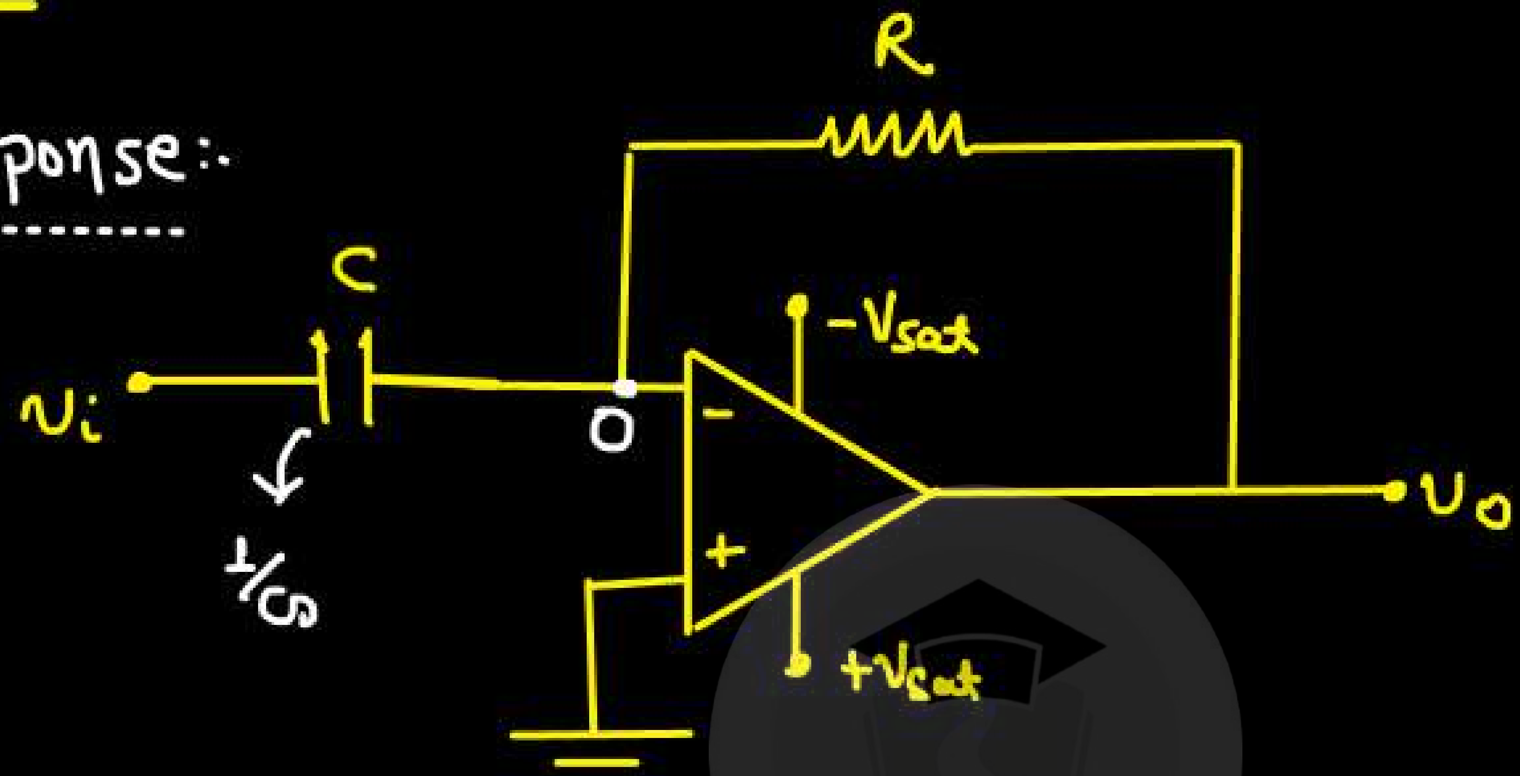






Differentiator :-

Frequency response :-



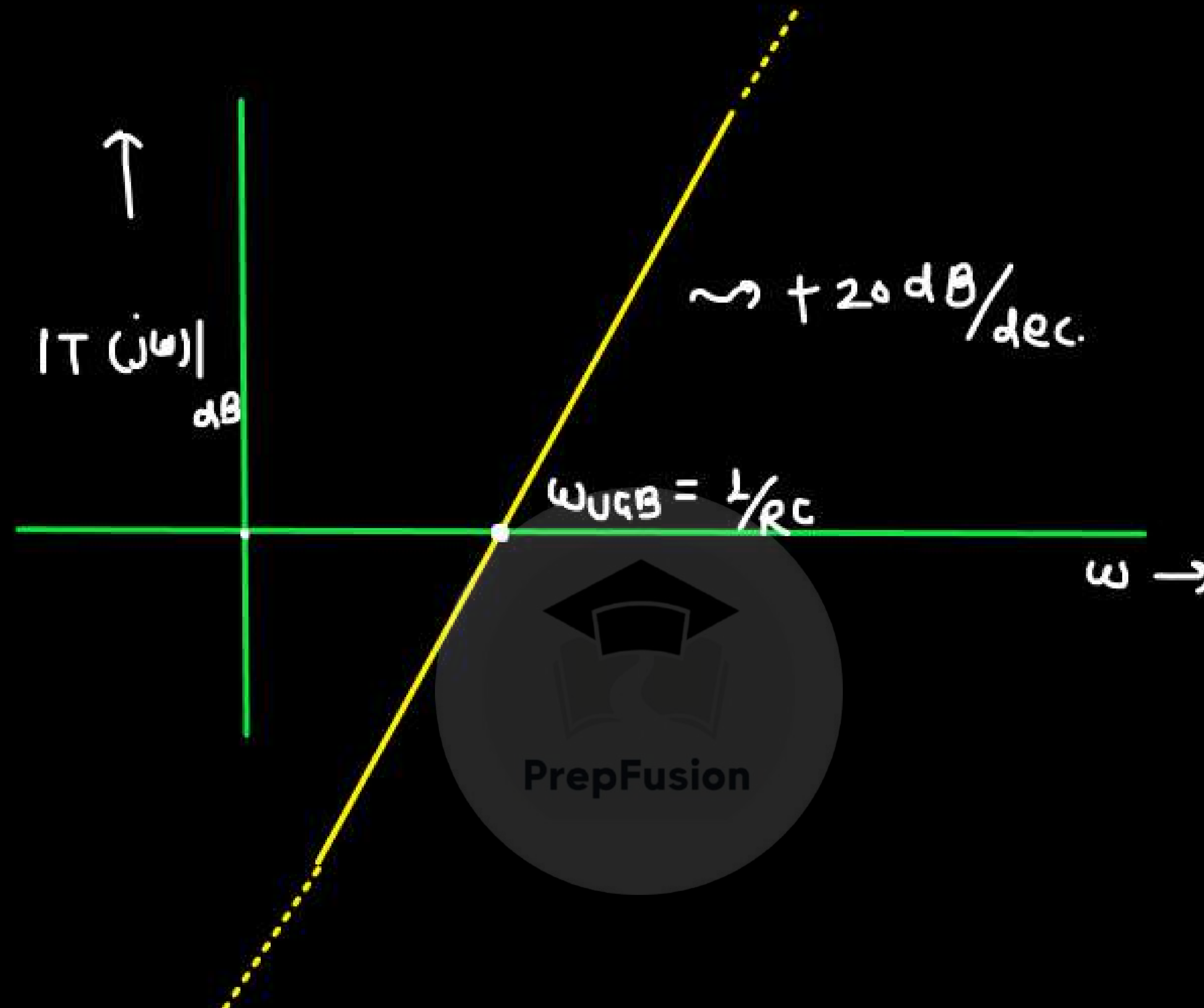
$$\frac{v_o(s)}{v_i(s)} = \frac{-R}{1/Cs} = -RCs = T(s) \rightarrow \begin{array}{l}\omega_z = 0 \\ \omega_p = \infty\end{array}$$

$$\frac{v_o(s)}{v_i(s)} = -sRC$$

$$|T(j\omega)| = \omega RC$$

$$v_o(s) = -sRC \times v_i(s)$$

$$\boxed{v_o(t) = -RC \frac{d}{dt} v_i(t)}$$ $\rightarrow$ acting as differentiator

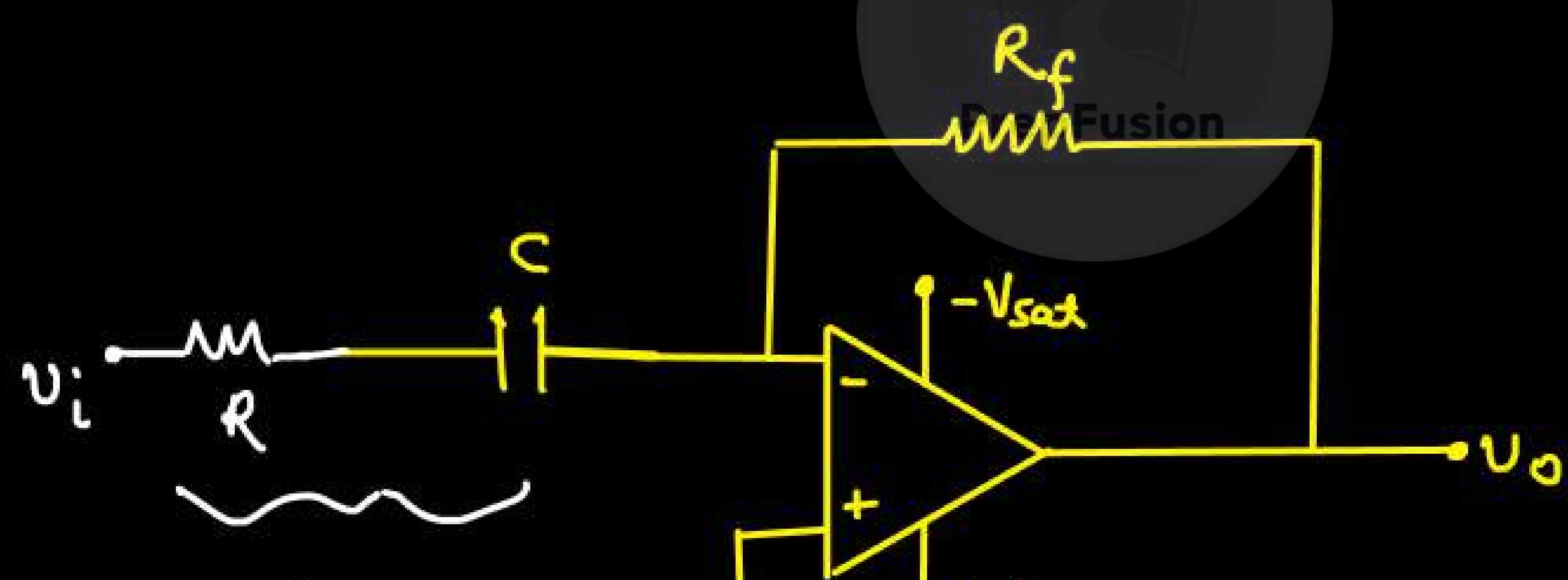

|T(jω)|
dB
+20 dB/dec.
ω_UGB = 1/RC
ω →
PrepFusion

Drawback:-

↳ Very High gain at High freq.

(High freq. Noise will be Amplified)

Practical Differentiator:-



$$\underbrace{R + \frac{1}{Cs}}= \frac{RCs+1}{Cs}$$

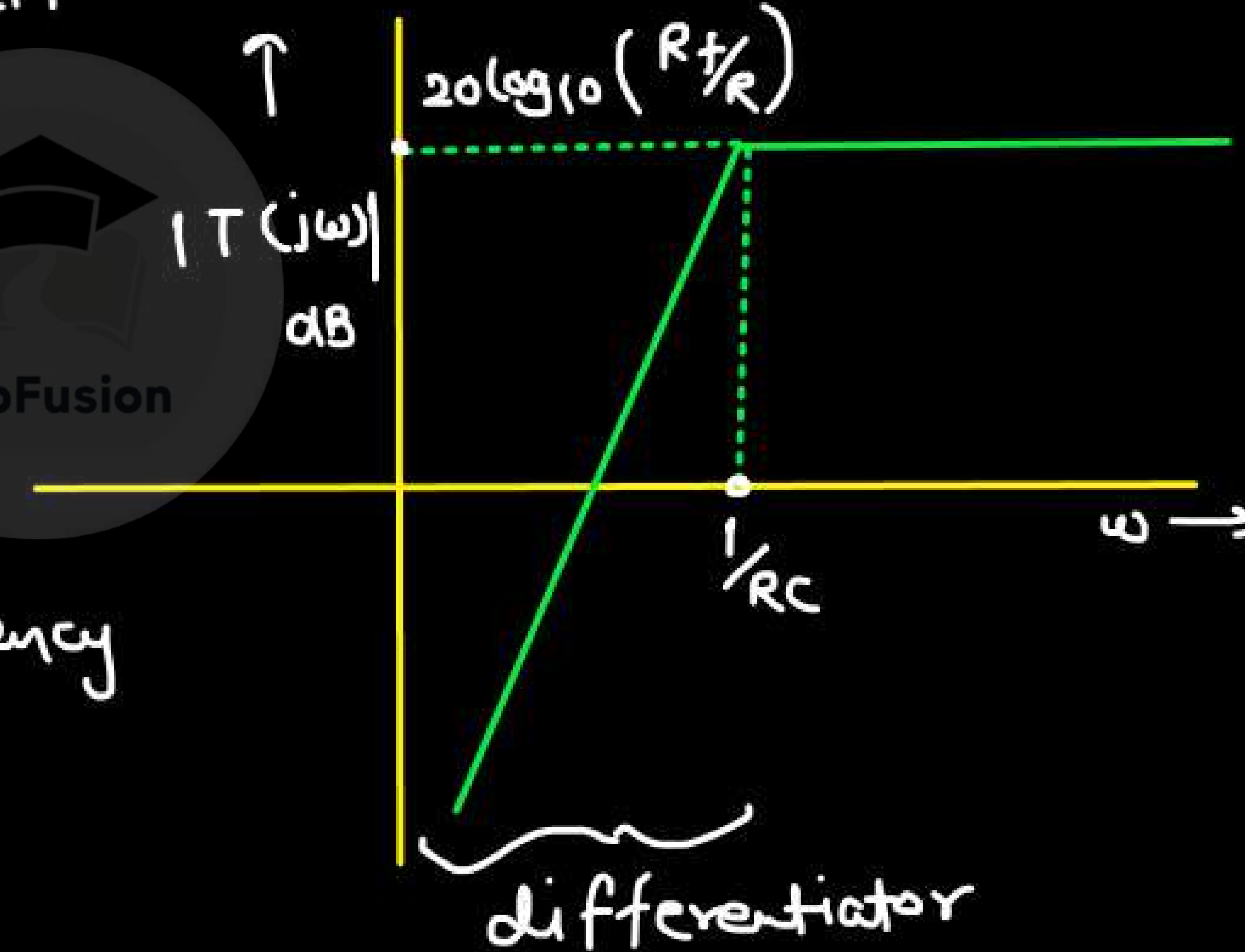
$$\frac{v_o(s)}{v_i(s)} = \frac{-R_f C s}{RCs+1} = T(s)$$

$\rightarrow \omega_z = 0$

$\omega_p = 1/RC$

$$|T(j\omega)| = \frac{\omega R_f C}{\sqrt{\omega^2 R^2 C^2 + 1}}$$

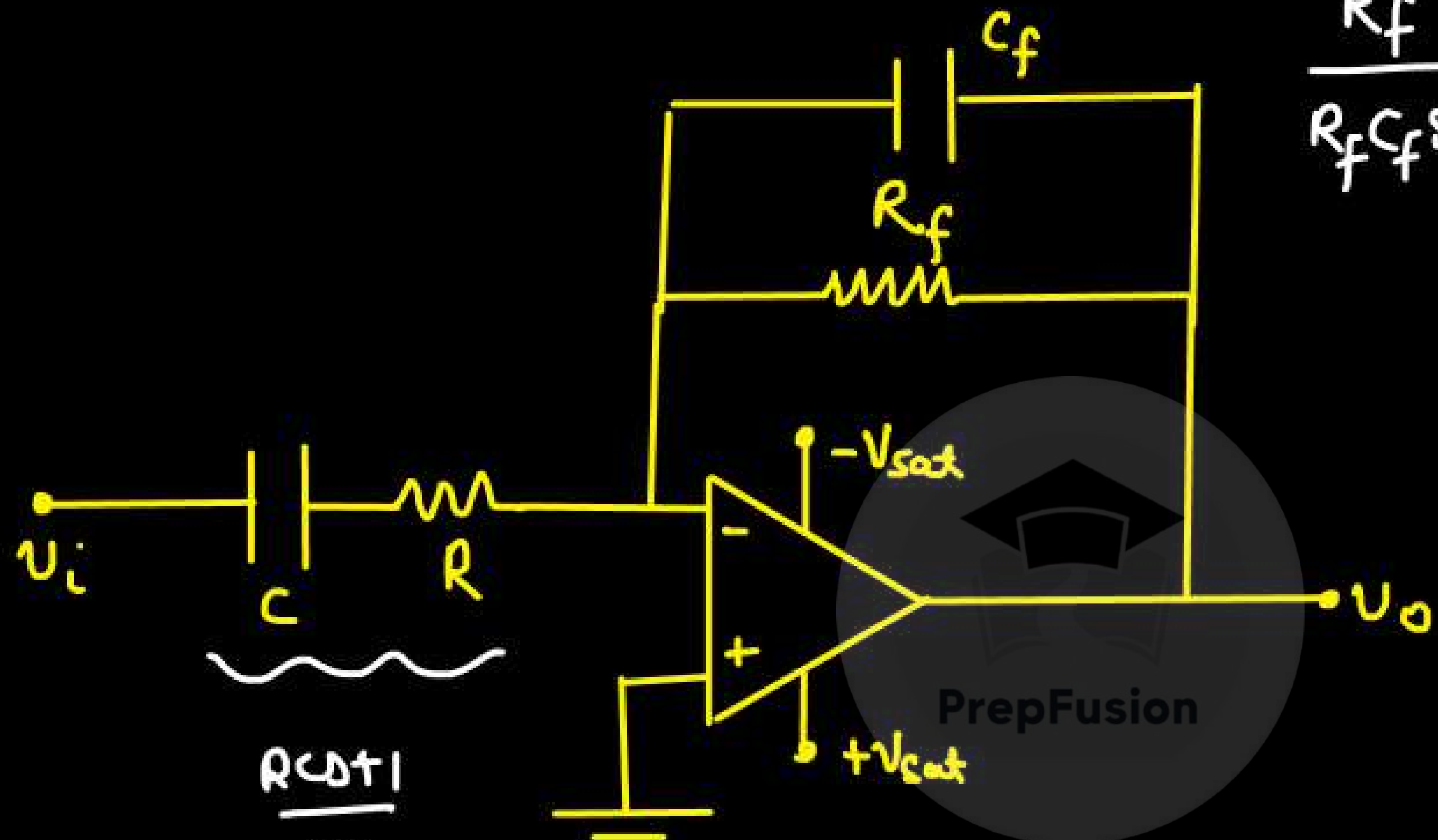
$$\boxed{|T(j\infty)| = R_f/R}$$



→ we will try to reduce High frequency noise more.

Modified Practical Differentiator :-

$$\frac{R_f}{R_f C_f s + 1}$$



$$\frac{RCs+1}{Cs}$$

$$\boxed{\frac{v_o(s)}{v_i(s)} = \frac{\frac{-R_f}{R_f C_f s + 1}}{\frac{RCs+1}{Cs}} = \frac{-R_f C s}{(R_f C_f s + 1)(RCs + 1)}}$$

$$T(s) = \frac{-R_f C s}{(R_f C_f s + 1)(RCs + 1)} \rightarrow$$

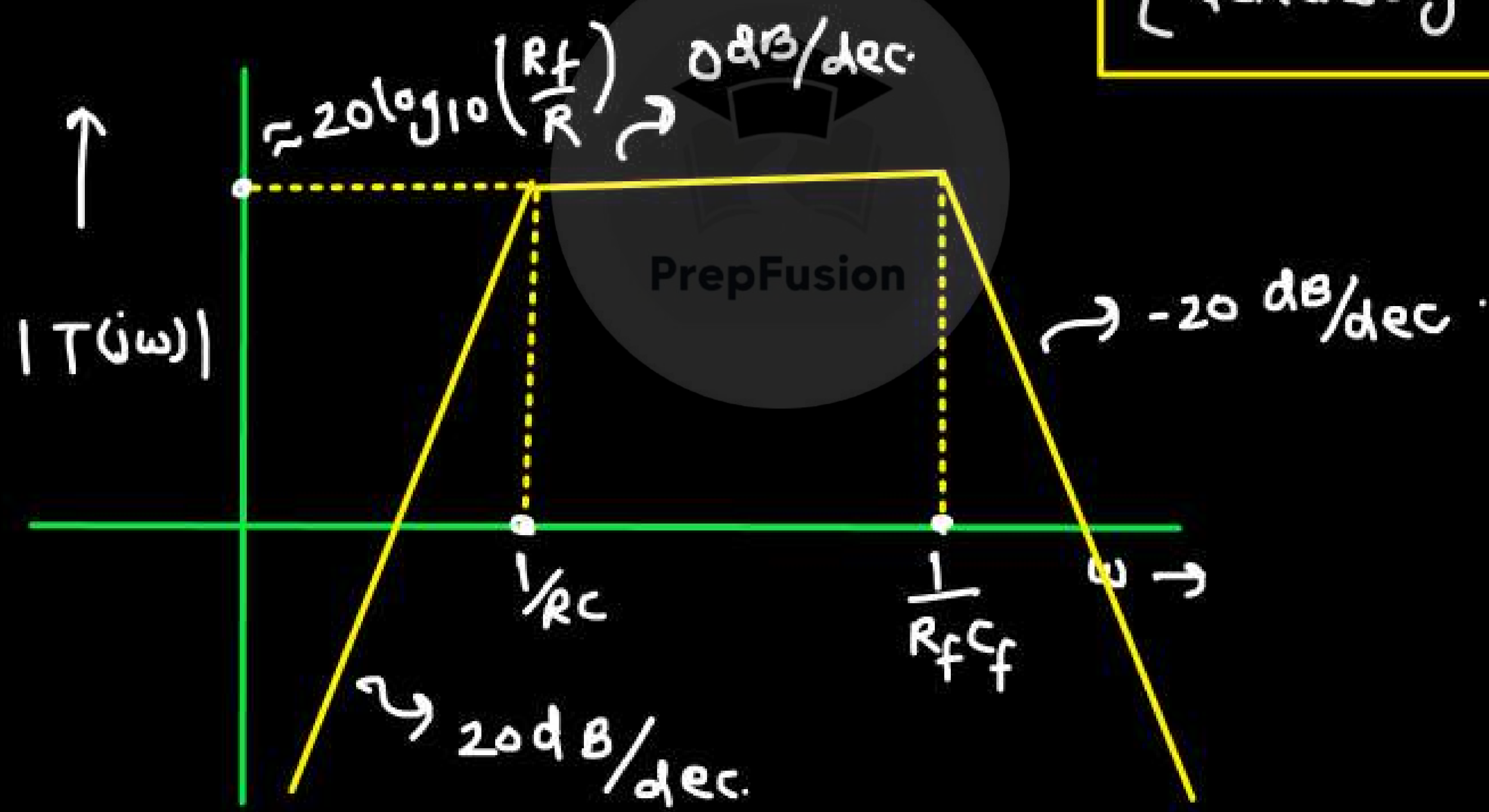
$$\omega_z = 0$$

$$\omega_{p_1} = \frac{1}{RC}$$

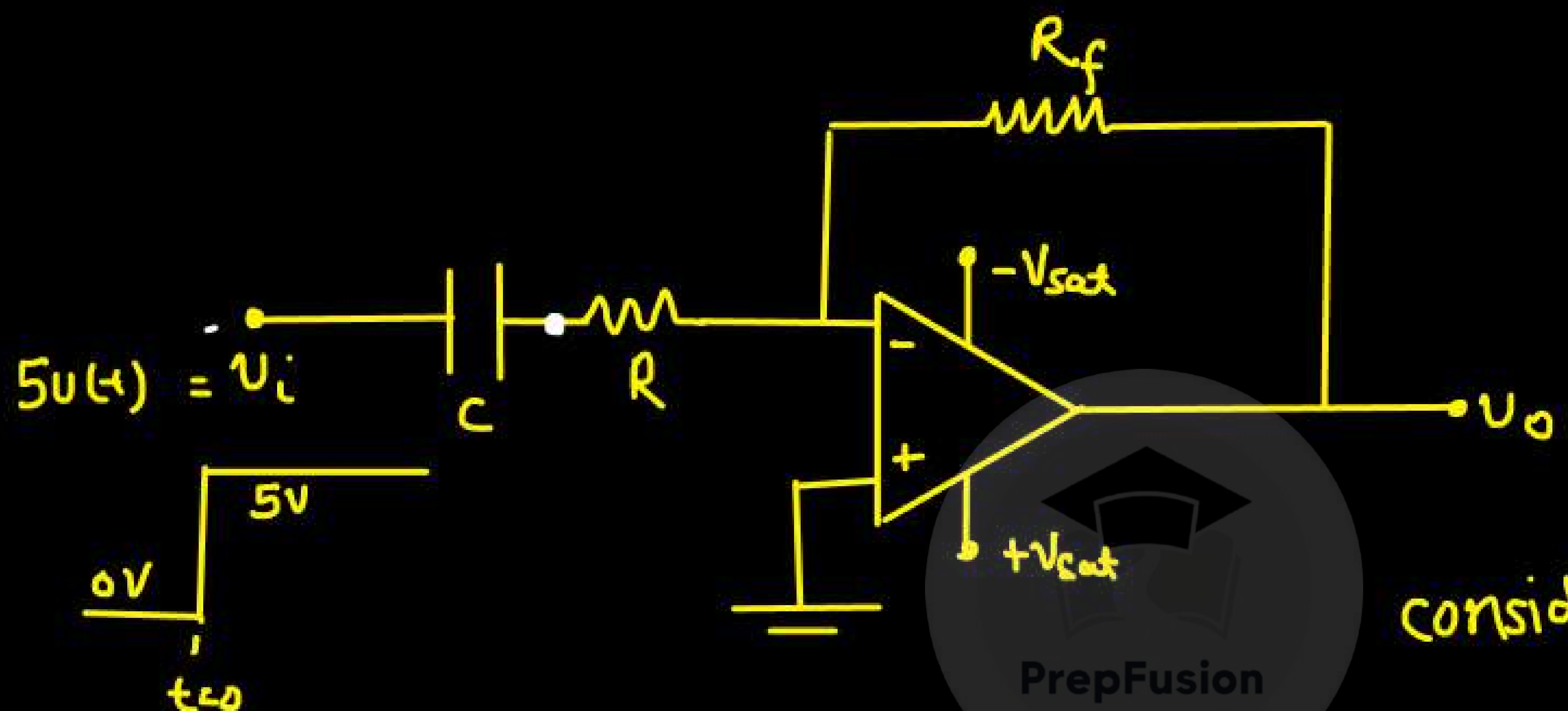
$$\omega_{p_2} = \frac{1}{R_f C_f}$$

$$\boxed{|T(j\infty)| = 0}$$

$$\boxed{\left[\text{Generally } R_f C_f < RC\right]}$$



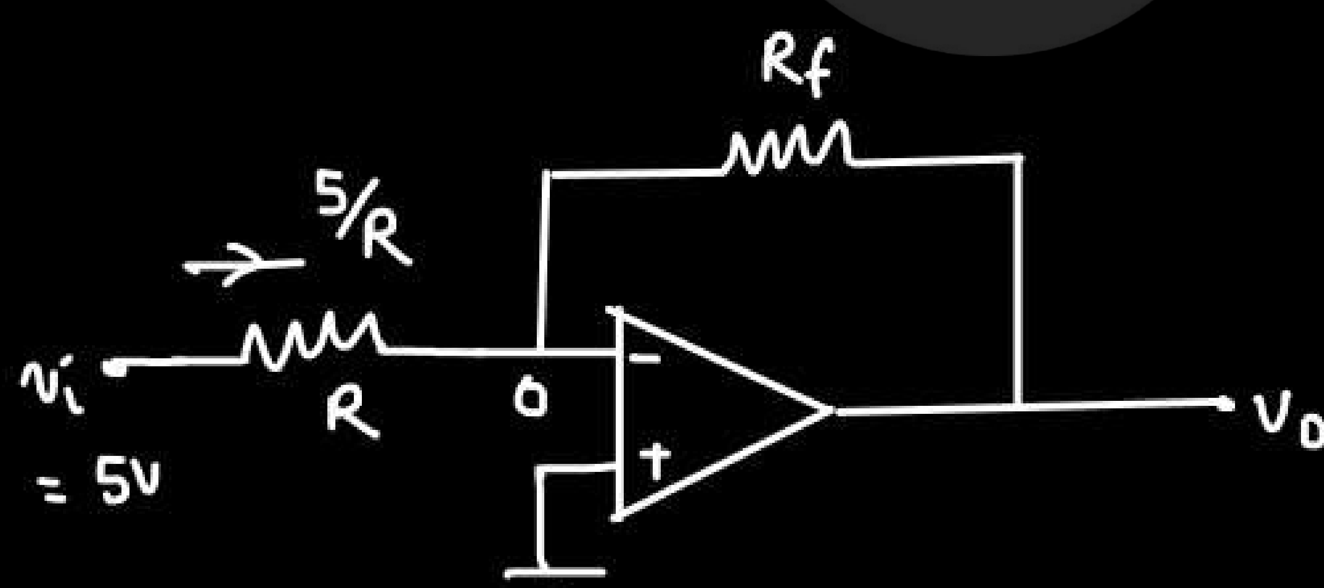
Time domain Analysis :-



consider $\pm V_{sat}$ to be very High.

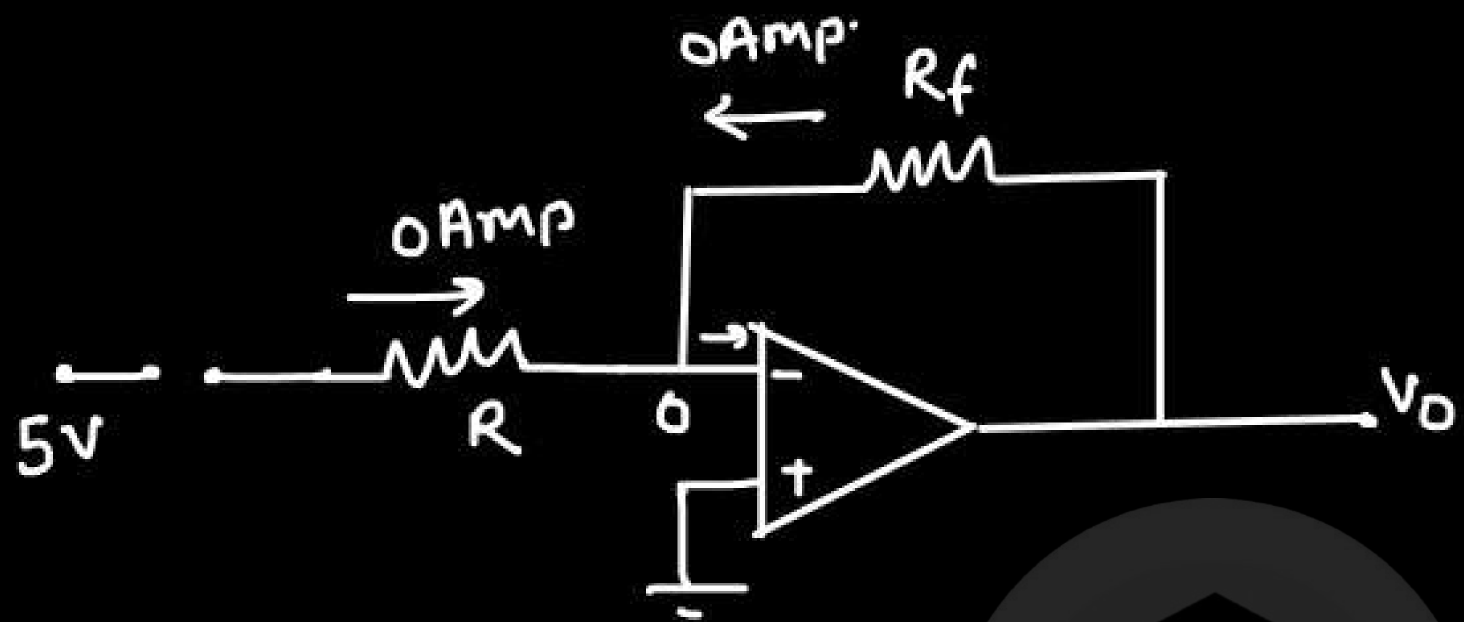
at $t = 0^+$

cap → s.c.

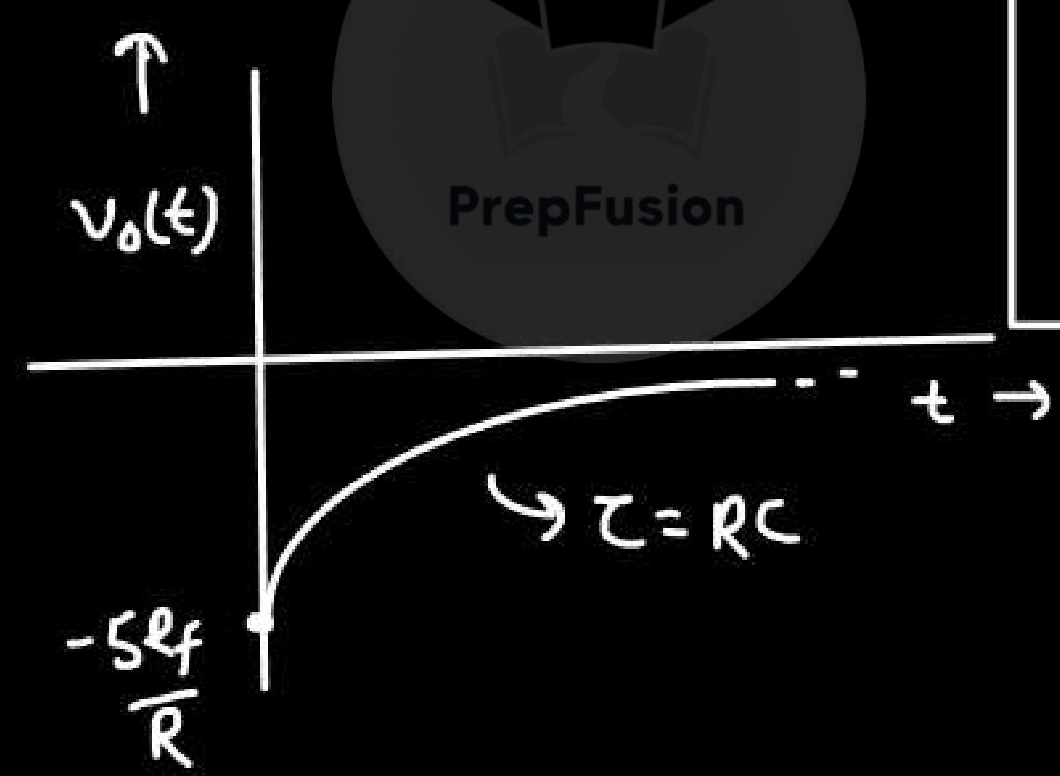


$$v_o(0^+) = -\frac{R_f}{R} \times 5$$

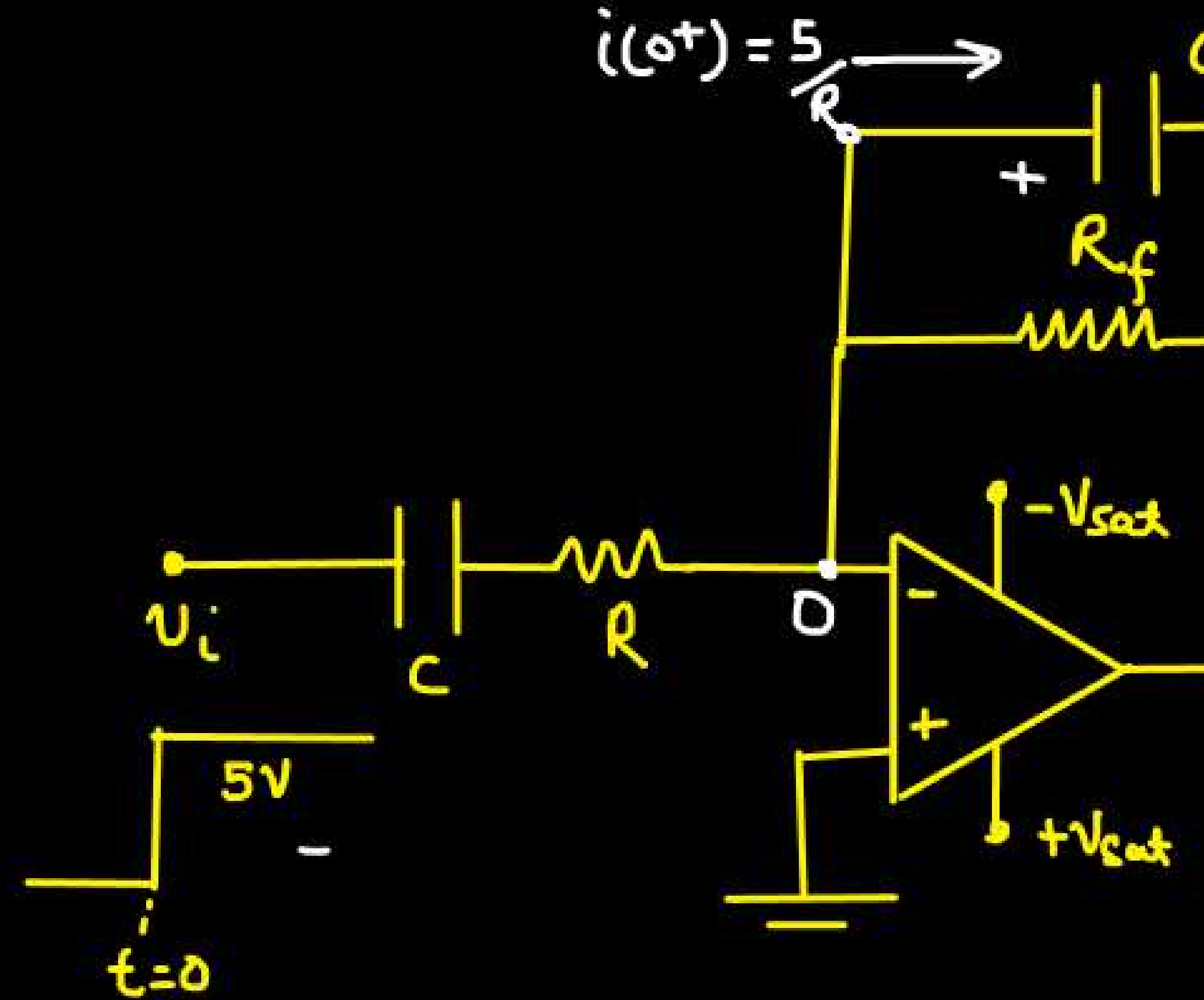
at $t=\infty \rightarrow$ Cap $\Rightarrow$ o.c.



$$v_0(\infty) = 0\,V$$



$$\boxed{v_0(t) = -\frac{5R_f}{R} e^{-t/RC} u(t)}$$

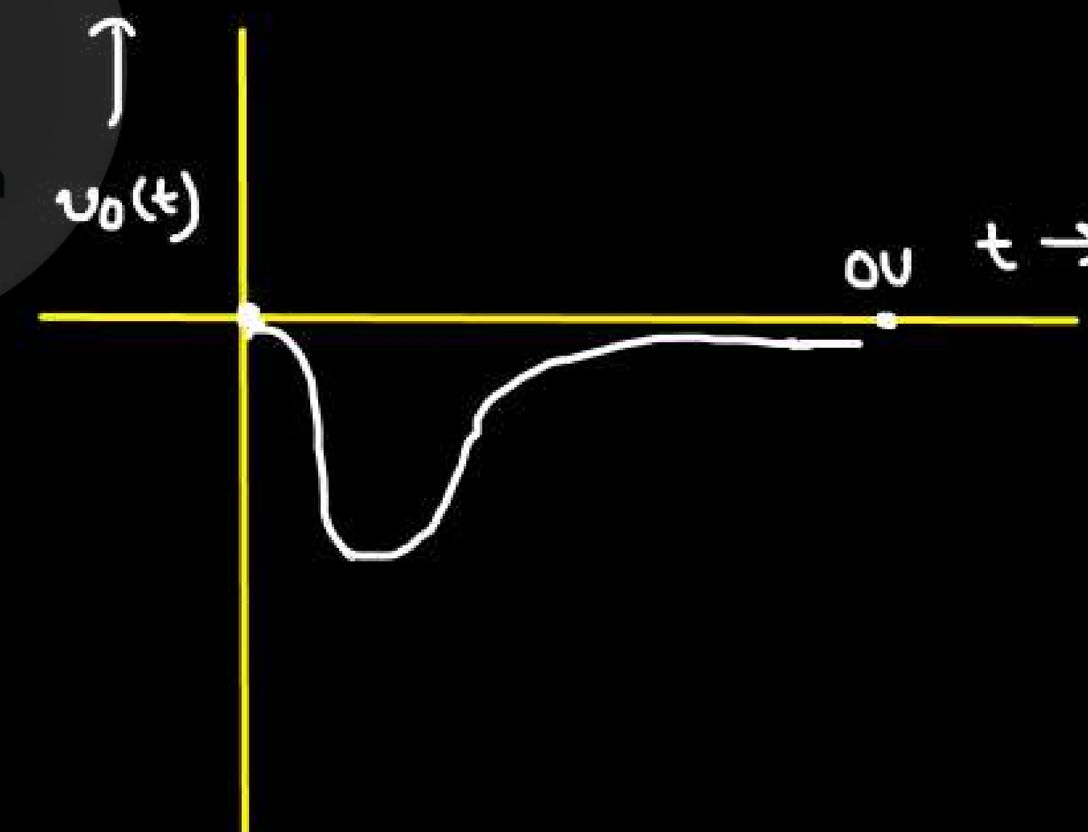


Draw v_o waveform.
[Considering $\pm V_{sat}$ to be very High]

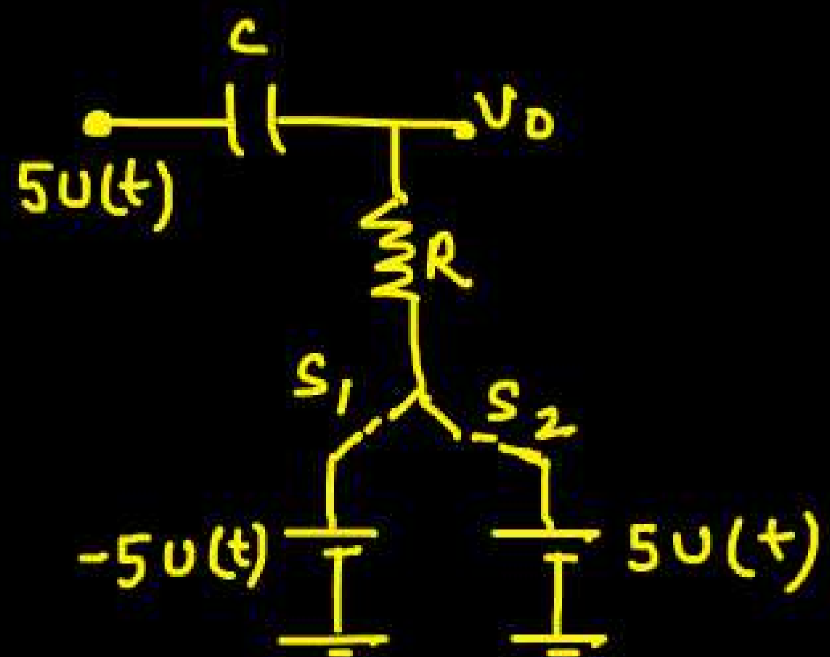
→ order = 2^{nd} order

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

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



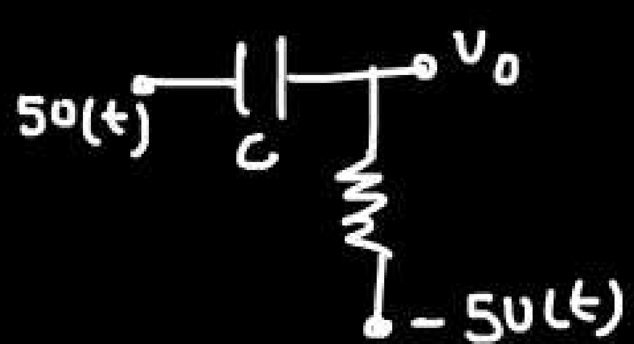
⇒ Interesting concept of Differentiator:-



initially switch S_1 is closed and swith S_2 is open.

at time $t = RC\ln(2)$, switch S_1 is opened and S_2 is closed.
Draw v_o waveform.

→ $0 < t < RC\ln(2)$

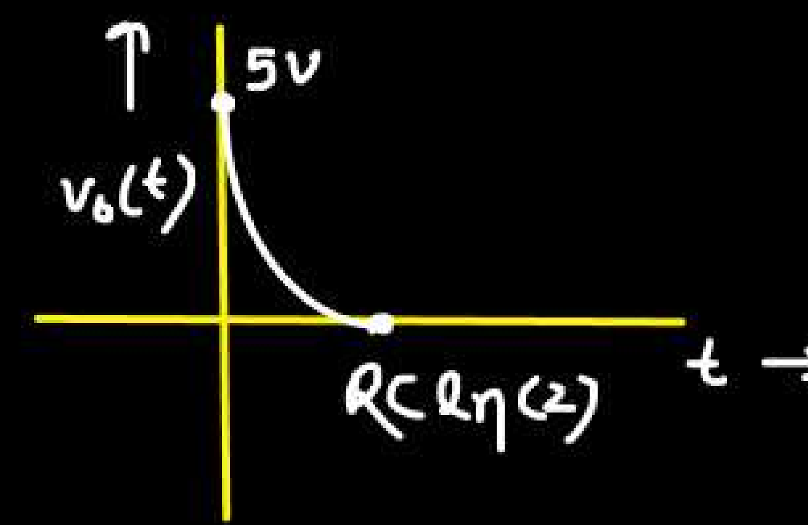


$$V_o(0^+) = 5V$$

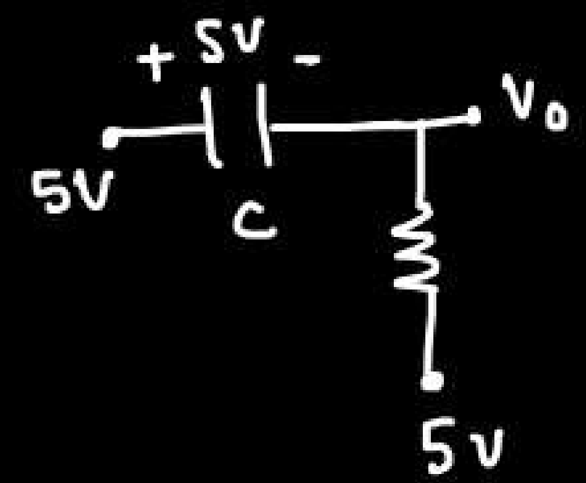
$$V_o(\infty) = -5V$$

$$V_o(t) = -5 + 10e^{-t/RC}$$

$$V_o(RC\ln 2) = 0$$

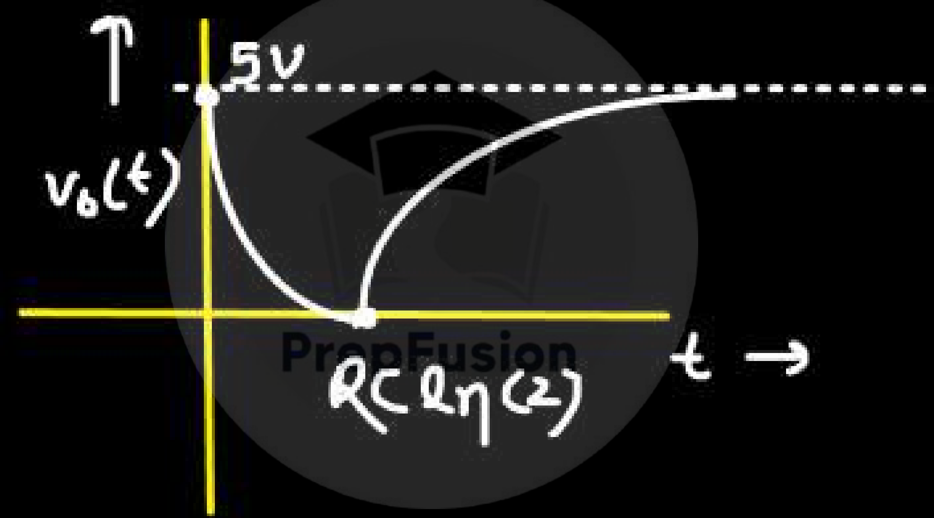


$t > RC\ln(2)$

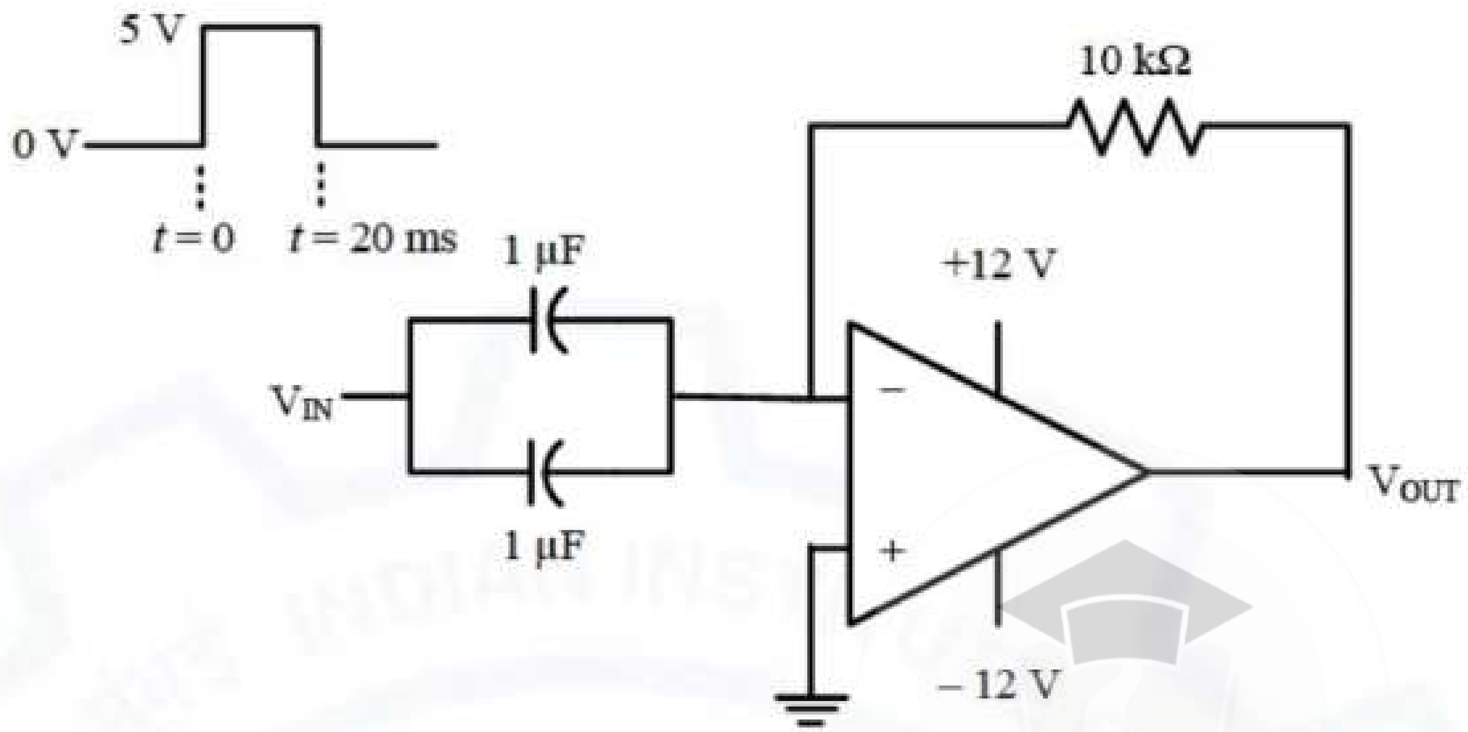


$V_0(RC\ln 2) = 0$

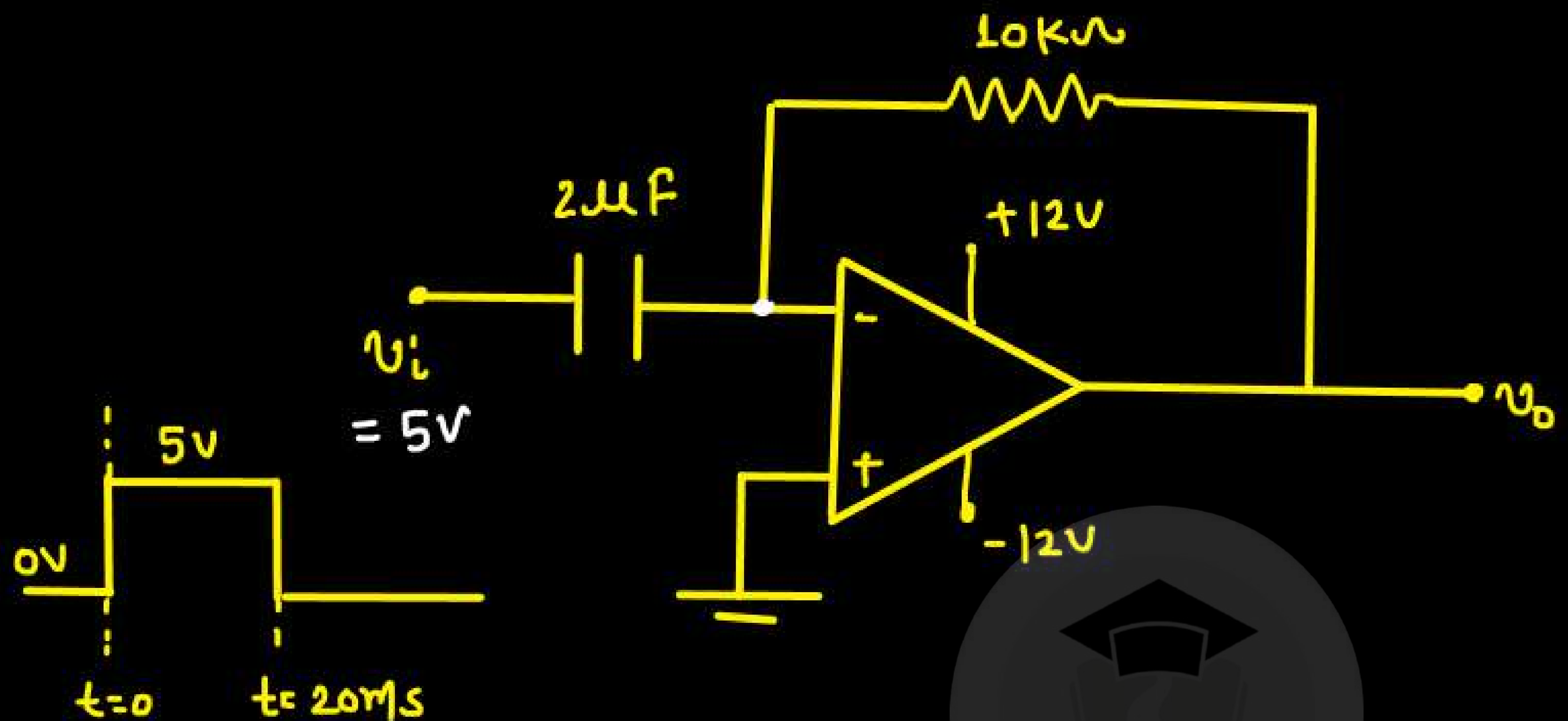
$V_0(\infty) = 5V$



Q.45	**A circuit with an ideal OPAMP is shown in the figure. A pulse V_{IN} of 20 ms duration is applied to the input. The capacitors are initially uncharged.**



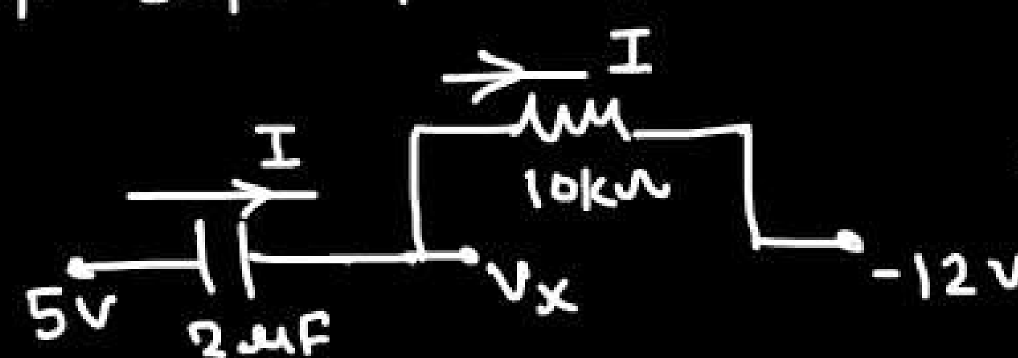
The output voltage V_{OUT} of this circuit at $t = 0^+$ (*in integer*) is ________ V.



$V_x(t=0^+) = 5V$

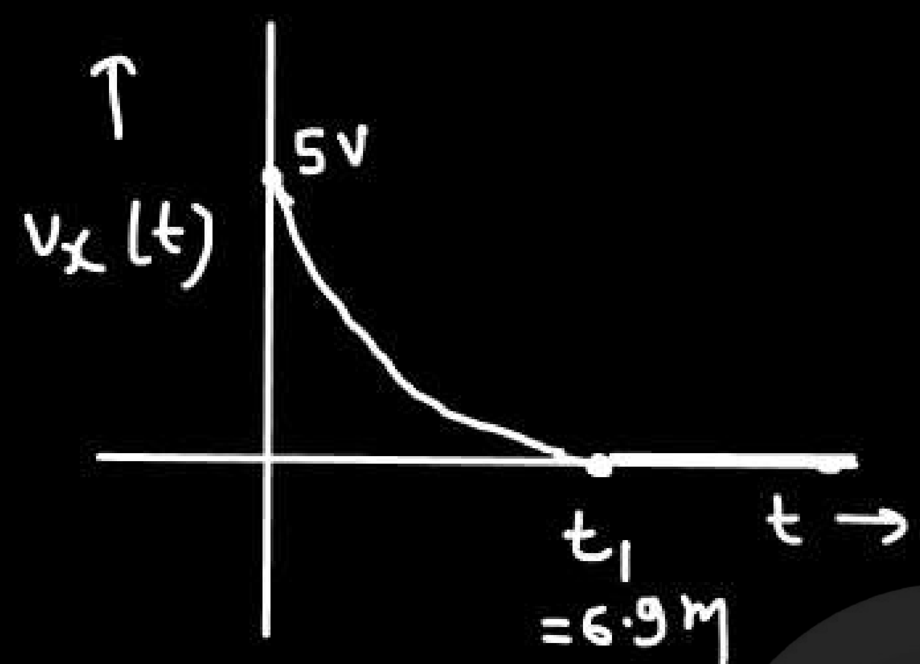
$v_o(t=0^+) = -12V$

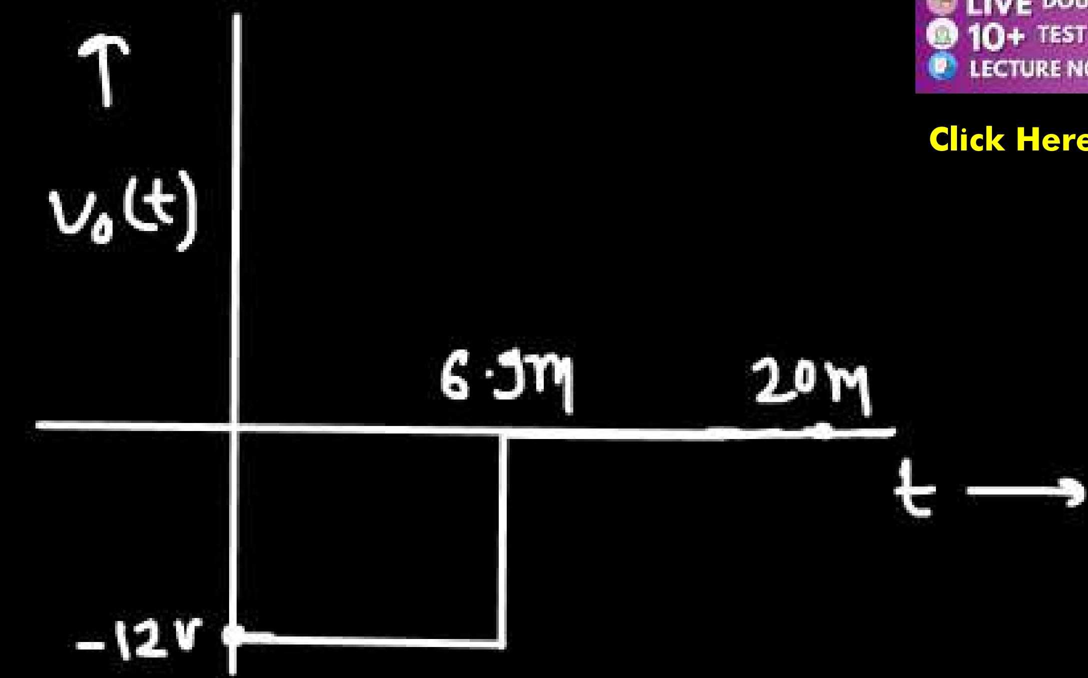
o/p saturated ⇒ virtual short NOT valid



→ First order series RC ckt

$V_x(0^+) = 5V$ $V_x(\infty) = -12V$





$$v_x(t) = -12 + 17e^{-t/20m}$$

$$v_x(t_1) = 0$$

$$t_1 = 20m \ln\left(17/12\right)$$

$$t_1 = 6.9m$$

For $t > t_1 \Rightarrow v_x$ goes negative

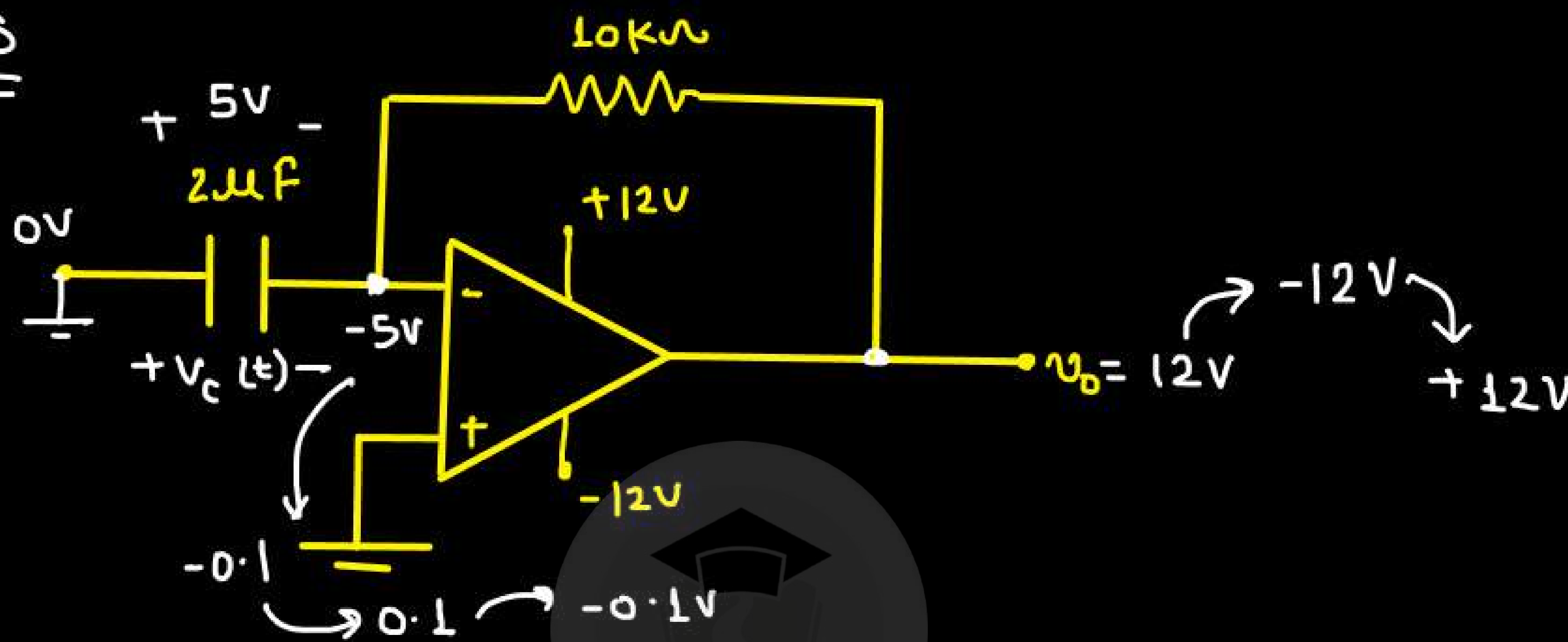
$\Downarrow$

o/p goes +12V

$\Downarrow$

It will force v_x to go to +12V $\Rightarrow$ v_x goes +ve $\Rightarrow$ o/p goes -12V $\Rightarrow$ forces v_x to -12V $\Rightarrow$ v_x stays at 0V forever

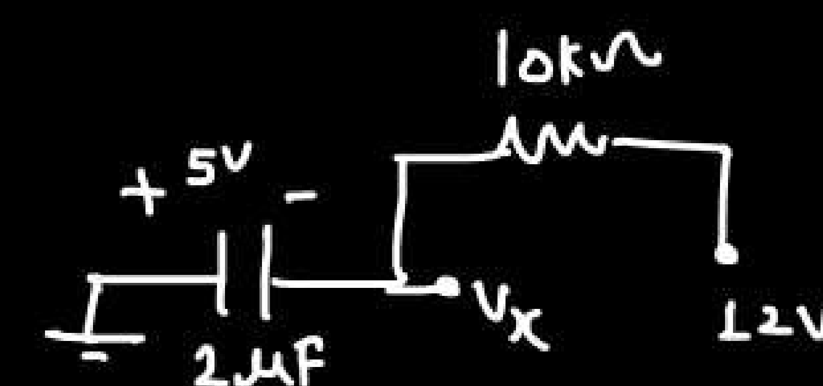
For t>20ms



$V_c(20ms^-) = 5V$

$V_c(20ms^+) = 5V$

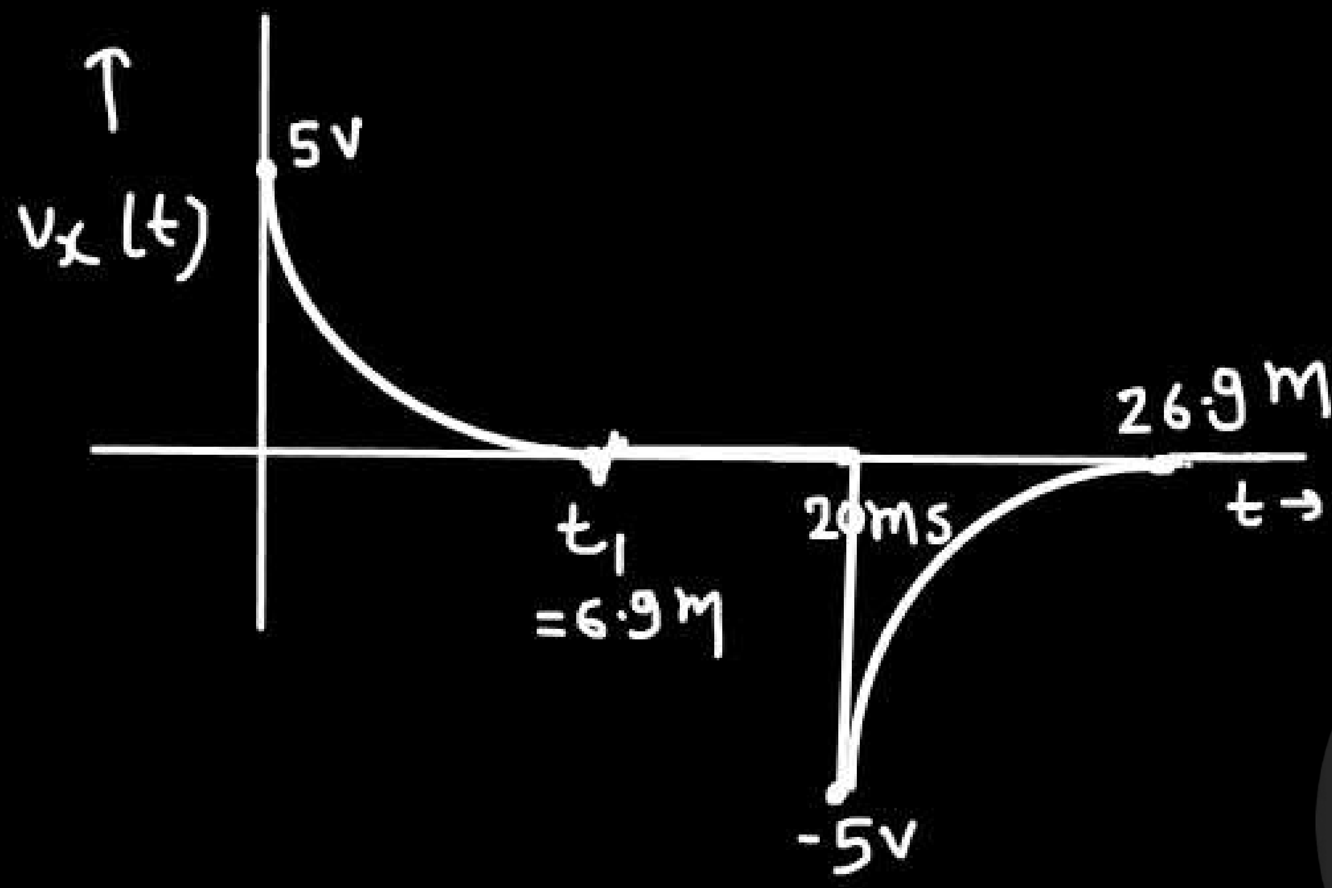
$V_0(20ms^+) = +12V$

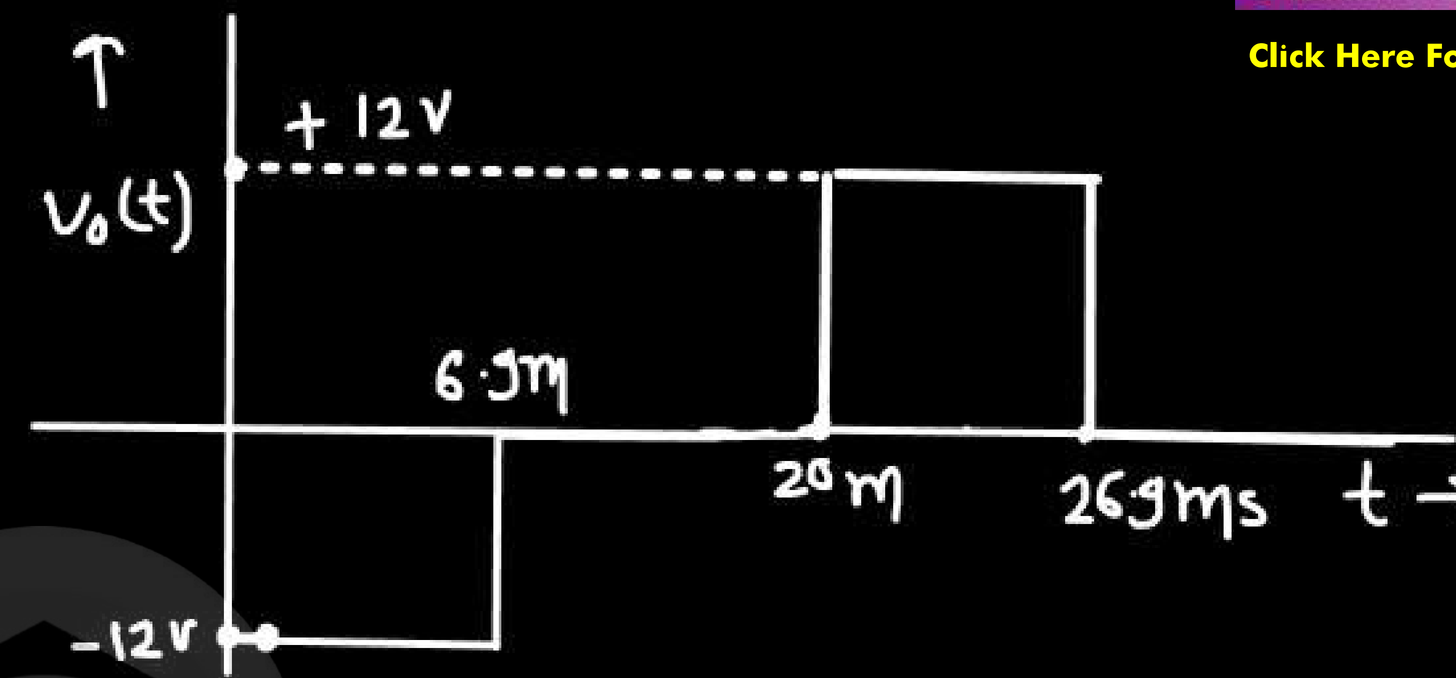


$V_x(20ms^+) = -5V$

$V_x(\infty) = 12V$

O/P saturated ⇒ virtual short NOT valid

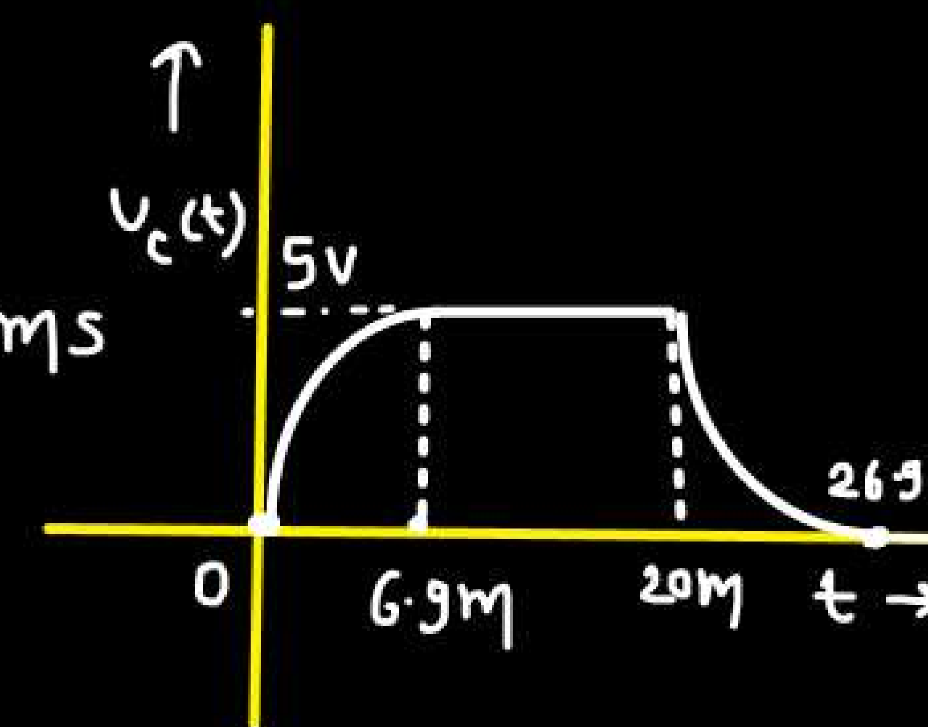




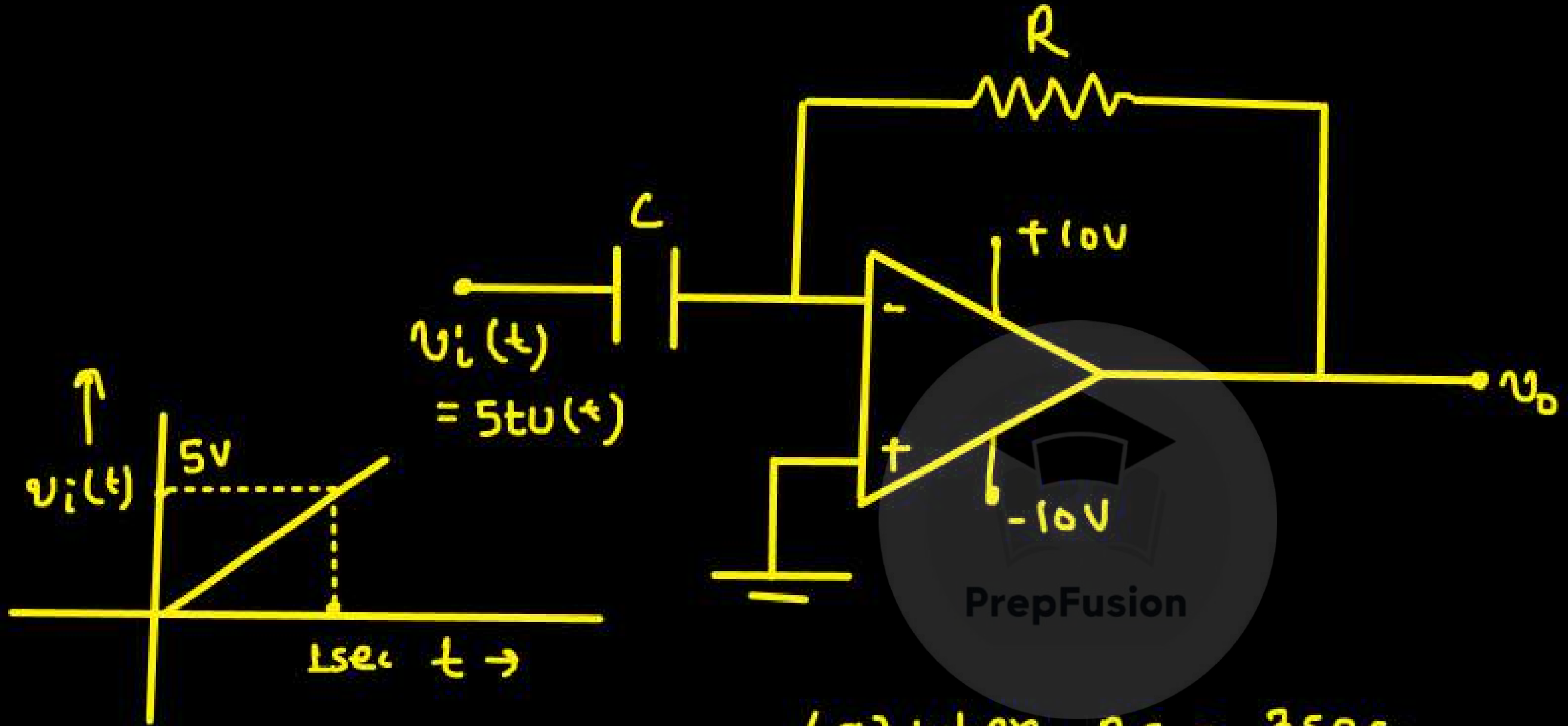
$$v_x(t) = 12 - 17e^{-(t-20ms)/20ms}$$

at $v_x(t_2) = 0$

$$t_2 = 26.9\,msec.$$

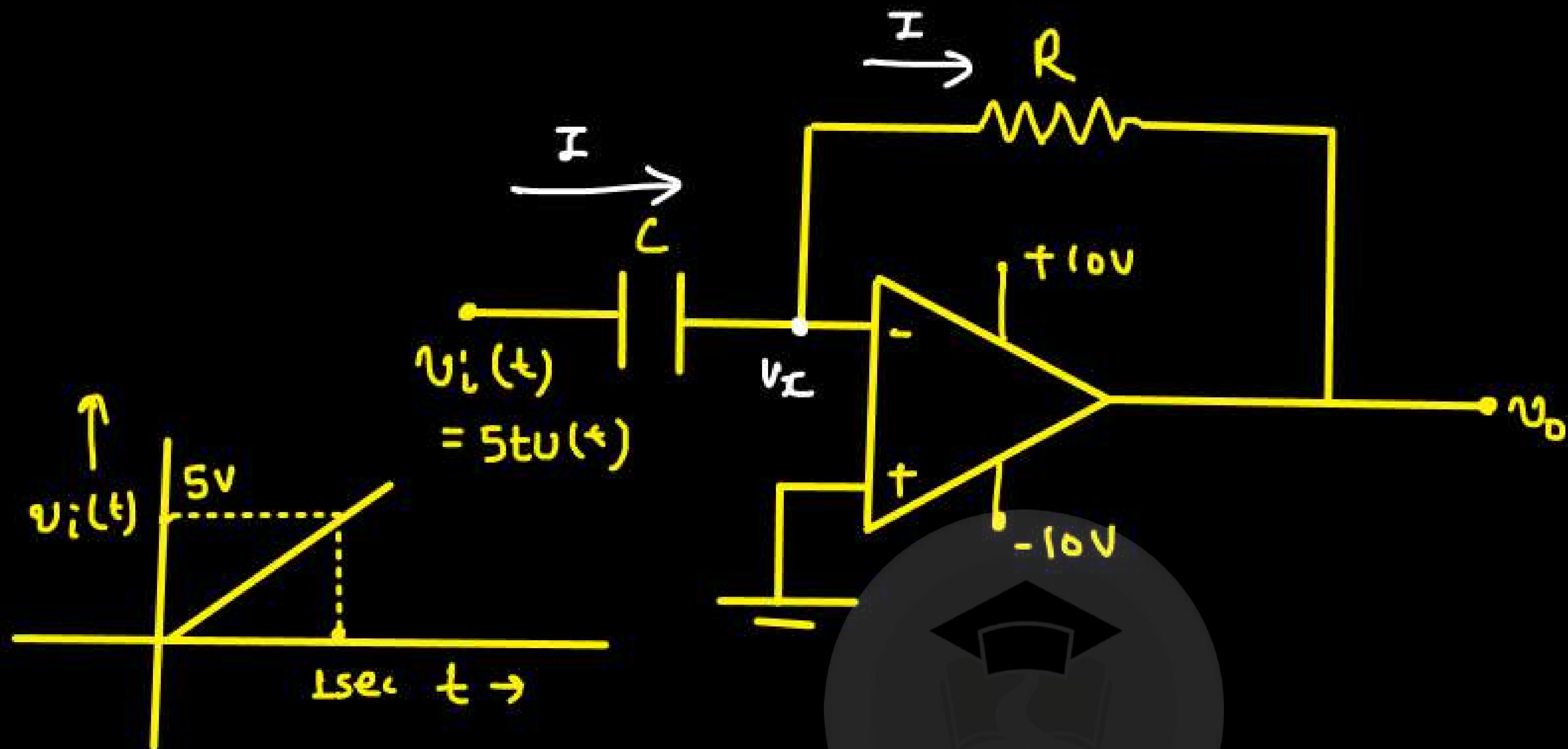


Q. For the given ckt, find steady state o/p voltage.



(a) when $RC = 3$ sec.

(b) when $RC = 1$ sec.



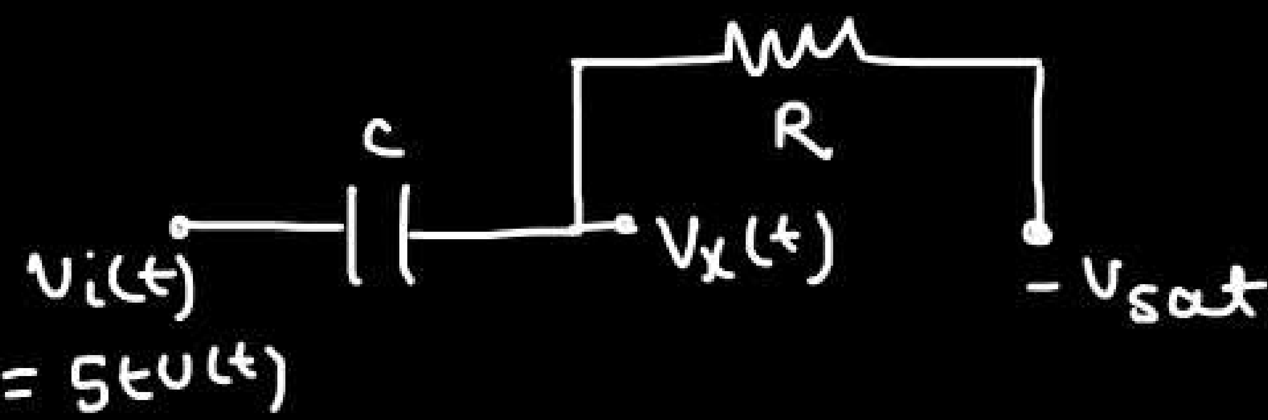
at $t = 0^+$;

$V_x(0^+) = 0^+ = V_-$

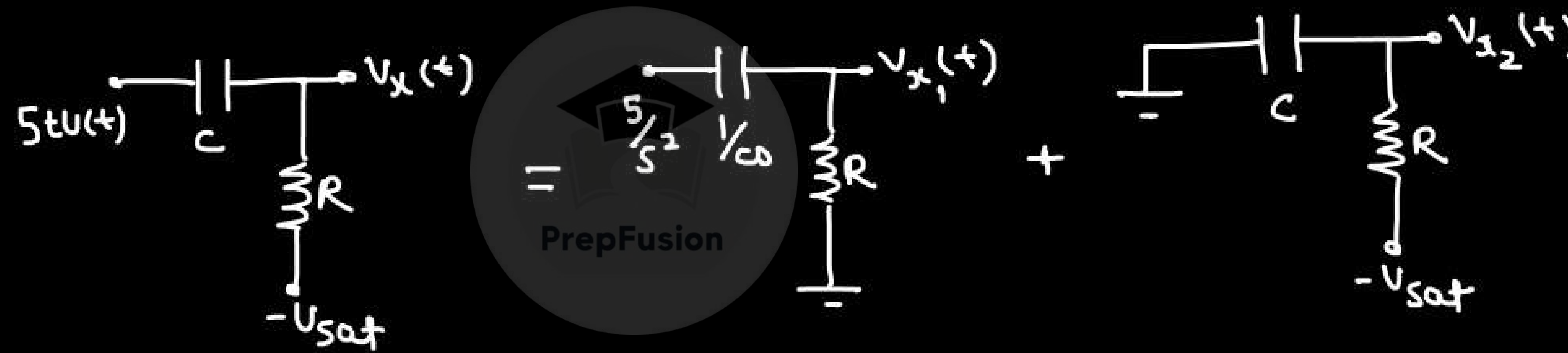
$V_+ = 0$

$\Rightarrow v_o(0^+) = -V_{sat} = -10\,V$

$\Rightarrow$ O/P saturated $\Rightarrow$ Virtual short NOT Valid



|||



$$V_{x_1}(s) = \frac{RCs}{RCs+1} \times \frac{5}{s^2}$$

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

$$V_{x_2}(0^+) = 0V$$

$$V_{x_2}(\infty) = -V_{sat}$$

$$V_{x_1}(s) = \frac{5RC}{s(sRC+1)} = \left[\frac{1}{s} - \frac{RC}{sRC+1}\right] \times 5RC$$

$$V_{x_1}(s) = 5RC\left[\frac{1}{s} - \frac{1}{s+1/RC}\right]$$

$$v_{x_1}(t) = 5RC\left[1 - e^{-t/RC}\right]u(t)$$

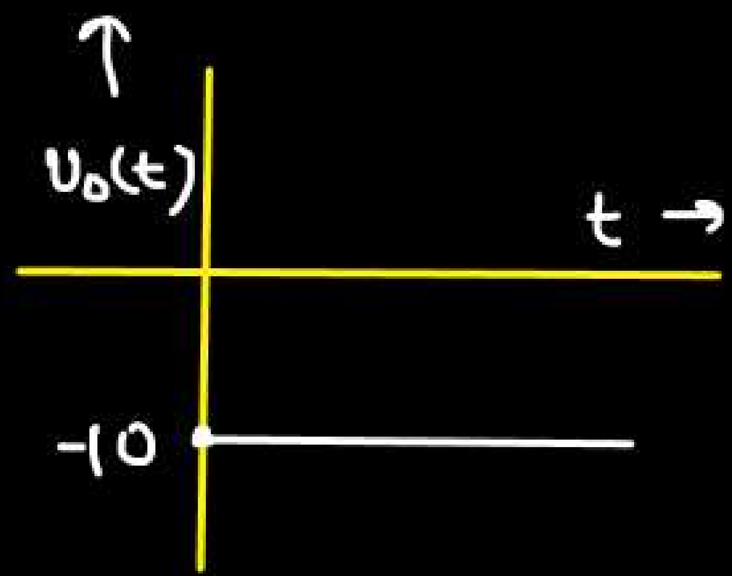
$$v_{x_2}(t) = -V_{sat}\left[1 - e^{-t/RC}\right]u(t)$$

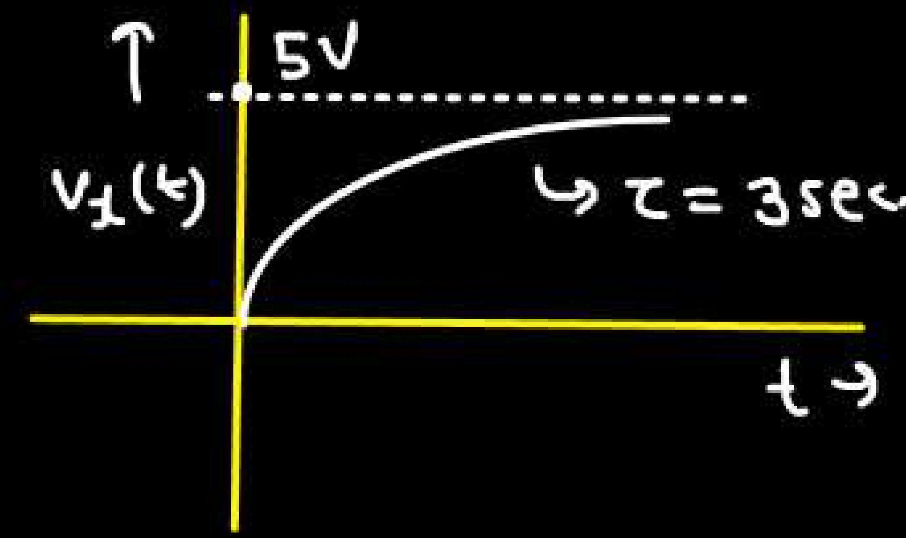
$$\boxed{v_x(t) = \left[5RC - V_{sat}\right]\left[1 - e^{-t/RC}\right]u(t)}$$

(a) $RC = 3\,sec.$

$$v_x(t) = [15 - 10]\left[1 - e^{-t/3}\right]u(t)$$

$$\boxed{v_x(t) = 5\left(1 - e^{-t/3}\right)u(t)} \Rightarrow 0 \longrightarrow 5$$



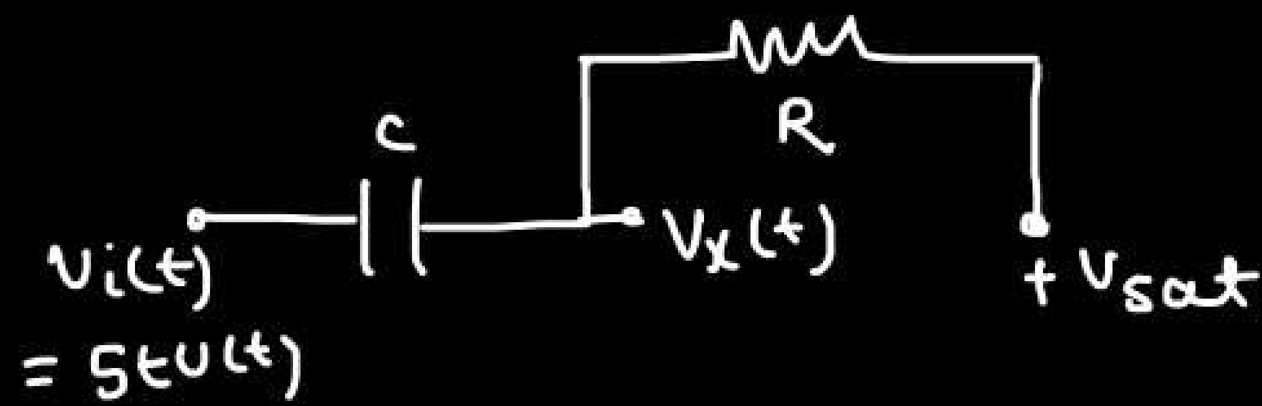


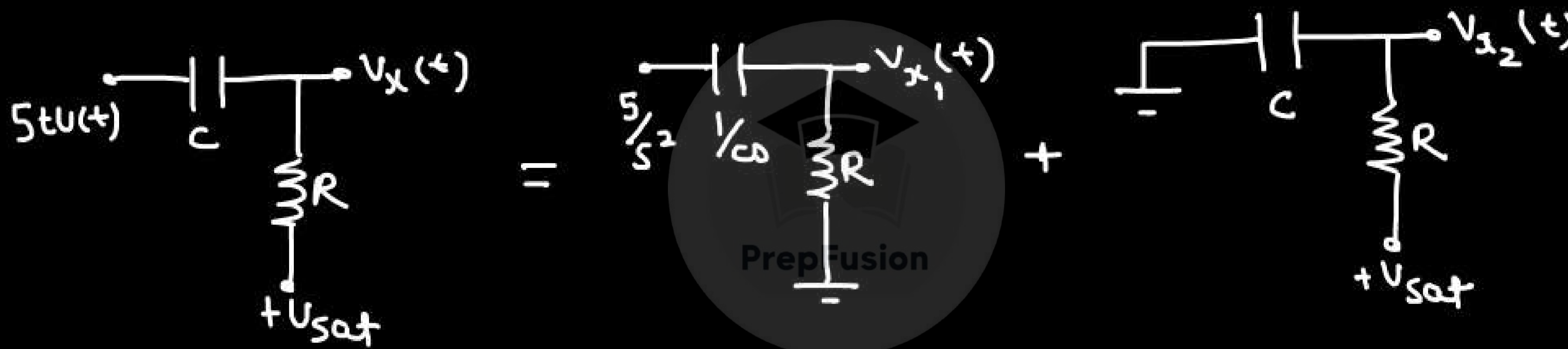
(b) RC = 1 sec.

$$v_x(t) = [5-10]\left[1-e^{-t/1}\right]u(t)$$

$$\boxed{v_x(t) = -5\left(1-e^{-t}\right)u(t)} \Rightarrow 0 \rightarrow -5V$$

⇒ @ $t=0^+$ only o/p will move to $+v_{sat}$.





$$V_{x_1}(s) = \frac{RCs}{RCs+1} \times \frac{5}{s^2}$$

$$V_{x_2}(0^+) = 0V$$

$$V_{x_2}(\infty) = +V_{sat}$$

$$V_x(t) = [5RC + V_{sat}]\left[1 - e^{-t/RC}\right]u(t)$$

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

$$\boxed{v_x(t) = 15\left(1 - e^{-t}\right)u(t)} \Rightarrow 0 \rightarrow 15V$$

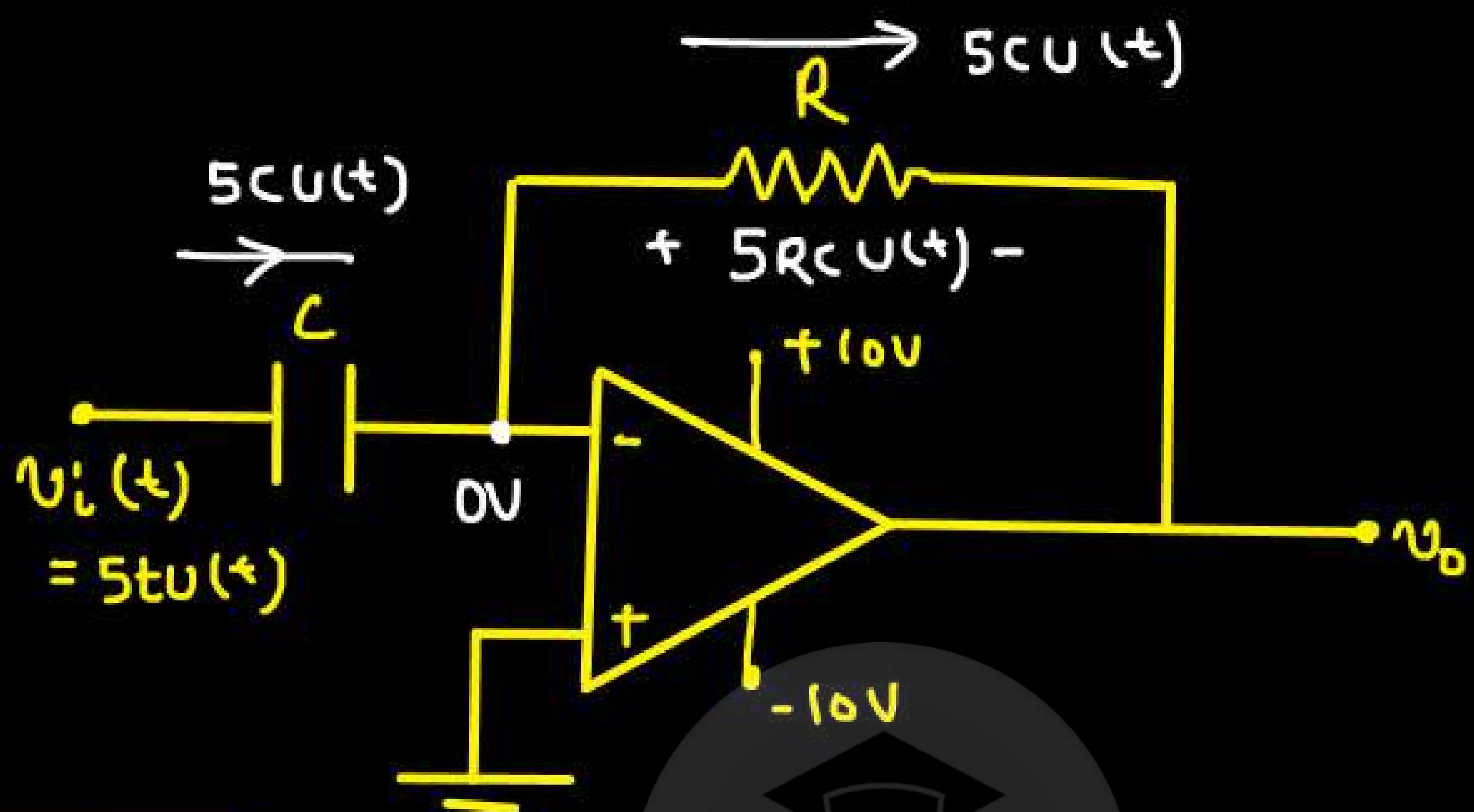
O/P will immediately move to $-V_{sat}$

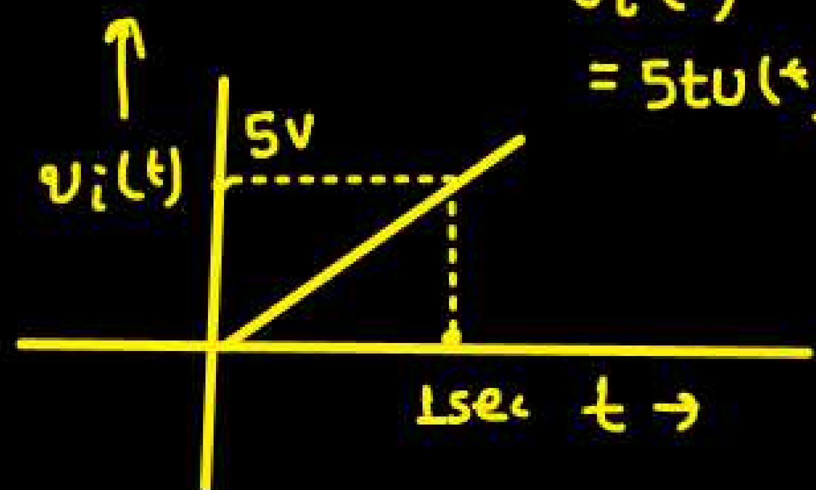
$$0.1V$$

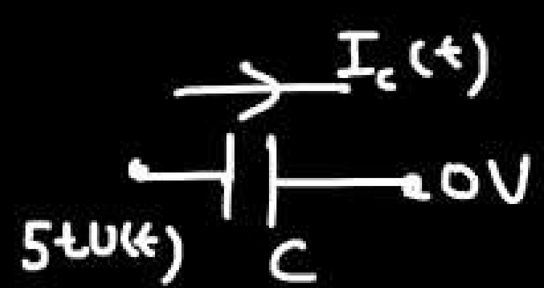
$$v_x = 0$$

$$-0.1V$$

v_x node will be fixed @ $v_x = 0V$





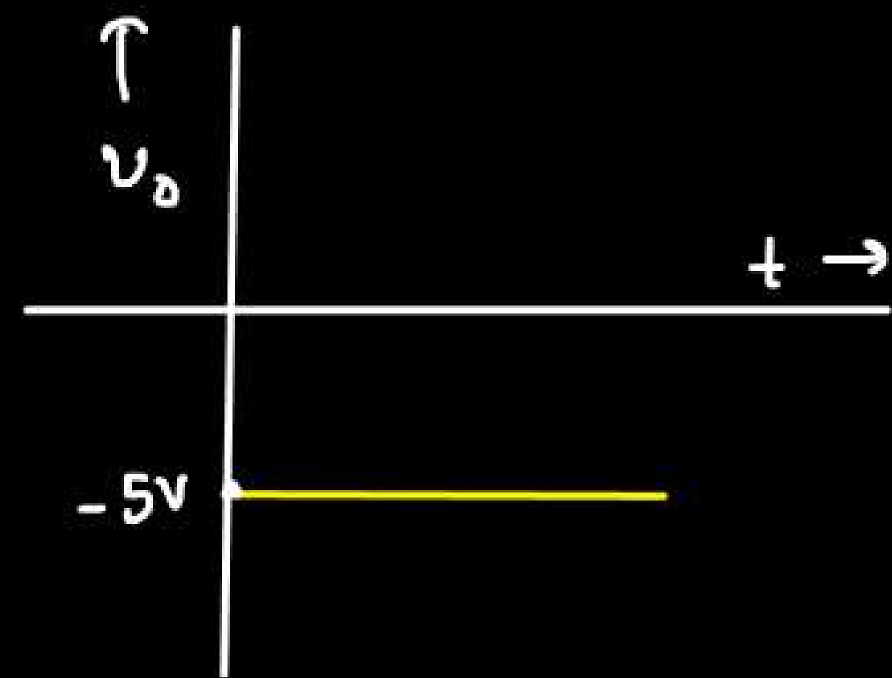


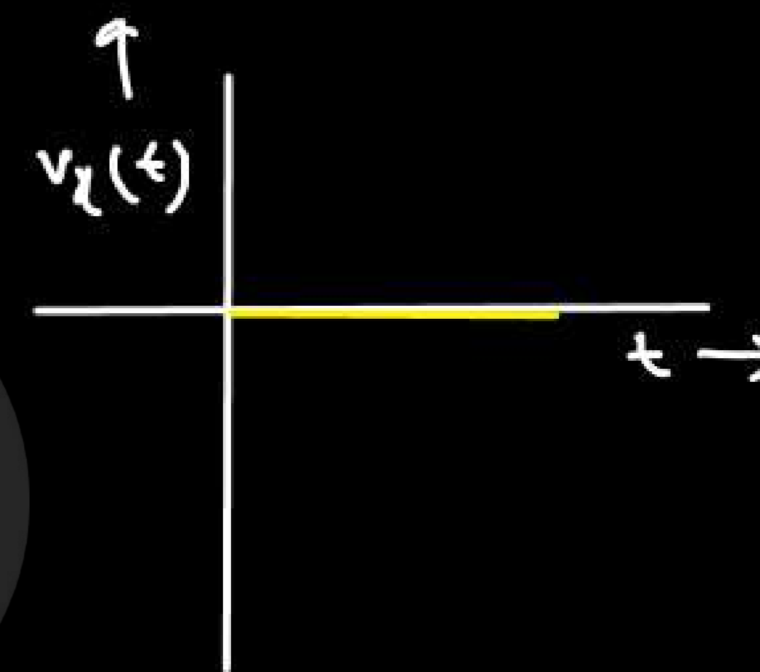
$$I_c(t) = C\frac{dv_c(t)}{dt} = C\frac{d}{dt}5tU(t) = 5C\left[t\,\delta(t) + U(t)\right]$$

$$= 5CU(t)$$

$v_0 = -5RC\,u(t)$

$\boxed{v_0 = -5u(t)}$ $\{RC = 1\ \text{sec.}\}$

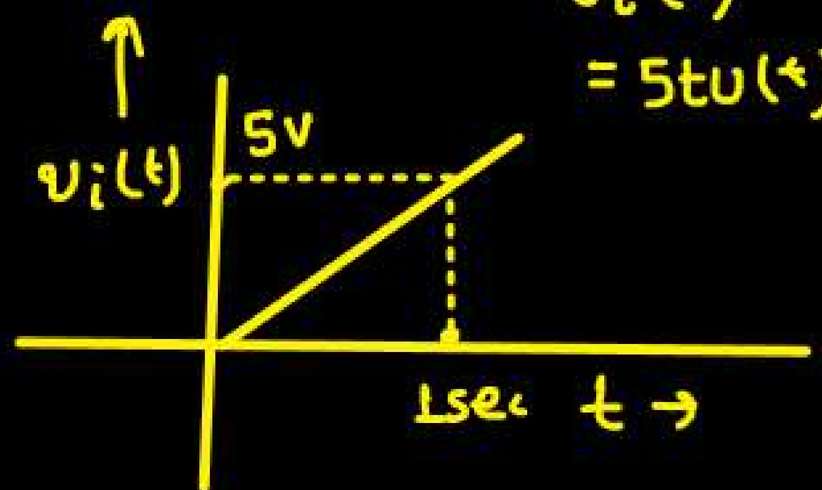


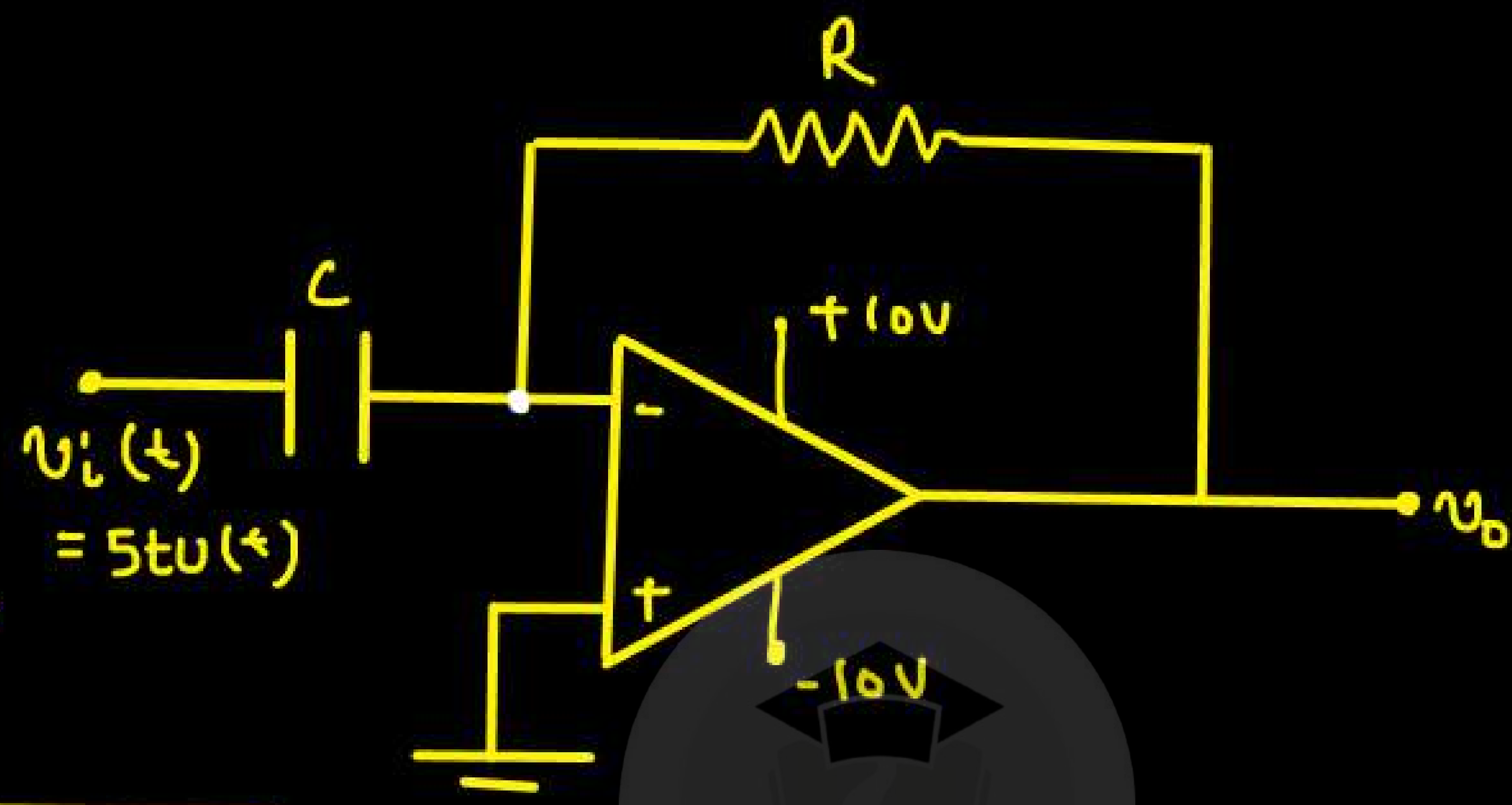


ANS.

(a)	$RC = 3$ sec.	$v_0(t) = -10V$
(b)	$RC = 1$ sec.	$v_0(t) = -5V$

M-II





$$\frac{V_o(s)}{V_i(s)} = -sRC$$

$$v_o(t) = -RC \frac{d}{dt} v_{in}(t)$$

$$v_o(t) = -RC \times 5u(t)$$

$$\boxed{v_o(t) = -5RC\, u(t)}$$

(a) $RC = 3\,\text{sec.}$

$$v_o(t) = -5RC\,u(t)$$
$$= -5(3)\,u(t)$$
$$= -15u(t) \times \quad \{-V_{sat} = -10\}$$

$$\boxed{v_o(t) = -10u(t)}$$

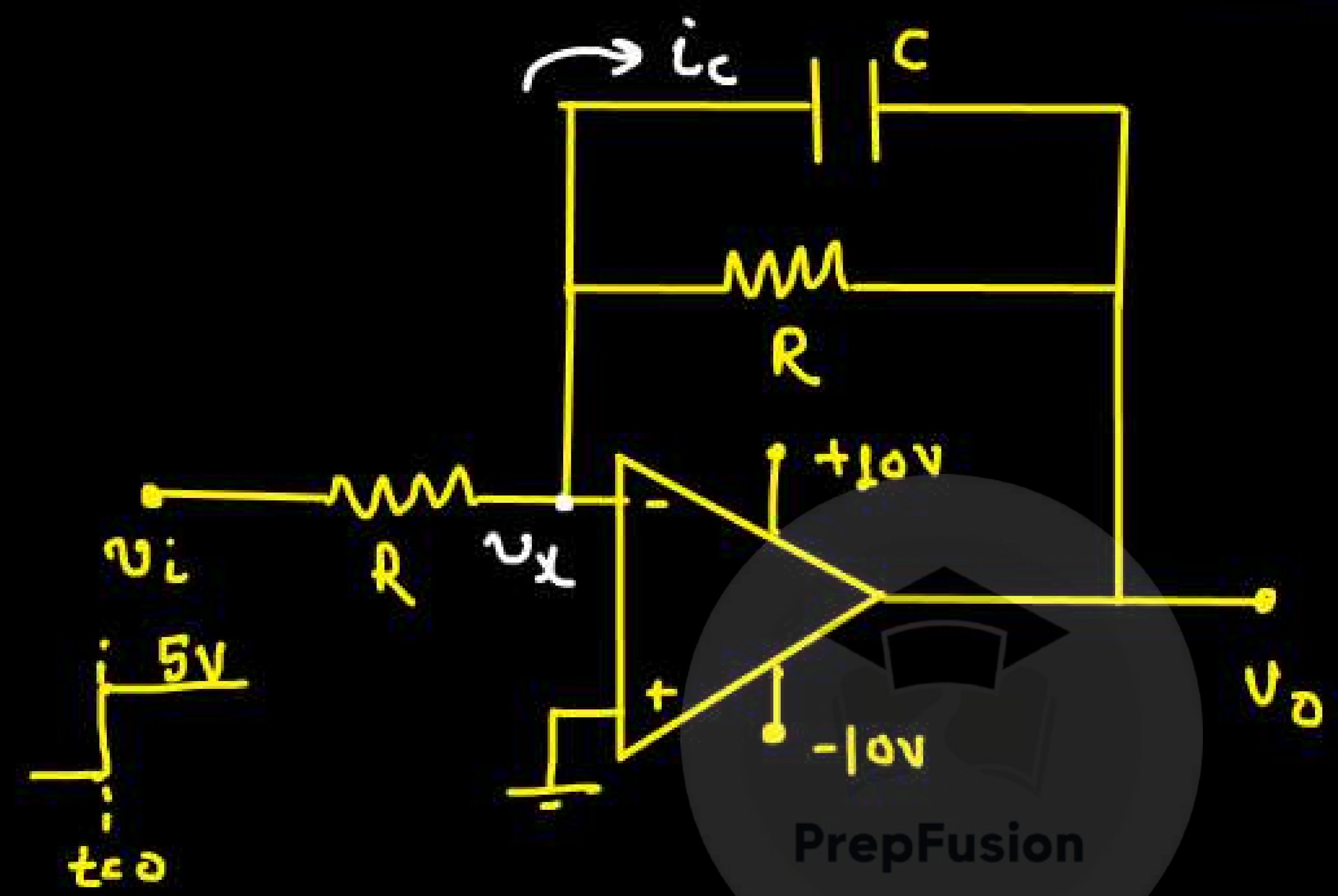
(b) $RC = 1\,\text{sec.}$

$$v_o(t) = -5RC\,u(t)$$

$$\boxed{v_o(t) = -5u(t)}$$

Assignment - 15 (Fusion_Special)

Q.



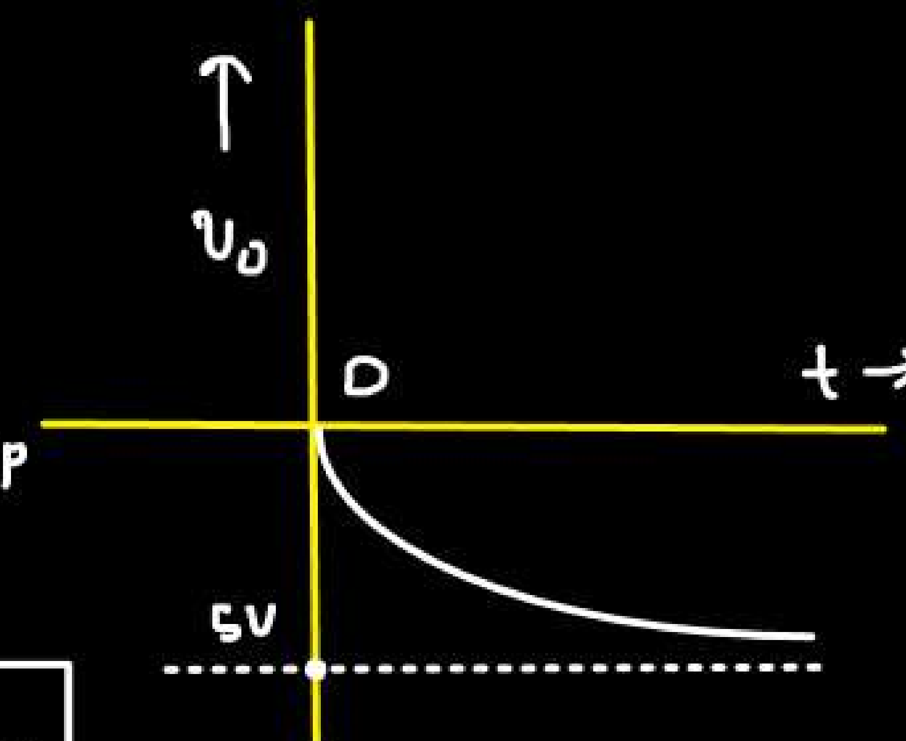
$\boxed{v_x = 0V}$

Draw v_o waveform.

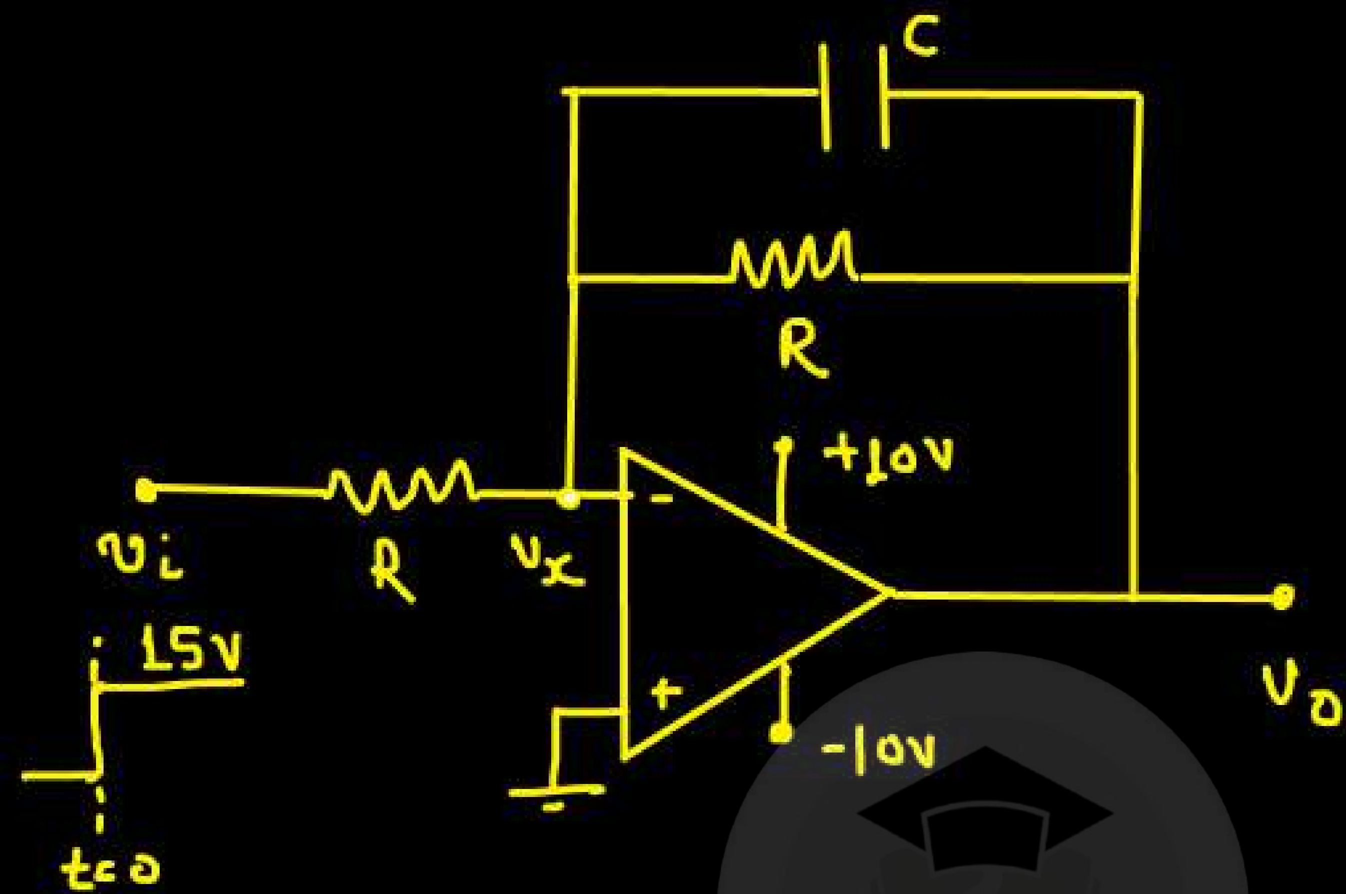
$\rightarrow$ $v_o(t=0^+) = 0$; $i_c(0^+) = 5/R$, $i_c(\infty) = 0 \text{ Amp}$

$v_o(t=\infty) = -5V$ [NOT saturated]

$\boxed{v_o(t) = -5\left[1 - e^{-t/RC}\right]u(t)}$, $\boxed{i_c(t) = \frac{5}{R} e^{-t/RC}\, u(t)}$



Q.2



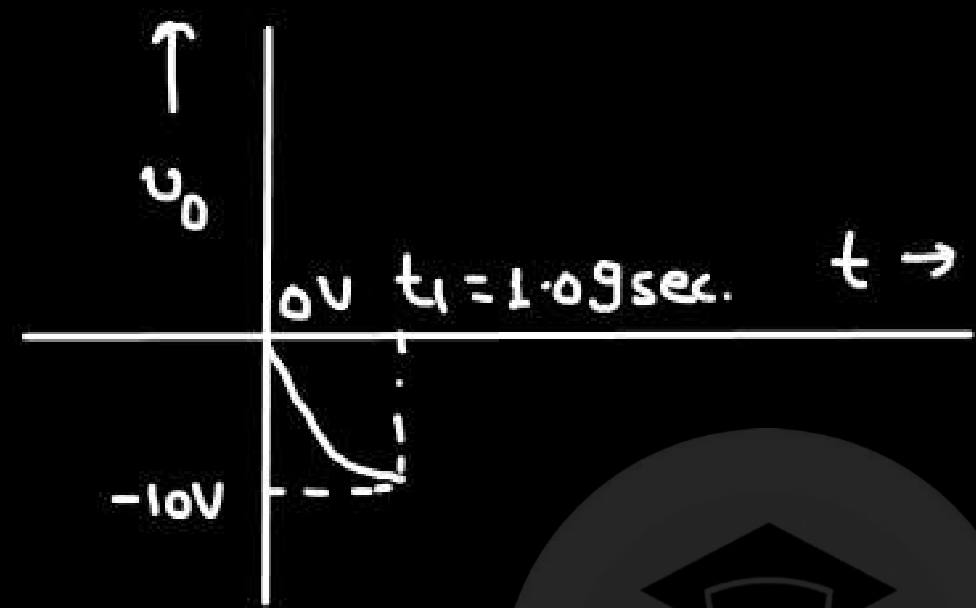
Take $RC = 1$ sec.

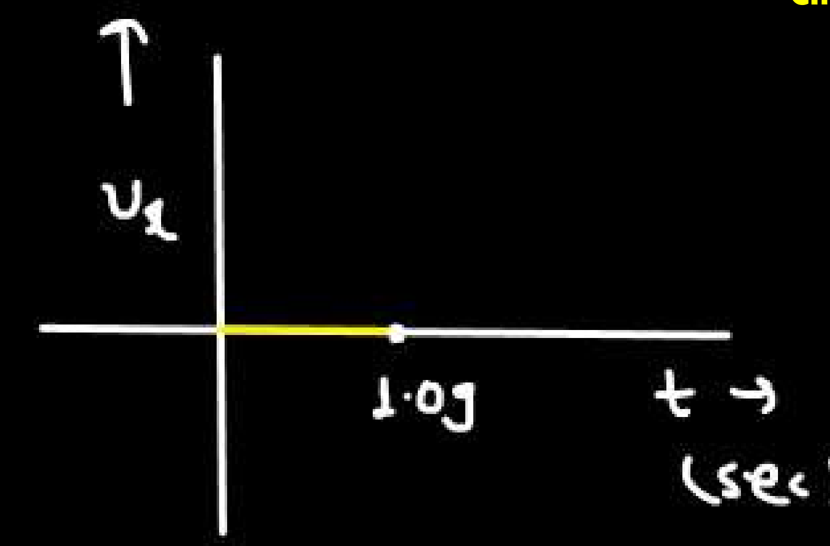
The value of v_x @ $t = 2$ sec.

(a) 0 V (b) 1 V (c) −10 V (d) 1.5 V

→ $v_o(0^+) = 0V$, $v_o(\infty) = -1.5V$

$$v_0(t) = -15\left(1 - e^{-t/RC}\right)u(t)$$





@ $t = t_1$; $v_0(t_1) = -10 \Rightarrow$ o/p saturated

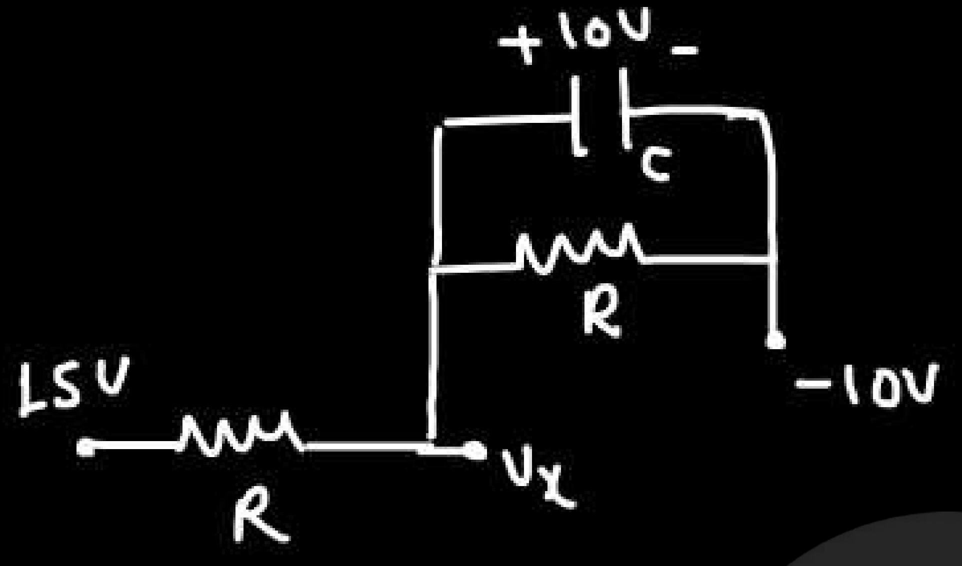
$\Downarrow$

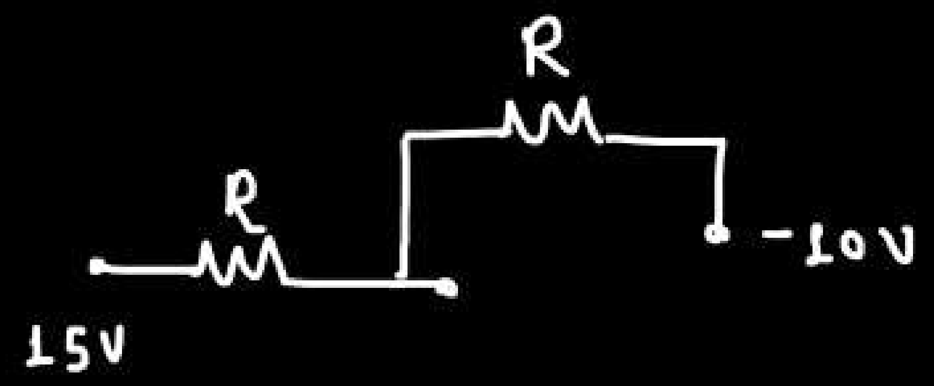
After $t > t_1 \Rightarrow$ virtual short NOT valid

$$-10 = -15\left(1 - e^{-t_1/1}\right)$$

$$\boxed{t_1 = 1.09 \text{ sec.}}$$

For $t > 1.09$ sec $\Rightarrow$ virtual short NOT valid





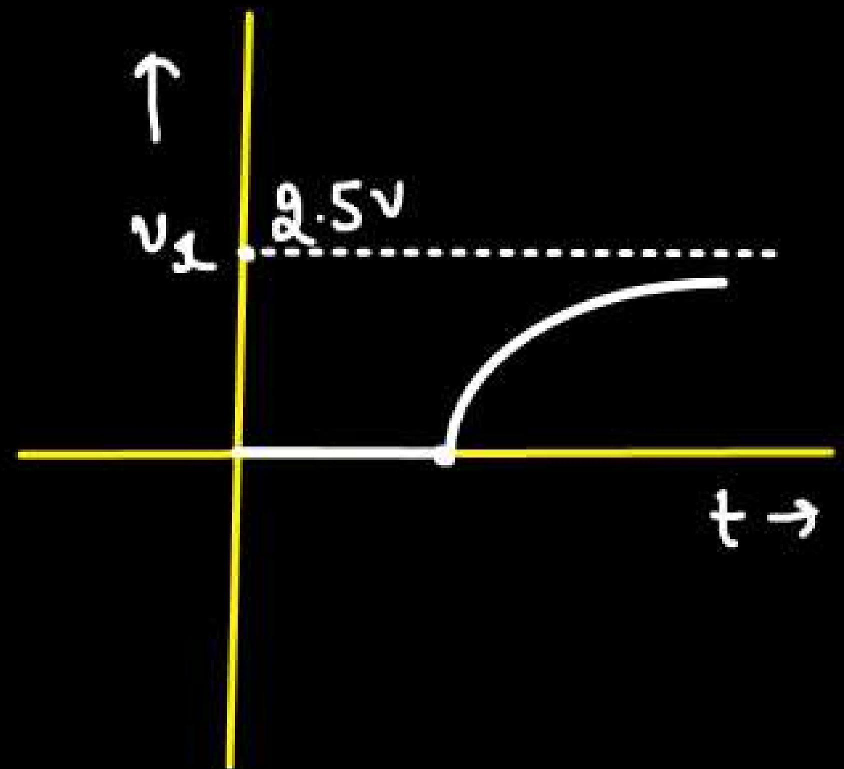
$$v_x(t = 1.09^+) = 0$$

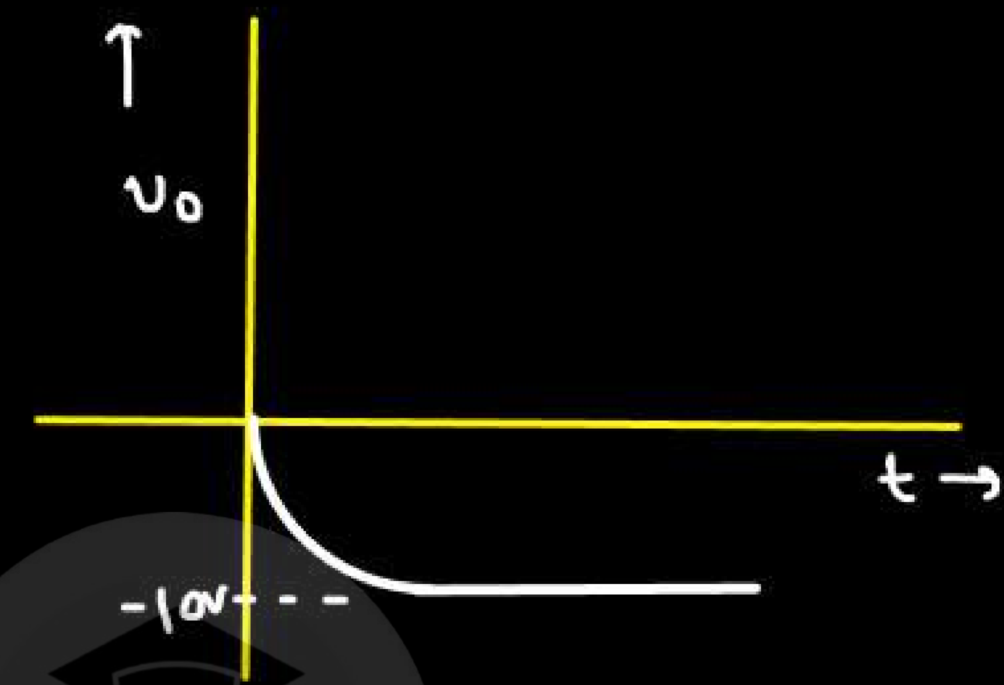
$$v_x(\infty) = 2.5V$$

$$v_x(t) = 2.5\left(1 - e^{-(t-1.09)/1sec}\right)$$

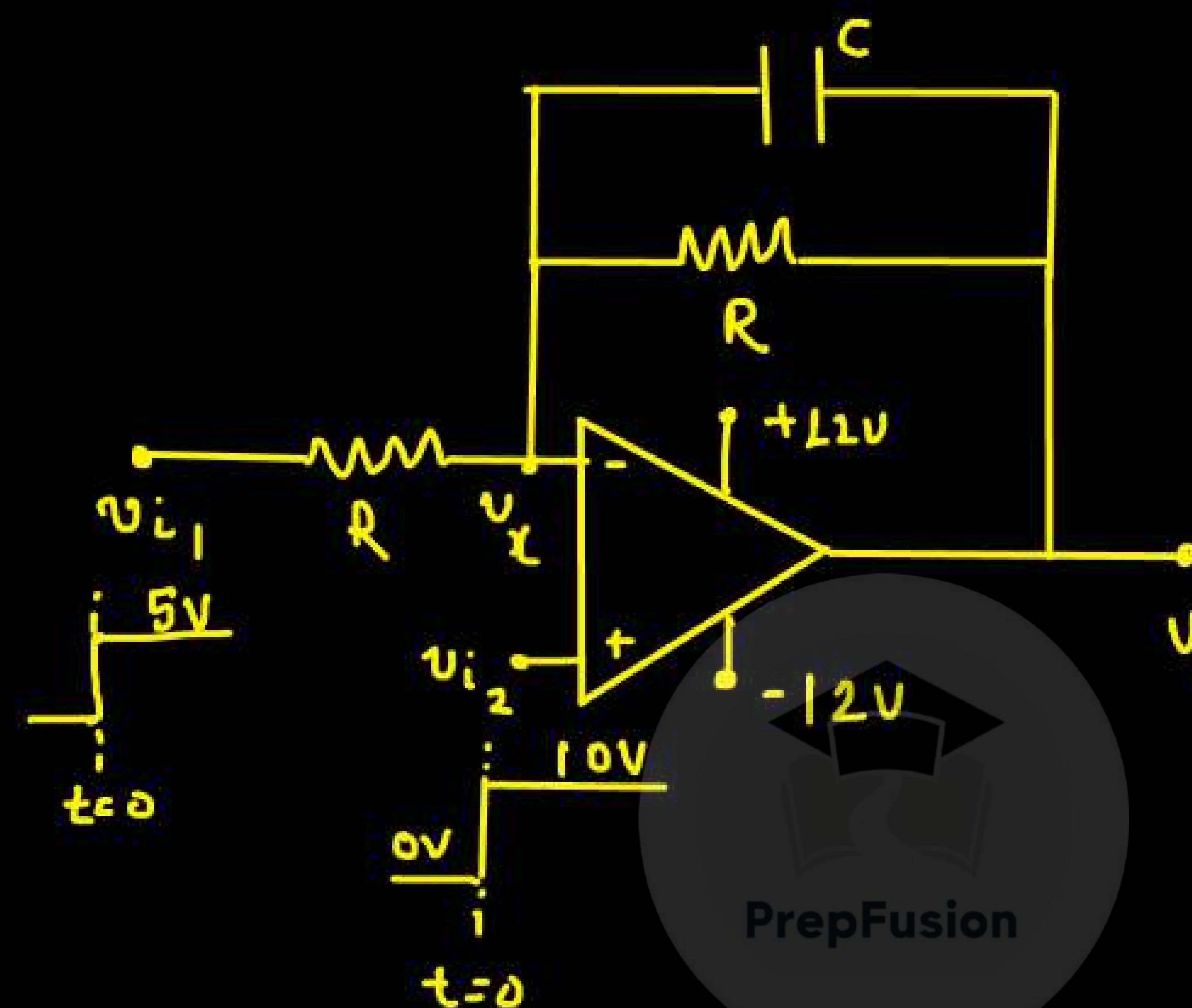
$$v_x(2sec.) = 2.5\left(1 - e^{-(2-1.09)/1sec}\right)$$

$$\boxed{v_x(2sec.) \approx 1.48V}$$


v_1
2.5V
t →


v_0
-10V
t →

Q. 3



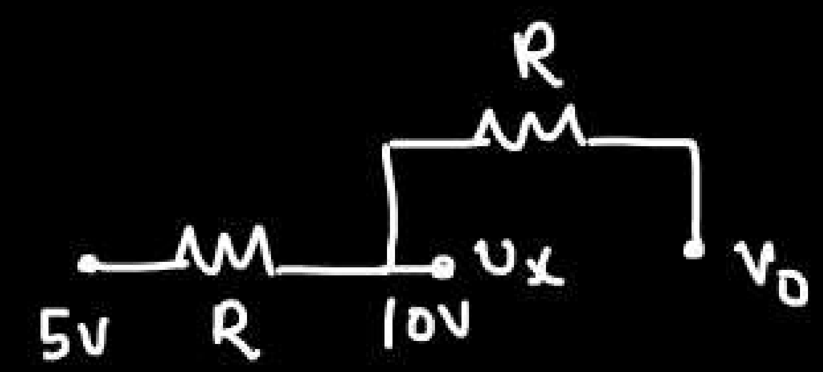
RC = 1 sec.

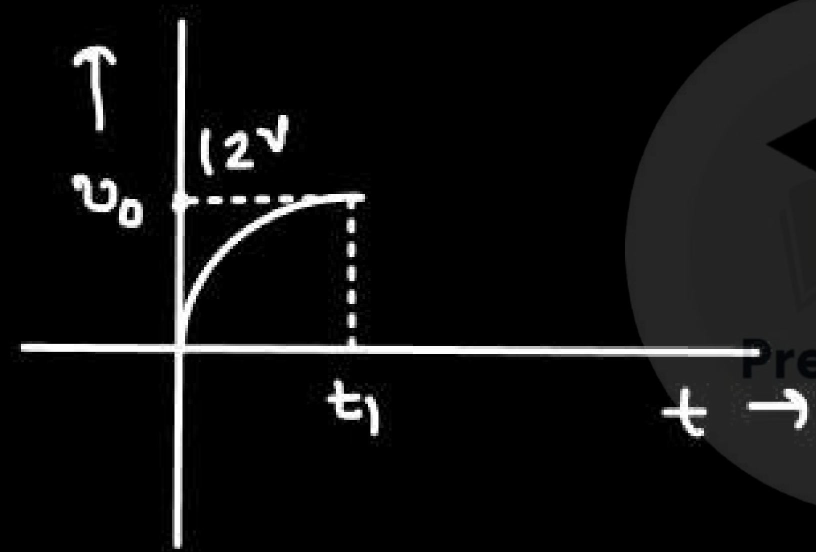
Draw v_x and v_0 waveforms.

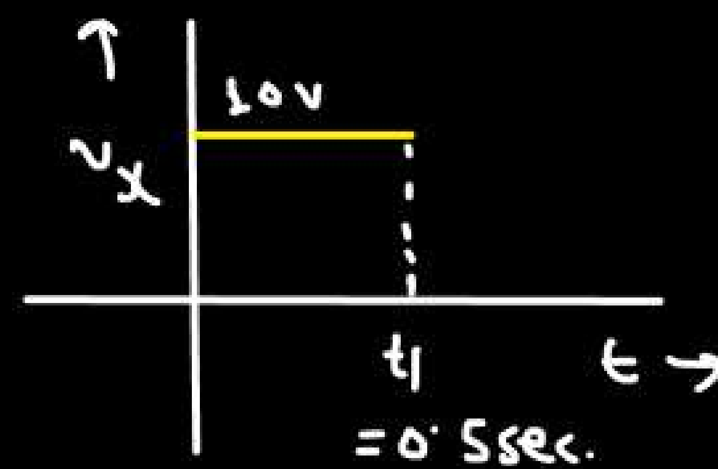
→ $v_0(0^+) = 10V$

$v_0(\infty) = 15V$

$v_0(t) = \left[15 - 5e^{-t/RC}\right]u(t)$





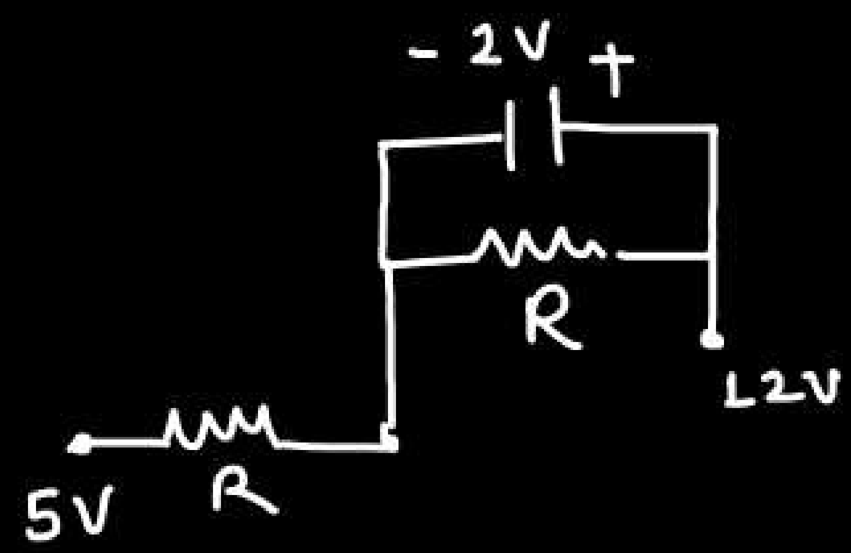


@ $t = t_1 \Rightarrow$ o/p saturates @ 12V

$12 = 15 - 5e^{-t_1/1}$

$$\boxed{t_1 = 0.5\,\text{sec.}}$$

$t > 0.5 \text{ sec.}$

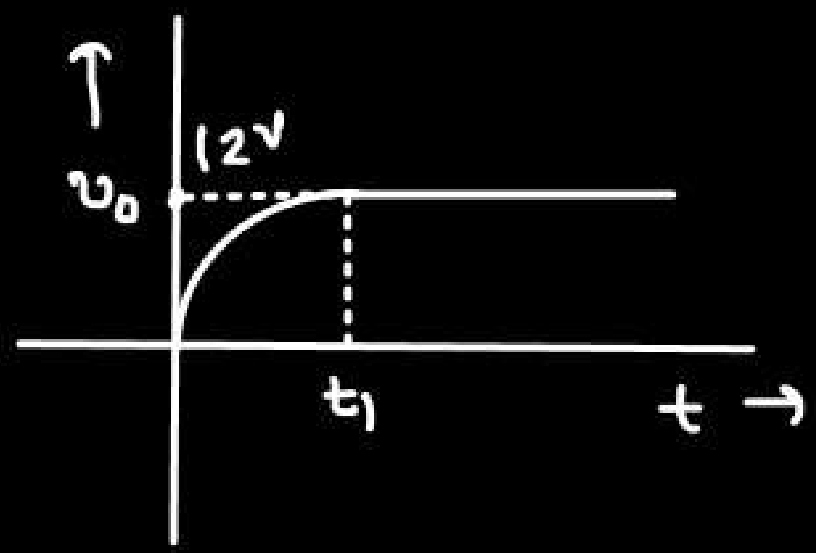


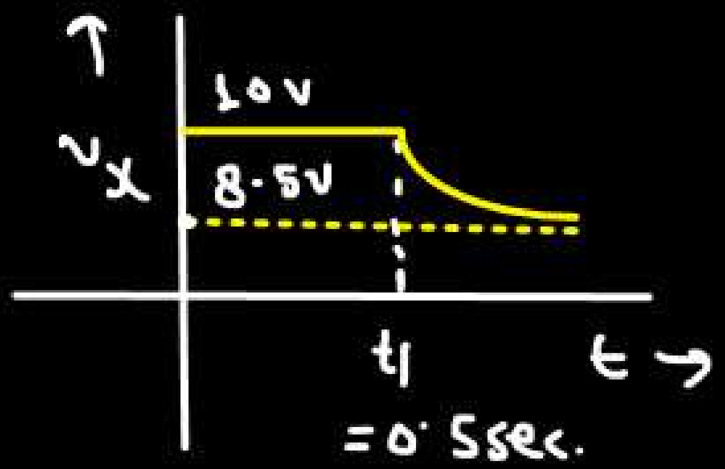
$$v_x(t = 0.5^+) = 10V$$

$$v_x(\infty) = \frac{12R + 5R}{2R} = 8.5V$$

$$v_x(t) = \left[8.5 + 1.5\, e^{-(t-0.5)/1}\right] u(t - 0.5)$$

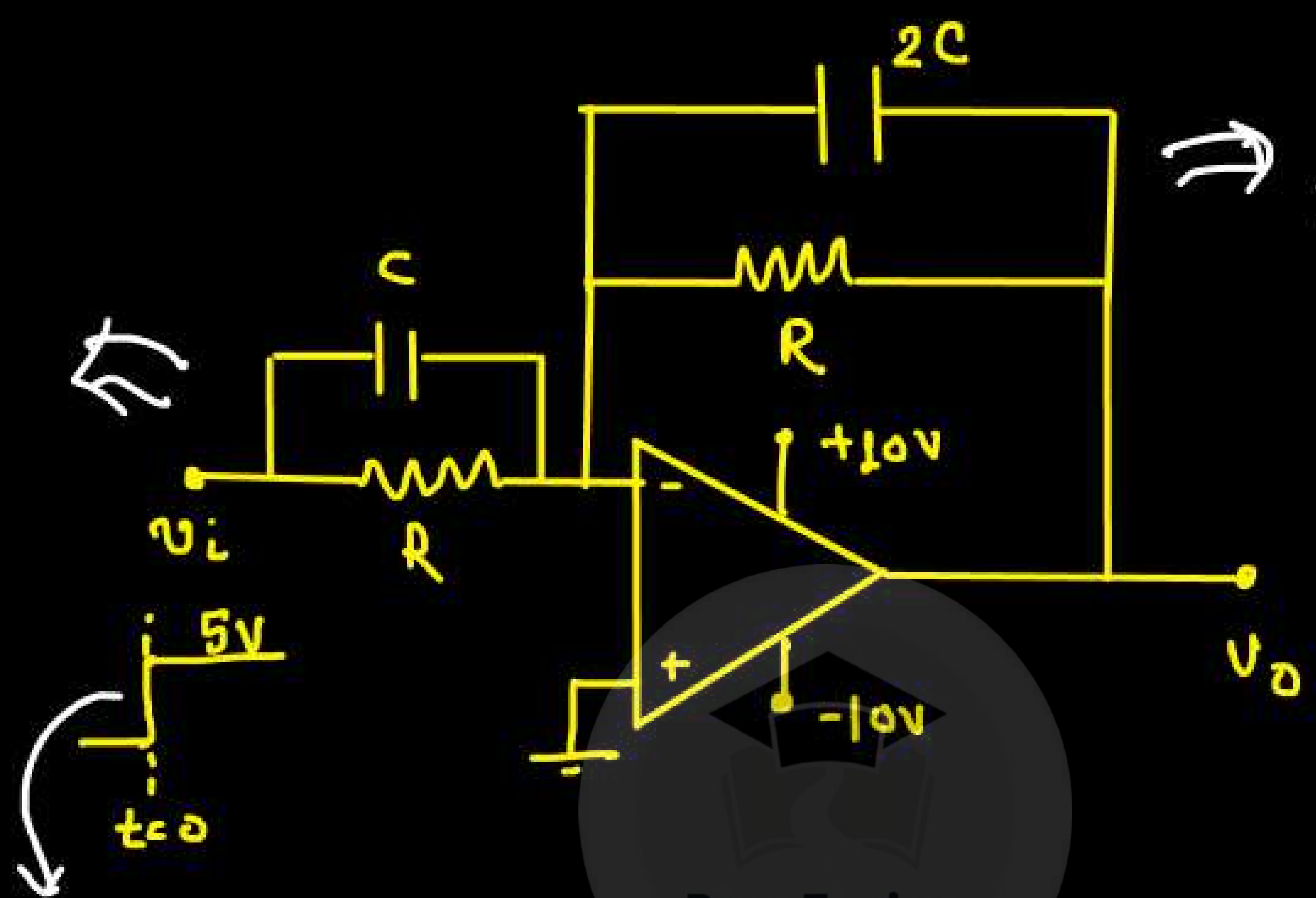
$$v_0(t) = 12\, u(t - 0.5)$$


12V
v_0
t_1
t


10V
v_x
8.5V
t_1
= 0.5sec.
t

Q.

$\frac{R}{RCs+1}$



$\Rightarrow \frac{R}{2RCs+1}$

$\omega = \infty$

Draw V_o waveform.

$$\boxed{\frac{V_o(s)}{V_i(s)} = -\frac{(RCs+1)}{2RCs+1}}$$

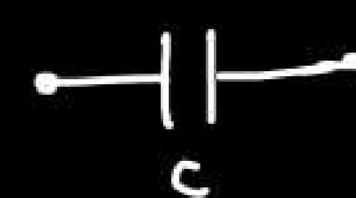
$$\boxed{\begin{array}{c}\text{First order} \\ \tau = 2RC\end{array}}$$

→ @ $t=0^+$ $\Rightarrow$ $\omega = \infty$ $\Rightarrow$

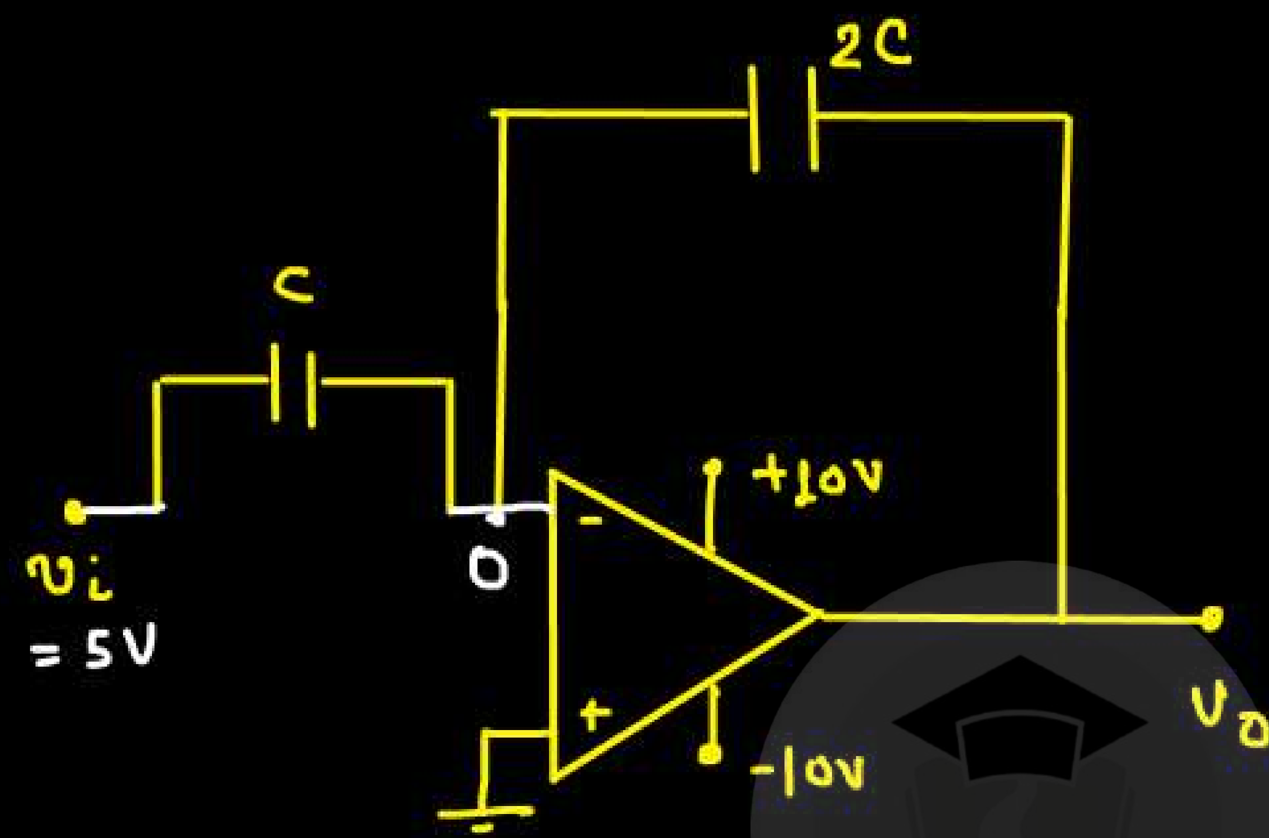
R → Finite impedance

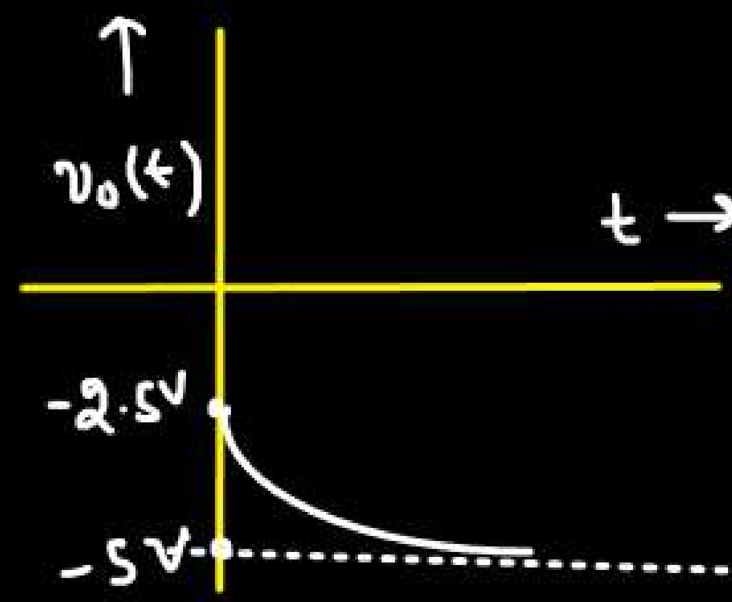
C → low impedance

$\Rightarrow$



at $t=0^+$:-





$$\left.\begin{aligned}&[0-v_i]Cs + [0-V_0]2Cs = 0\\&\frac{v_0}{v_i} = -\frac{1}{2}\end{aligned}\right\} @\ t=0^+$$

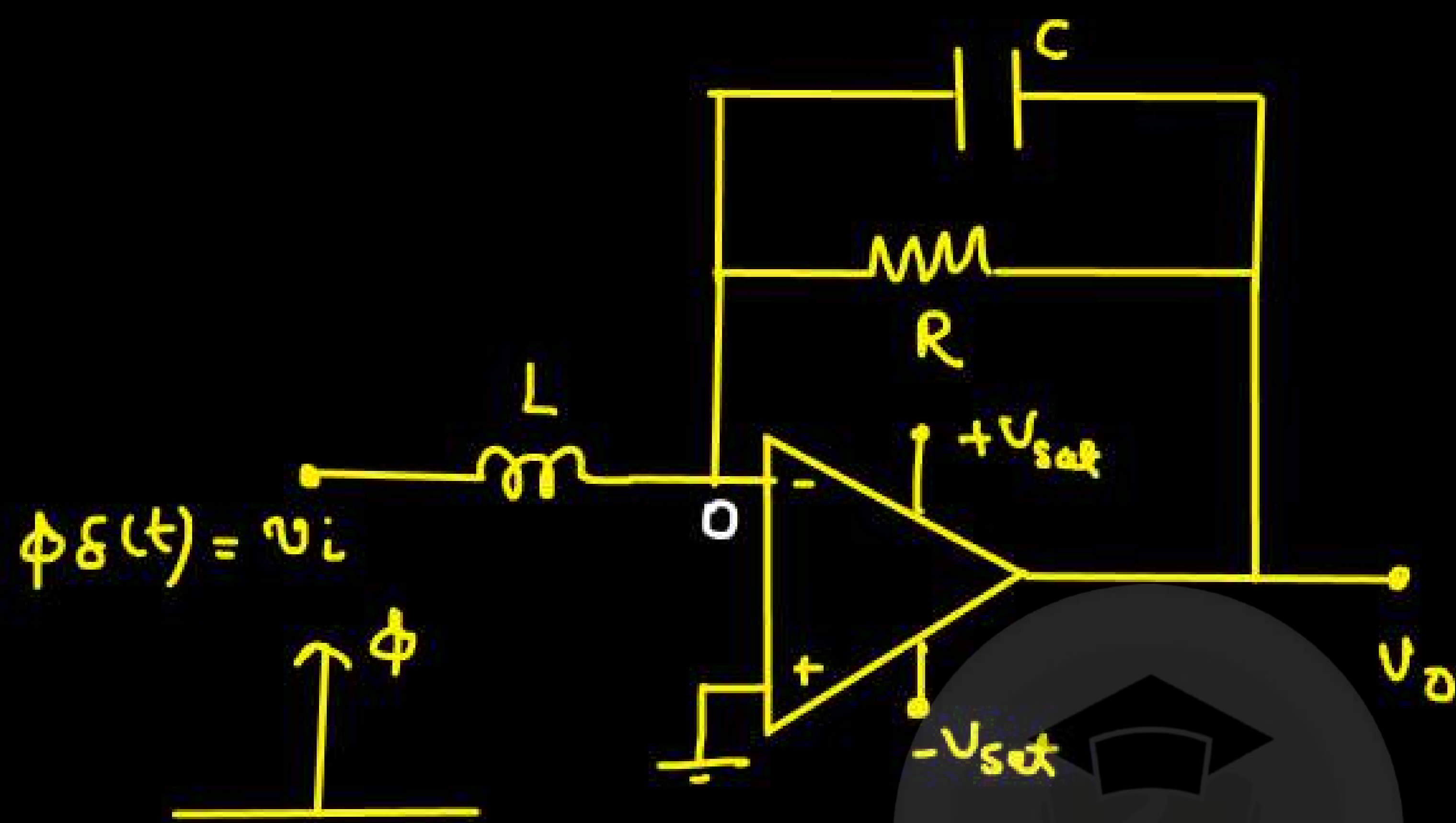
$$\boxed{v_0(t=0^+) = -2.5V}$$

at $t=\infty$

$$\boxed{v_0(\infty) = -5V}$$

$$\boxed{v_0(t) = -5 + 2.5e^{-t/2RC}}$$

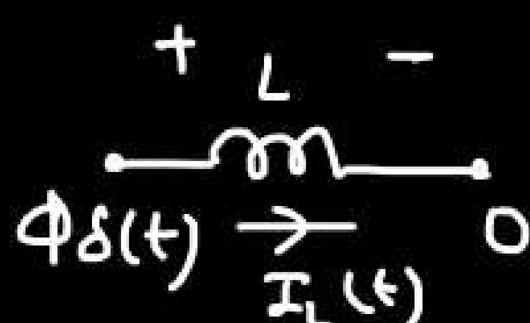
Q.



Taking V_{sat} to be very High.

→ at $t = 0^+$ ⇒ Negative f/b "nt" ⇒ virtual short is valid

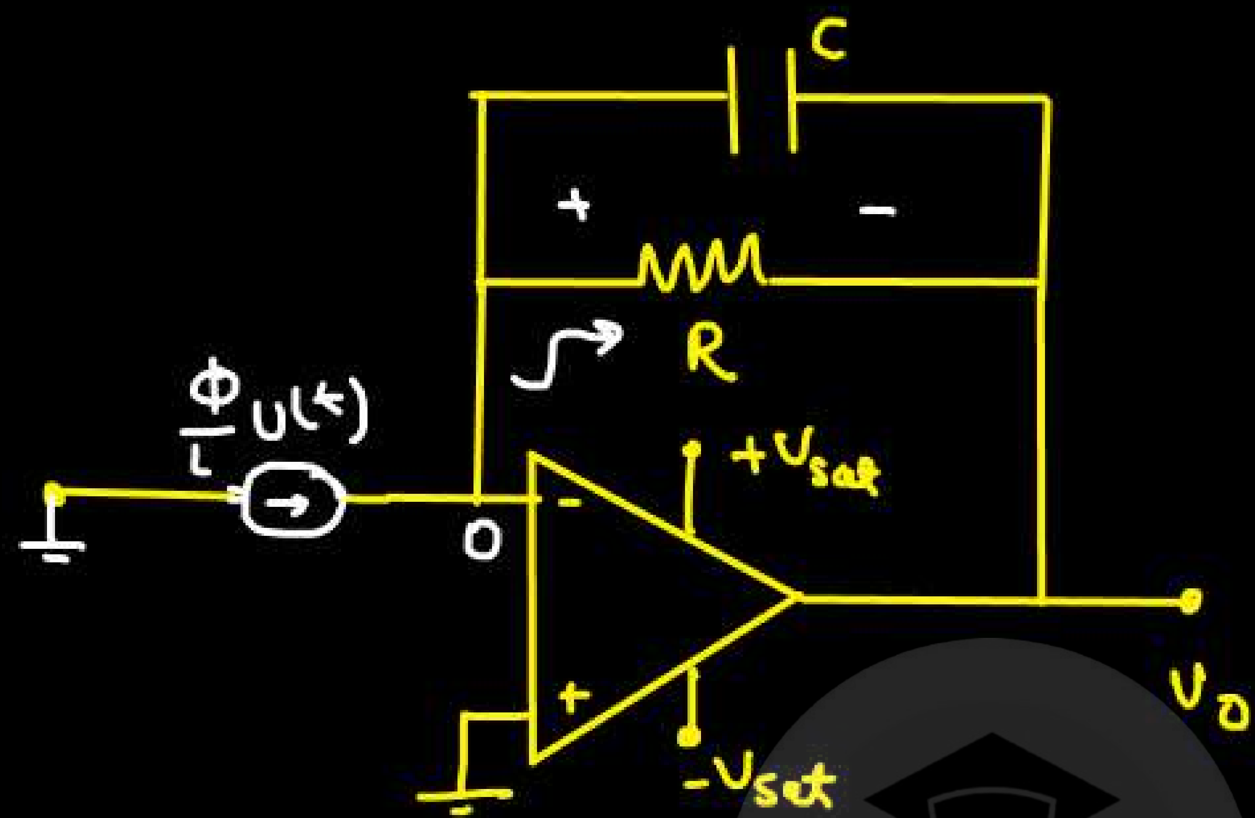
at $t = 0^+$



$$I_L(t) = \frac{1}{L}\int_{0^-}^{t} V(t)\cdot dt = \frac{1}{L}\int_{0^-}^{t} \phi\delta(t)\cdot dt$$

$I_L(0^-) = 0\ \text{Amp}$ $\quad \boxed{I_L(0^+) = 0\ \text{Amp}}$ ✗ $= \phi/L$

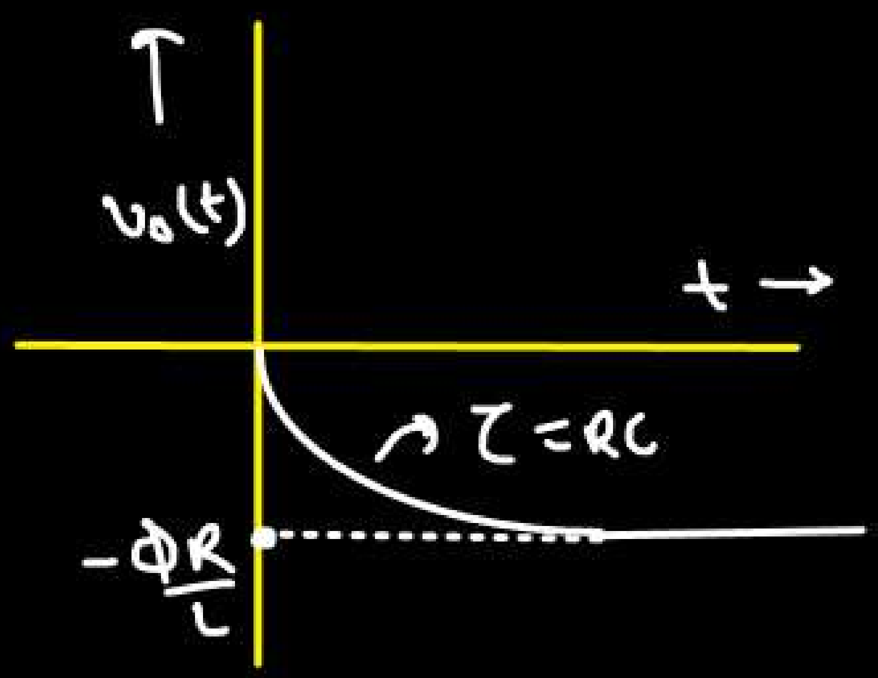
$$\boxed{I_L(t) = \frac{\phi}{L}u(t)}$$ ✓



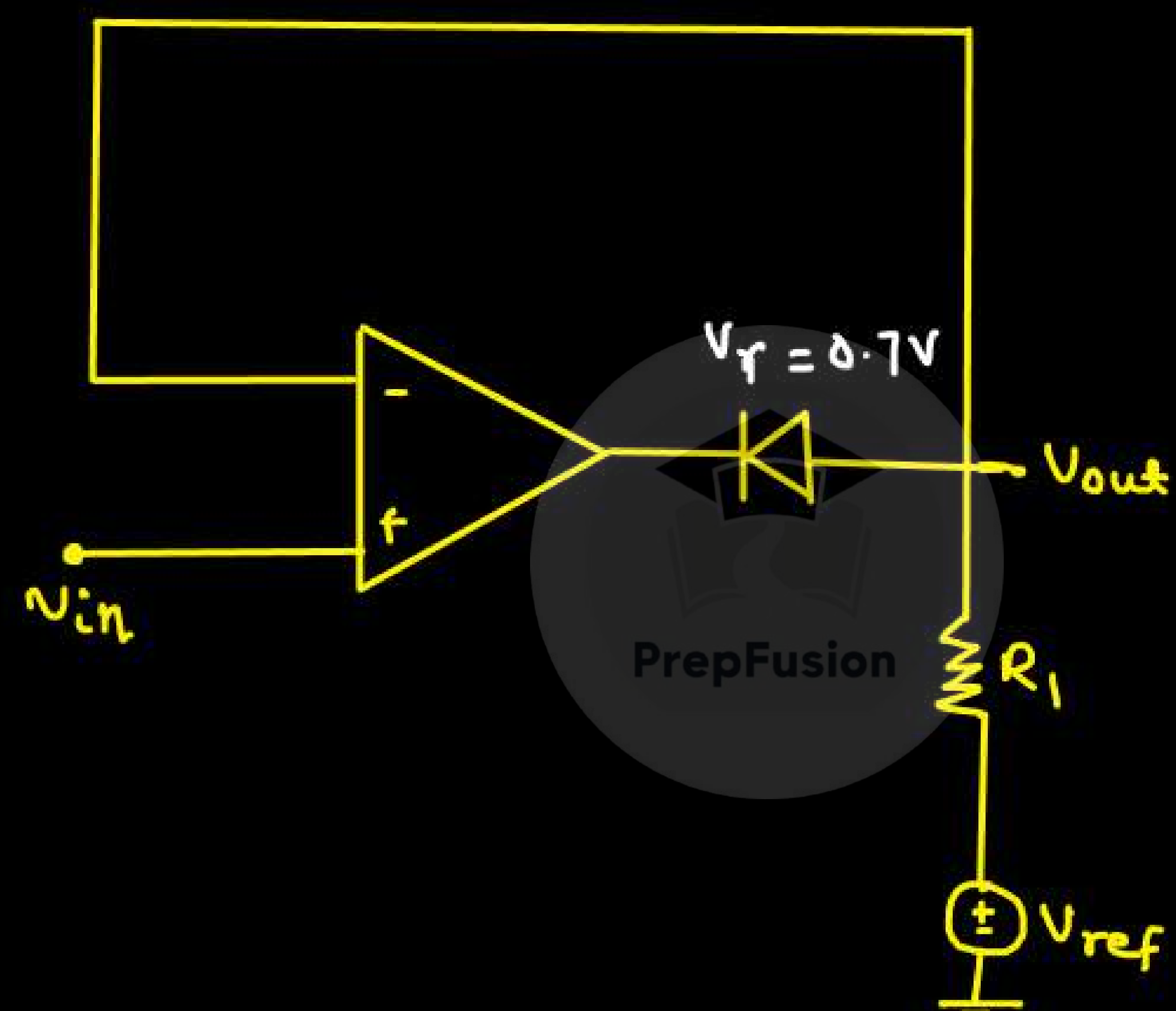
$$v_o(0^+) = 0\,V$$

$$v_o(\infty) = -\frac{\Phi}{L} R$$

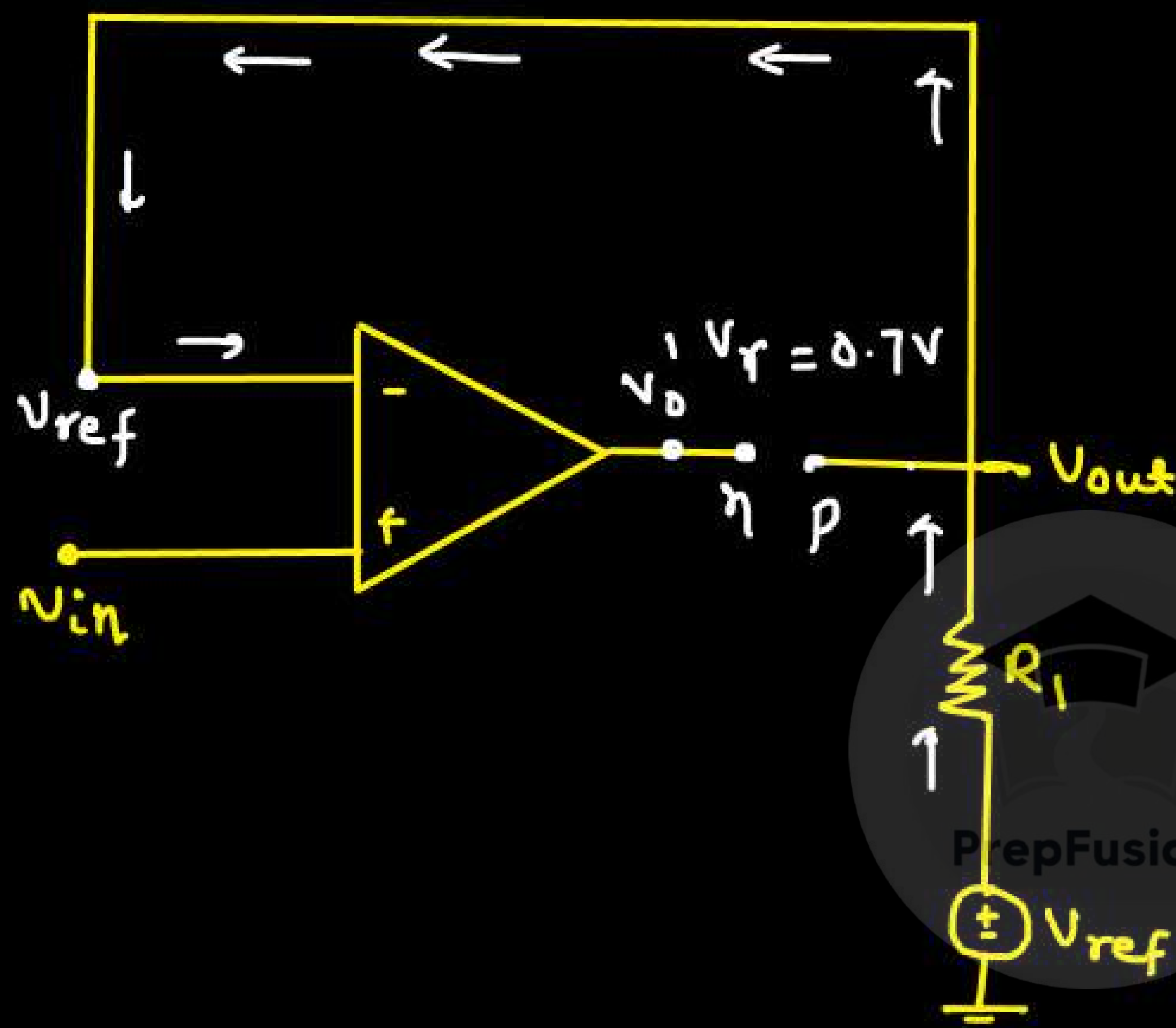
$$v_o(t) = -\frac{\Phi R}{L}\left(1 - e^{-t/RC}\right) u(t)$$



Active Clipper Circuit:-



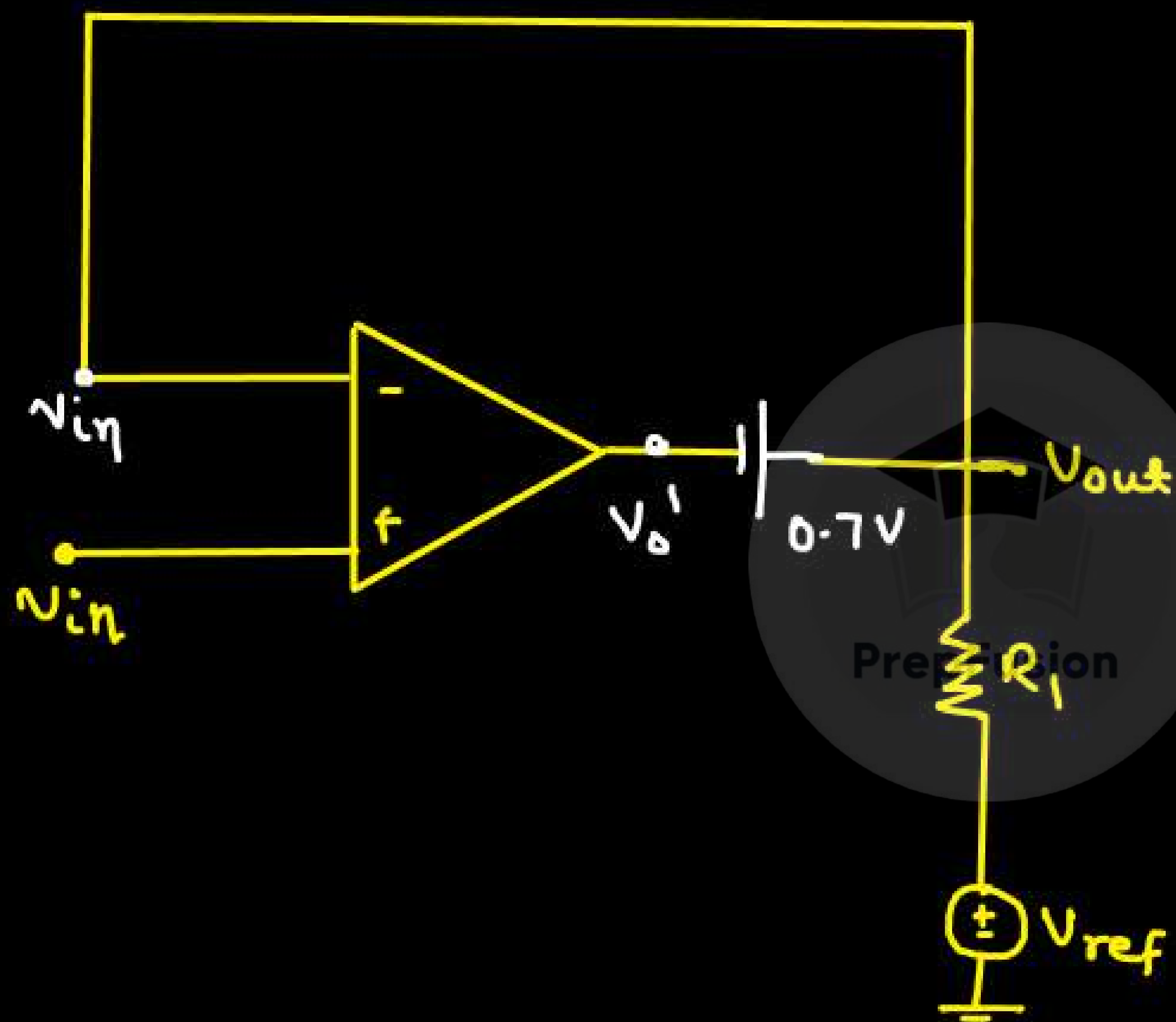
Take V_{ref} to be +ve.



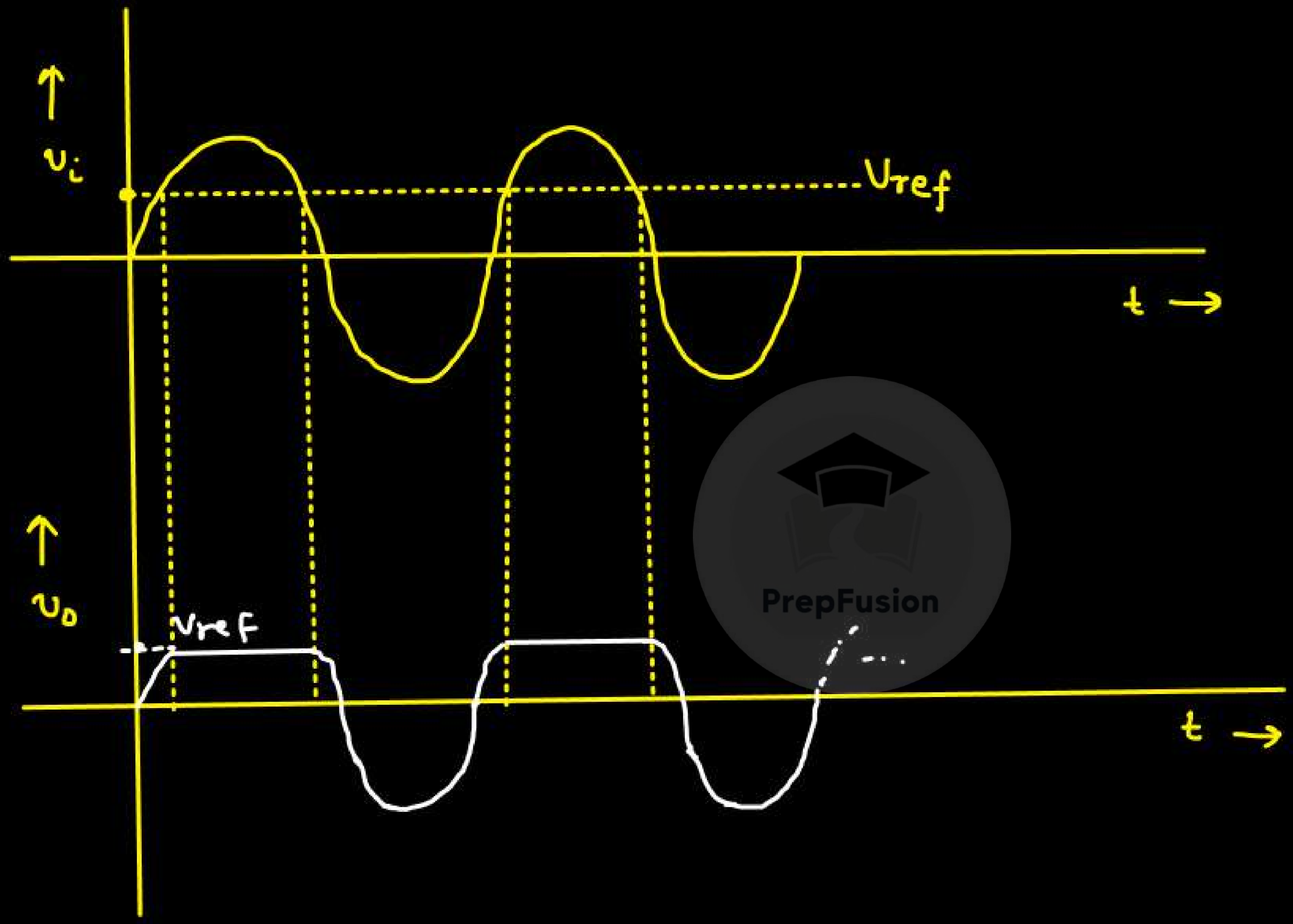
$$\boxed{\begin{matrix} V_{in} > V_{ref} \\ V_0 = V_{ref} \end{matrix}}$$

$\Rightarrow V_0' = +V_{sat}$ $\quad +V_{sat}$ $\quad V_{ref}$ $\Rightarrow$ diode off

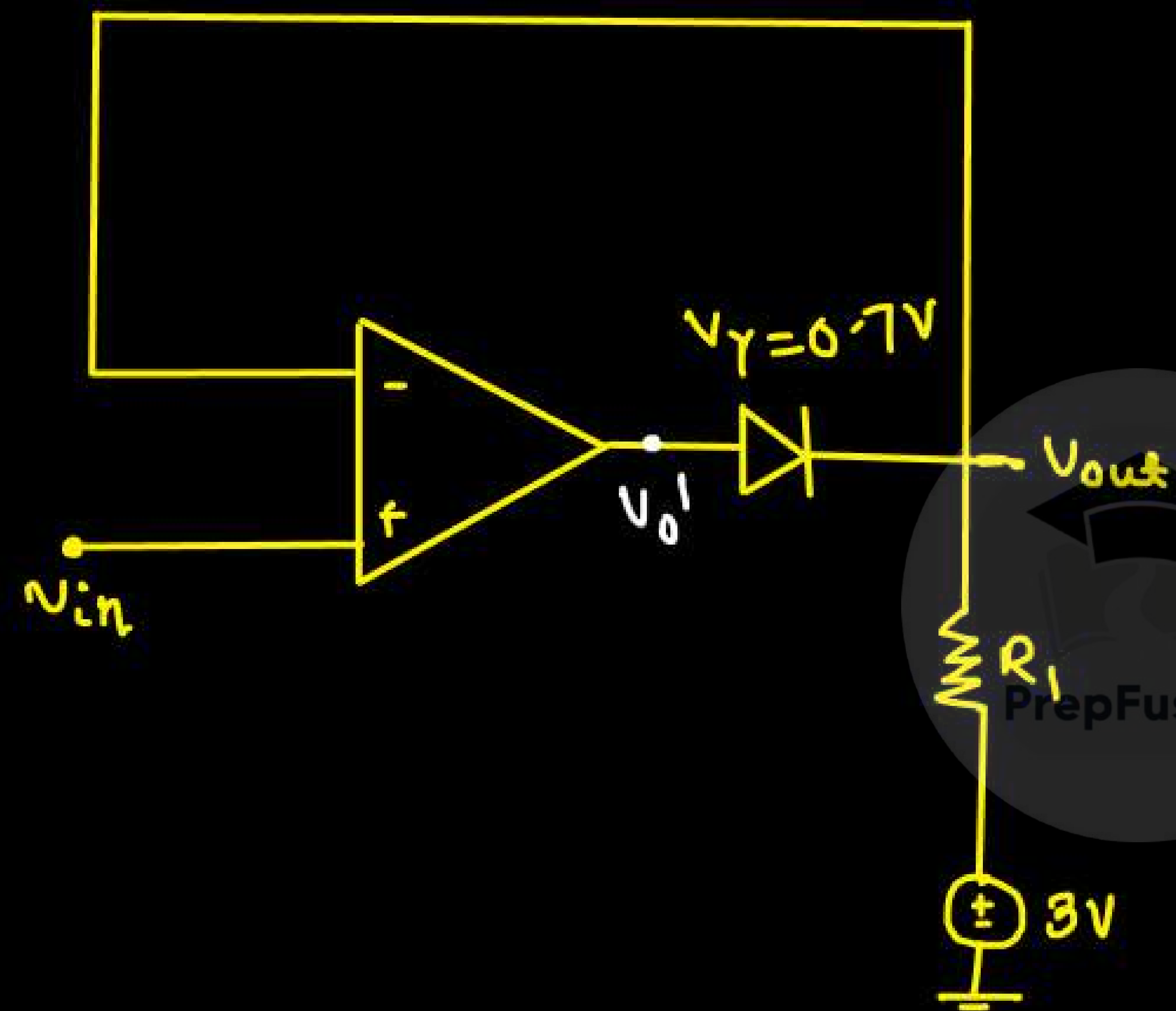
$$\boxed{v_{in} < v_{ref}} \Rightarrow V_0' = -V_{sat} \Rightarrow \text{diode ON} \Rightarrow \text{Negative f/b}$$



$$\boxed{v_0 = v_{in}}$$


v_i
Vref
t
v_0
Vref
t

Q. Draw Transfer Characteristics.



O.C. Test

(i) $v_{in} > 3V$

$v_0' = +v_{sat}$

$\Rightarrow$ diode ON

$\Rightarrow$ Negative f/b present

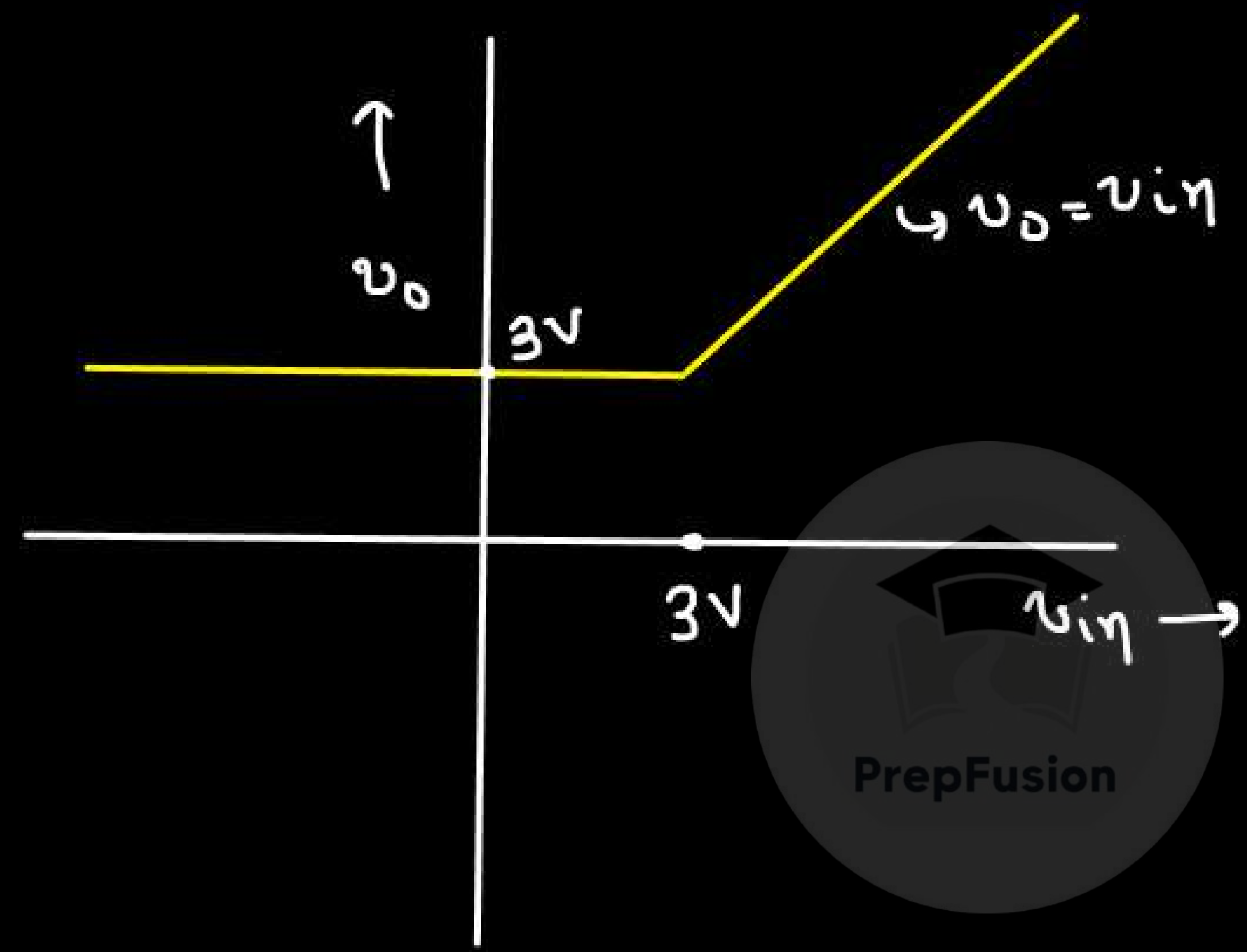
$$\boxed{v_0 = v_i}$$

(ii) $v_{in} < 3V$

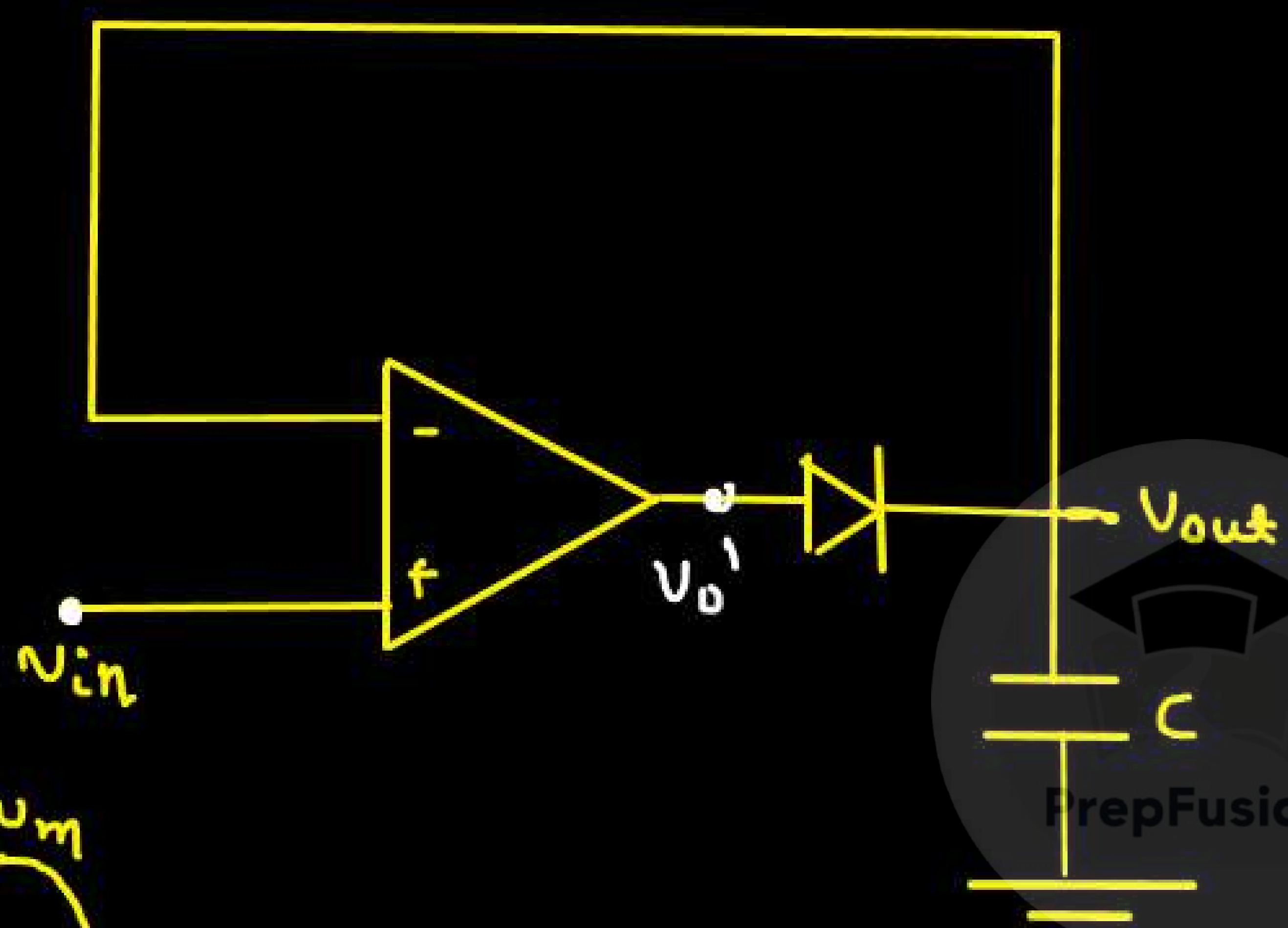
$v_0' = -v_{sat}$

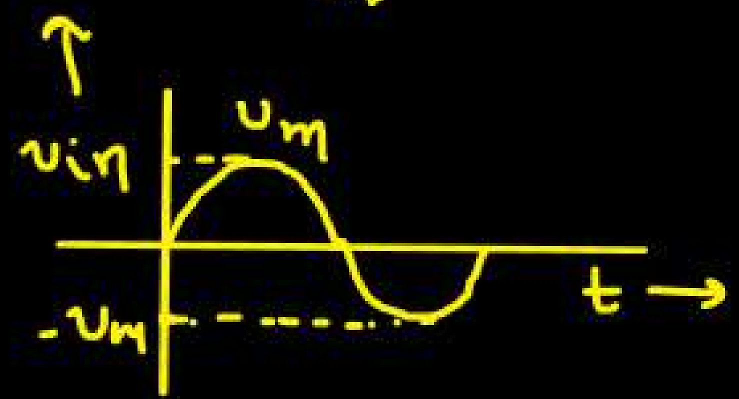
$\Rightarrow$ diode OFF

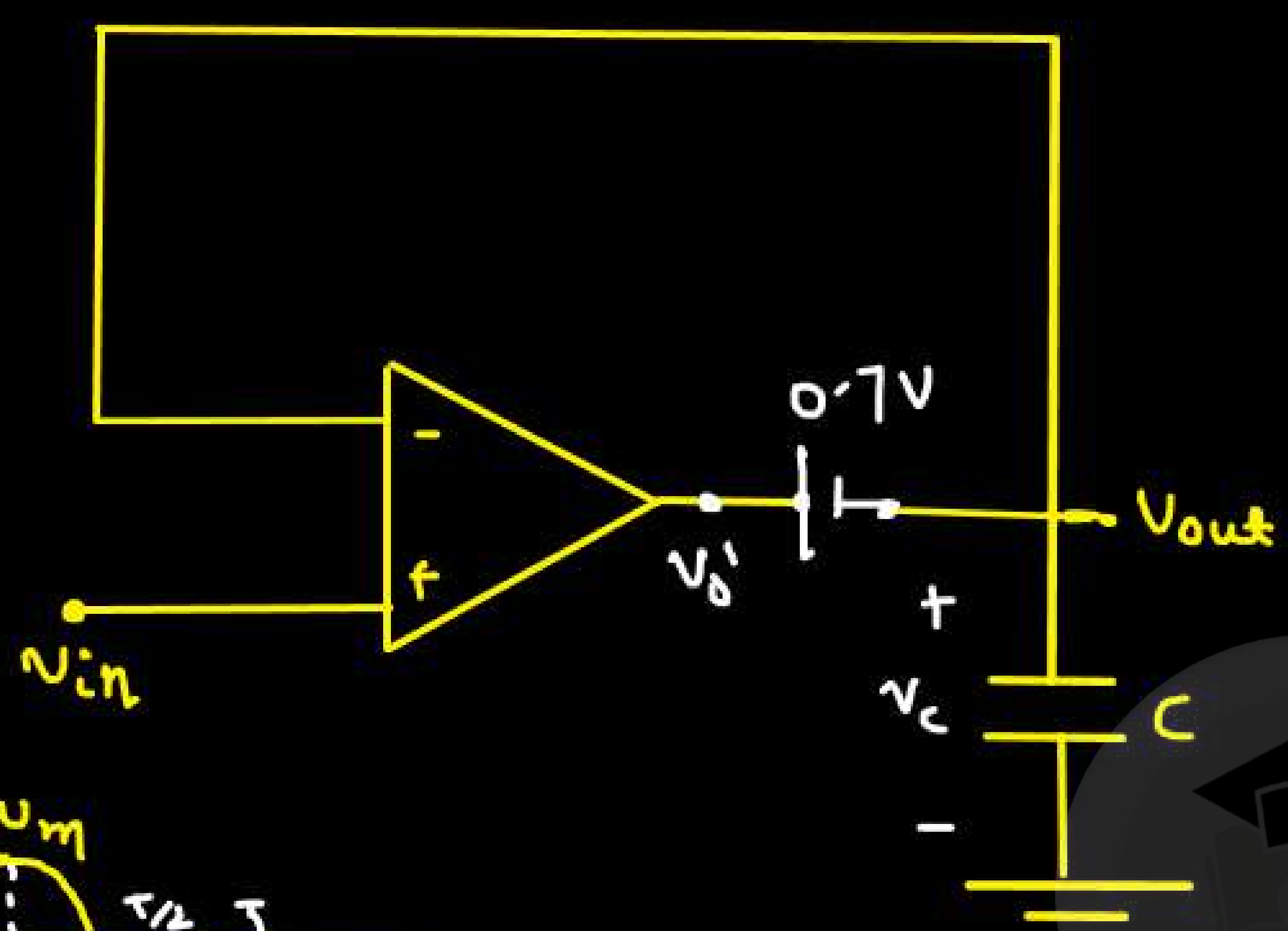
$$\boxed{v_{out} = 3V}$$

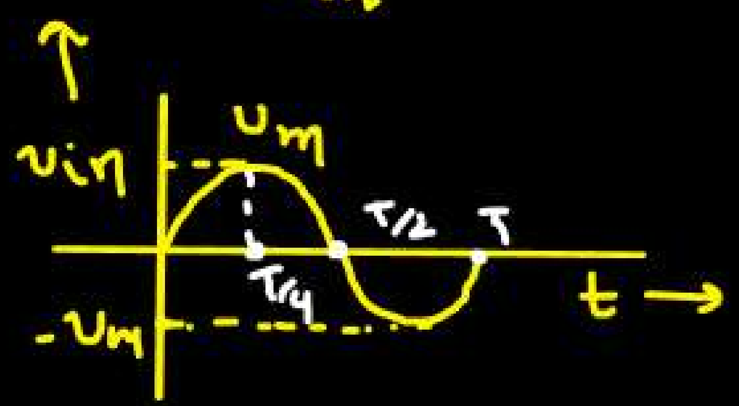

v_0
3V
$v_0 = v_{in}$
3V
v_{in}

* Active Peak detector :-









O.C. Test.

@ $t=0^+$

$v_{in}>0 \Rightarrow V_+>0$

$V_c=0 \Rightarrow V_-=0$

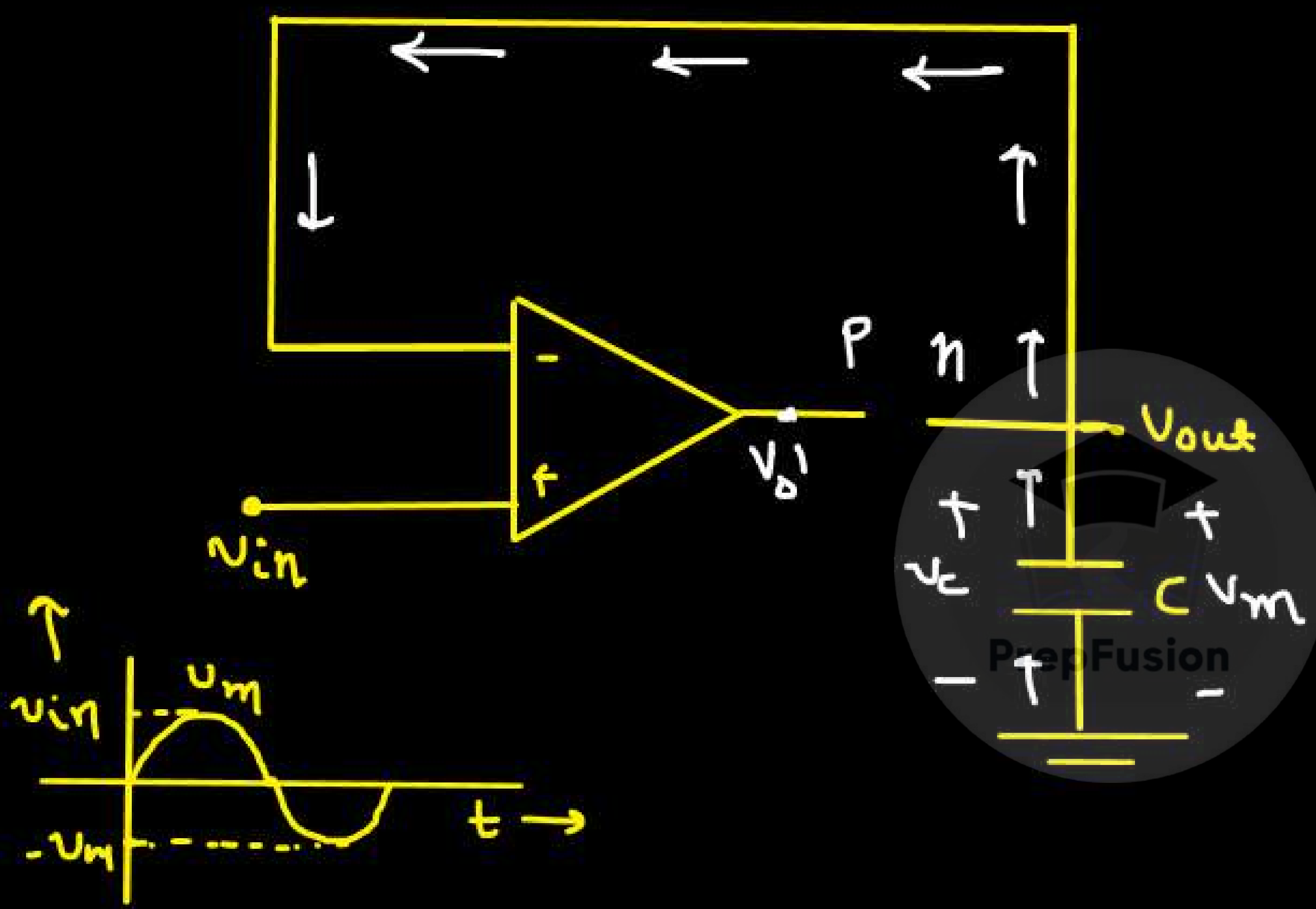
$\Rightarrow v_o' = +V_{sat} \Rightarrow$ diode ON

$\Downarrow$

Neg. f/b ckt

$v_o = v_{in} \quad \{0<t<T/4\}$

at $t = T/4^{+}$



$v_+ = v_{in} < v_m$

$v_- = v_m$

Here $v_- > v_+$

$\Rightarrow v_o' = -v_{sat}$

$\Downarrow$

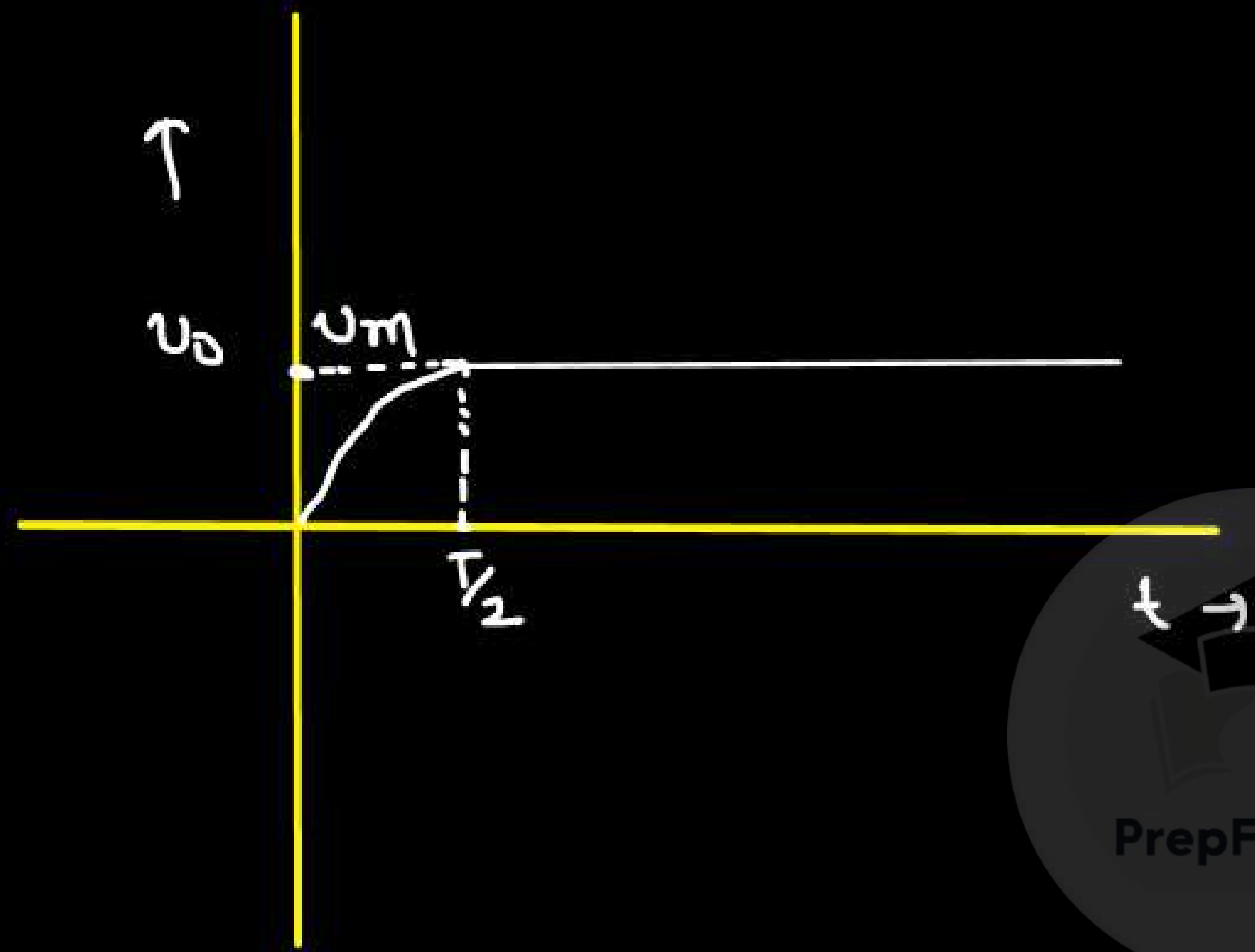
diode off

$$\boxed{v_o = v_m}$$

To turn on the diode,

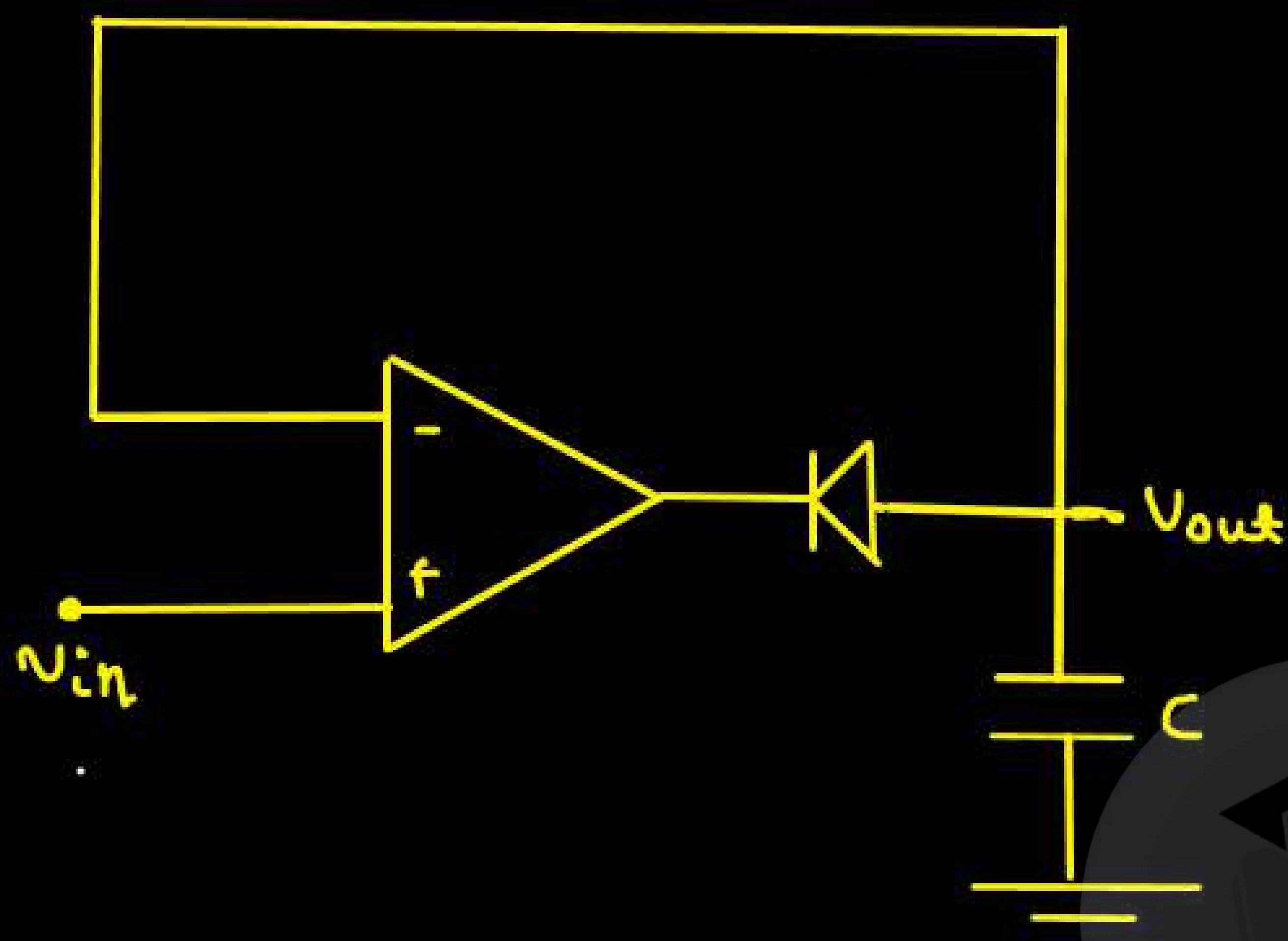
$v_o' = +v_{sat}$ ← required

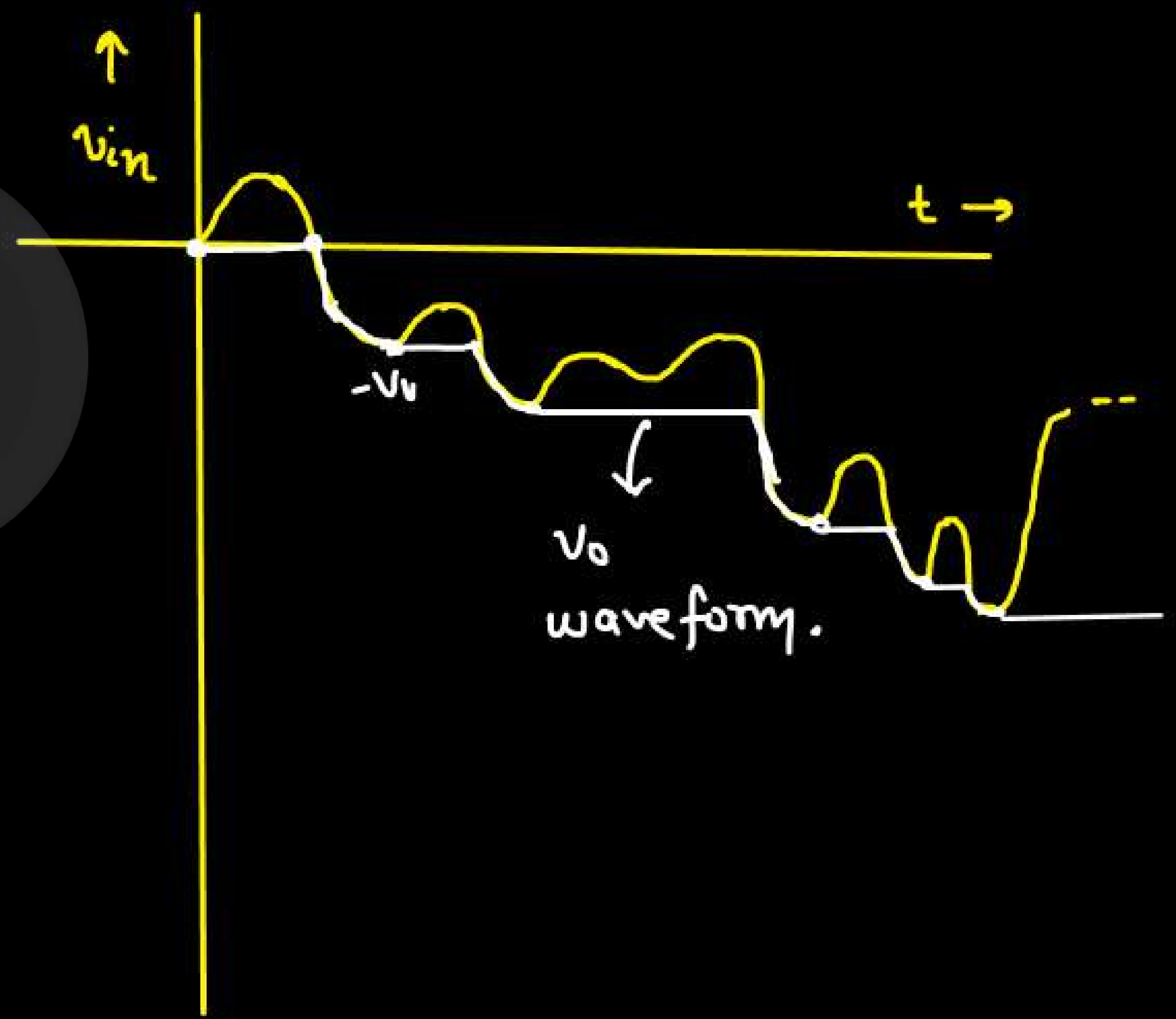
$\boxed{v_{in} > v_m}$ → NOT POSSIBLE



$\uparrow$
v_0
v_m
$T/2$
$t \rightarrow$

Q.



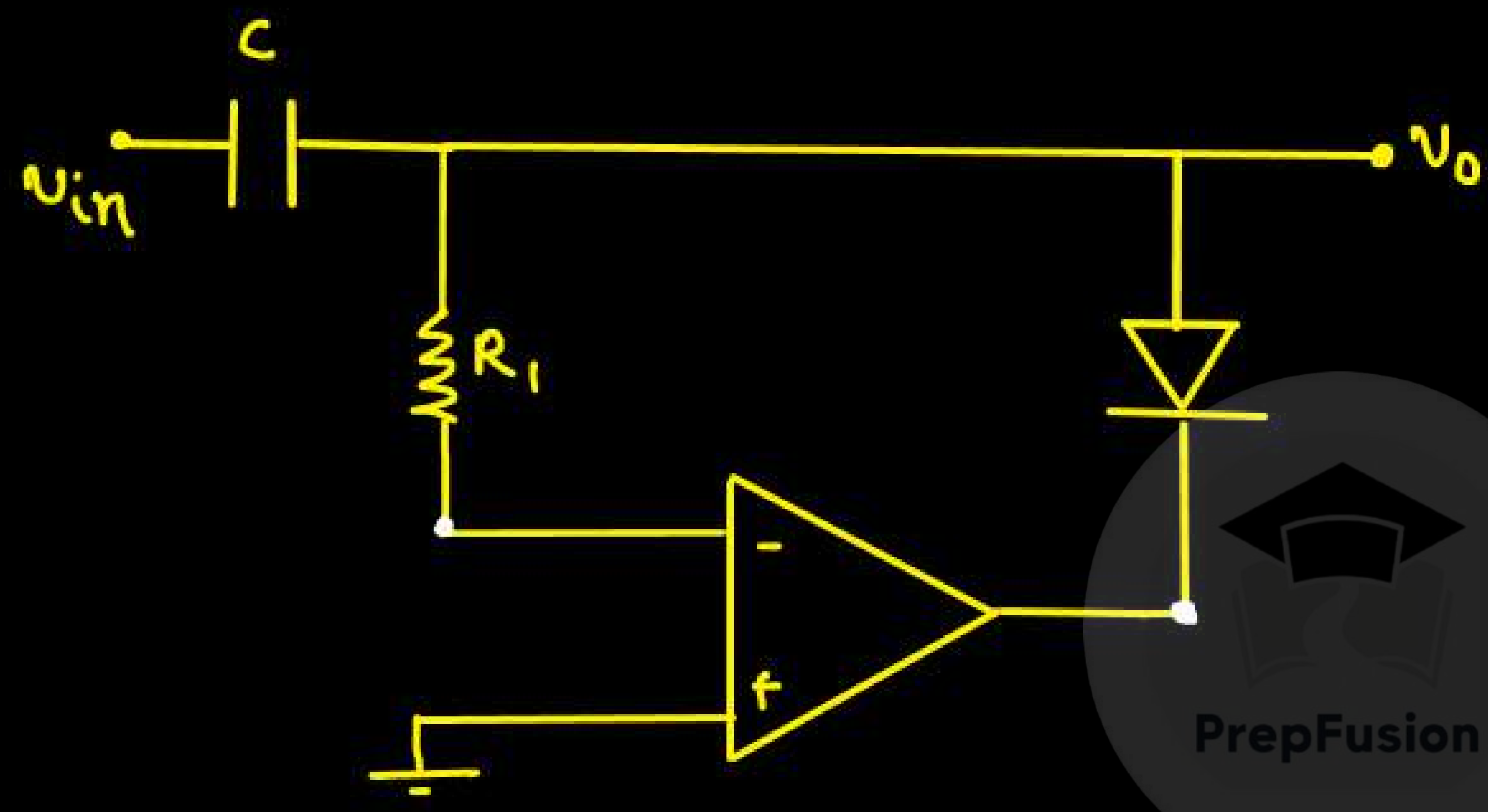


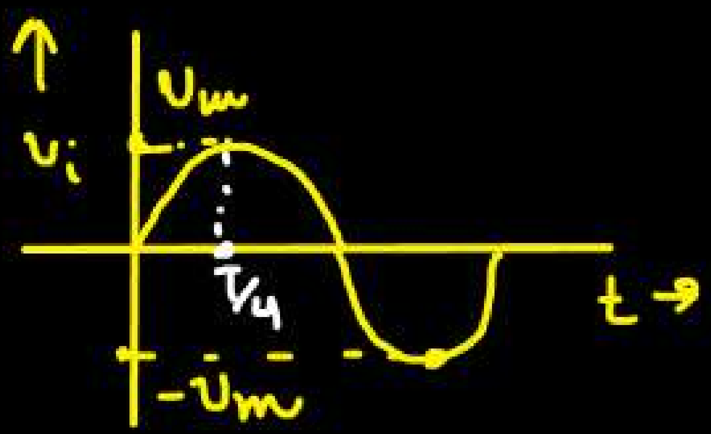
Draw V_0 waveform.

⇓

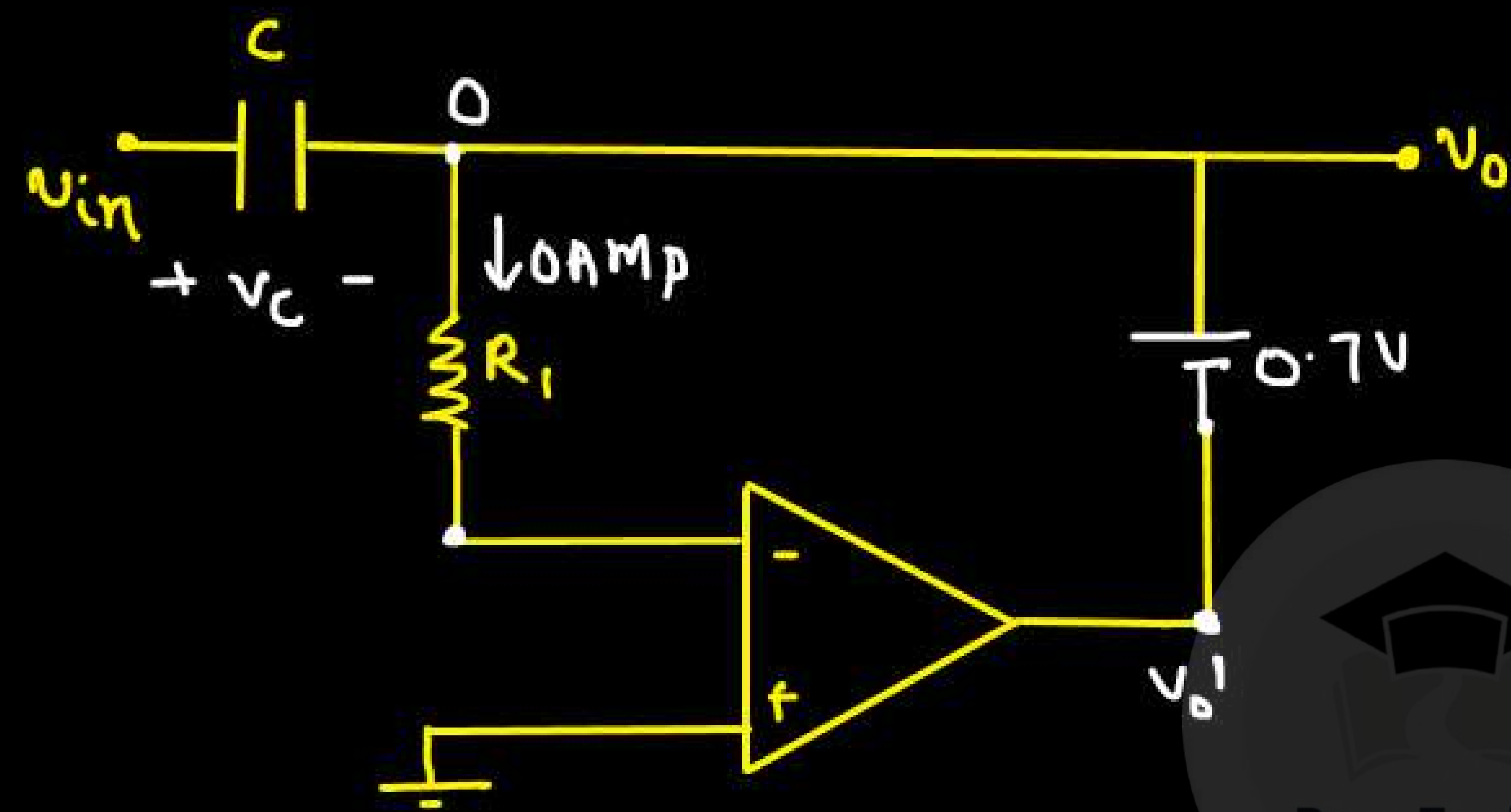
negative peak detector

☆ Active Clamper Circuit:-





O.C. Test:-



@ $t=0^+$

$v_{in}>0 \Rightarrow v_+ > 0$

$v_- = 0$

$\Rightarrow v_o' = -V_{sat}$

$\Downarrow$

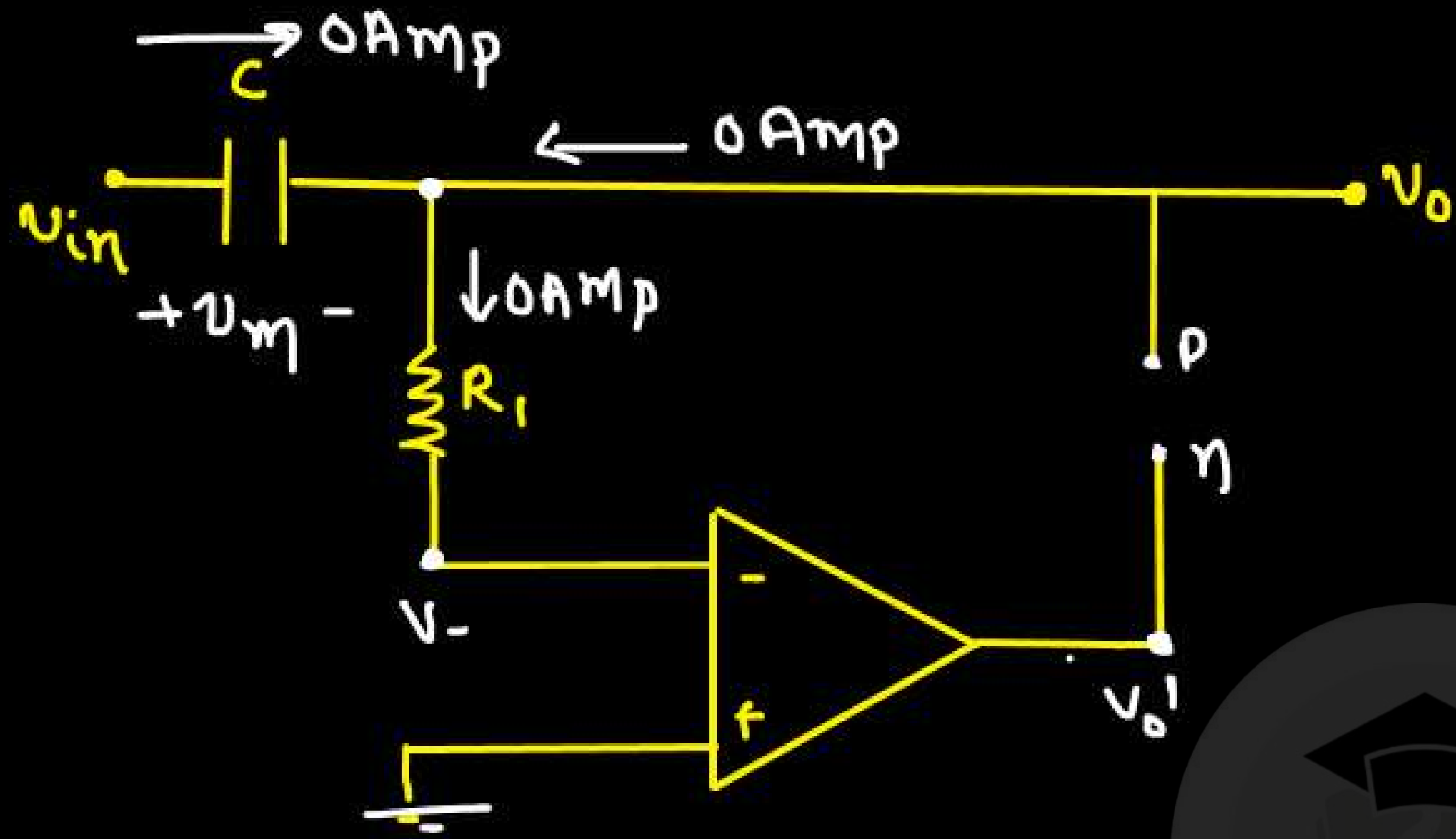
diode ON

$\Downarrow$

Negative f/b ckt

$0<t<T/4$

$v_o = 0V$



@ $t = T/4^+$

$v_{in} < v_m$

$v_- < 0$

$\Rightarrow v_0' = +v_{sat}$

⇓

diode is off

⇓

cap. holds its voltage

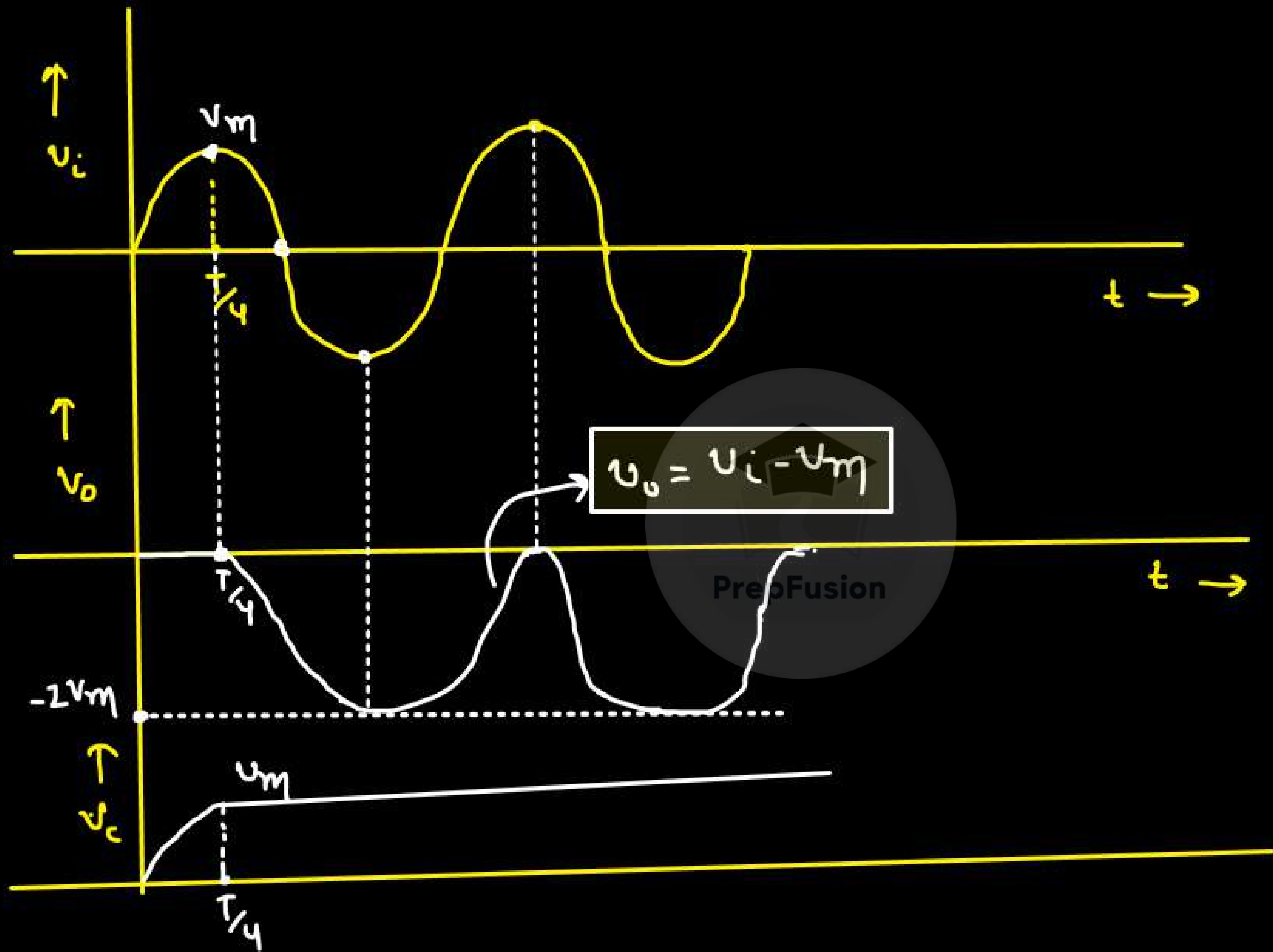
$\boxed{v_0 = v_i - v_m}$ → steady state

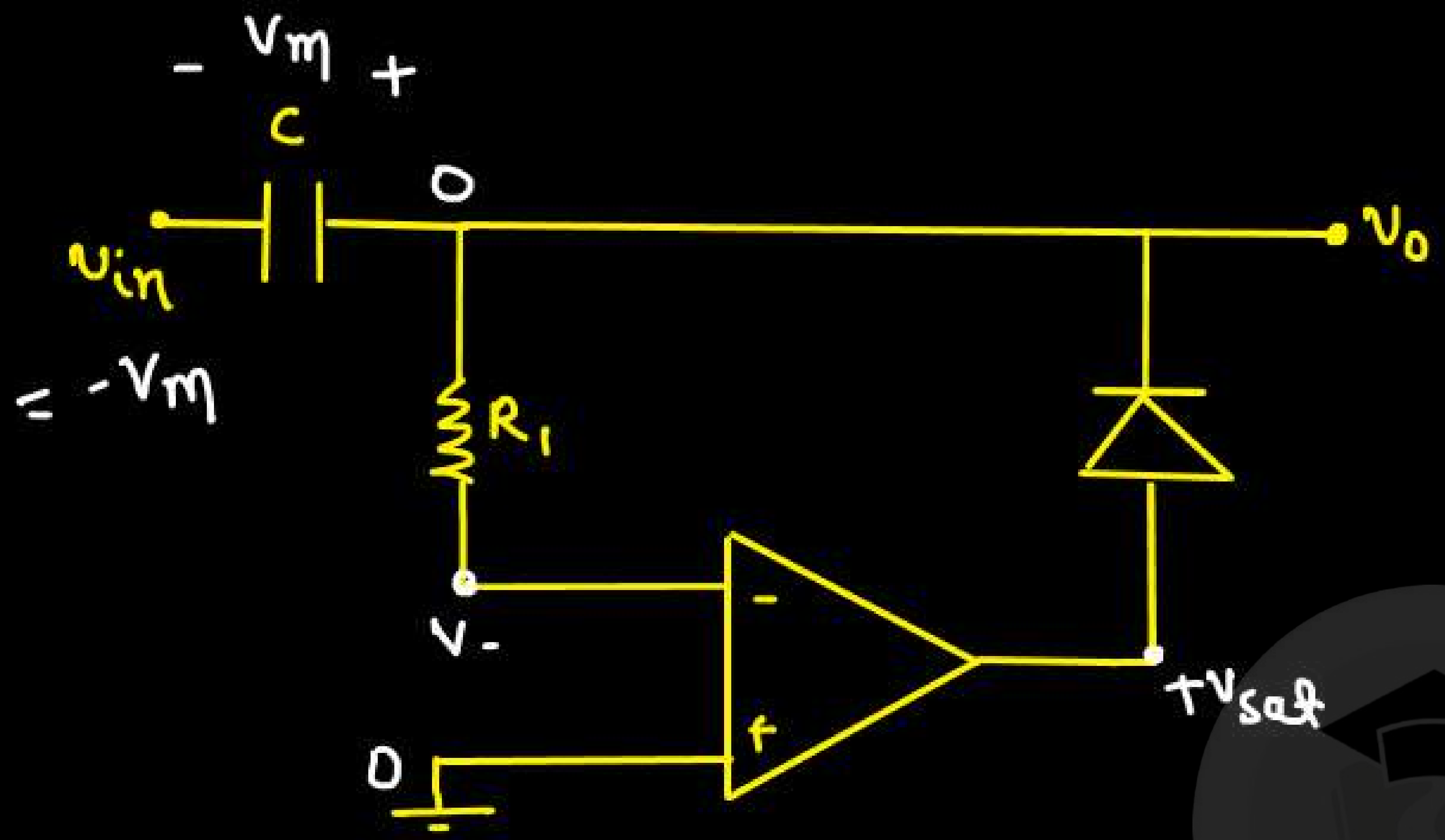
To turn on the diode

$v_- > 0$

$v_{in} - v_m > 0$

$\boxed{v_{in} > v_m}$ → NOT possible


v_i
V_m
$T/4$
$t \rightarrow$
v_o
$v_o = v_i - V_m$
$-2V_m$
v_c
V_m
$T/4$
$T/4$
$t \rightarrow$
PrepFusion

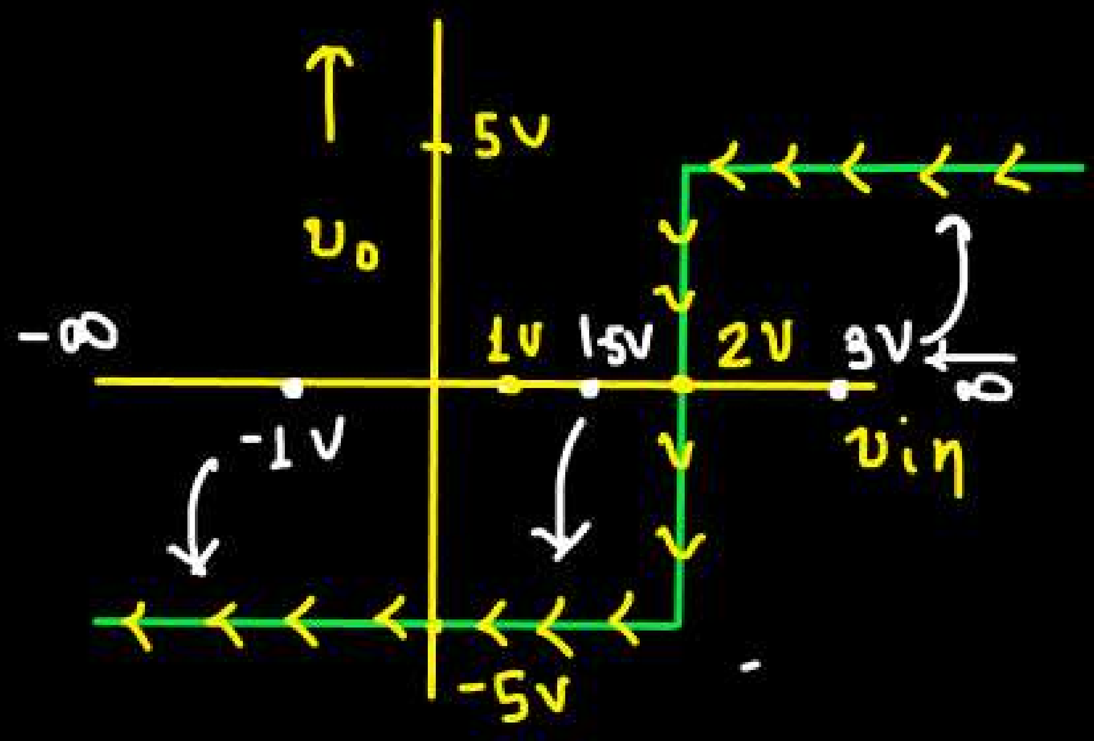


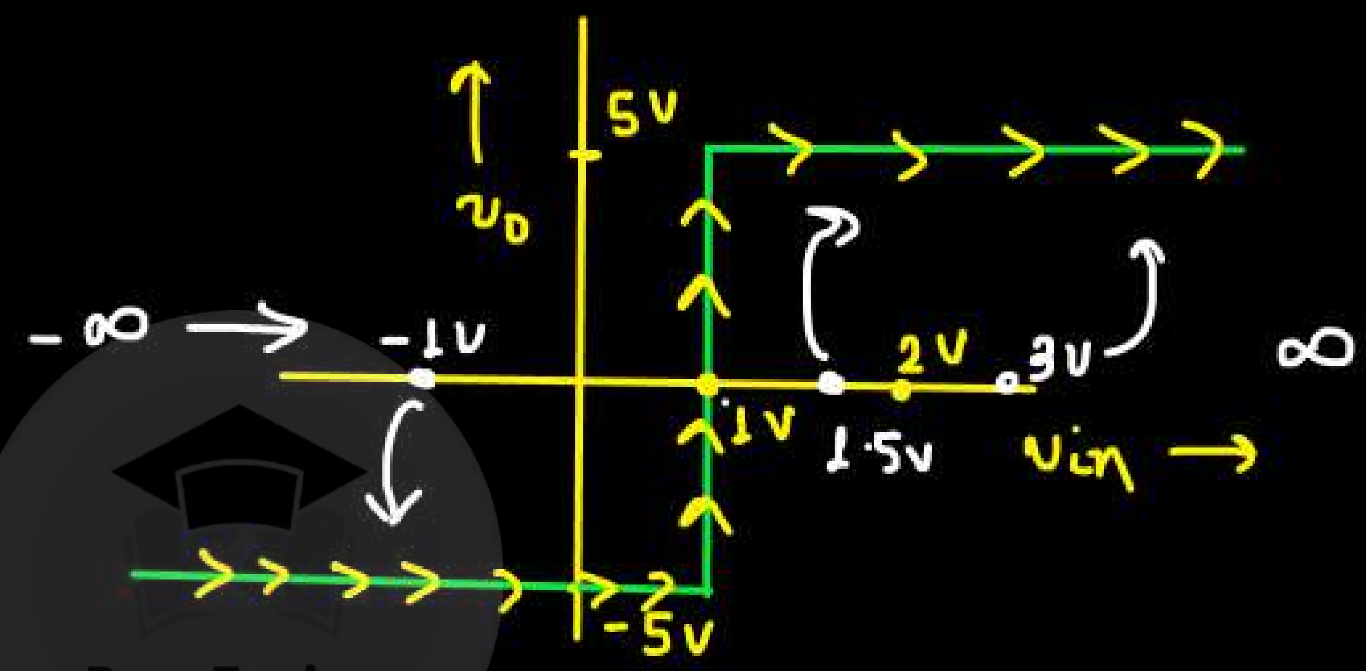
Q. steady state o/p?

$$\boxed{(v_0)_{s.s.} = v_{in} + v_m}$$

⇒ Op-Amp in positive feedback :-

Q.





Based on the transfer characteristic given, Find v_0 value for -

(a) $v_{in} = -1V$

⇓

$V_0 = -5V$

(b) $v_{in} = 3V$

⇓

$V_0 = +5V$

(c) $v_{in} = 1.5V$

⇓

can't determine (Insufficient Info)

(d) $v_{in} = 1.5$ {v_{in} is changing from $-\infty$ to ∞}

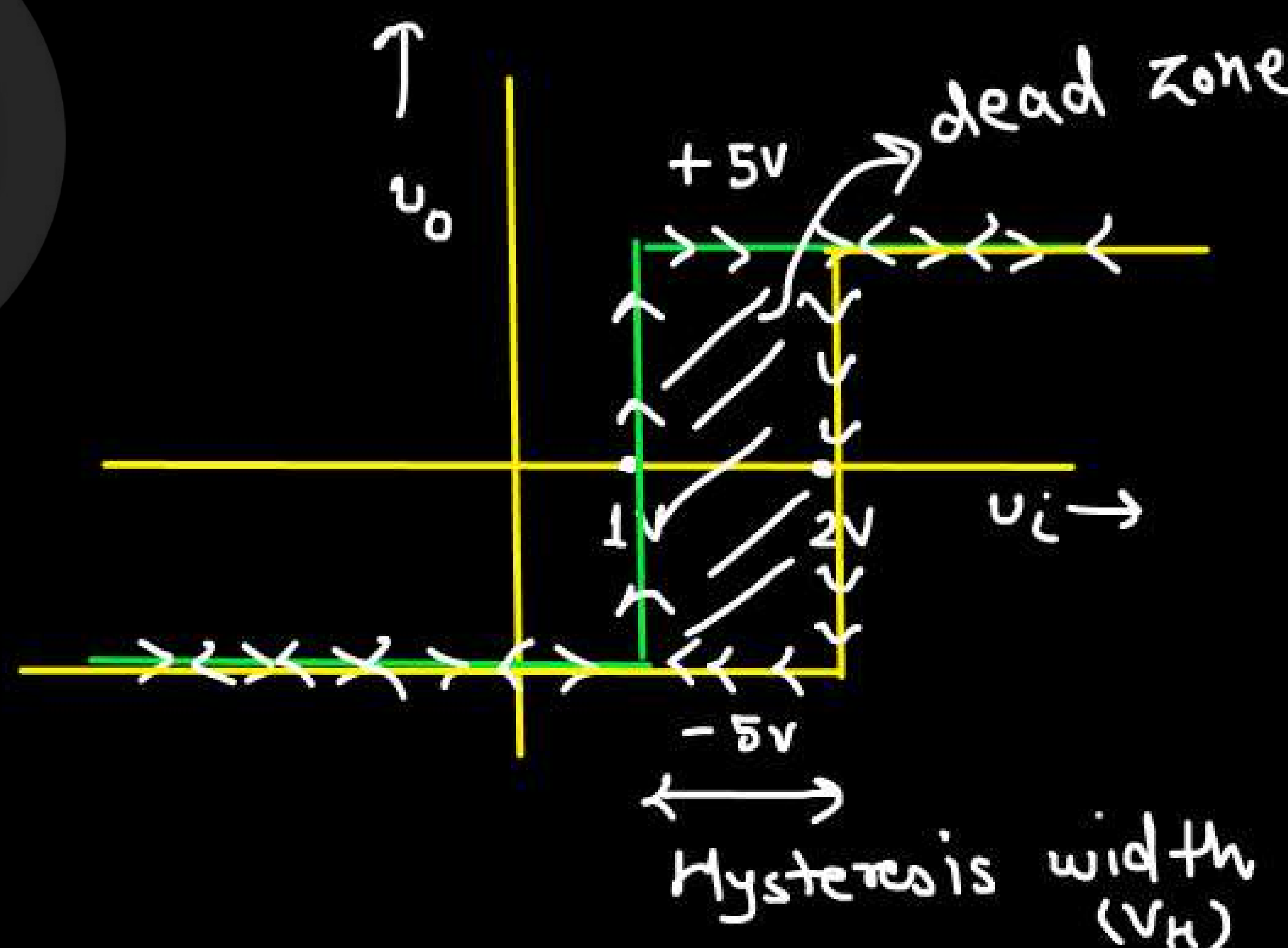
$\Downarrow$

$+5V$

(e) $v_{in} = 1.5$ {v_{in} is changing from ∞ to $-\infty$}

$\Downarrow$

$-5V$



* $v_{in} > 2V \Rightarrow v_o = +5V$ [always]

$v_{in} < 1V \Rightarrow v_o = -5V$ [always]

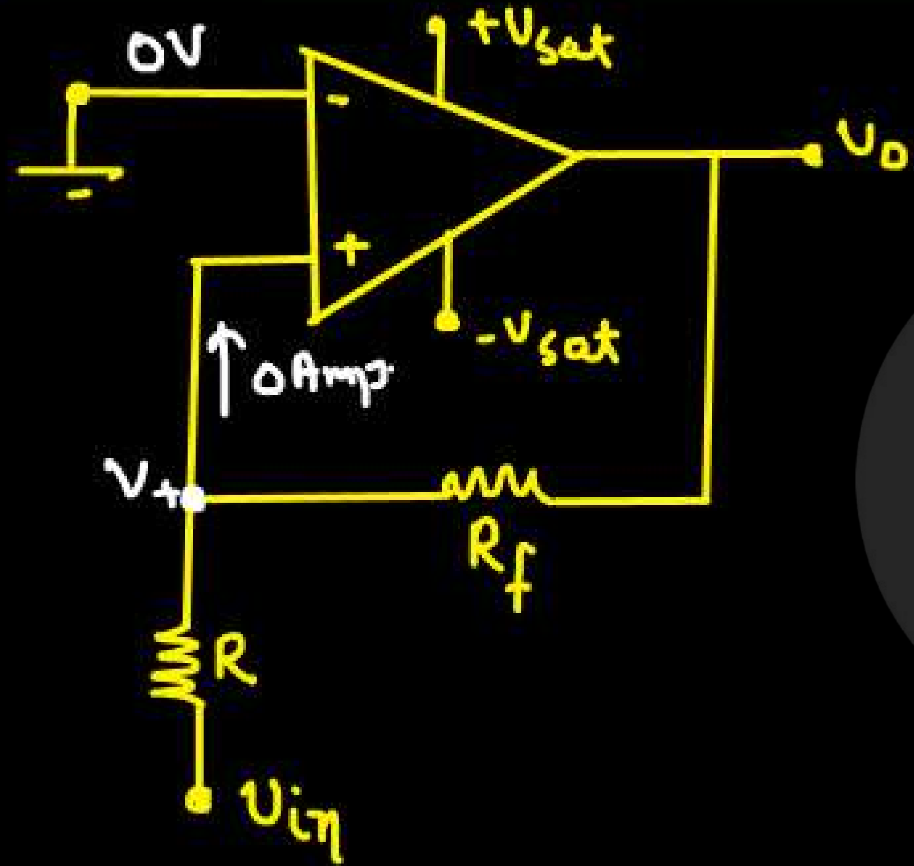
Threshold voltage = 2V, 1V

Upper threshold voltage = 2V (V_{UTP})

Lower threshold voltage = 1V (V_{LTP})

⇒ Concept of Schmitt trigger :-

(i) Non-inverting Schmitt trigger :-



$$\boxed{v_0 = -\frac{R_f}{R} v_{in}}$$

concept of virtual short is not valid in positive f/b

v_0 can be either $+V_{sat}$ or $-V_{sat}$

$$V_- = 0V$$

$$V_+ = \frac{V_{in}R_f + V_0 R}{R_f + R}$$

(i) $\boxed{\text{Assuming } v_o = +V_{sat}}$

$$V_+ = \frac{V_{sat}R + v_{in}R_f}{R + R_f}, \quad V_- = 0\,V$$

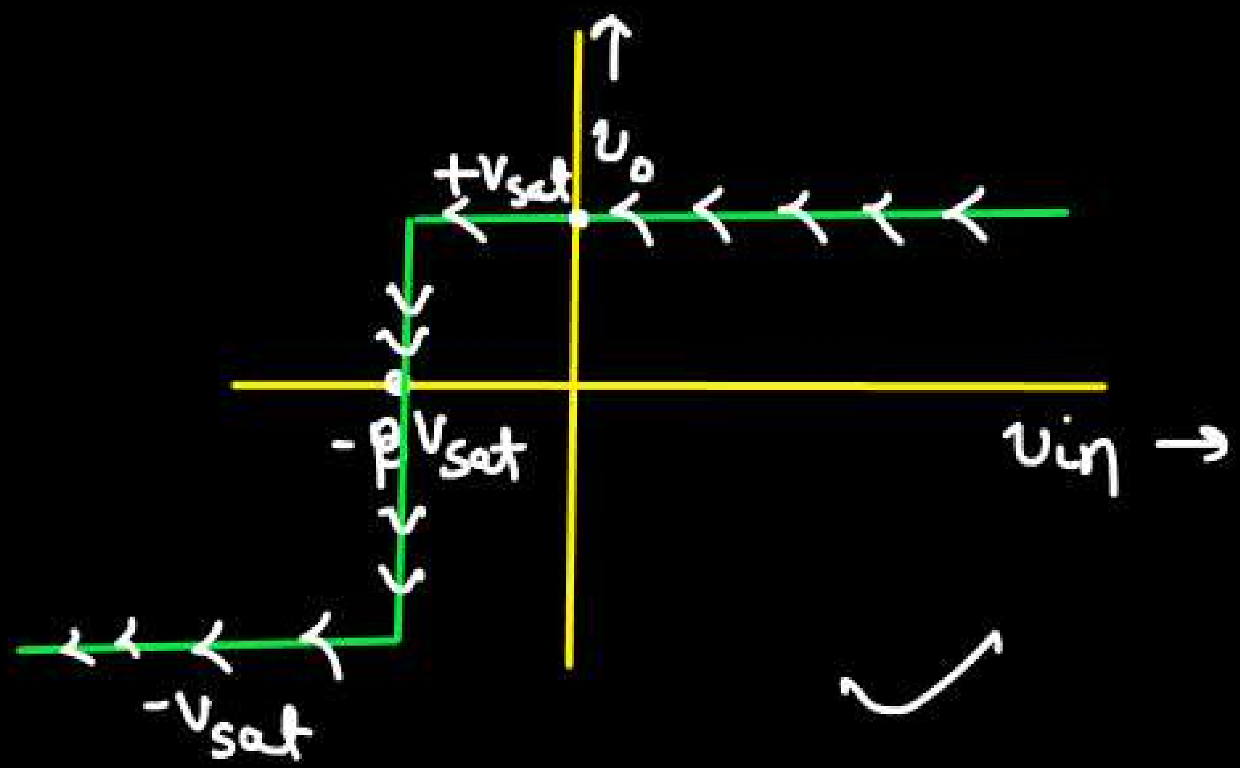
$$V_+ > V_- \Rightarrow \boxed{V_o = +V_{sat}}$$

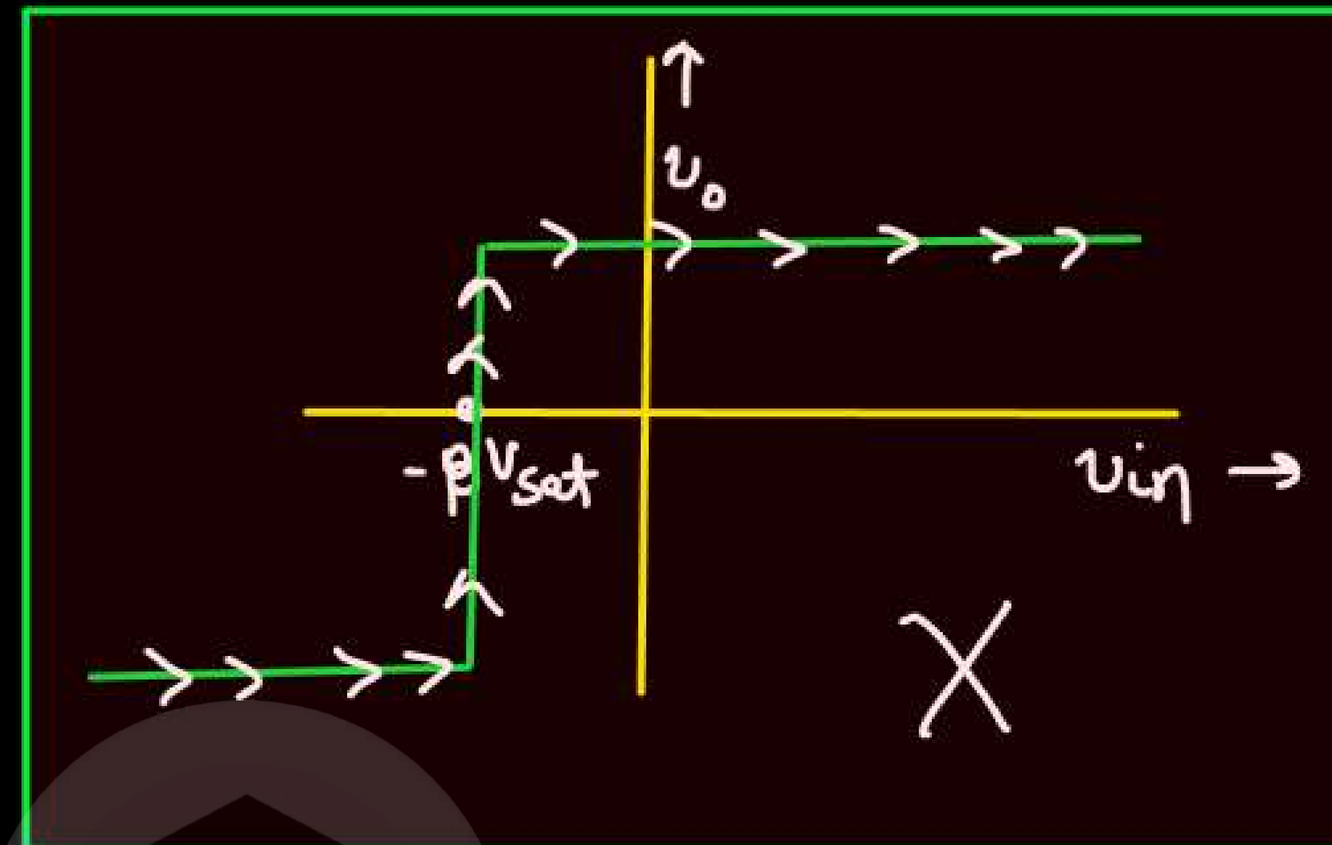
$$\frac{V_{sat}R + v_{in}R_f}{R + R_f} > 0$$

$$v_{in} > -V_{sat}\frac{R}{R_f}$$

$\boxed{v_{in} > -\beta V_{sat}}$ where $\boxed{\beta = R/R_f}$ $\Rightarrow \boxed{v_o = +V_{sat}}$

$\boxed{v_{in} < -\beta V_{sat}}$ $\Rightarrow \boxed{v_o = -V_{sat}}$





(ii) $\boxed{\text{Assuming } v_o = -v_{sat}}$

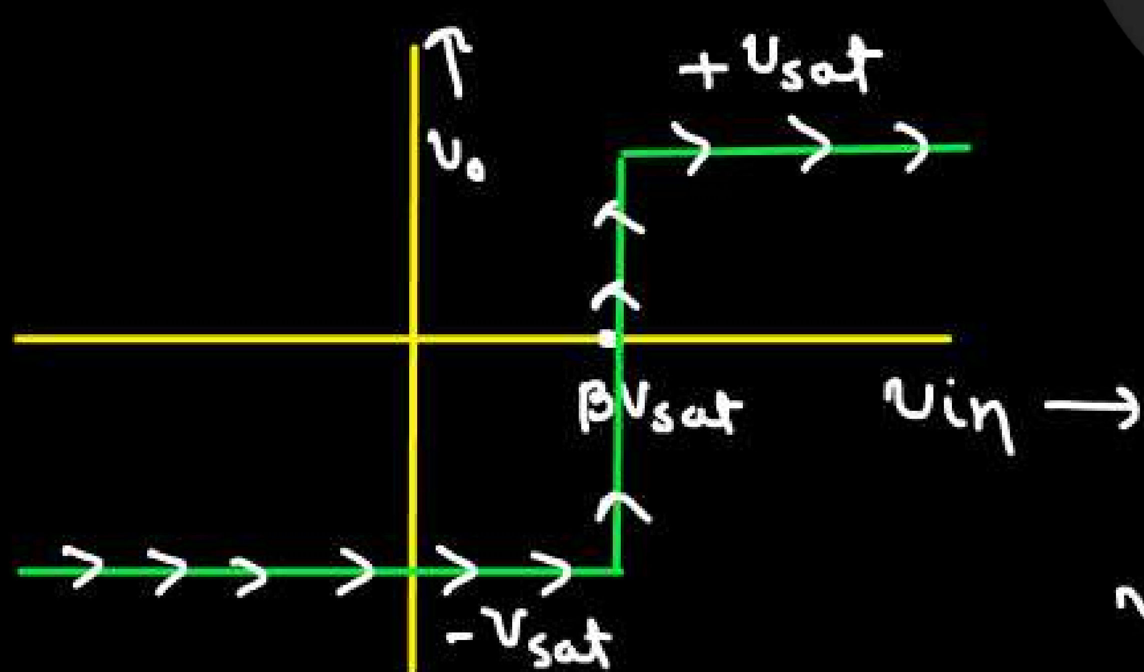
$$V_+ = \frac{-v_{sat} R + v_{in} R_f}{R_f + R} \quad , \quad V_- = 0V$$

$$V_+ < V_- \Rightarrow v_o = -V_{sat}$$

$$\frac{-V_{sat}\, R + v_{in} R_f}{R_f + R} < 0$$

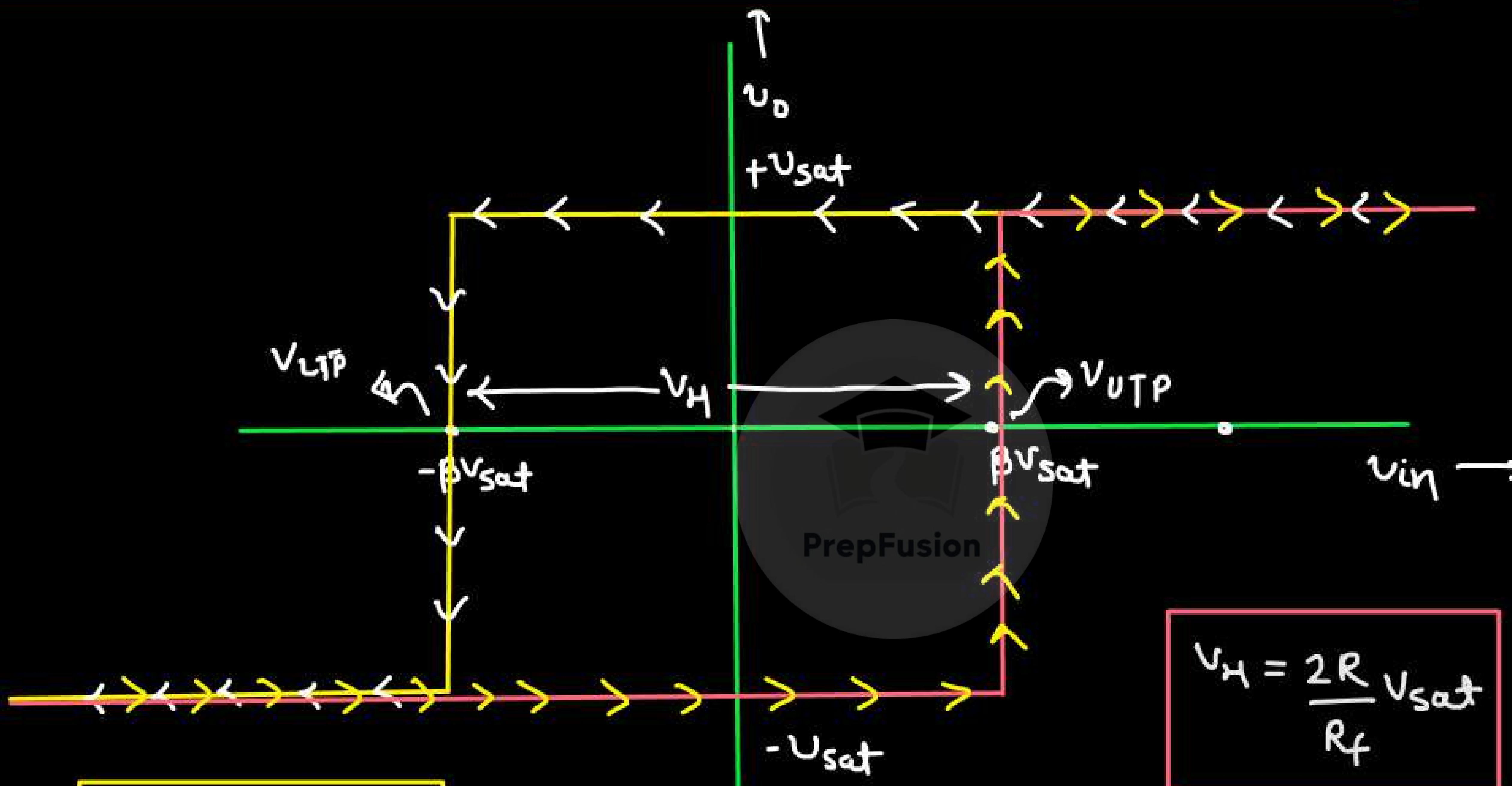
$$v_{in} < \frac{R}{R_f} v_{sat}$$

$$\Rightarrow \boxed{\begin{array}{ll} v_{in} < \beta v_{sat} & \Rightarrow v_o = -V_{sat} \\ v_{in} > \beta v_{sat} & \Rightarrow v_o = +v_{sat} \end{array}}$$



✓

✿ For Non-inverting Schmitt trigger, Hysteresis is ACW.



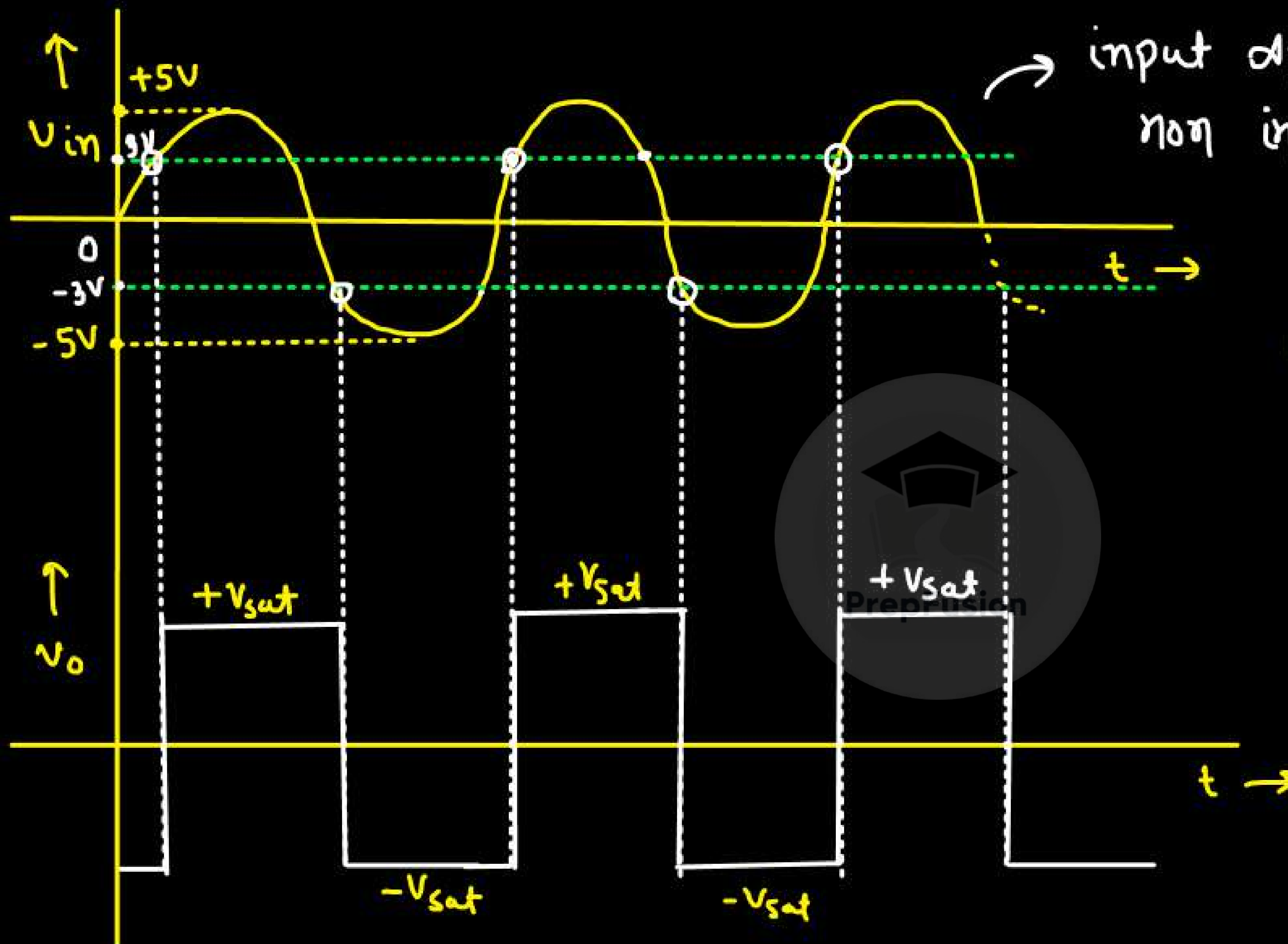
$$V_H = \frac{2R}{R_f} V_{sat}$$ → Hysteresis width

$V_{UTP} = \beta V_{sat}$

$V_{LTP} = -\beta V_{sat}$

$v_{in} > \beta v_{sat} \Rightarrow v_o = +v_{sat}$

$v_{in} < -\beta v_{sat} \Rightarrow v_o = -v_{sat}$

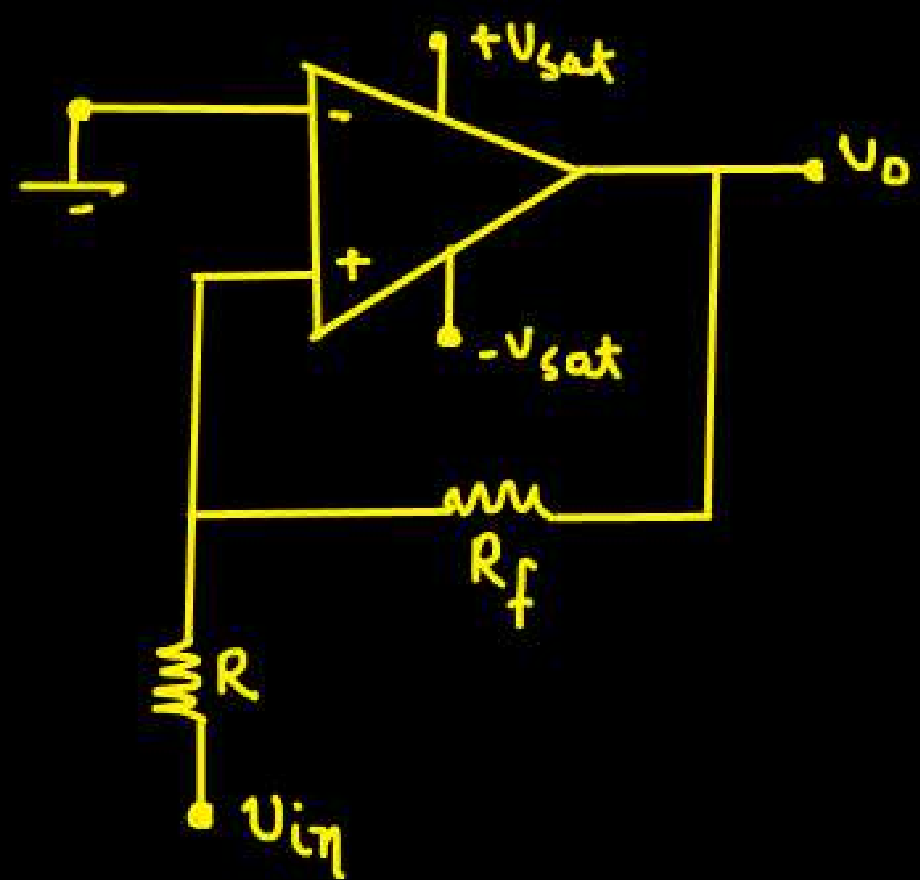


input applied to non inverting schmitt trigger.

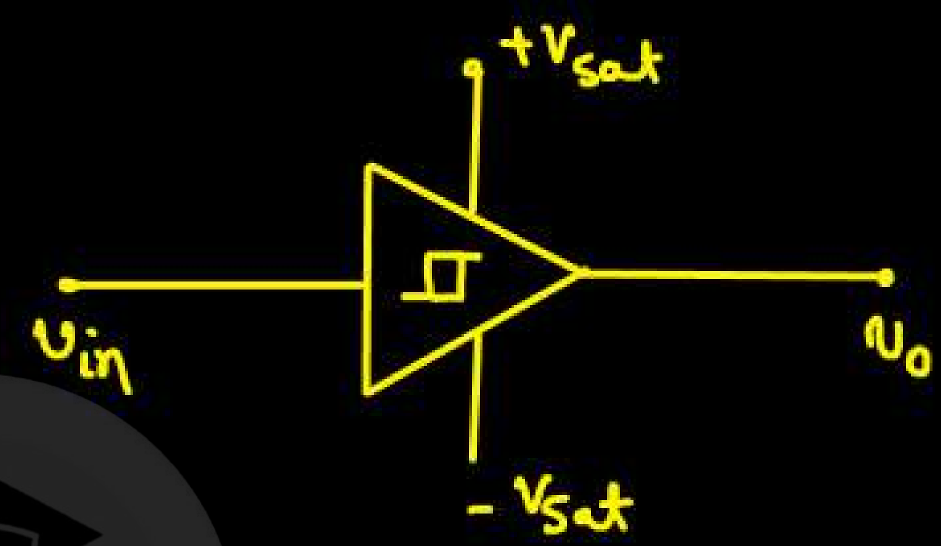
let $V_{UTP} = 3V$

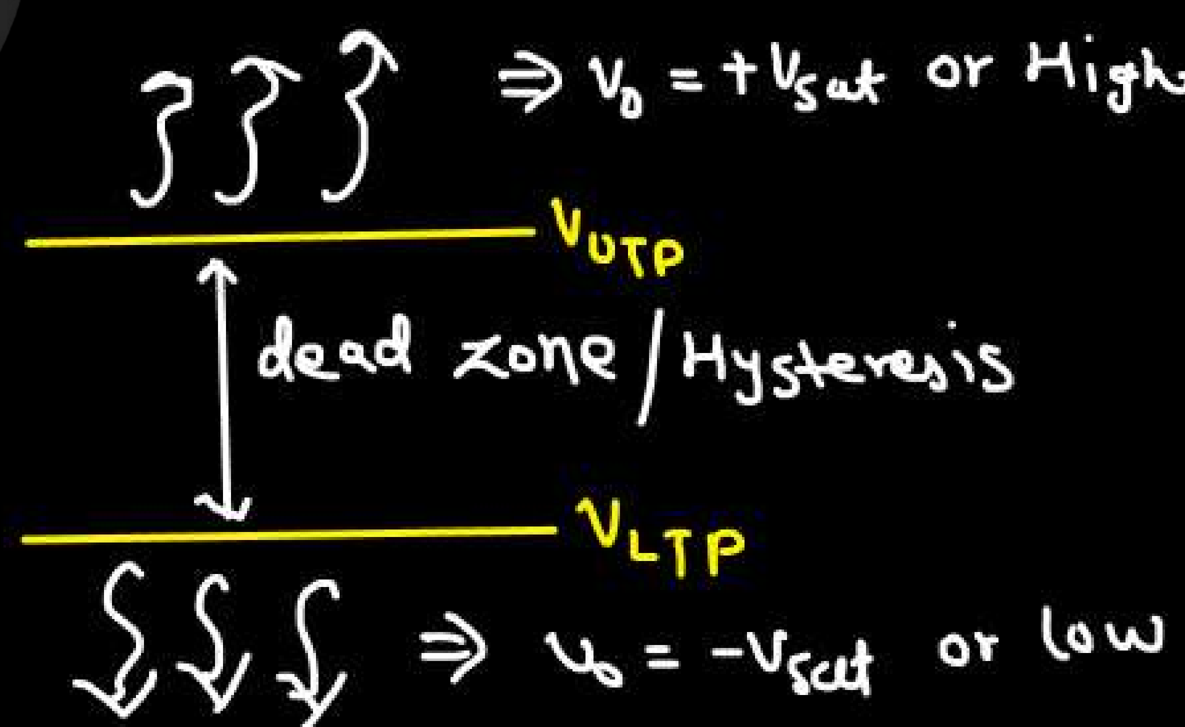
$V_{LTP} = -3V$

Non-inverting schmitt Trigger:-

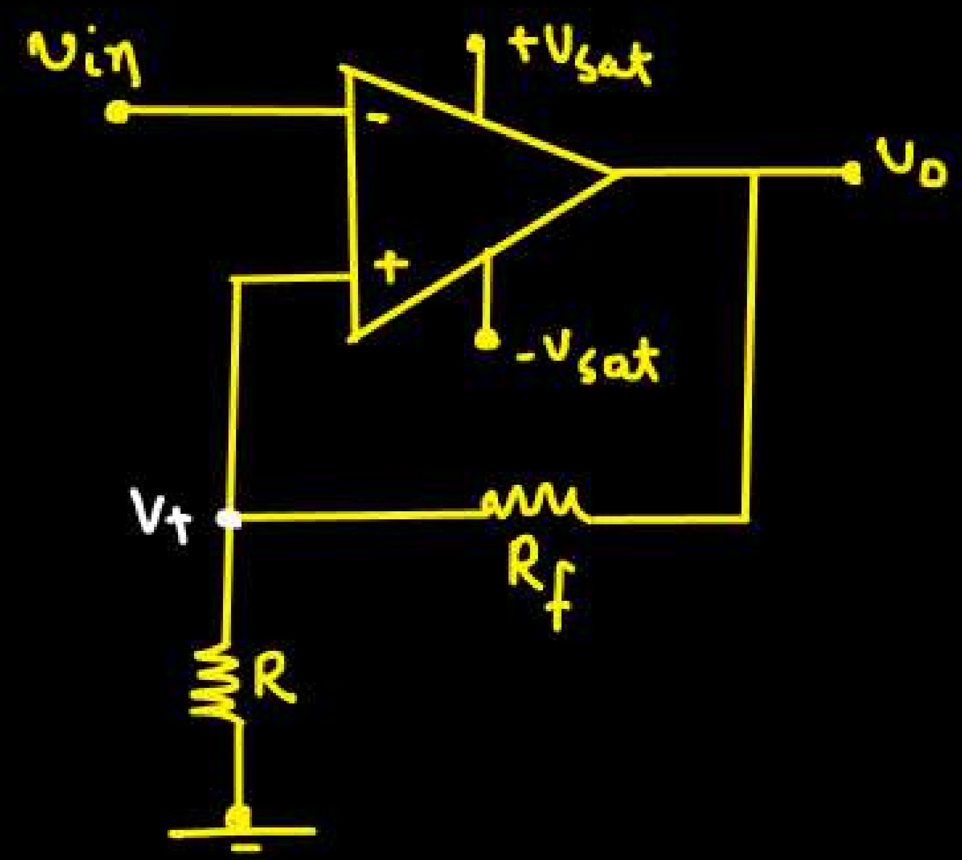


$\equiv$





(ii) Inverting Schmitt trigger:-



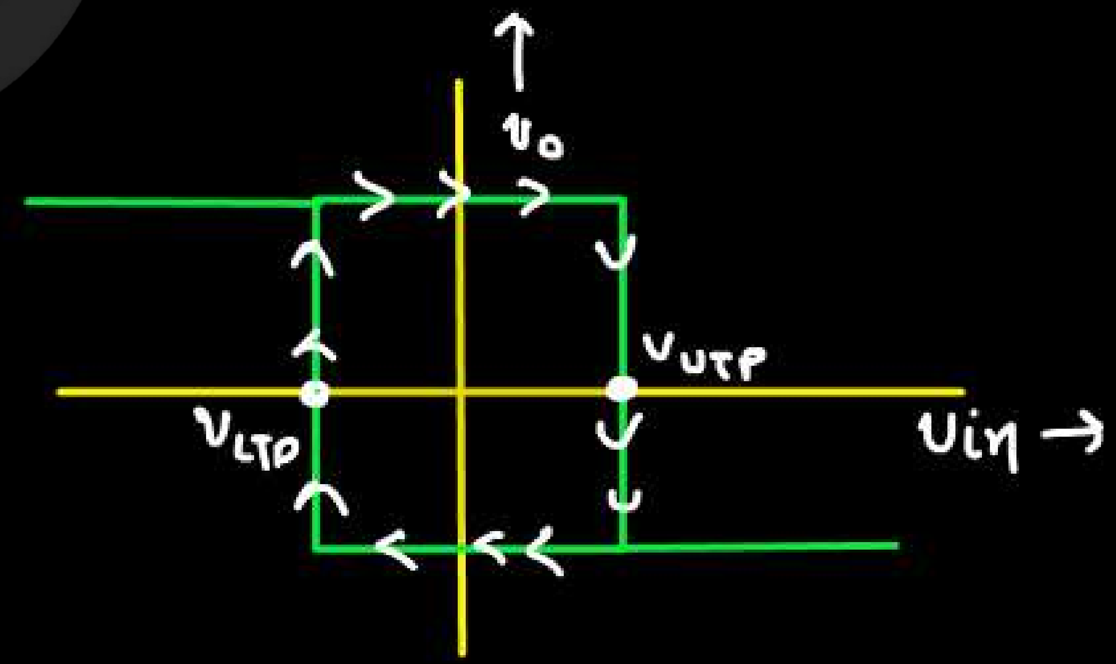
$$v_+ = \frac{v_o R}{R+R_f}, \quad v_- = v_{in}$$

Trick:-

$$v_+ = \frac{v_o R}{R+R_f}, \quad v_- = v_{in}$$

$$v_{in} = \frac{v_o R}{R+R_f}$$

$$\boxed{V_{UTP} = \frac{V_{sat} R}{R+R_f}}, \quad \boxed{V_{LTP} = \frac{-V_{sat} R}{R+R_f}}$$



(i) $\boxed{\text{Assuming } V_0 = -V_{sat}}$

$$V_+ = \frac{-V_{sat} R}{R + R_f} \quad , \quad V_- = v_{in}$$

$$V_+ < V_- \Rightarrow V_0 = -V_{sat}$$

$$v_{in} > \frac{-V_{sat} \times R}{R + R_f} \Rightarrow V_0 = -V_{sat}$$

$$\boxed{\begin{array}{l} v_{in} > -\beta V_{sat} \Rightarrow v_0 = -V_{sat} \\ v_{in} < -\beta V_{sat} \Rightarrow v_0 = +V_{sat} \end{array}}$$

$$\boxed{\beta = \frac{R}{R + R_f}}$$

(ii) assuming $v_0 = +V_{sat}$

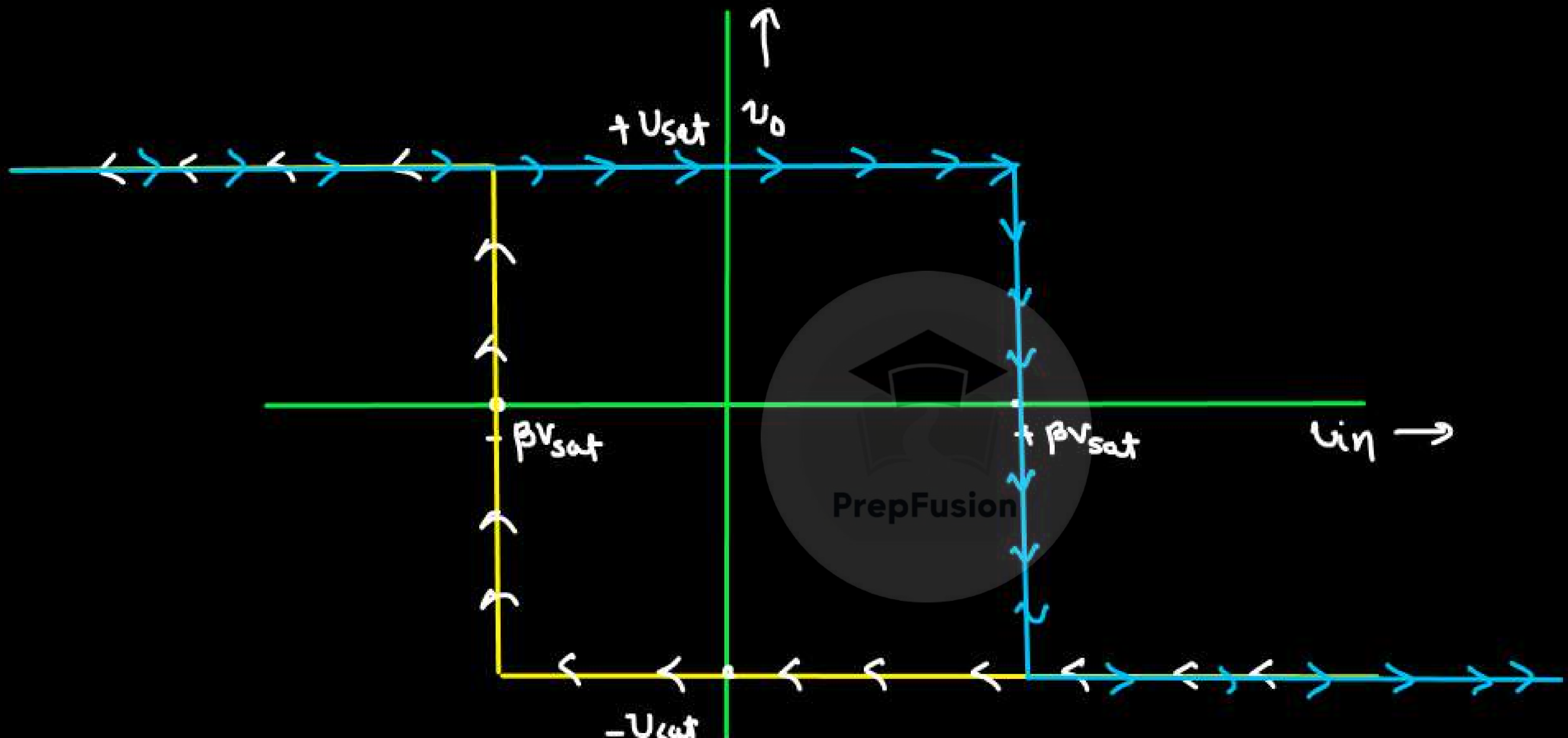
$$V_+ = \frac{V_{sat} \times R}{R + R_f} \quad , \quad V_- = v_{in}$$

$$V_+ > V_- \Rightarrow v_0 = +V_{sat}$$

$$v_{in} < \frac{V_{sat} R}{R + R_f} \Rightarrow v_0 = +v_{sat}$$

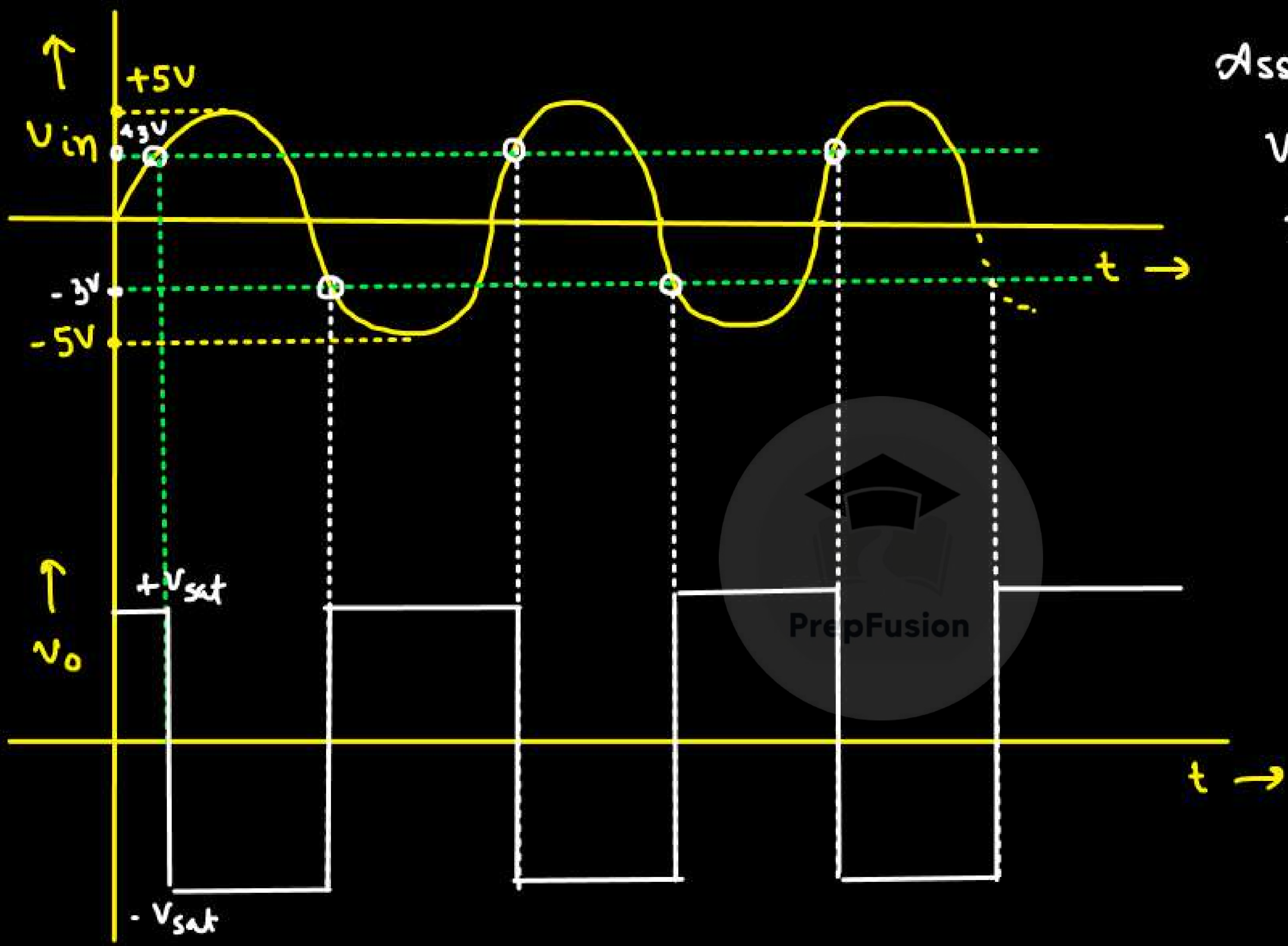
$$\boxed{\begin{array}{l} v_{in} < \beta V_{sat} \Rightarrow v_0 = +V_{sat} \\ v_{in} > \beta V_{sat} \Rightarrow v_0 = -V_{sat} \end{array}}$$

For Inverting schmitt trigger, the dir^n of Hysteresis is cw



$$V_{UTP} = +\beta V_{sat}$$
$$V_{LTP} = -\beta V_{sat}$$

$$V_H = 2\beta V_{sat} = \frac{2R}{R+R_f} V_{sat}$$

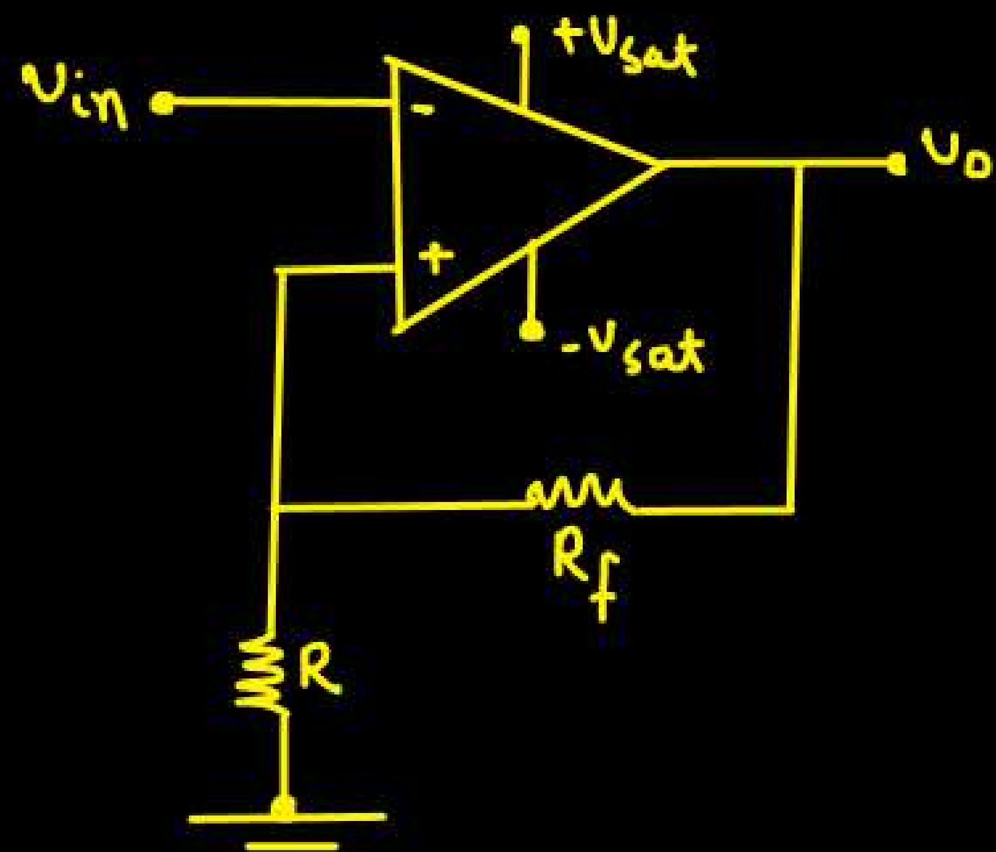


Assuming

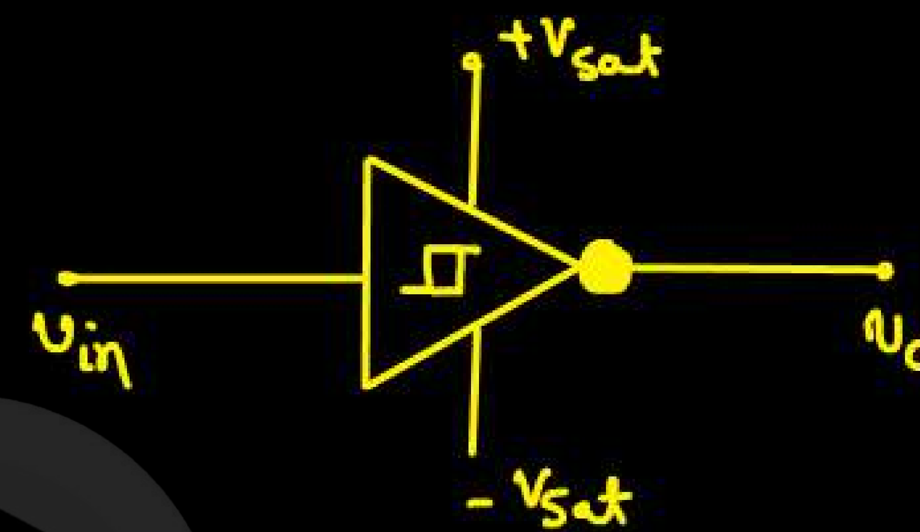
$V_{UTP} = 3V$

$V_{LTP} = -3V$

Inverting Schmitt Trigger:-



$\equiv$



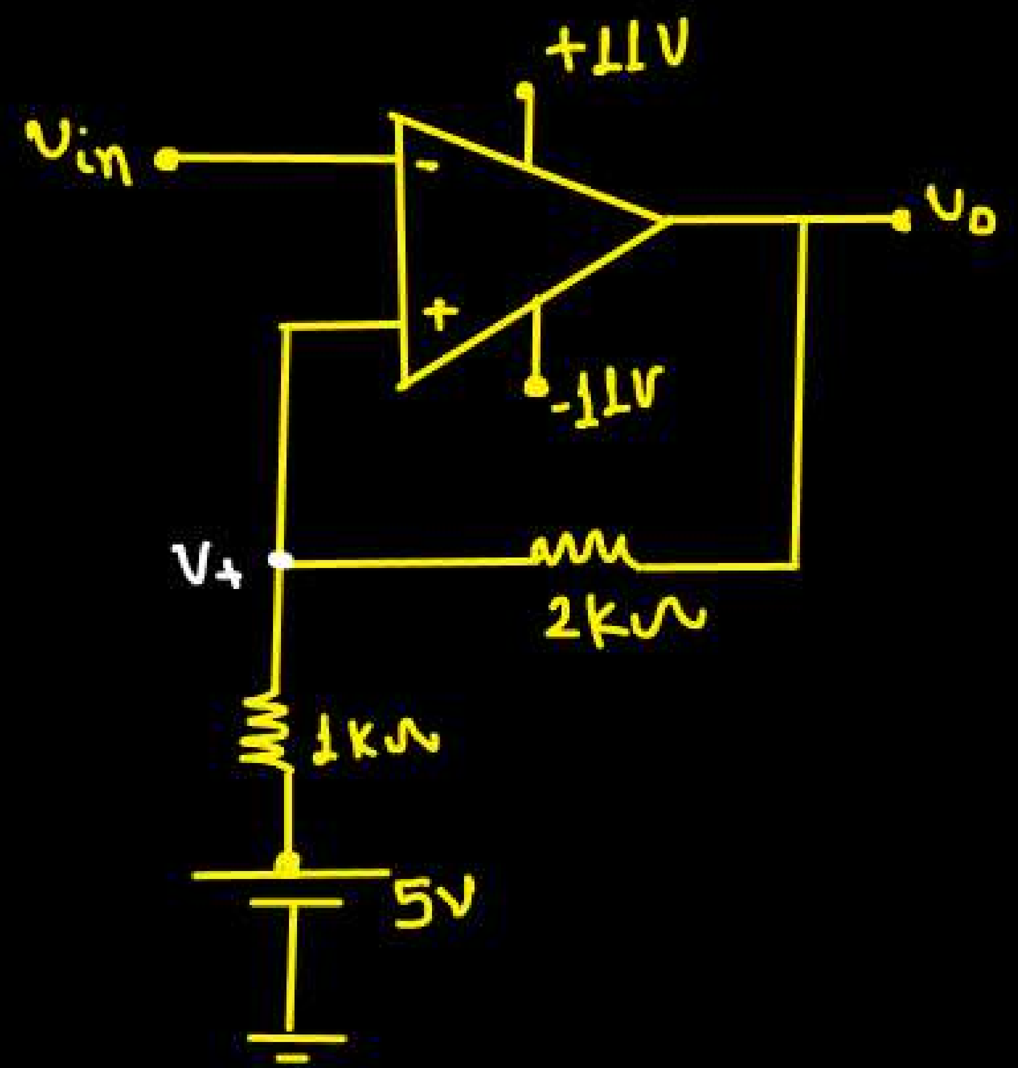
$\Rightarrow v_o = -V_{sat} \Rightarrow$ low

V_{UTP}

V_{LTP}

$\Rightarrow v_o = +V_{sat} \Rightarrow$ High

Q.



Draw Transfer characteristic.

Find V_{UTP}, V_{LTP}, V_H

→ Inverting schmitt trigger

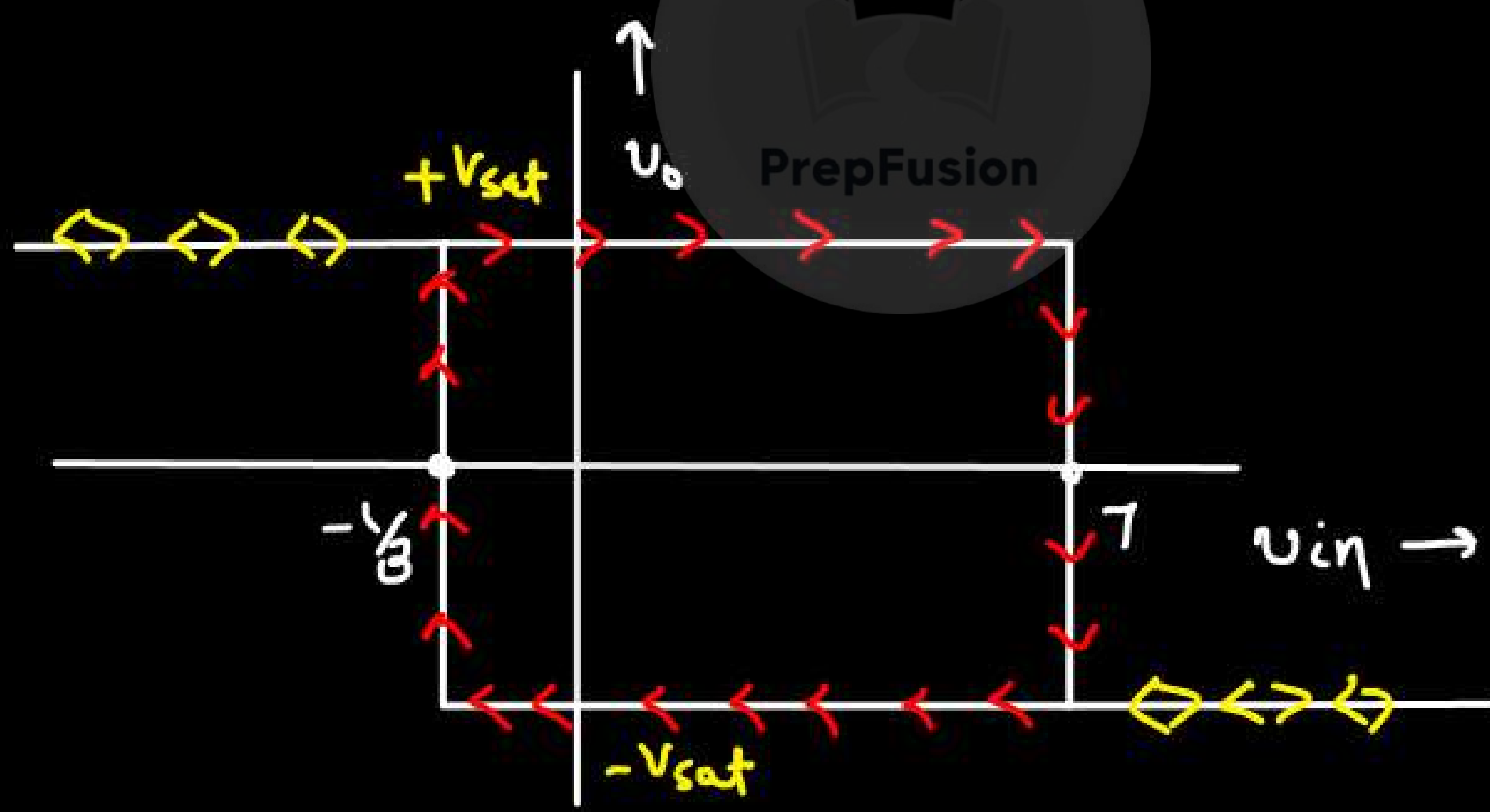
$$V_+ = \frac{10 + v_0}{3} \quad , V_- = v_{in}$$

$$v_{in} = \frac{10 + v_0}{3}$$

$$V_{UTP} = \frac{10 + 11}{3} = 7\,V$$

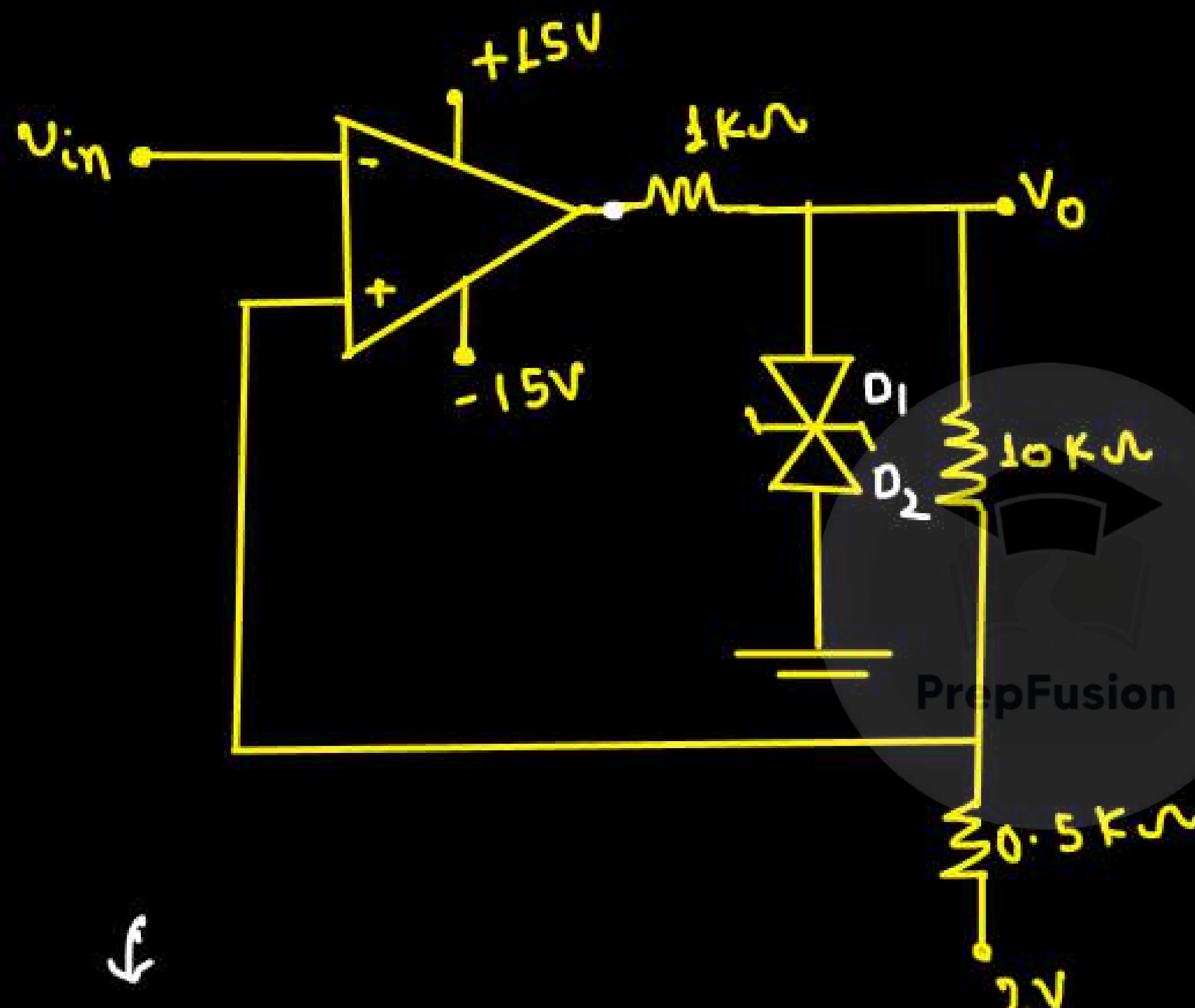
$$V_{LTP} = \frac{10 - 11}{3} = -\frac{1}{3}\,V$$

$$V_H = V_{UTP} - V_{LTP}$$
$$= 7 + \frac{1}{3} = 7.33\,V$$



Assignment - 16

Q.

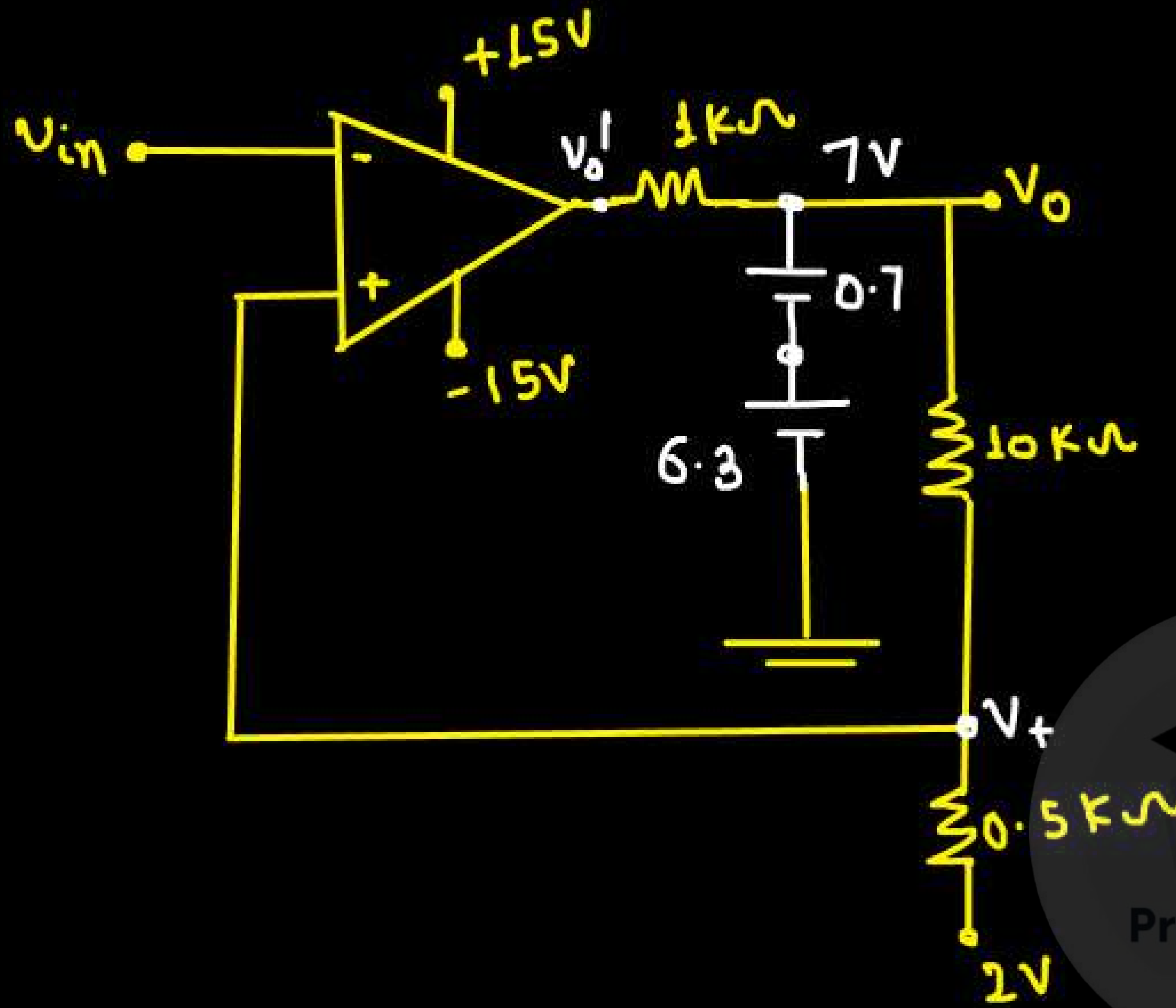


$v_z = 6.3V$

$v_\gamma = 0.7V$

Draw Transfer characteristics and find Hysteresis width.

Inverting Schmitt trigger



if $V_0' = +15V$

$$v_x = \frac{15 \times 10.5 + 2 \times 1}{11.5}$$

$= 13.86\,V$

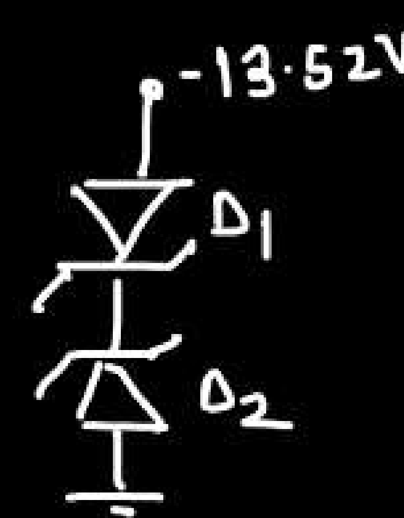
$\Rightarrow$ Zener D_1 goes into f.B.

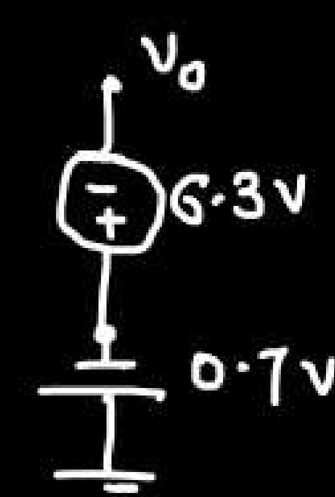
D_2 goes into B.D.

$\Rightarrow \boxed{v_0 = +7V}$

if $V_0' = -15V$

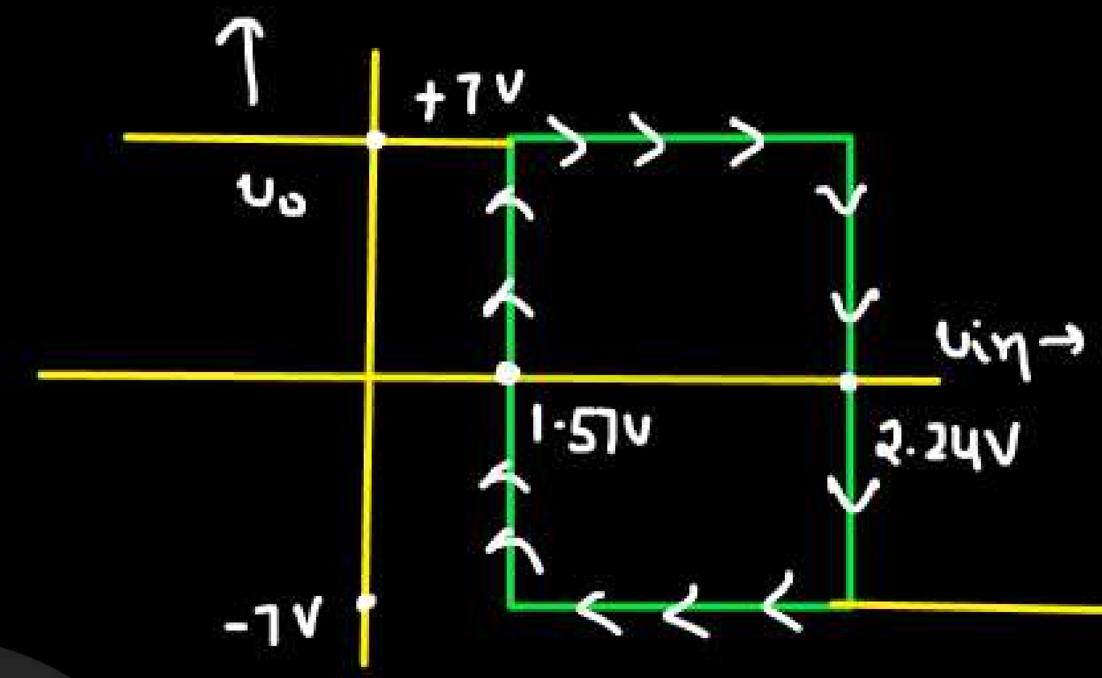
$$V_x = \frac{-15 \times 10.5 + 2 \times 1}{11.5} = -13.52\,V$$





$\boxed{v_0 = -7V}$

$$v_+ = \frac{v_o(0.5) + 2\times 10}{10.5}$$



$$v_- = v_{in}$$

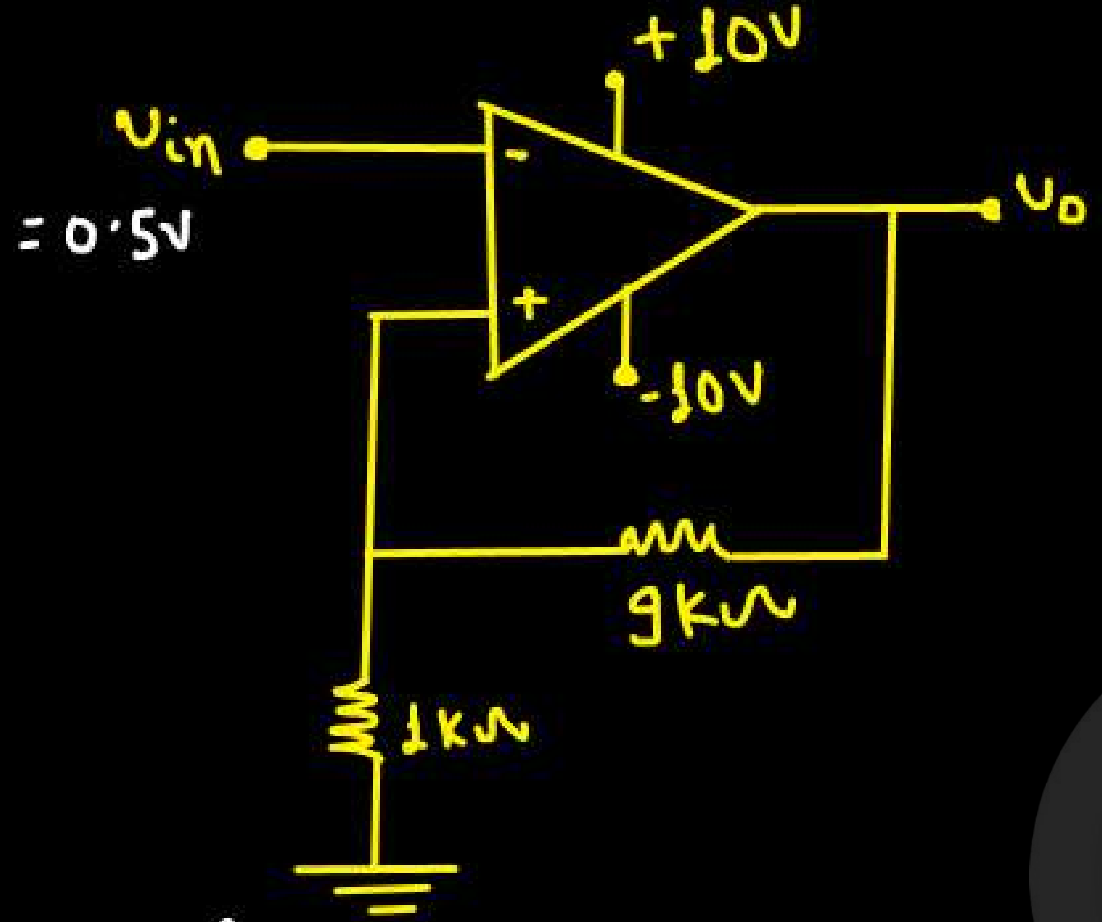
$$v_{in} = \frac{v_o/2 + 20}{10.5}$$

when $v_o = +7V \Rightarrow V_{UTP} = \frac{3.5+20}{10.5} = 2.24\,V$

$v_o = -7V \Rightarrow V_{LTP} = \frac{-3.5+20}{10.5} = 1.57\,V$

$$\boxed{V_H = 0.69V}$$

Q.



v_{in} is gradually increasing from 0 to 10V.

v_o will change from

(a) −10V to +10V, when $v_i = -1V$

(b) −10V to +10V, when $v_i = 1V$

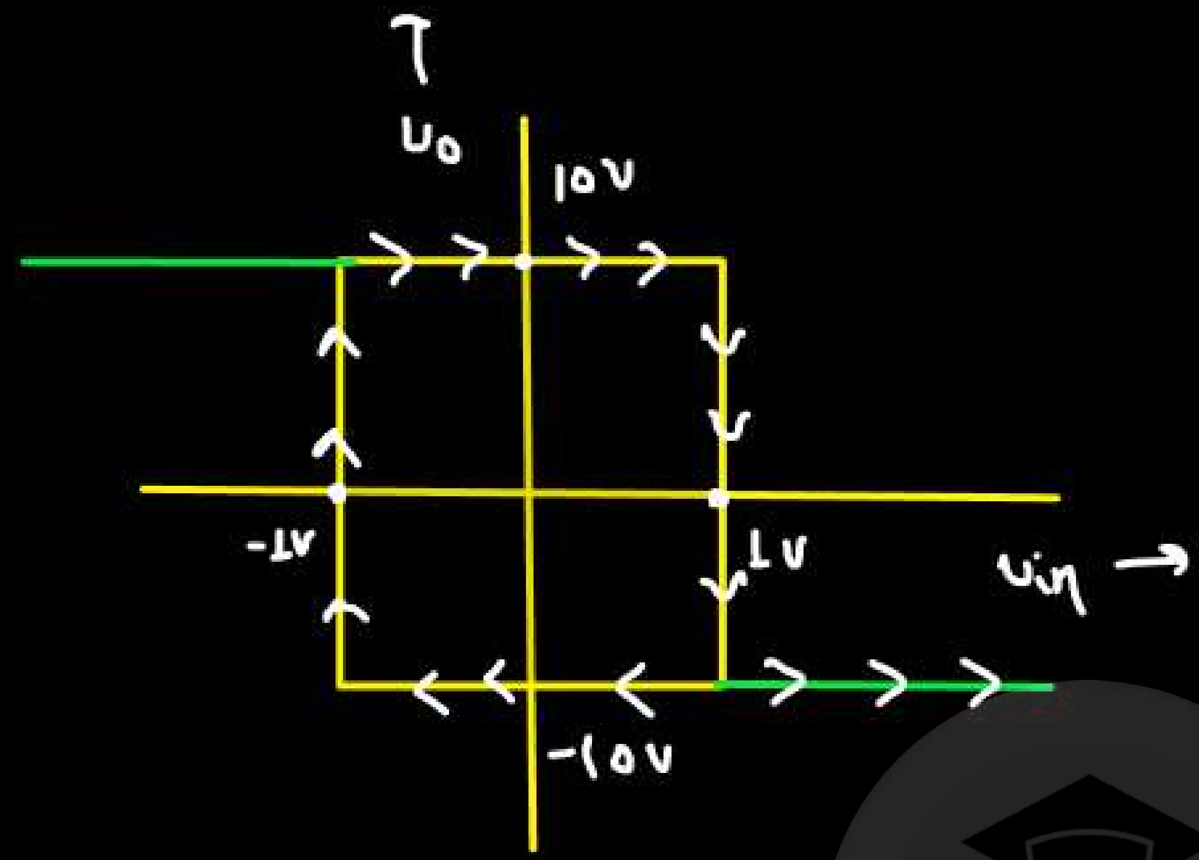
(c) +10V to −10V, when $v_i = 1V$

(d) +10V to −10V, when $v_i = -1V$

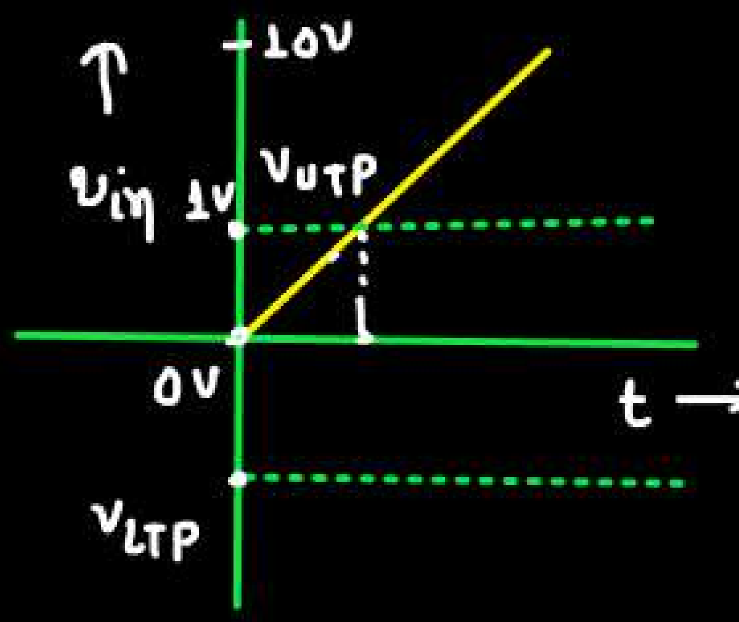
→ Inverting Schmitt trigger

$$V_+ = \frac{V_o}{10}, \quad V_- = V_{in}$$

$\boxed{V_{UTP} = 1V}$, $\boxed{V_{LTP} = -1V}$

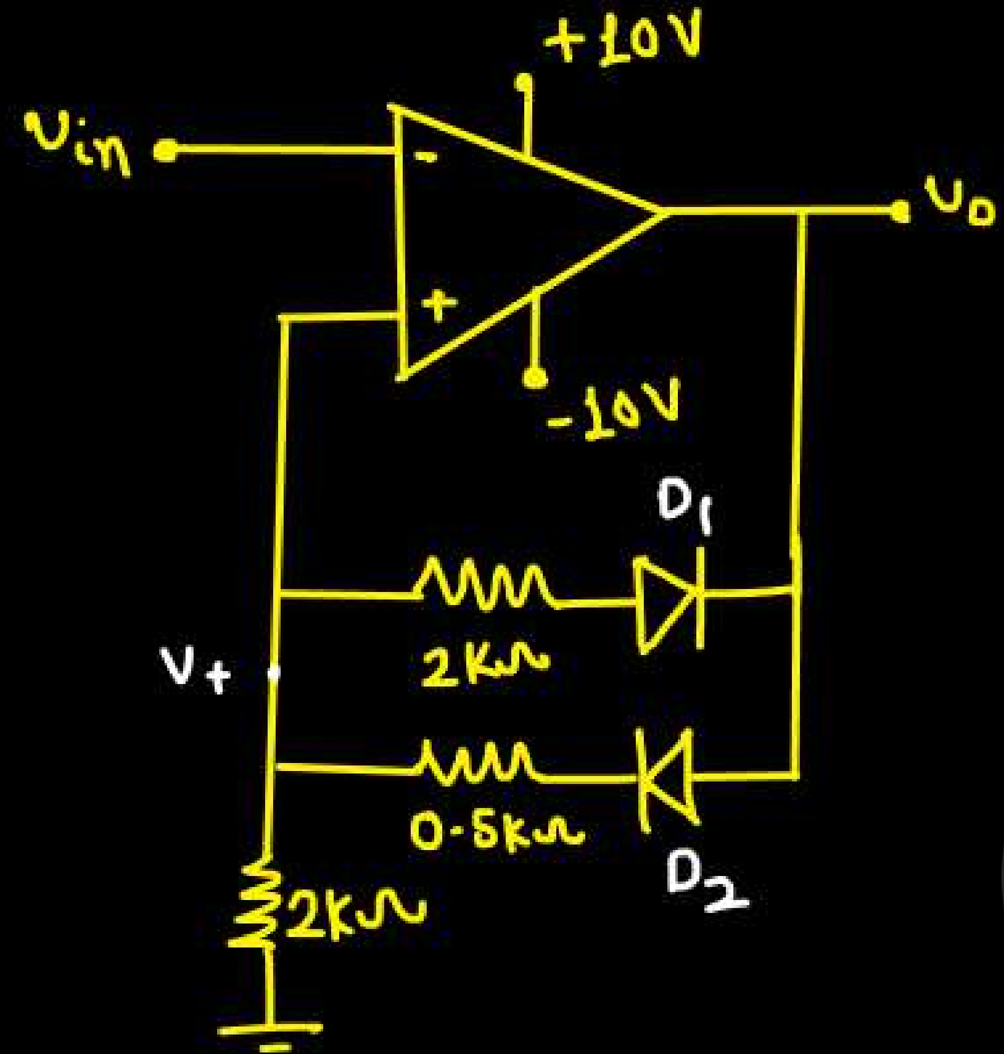


v_o
10V
-1V
1V
v_{in}
-10V



10V
v_{in} 1V
V_{UTP}
0V
t
V_{LTP}

Q.



Considering diodes are ideal.

Find Hysteresis width.

$\Rightarrow$ if $v_o = +10V \Rightarrow D_2$ ON, D_1 off

$$v_+ = \frac{2}{2.5} \times 10 = 8V \longrightarrow V_{UTP}$$

if $v_o = -10V \Rightarrow D_1$ ON, D_2 off

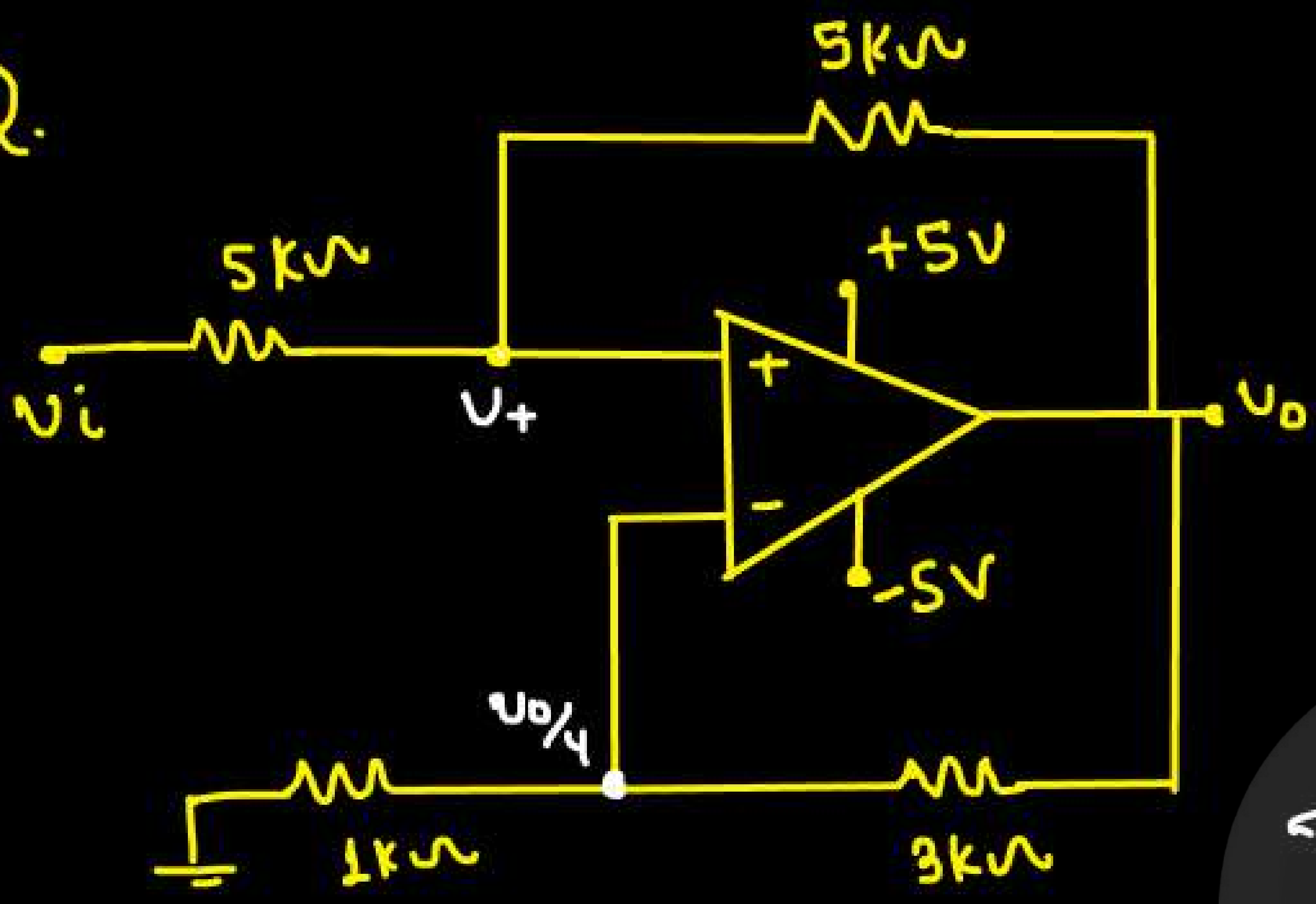
$$V_+ = \frac{2}{4} \times (-10) = -5V \longrightarrow V_{LTP}$$

$V_{UTP} = 8V$

$V_{LTP} = -5V$

$\boxed{V_H = 13V}$ Ans.

Q.



Draw Transfer characteristics.

$\boxed{\text{Non-inverting Schmitt trigger}}$

→ $V_+ = V_o/2$ $\quad V_- = \frac{V_o}{4}$

$\Rightarrow$ positive f/b

$$V_+ = \frac{V_i(5) + V_o(5)}{10} = \frac{V_i + V_o}{2}$$

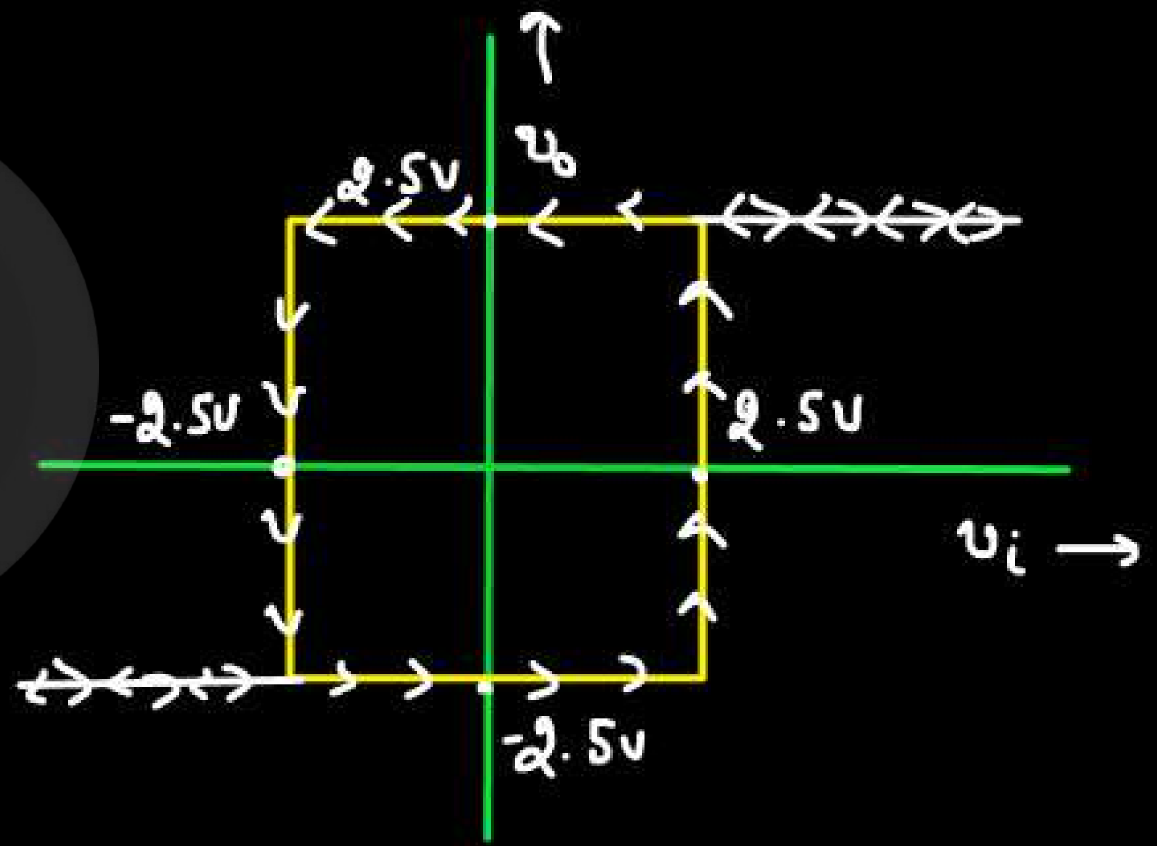
$$V_+ = V_-$$

$$\frac{v_i + v_0}{2} = \frac{v_0}{4}$$

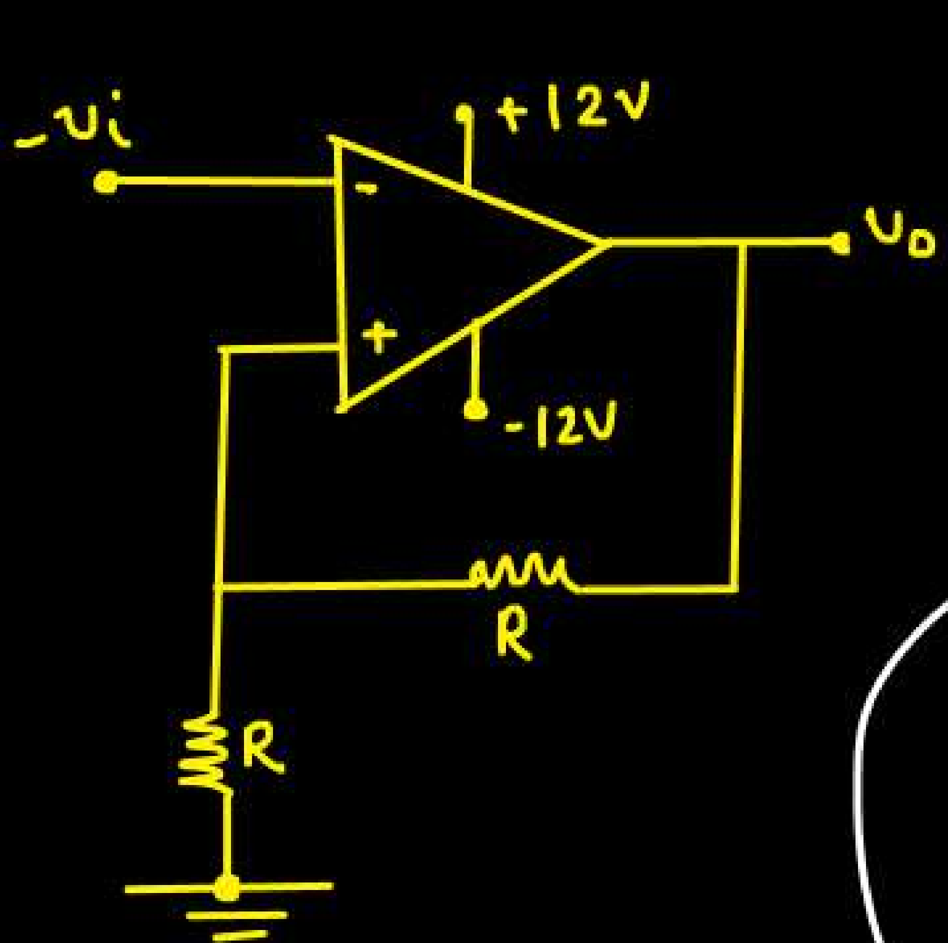
$$v_i = -\frac{v_0}{2}$$

$v_0 = +5V$, $V_{LTP} = -5/2 = -2.5V$

$v_0 = -5V$, $V_{UTP} = 5/2 = 2.5V$



Q.



$-v_{in} = \text{High} \Rightarrow v_0 = \text{Low}$

$v_{in} = \text{low} \Rightarrow v_0 = \text{low}$

$v_{in} = \text{High} \Rightarrow v_0 = \text{High}$

Draw Transfer characteristics v_0 v/s v_i.

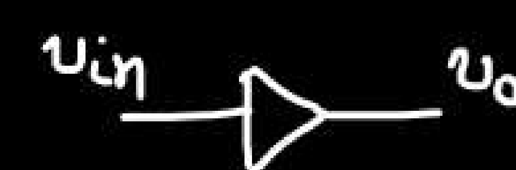
w.r.t. $-v_{in} \Rightarrow$ Inverting Schmitt trigger

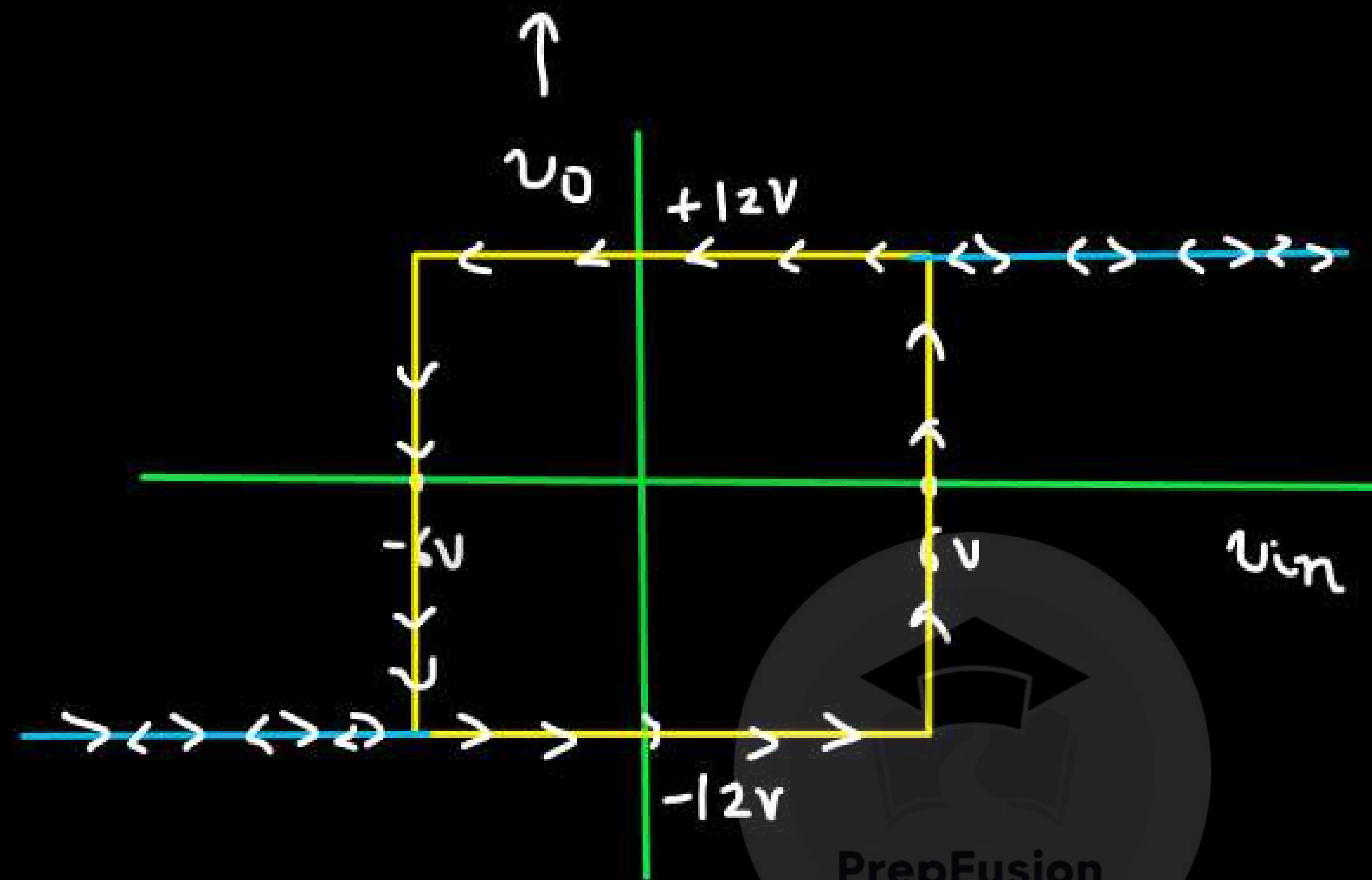
$\boxed{\text{w.r.t. } v_{in} \Rightarrow \text{Non-inverting " "}}$

$V_+ = v_0/2$, $v_- = -v_i$

$-v_i = v_0/2 \Rightarrow v_i = -v_0/2$

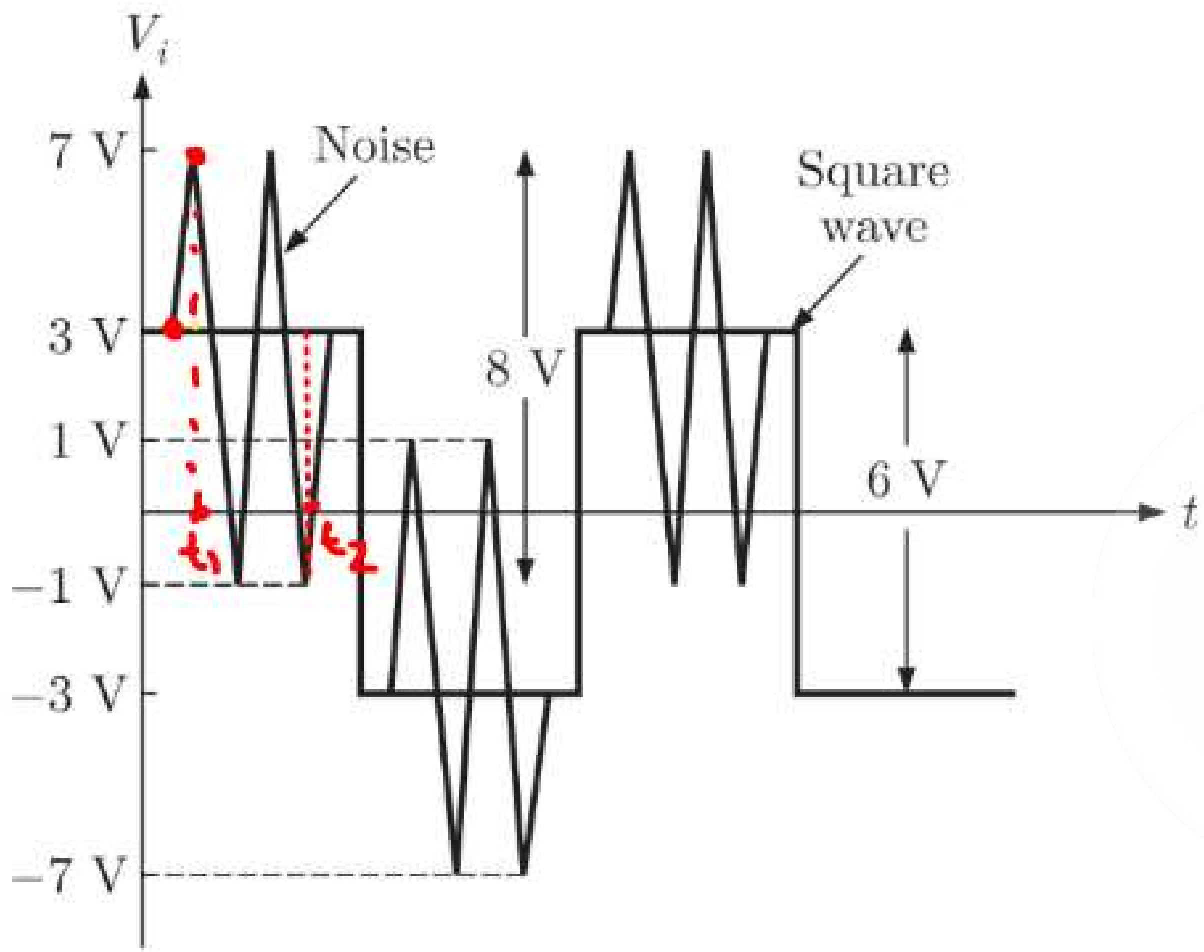
$$\boxed{\begin{array}{l} V_{UTP} = 6V \\ V_{LTP} = -6V \end{array}}$$




v_O
+12V
-6V
6V
v_{in}
-12V

Q.

The input signal shown in the figure below is fed to a Schmitt trigger. The signal has a square wave amplitude of 6 V p-p. It is corrupted by an additive by an additive high frequency noise of amplitude 8V p-p.



+ve cycle $\Rightarrow v_{in} : [2, 10]$

−ve cycle $\Rightarrow v_{in} : [-2, -10]$

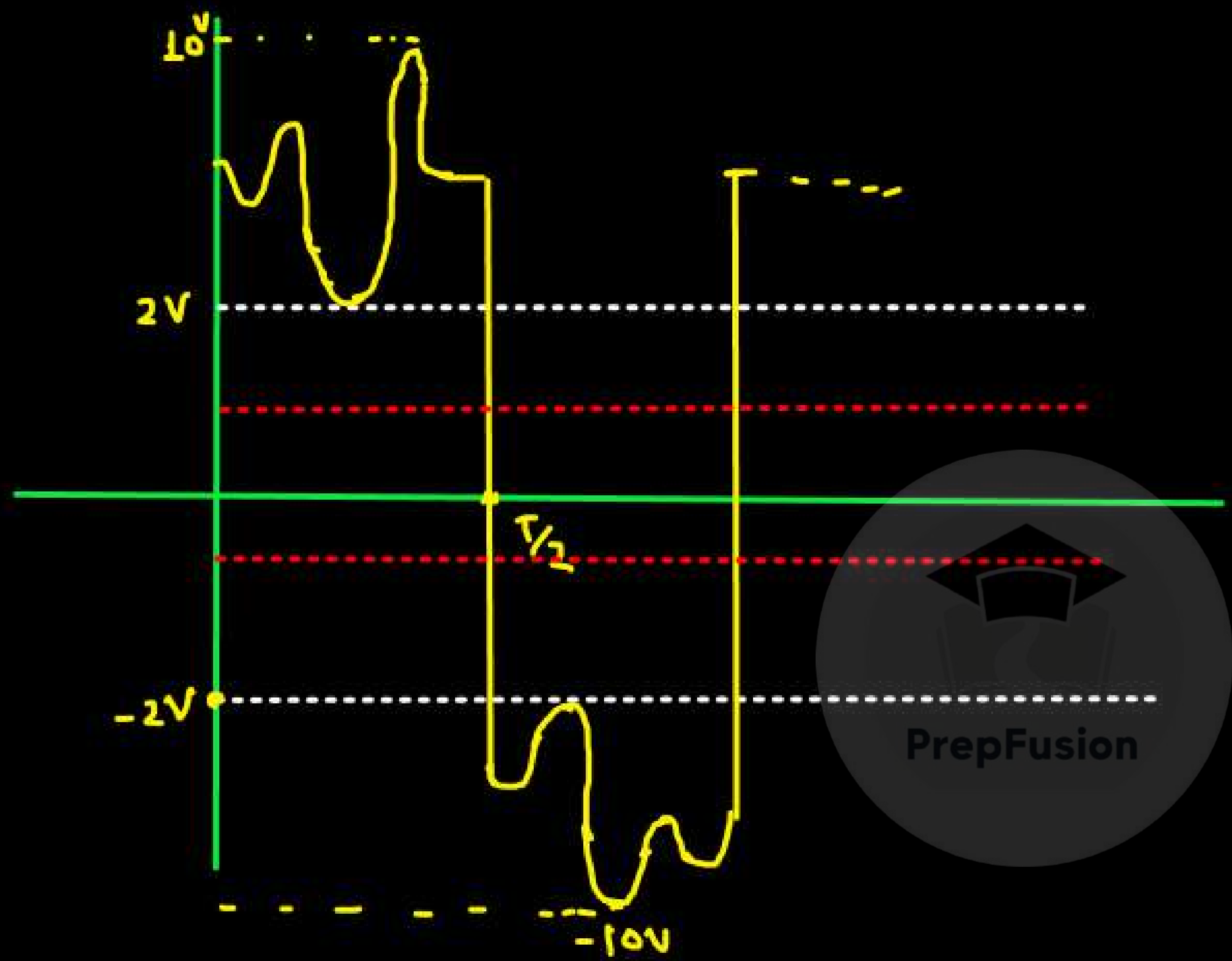
$v_{in}(t = t_1) = 7 + 3$
$= 10\text{V}$

$v_{in}(t = t_2) = 3 - 1$
$= 2\text{V}$

Which one of the following is an appropriate choice for the upper and lower trip points of the Schmitt trigger to recover a square wave of the same frequency from the corrupted input signal V_i ?

~~(A)~~ ±8.0 V   (B) ±2.0 V

? (C) ±0.5 V   ? (D) 0 V



$V_{UTP} = +2V$

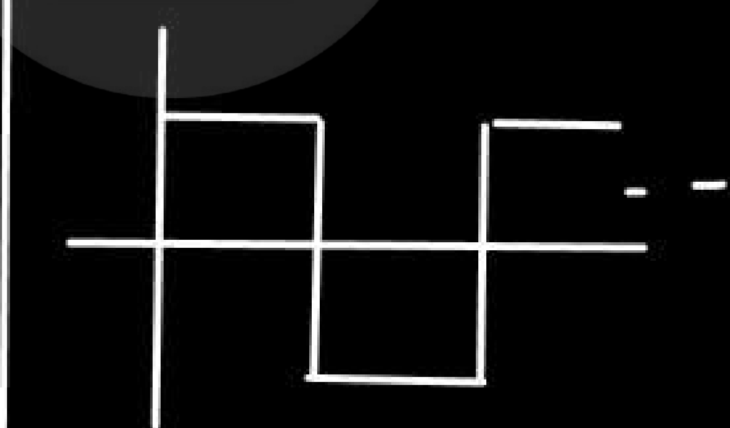
$V_{LTP} = -2V$

⇒ Concept of Multivibrators :-

Electronic circuits which are used to implement two state devices like oscillator, Timer and Flip-Flops.

- → Astable Multivibrators
- → Monostable
- → Bistable

→ Harmonic Oscillation (Sinusoid, Cosinusoid)

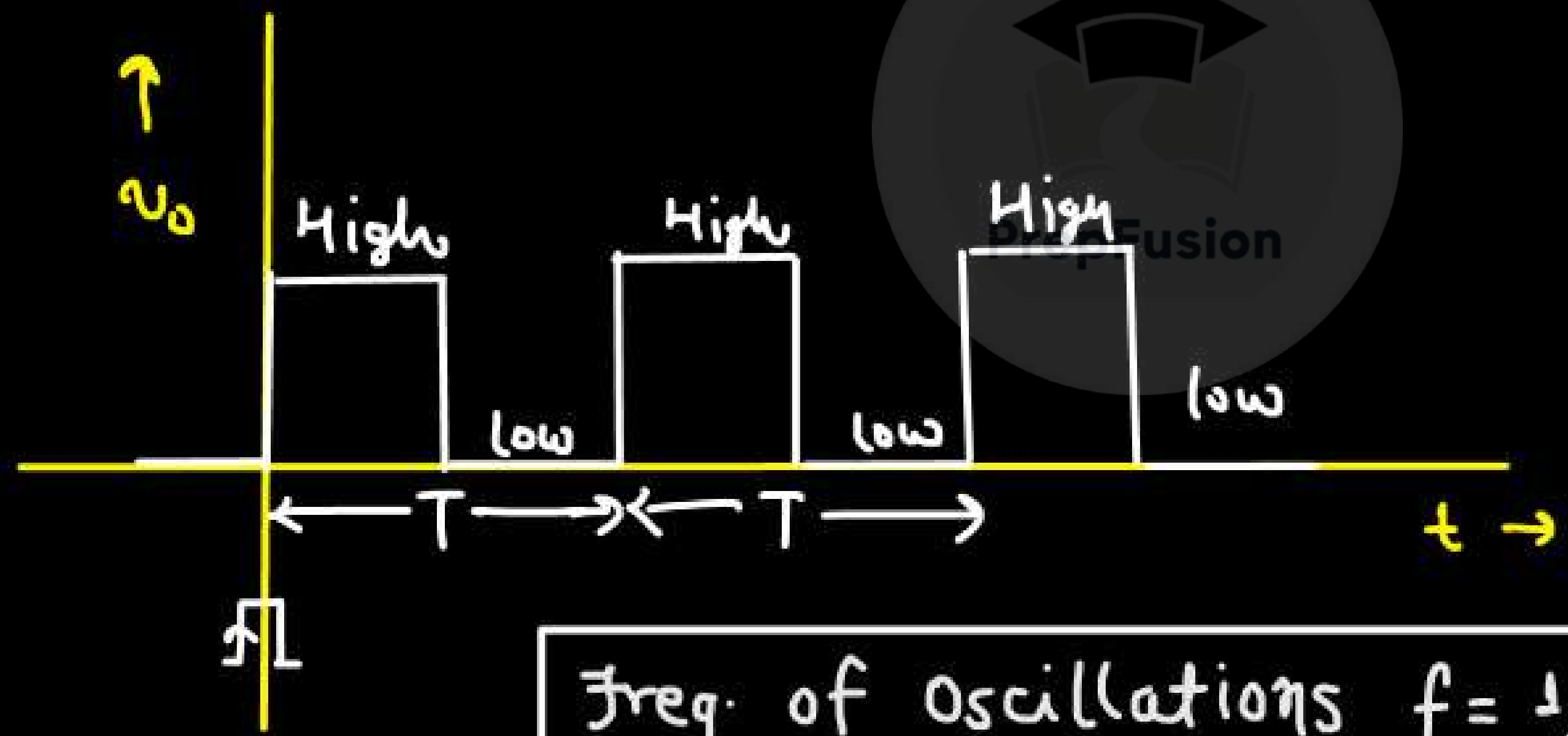


→ Relaxation Oscillation (Any oscillation which is not sinusoid / consinusoid)

N.B. →
we can generate Relax. osci. using Schmitt trigger.

☆ Astable Multivibrator :-

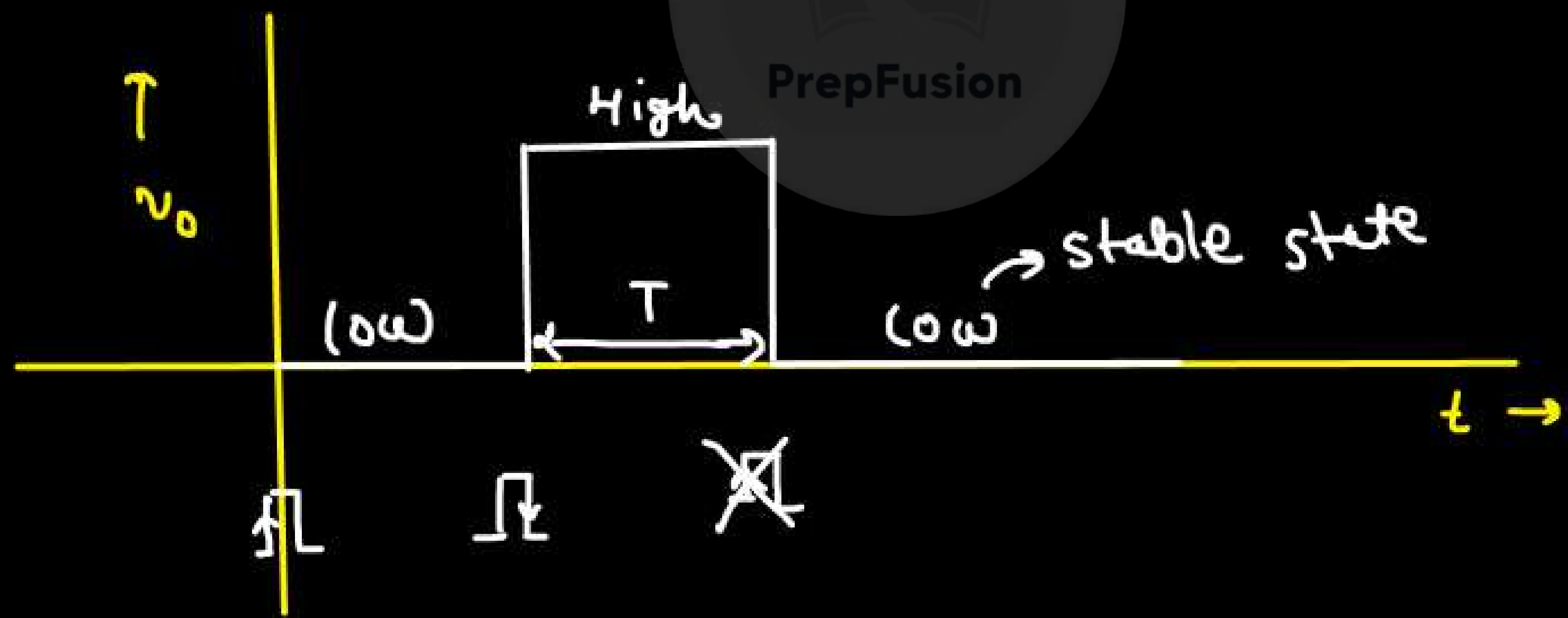
These are free running oscillators which oscillates b/w two states continuously producing two square-wave output waveforms.



$\boxed{\text{Freq. of Oscillations } f = 1/T}$

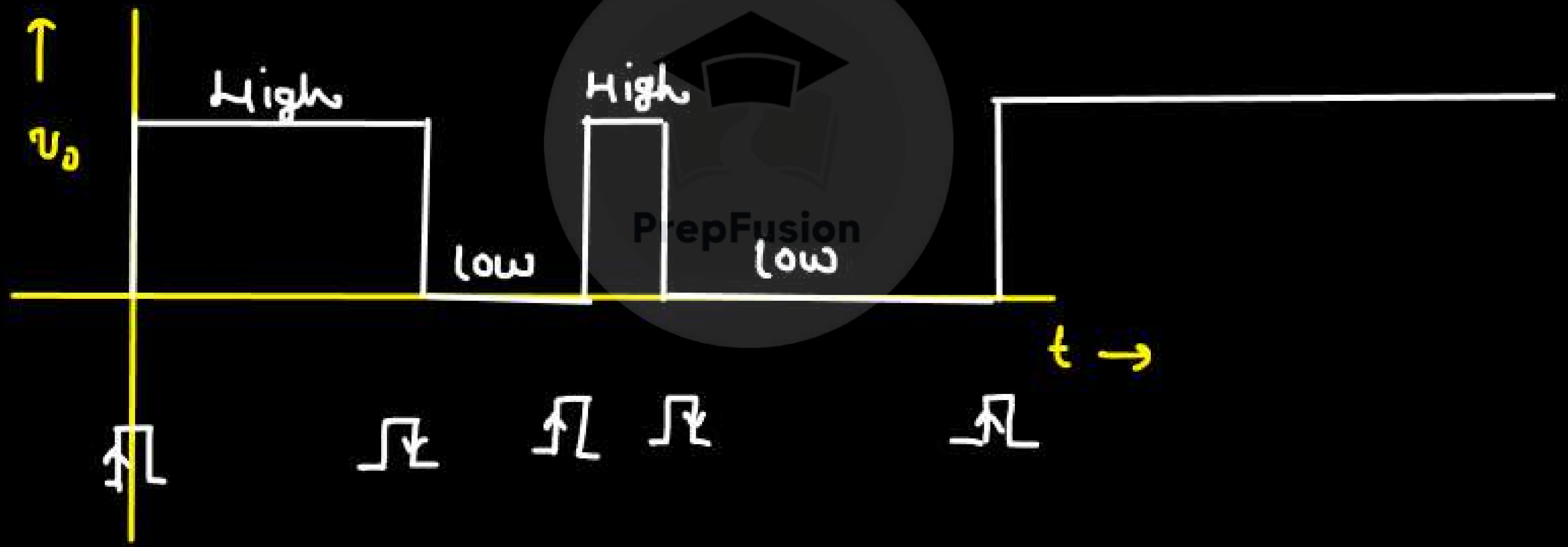
Monostable Multivibrators :-

They have one stable state and one monostable state, where a trigger (external signal) is required to enter the monostable state and return back to the stable state.

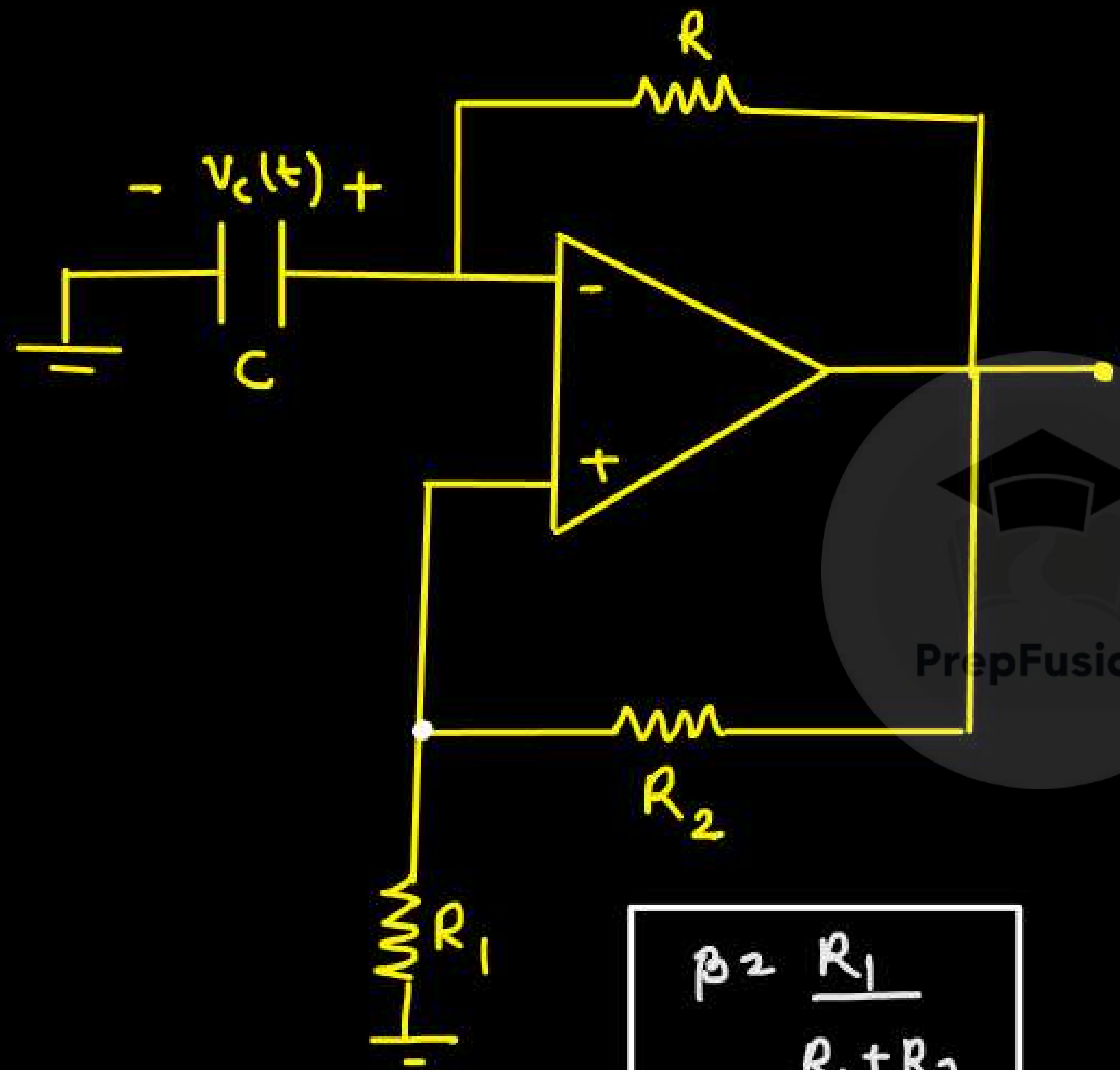


★ Bistable Multivibrator :-

It's a two stable state device where an external signal needs to be applied to change a particular state.



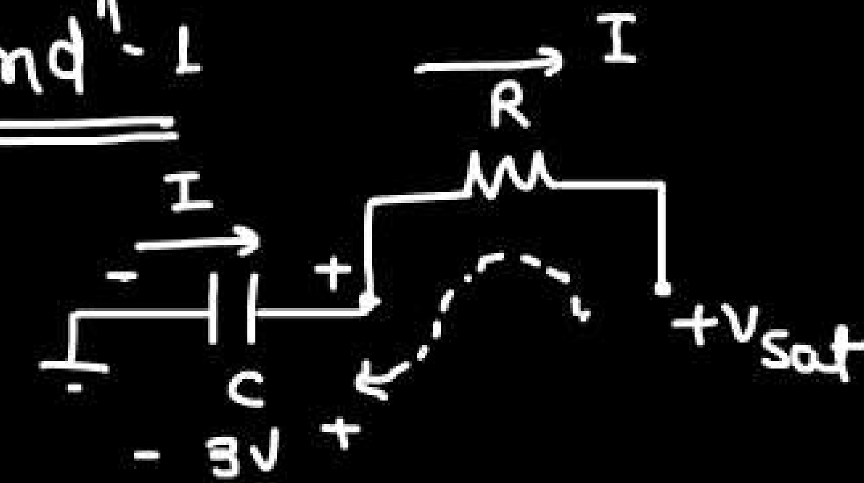
☆ Astable Multivibrator Using Schmitt trigger :-



$$\beta = \frac{R_1}{R_1 + R_2}$$

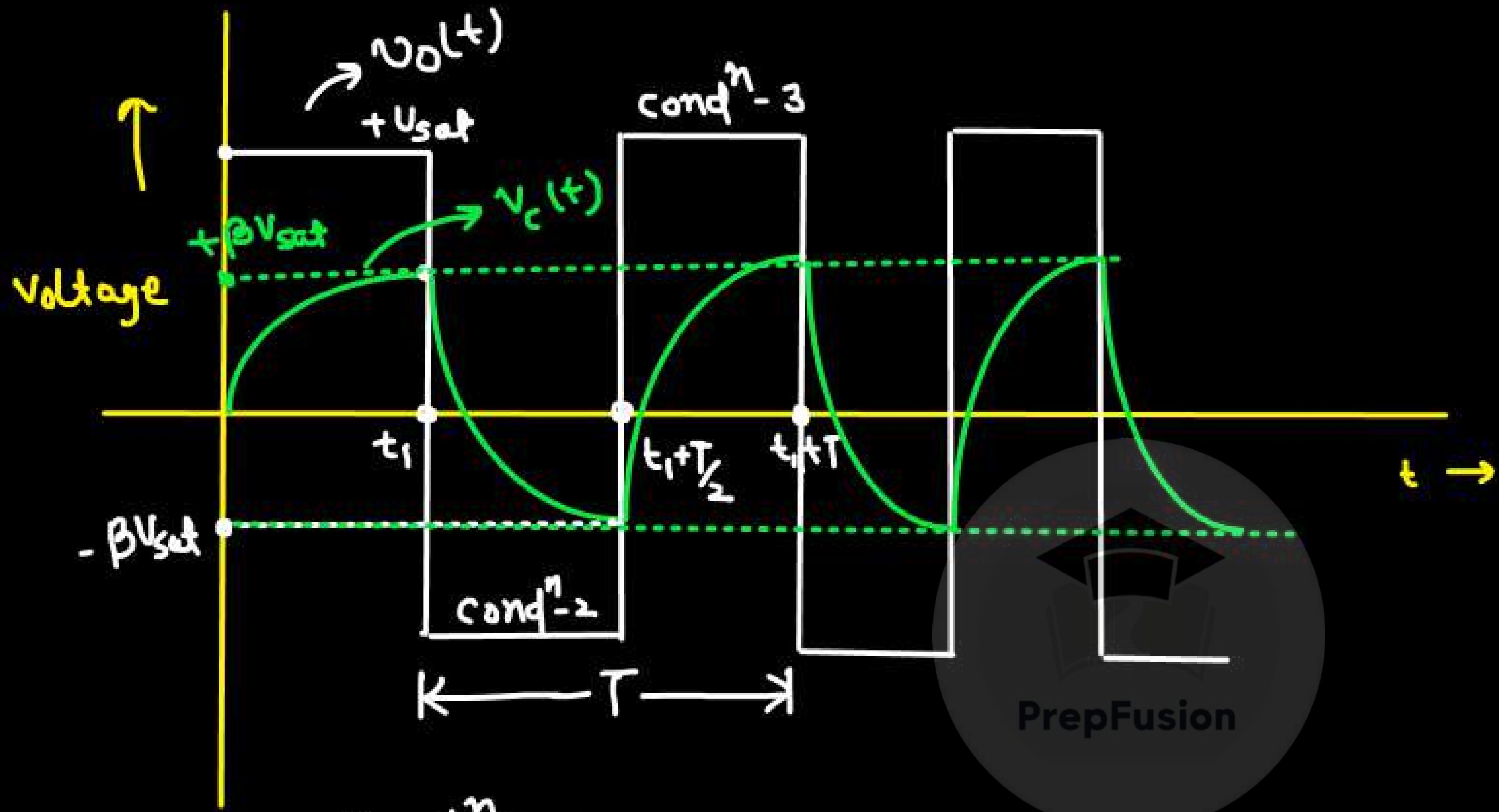
$-V_{sat} \rightarrow +V_{sat} \rightarrow -V_{sat}$

Cond^n - 1

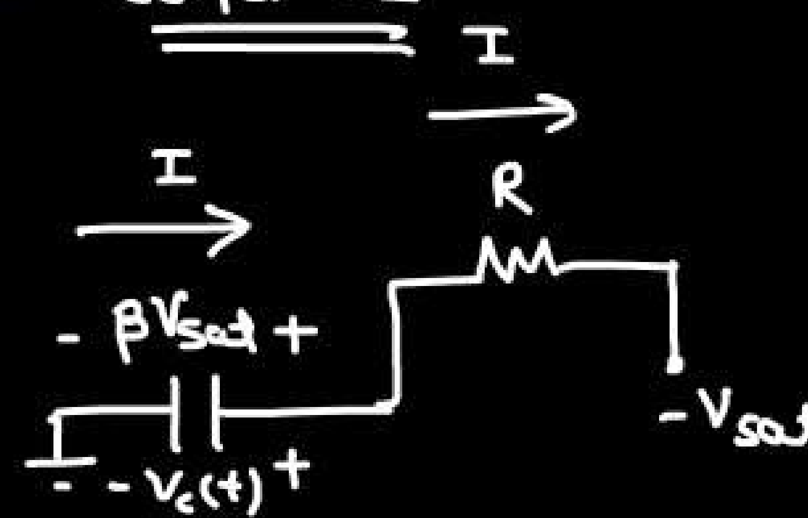


$V_c(0^-) = 0V$

$V_c(\infty) = +V_{sat}$



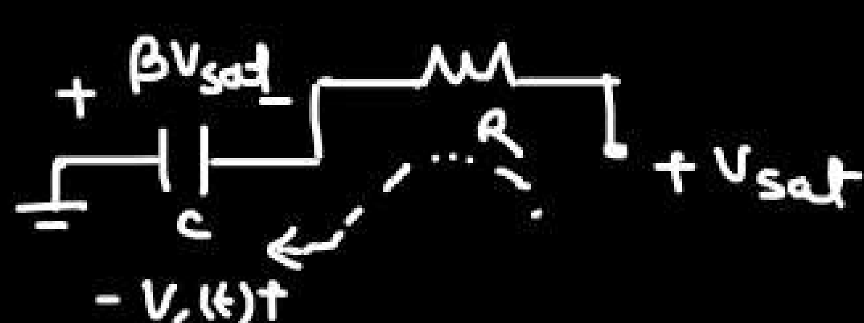
cond^n-2:-



$$V_c(t_1) = \beta V_{sat}$$

$$V_c(\infty) = -V_{sat}$$

Cond^n:-3

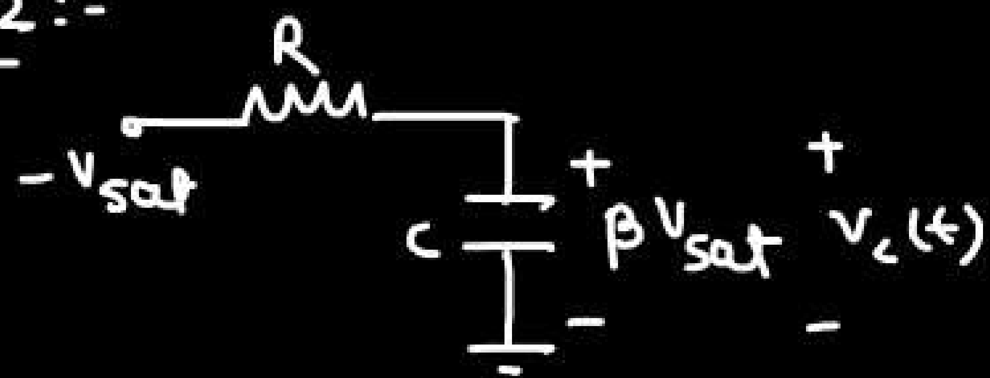


$$v_c(t_1+T/_2) = -\beta V_{sat} \ ; \ v_c(\infty) = +V_{sat}$$

How to find T → ?

$$\boxed{v_c(t) = \left[v_c(\infty) + \left[v_c(0^+) - v_c(\infty)\right] e^{-t/RC}\right] u(t)}$$

Cond^n 2:-



$$v_c(t_1) = \beta V_{sat}$$

$$v_c(\infty) = -V_{sat}$$

$$v_c(t) = -V_{sat} + (\beta V_{sat} + V_{sat}) e^{-(t-t_1)/RC}$$

But

$$@\ t = t_1 + T/2,\quad v_c(t_1 + T/2) = -\beta V_{sat}$$

$$-\beta V_{sat} = -V_{sat} + (\beta V_{sat} + V_{sat}) e^{-(t_1 + T/2 - t_1)/RC}$$

$$V_{sat}(1-\beta) = V_{sat}(1+\beta) e^{-T/2RC}$$

$$e^{-T/2RC} = \frac{1-\beta}{1+\beta}$$

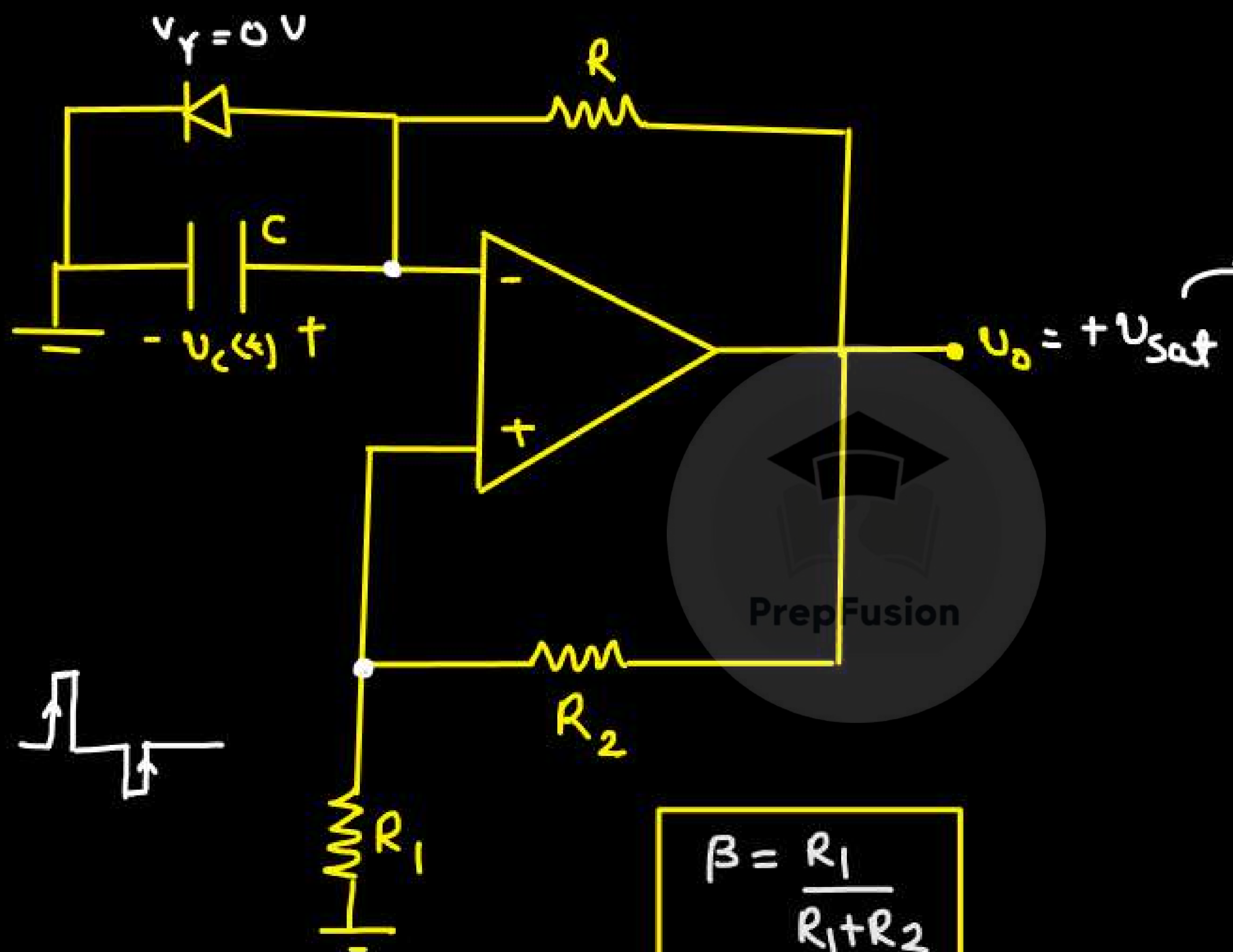
$$\frac{T}{2} = RC \ln\left(\frac{1+\beta}{1-\beta}\right)$$

★★

$$\boxed{T = 2RC \ln\left(\frac{1+\beta}{1-\beta}\right)} \qquad \boxed{\beta = \frac{R_1}{R_1+R_2}}$$

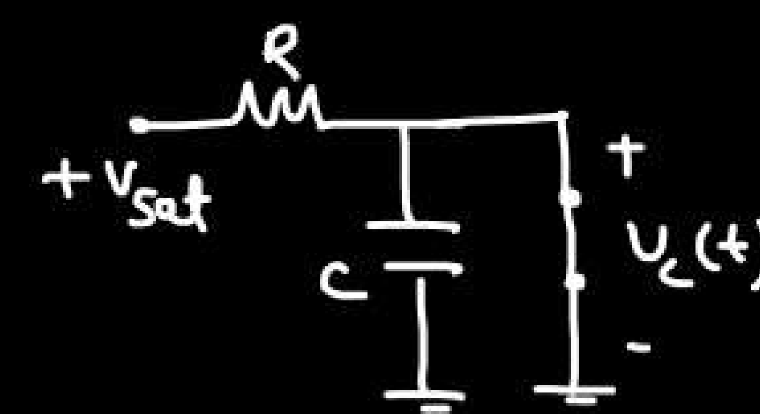
freq. of oscillation $\boxed{f = \frac{1}{T}}$

Monostable Multivibrator Using Schmitt trigger :-

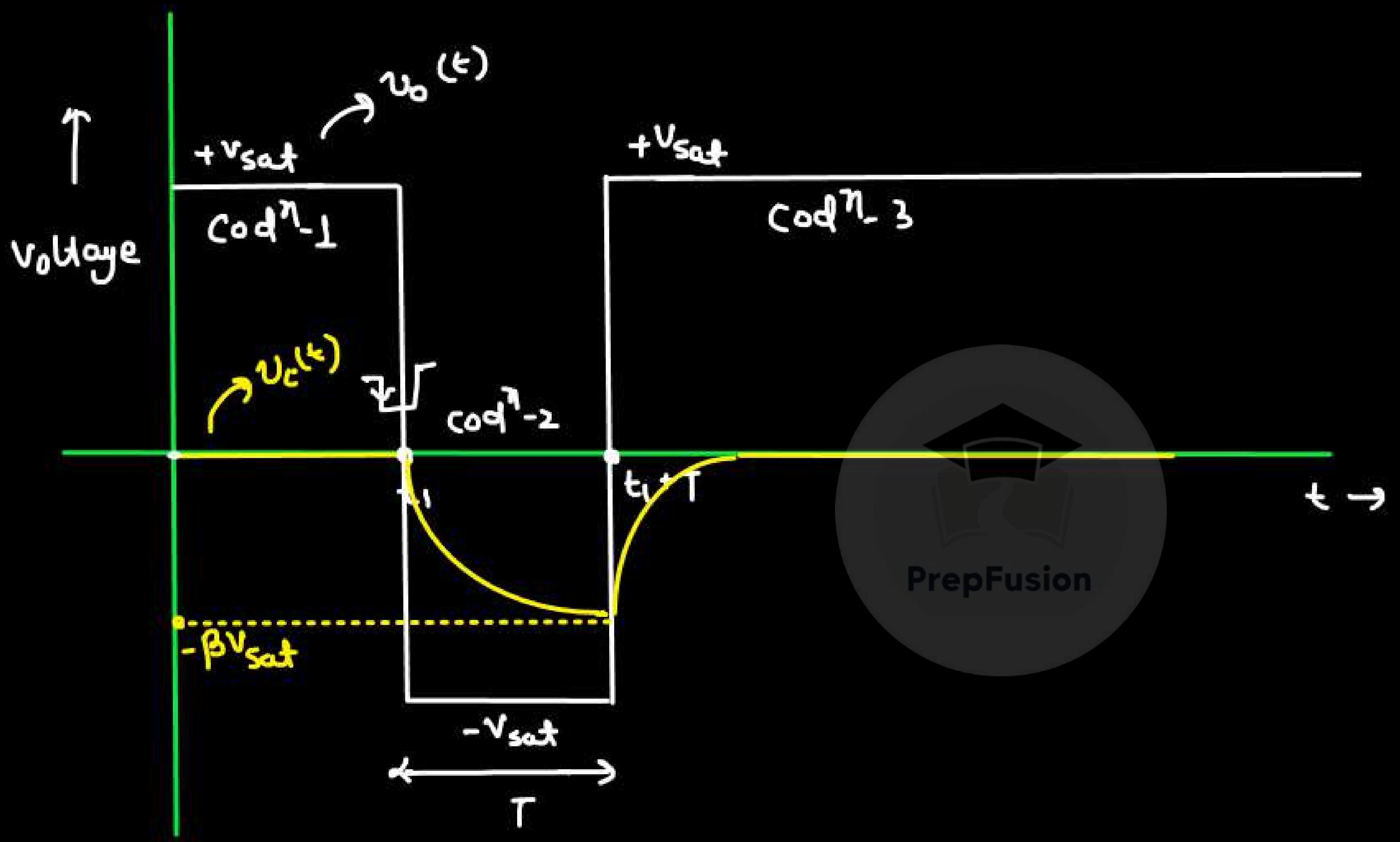


$$\boxed{\beta = \frac{R_1}{R_1+R_2}}$$

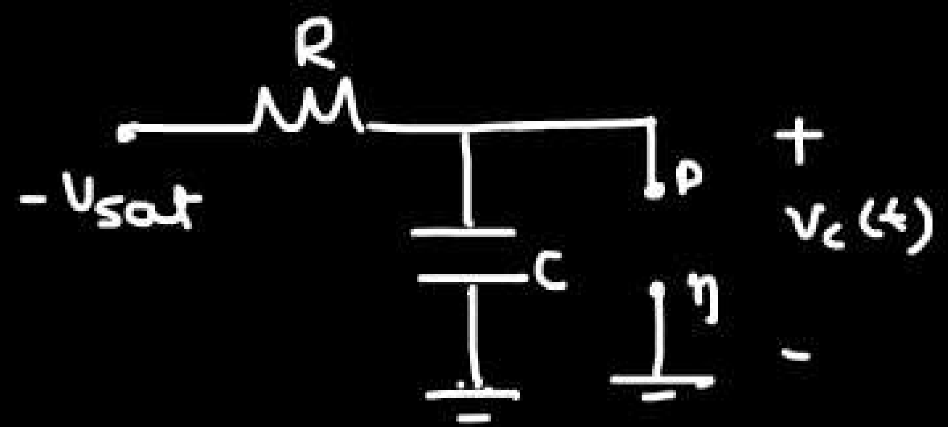
cond^n 1 :-



$v_c(t) = 0V$


Voltage
$v_o(t)$
$+v_{sat}$
$+V_{sat}$
Cod^n-1
Cod^n-3
$v_c(t)$
Cod^n-2
t_1
t_1+T
$t \rightarrow$
$-\beta V_{sat}$
$-V_{sat}$
T

cond^n 2 :-



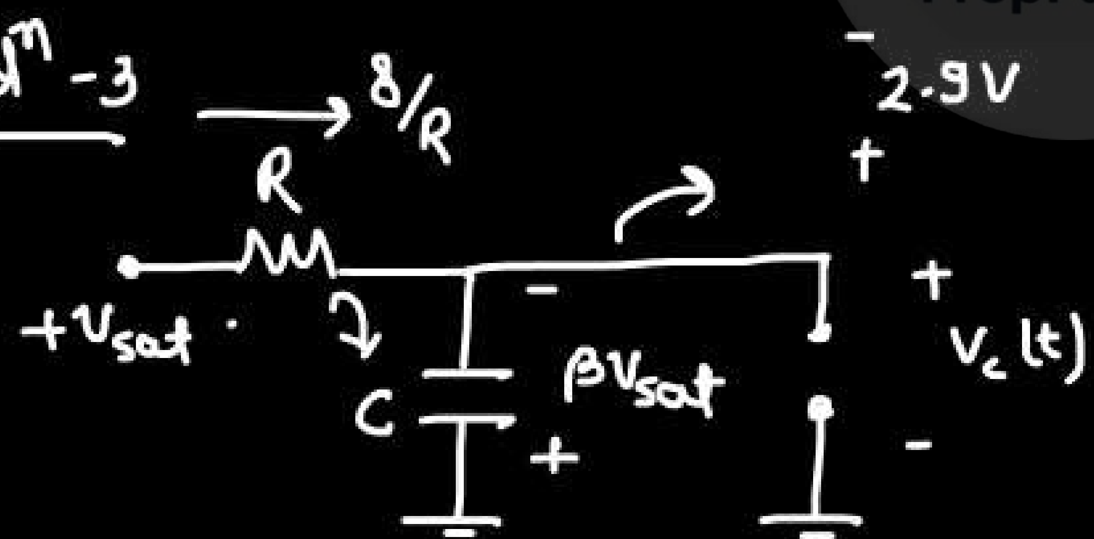
$$\boxed{V_+ = -\beta V_{sat}}$$

diode turned off

$$v_c(t_1) = 0\,V$$

$$v_c(\infty) = -V_{sat}$$

cond^n-3



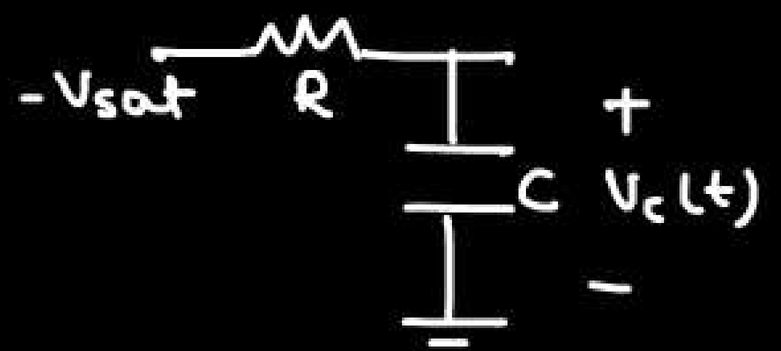
$$v_c(t_1 + T) = -\beta V_{sat}$$

$$v_c(\infty) = +V_{sat} \quad \times$$

when $v_c = 0V \Rightarrow$ diode will turn on

v_c potential remains at 0V only until some external Trigger makes o/p to go to $-V_{sat}$.

Pulse width (T) of Astable Multivibrator:-



$$V_c(t_1) = 0\,V$$

$$V_c(\infty) = -V_{sat}$$

$$V_c(t) = -V_{sat}\left[1 - e^{-(t-t_1)/RC}\right]$$

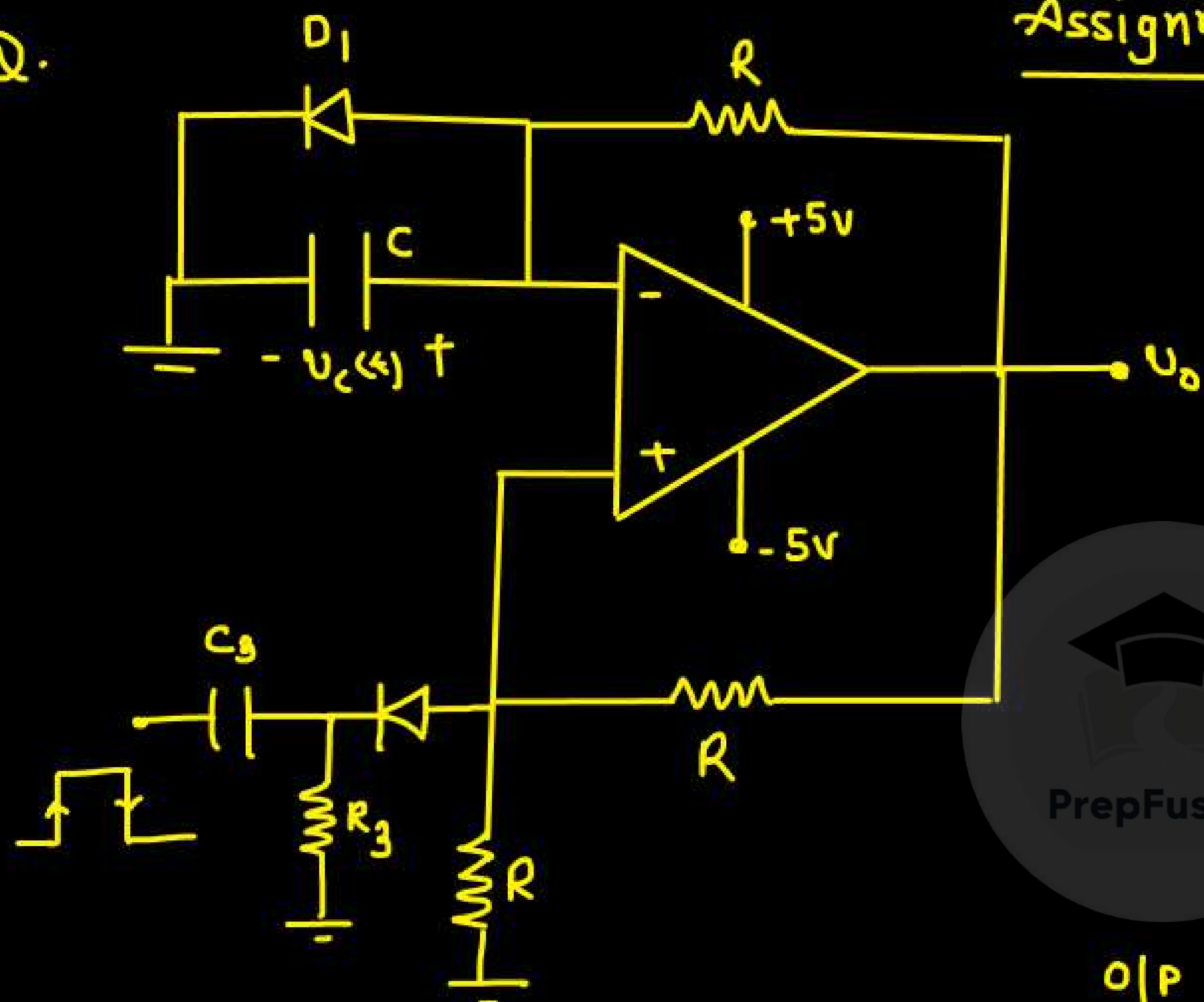
@ $t = t_1 + T$, $V_c(t_1+T) = -\beta V_{sat}$

$$-\beta V_{sat} = -V_{sat}\left[1 - e^{-(t_1+T-t_1)/RC}\right]$$

☆☆ $$\boxed{T = -RC\ln(1-\beta)}$$

$$\boxed{\beta = \frac{R_1}{R_1+R_2}}$$

Q.



Assignment-17

Given that

R_3C_3 value is very small.

$R = 1K\Omega$, $C = 1\mu F$

diode D_1 has $\boxed{V_\gamma = 0.7V}$

O/P will be there in unstable state for ____

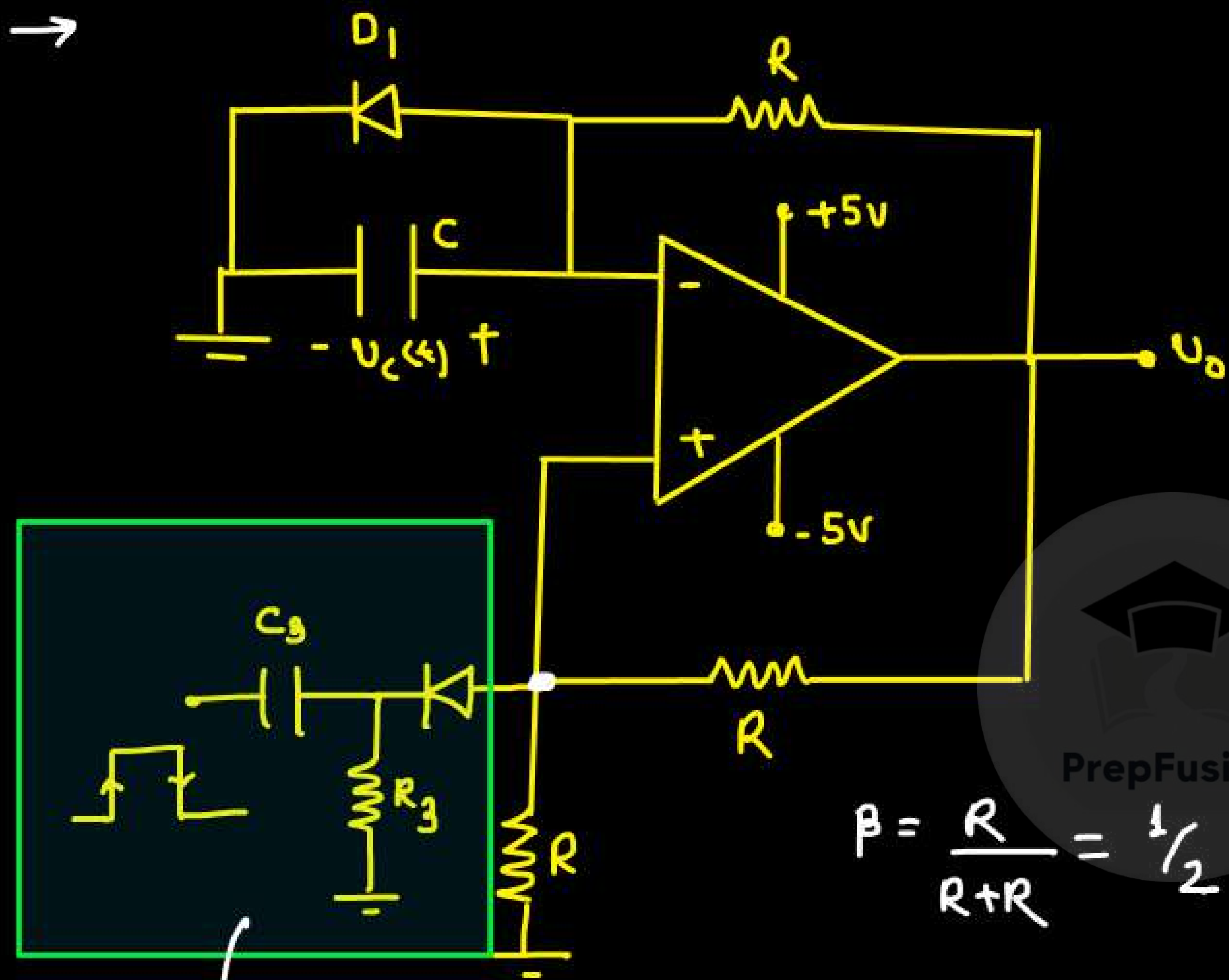
(a) 0.693 ms

(b) 0.724 ms

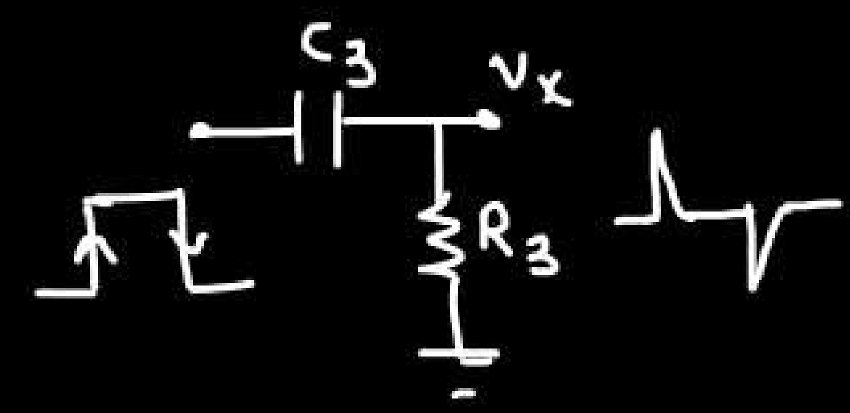
(c) 0.824 ms

(d) 0.937 ms

→



For producing the trigger



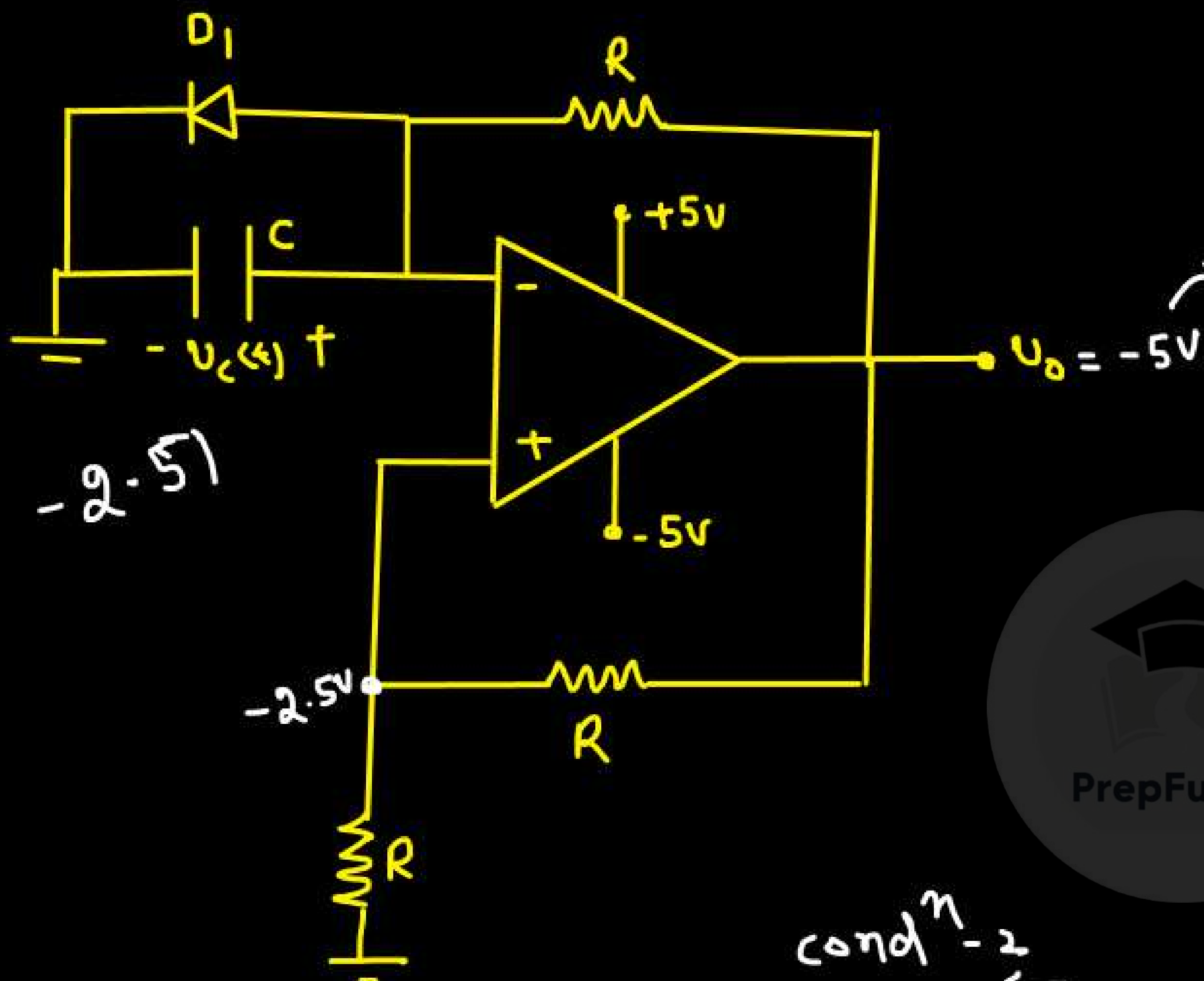
$$\beta = \frac{R}{R+R} = \frac{1}{2}$$

$$T = -RC \ln(1-\beta)$$

$$= -1m \ln\left(1-\frac{1}{2}\right)$$

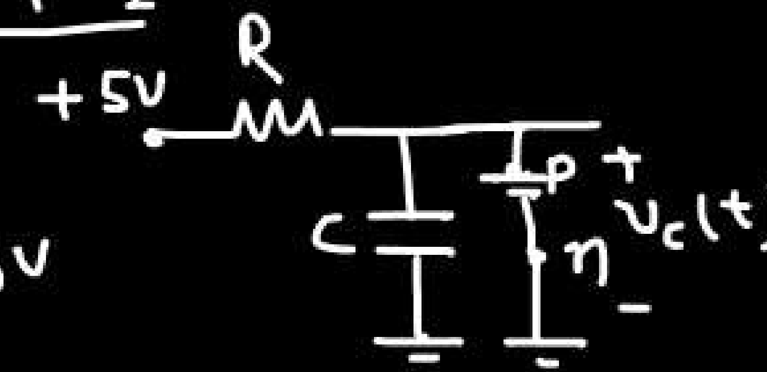
$$= 1m \ln(2)$$

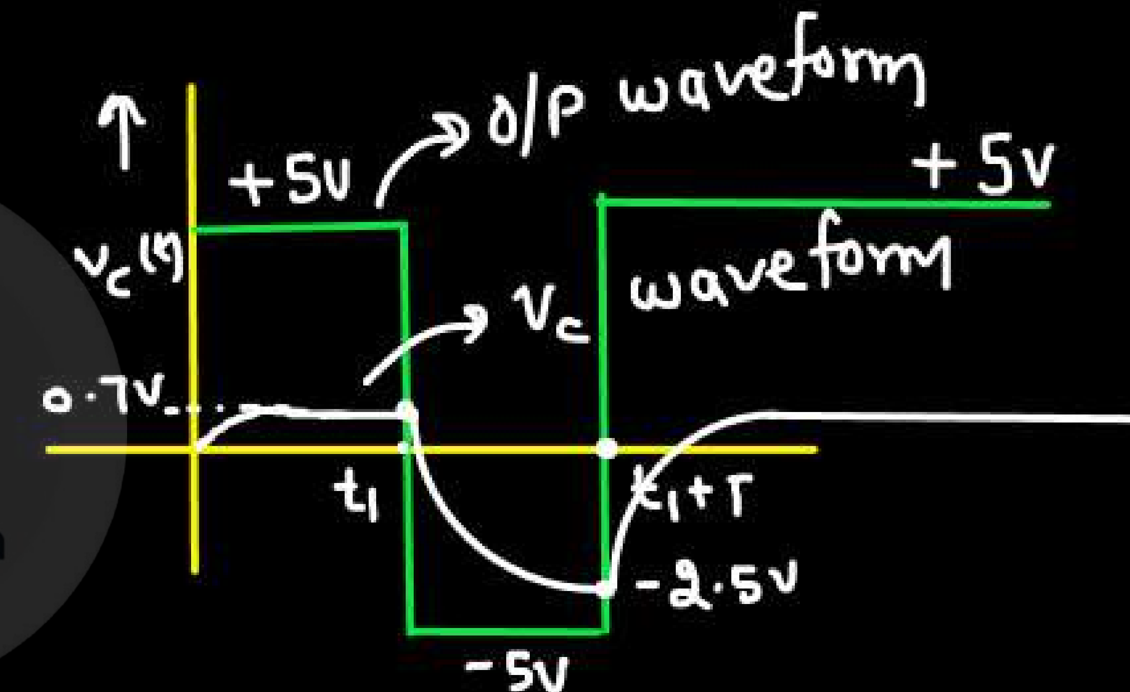
$$T = 0.693\,ms$$



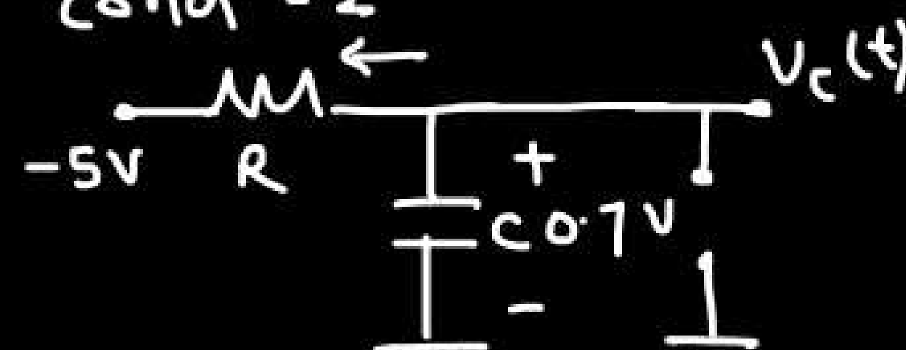
-2.51

cond^n-1





cond^n-2



$$\boxed{v_c(t) = -5 + 5.7\, e^{-(t-t_1)/RC}}$$

$v_c(t_1) = 0.7\,V\ ,\qquad v_c(\infty) = -5V$

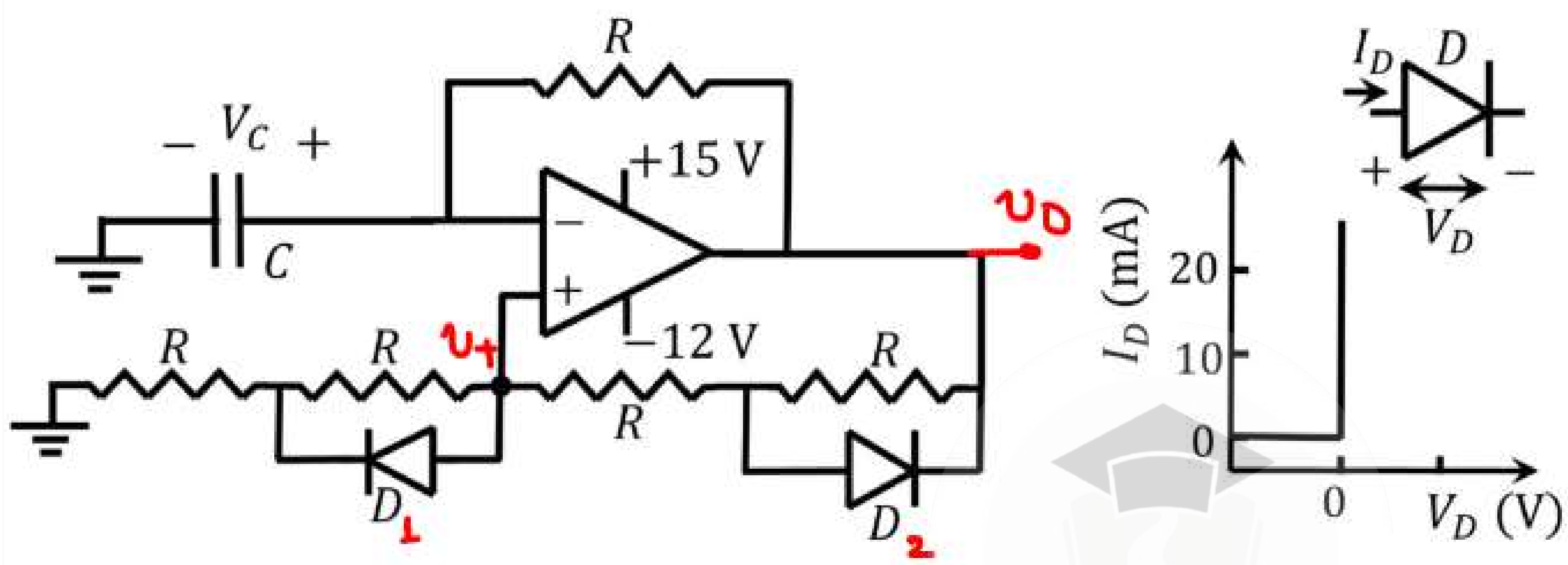
at $t = t_1 + T$; $v_c(t_1 + T) = -2.5\,V$

$$-2.5V = -5 + 5.7\, e^{-T/RC}$$

$$T = RC \ln\left(\frac{5.7}{2.5}\right)$$

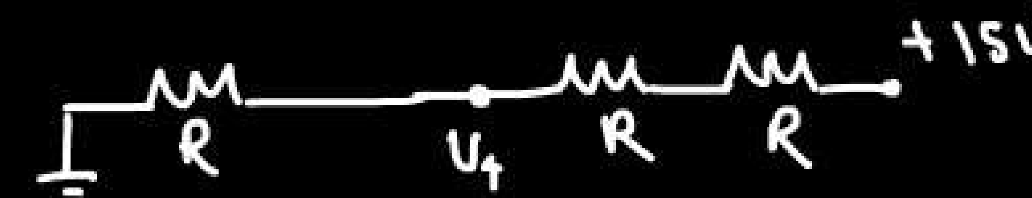
$$= 1m \ln(2.28)$$

$$\boxed{T = 0.824\ msec.}$$

Q.41	For the following circuit with an ideal OPAMP, the difference between the maximum and the minimum values of the capacitor voltage (V_c) is ____________.
	
(A)	15 V
(B)	27 V
(C)	13 V
(D)	14 V

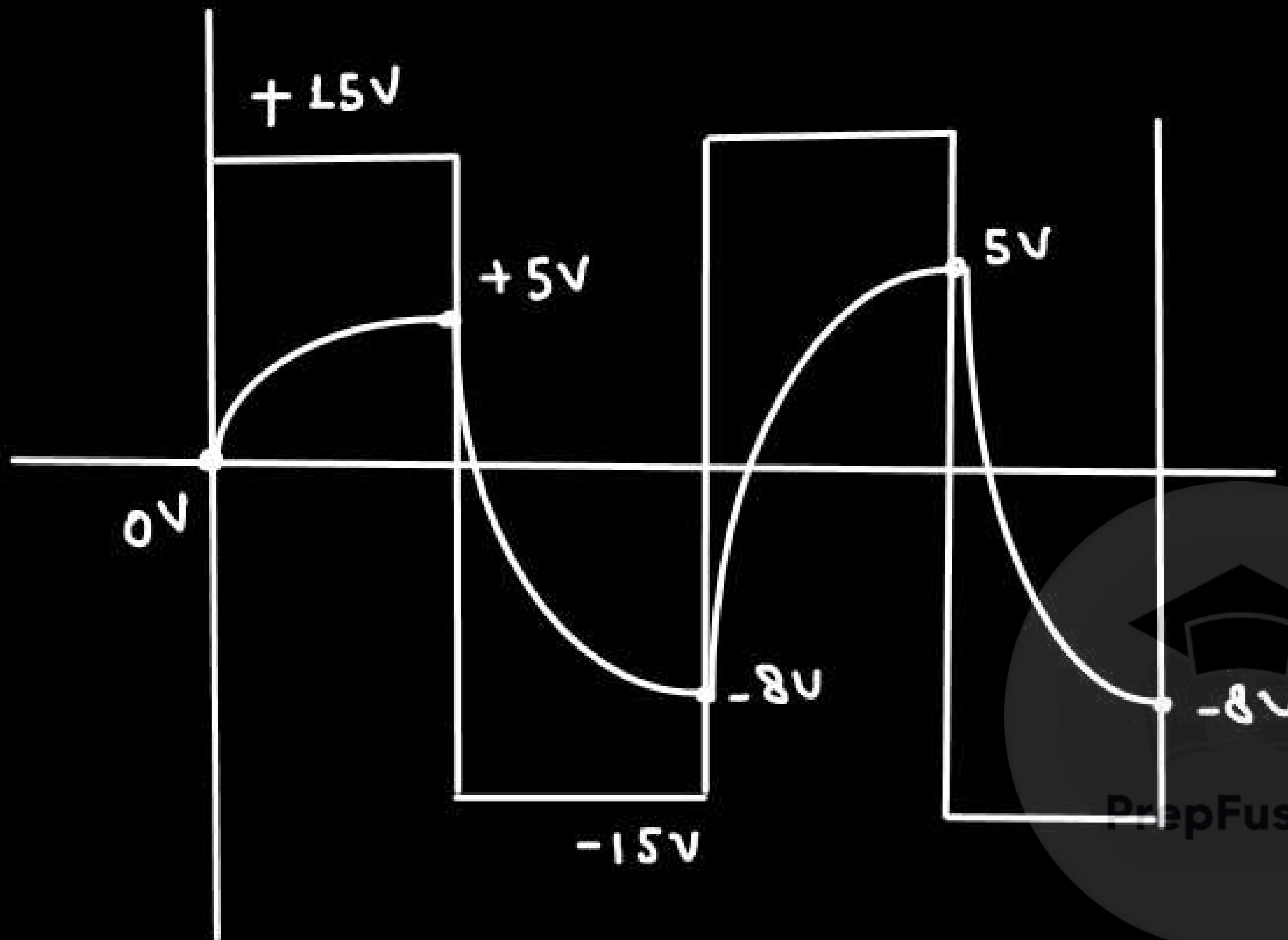
if $v_o = +15V$, $D_1 \to ON$

$$v_+ = \frac{15}{3} = +5V$$



if $v_o = -12V$, $D_2 \to ON$

$$v_+ = \frac{2}{3} \times (-12) = -8V$$

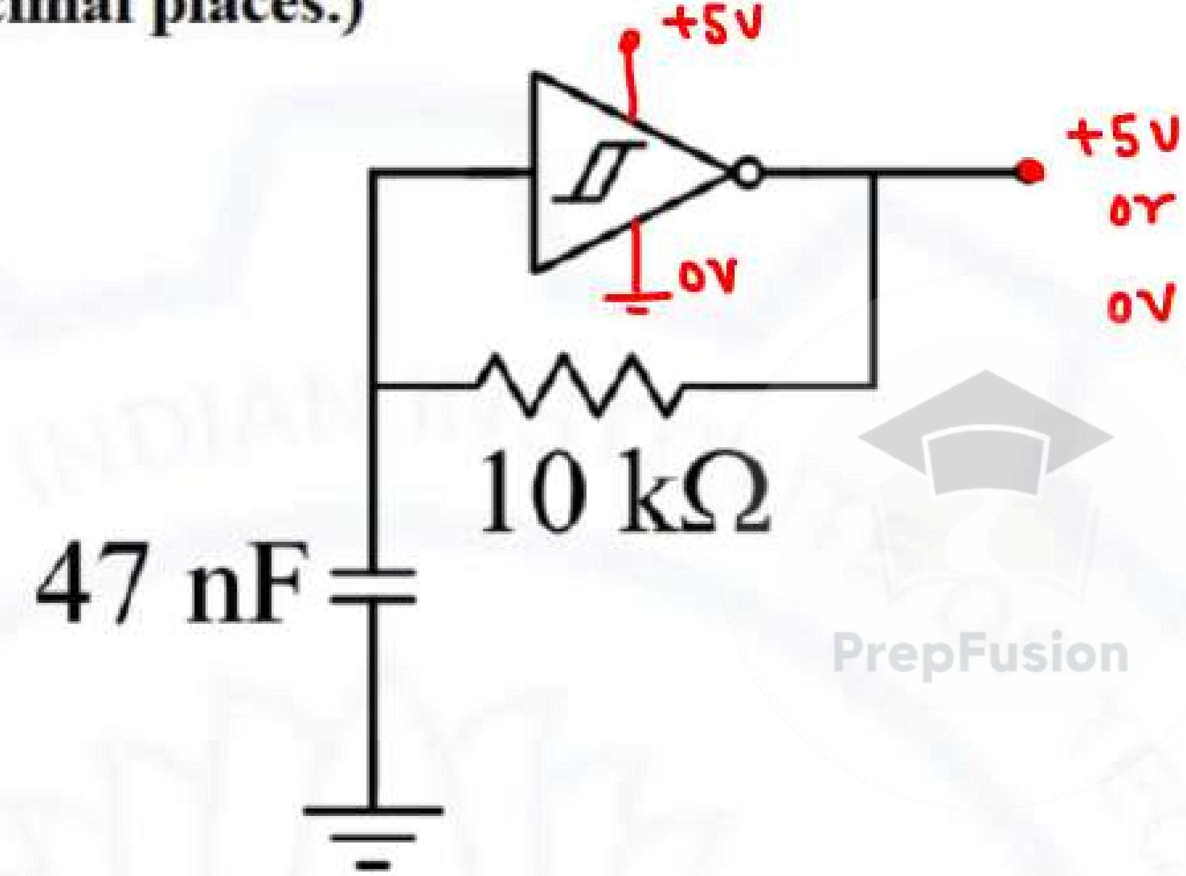


$$(v_c)_{max} = +5V$$

$$(v_c)_{min} = -8V$$

$$(v_c)_d = 5 + 8 = 13V$$

A CMOS Schmitt-trigger inverter has a low output level of 0 V and a high output level of 5 V. It has input thresholds of 1.6 V and 2.4 V. The input capacitance and output resistance of the Schmitt-trigger are negligible. The frequency of the oscillator shown is _______ Hz.
(Round off to 2 decimal places.)

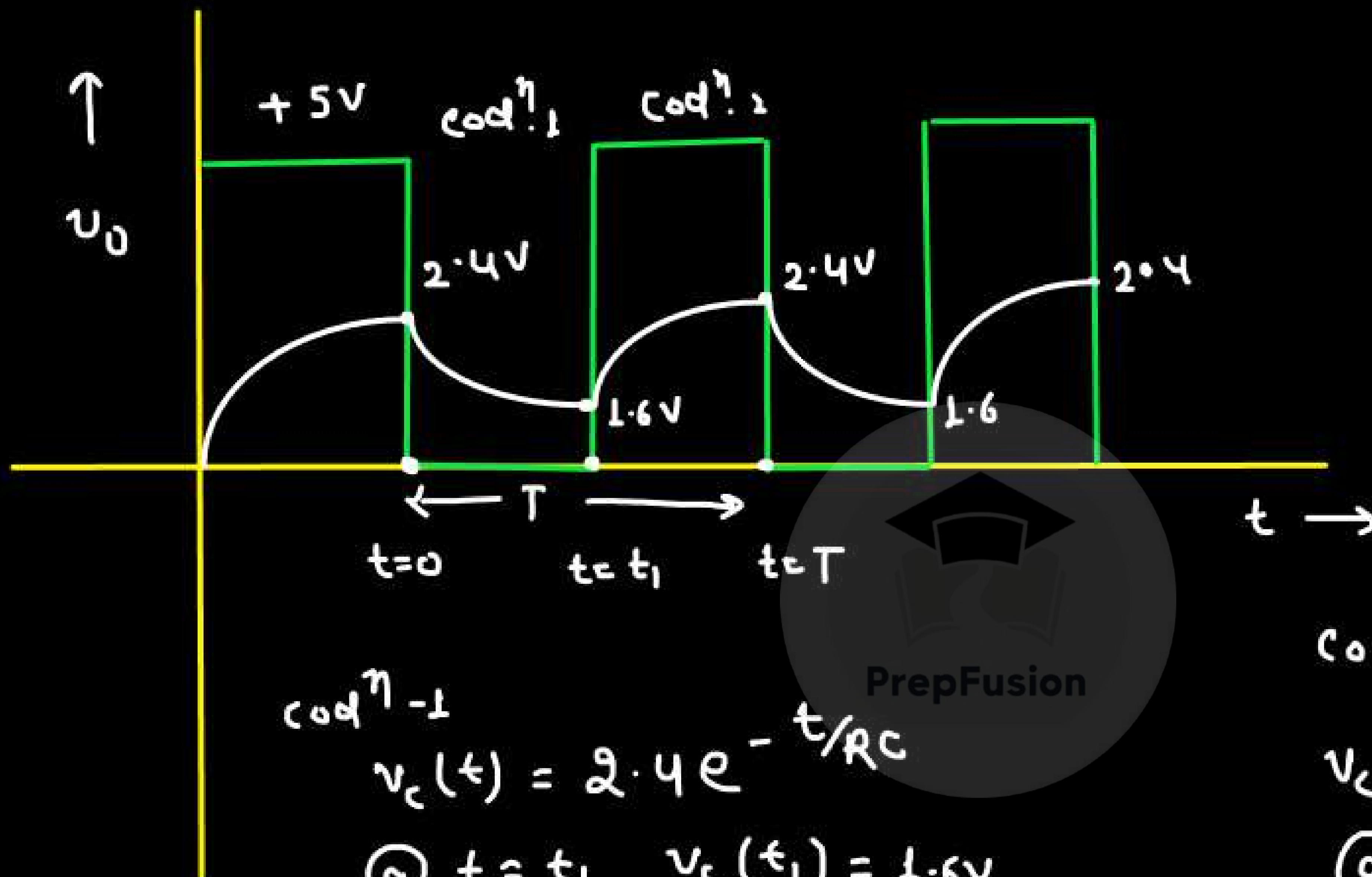


$\Rightarrow$ O/P Low $\Rightarrow v_o = 0V$

2.4 V

1.6 V

$\Rightarrow$ O/P High $\Rightarrow v_o = +5V$



cod^n-1

$$v_c(t) = 2.4e^{-t/RC}$$

@ $t = t_1$ $\quad v_c(t_1) = 1.6V$

$$1.6 = 2.4e^{-t/RC}$$

$$\boxed{t_1 = RC\ln\left(\frac{3}{2}\right)}$$

cod^n-2

$$v_c(t) = 5 - 3.4e^{-(t-t_1)/RC}$$

@ $t = T \Rightarrow v_c(T) = 2.4$

$$2.4 = 5 - 3.4e^{-(T-t_1)/RC}$$

$$\boxed{T - t_1 = RC\ln\left(\frac{17}{13}\right)}$$

$$T - t_1 + t_1 = RC\ln\left(\frac{17}{13}\right) + RC\ln\left(3/2\right)$$

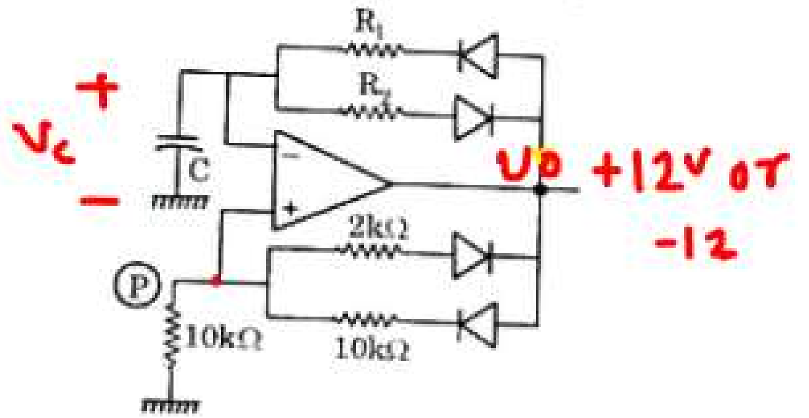
$$= RC\ln\left(\frac{17}{13} \times 3/2\right)$$

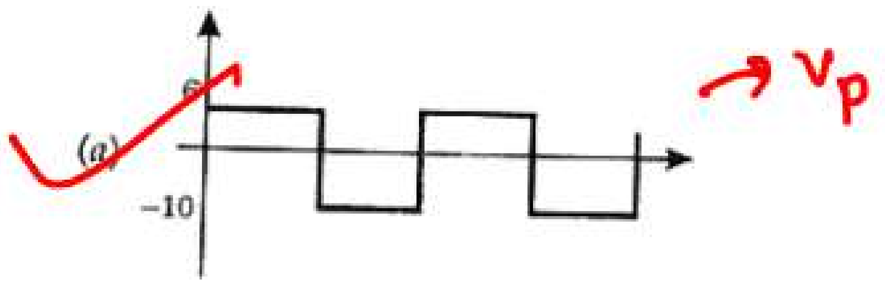
$$T = 47n \times 10k \ln\left(\frac{51}{26}\right)$$

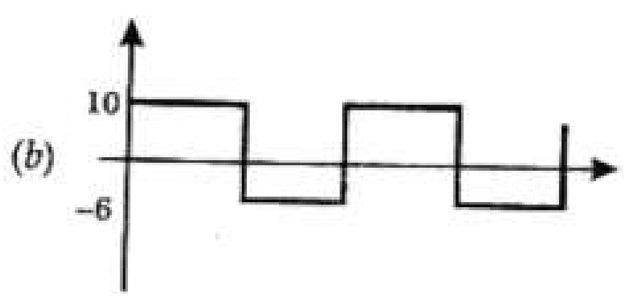
$$f = \frac{1}{T}$$

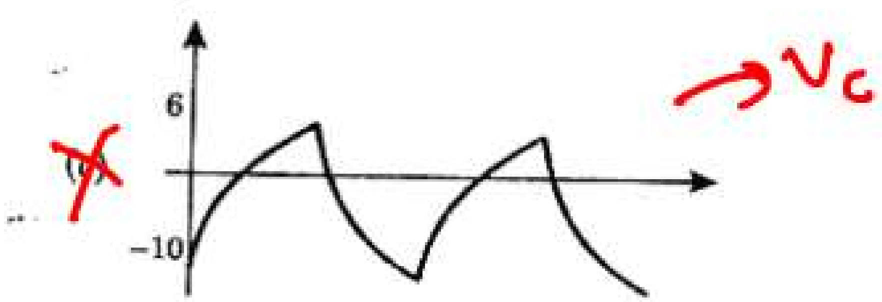
$$\boxed{f = 3158.03\,Hz}$$

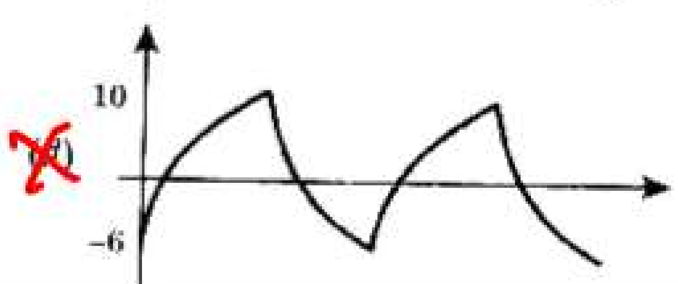
59. A relaxation oscillator is made using OPAMP as shown in figure. The supply voltages of the OPAMP are ± 12V. The voltage waveform at point P will be









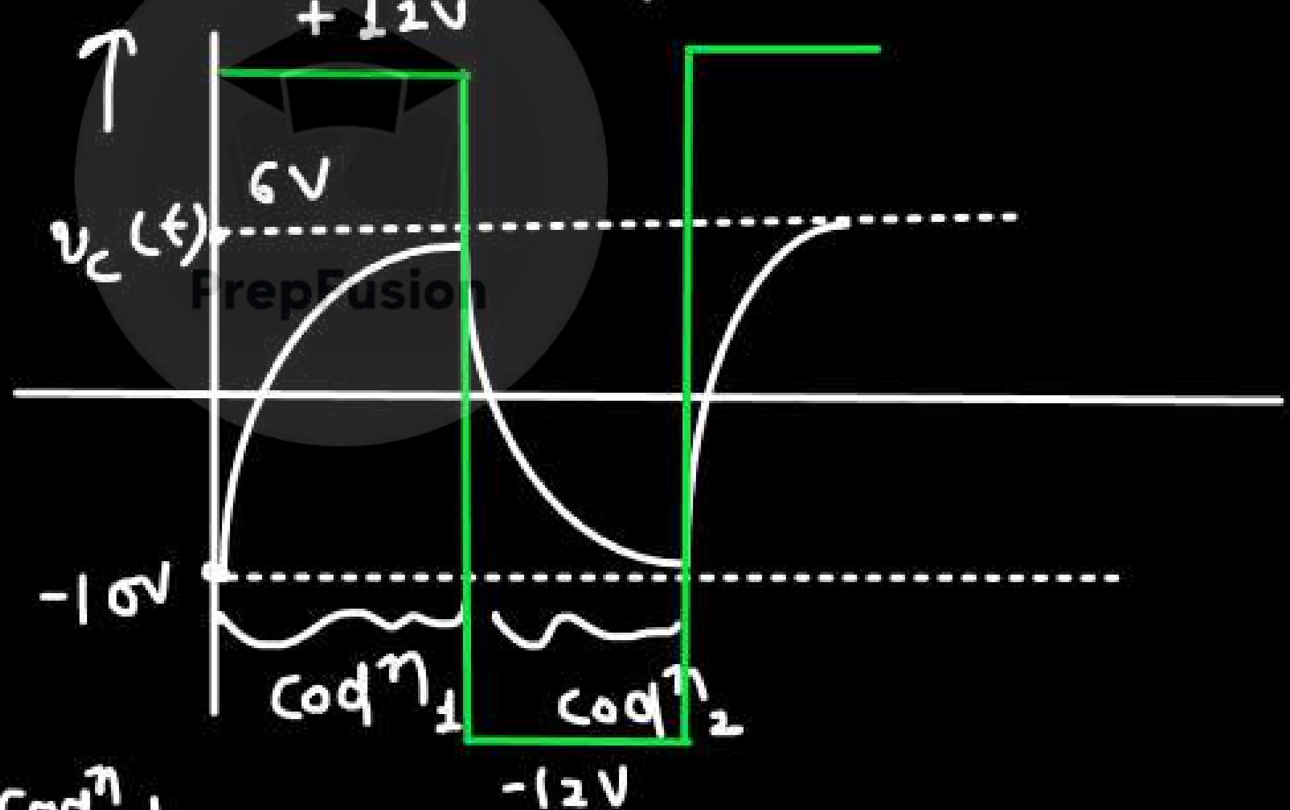


→ if $v_o = +12V$

$$v_p = +\frac{12}{2} = +6V$$

if $v_o = -12V$

$$v_p = -12 \times \frac{10}{12} = -10V$$



cond^n-1

$$v_c(t) = 12 - 22e^{-t/R_1C}$$

$$6 = 12 - 22 e^{-t_1/R_1 C}$$

$$\boxed{t_1 = R_1 C \ln\left(22/6\right)}$$

$$\boxed{v_c(t) = v_c(\infty) + \left(v_c(0^+) - v_c(\infty)\right) e^{-t/RC}}$$

cond^n - 2

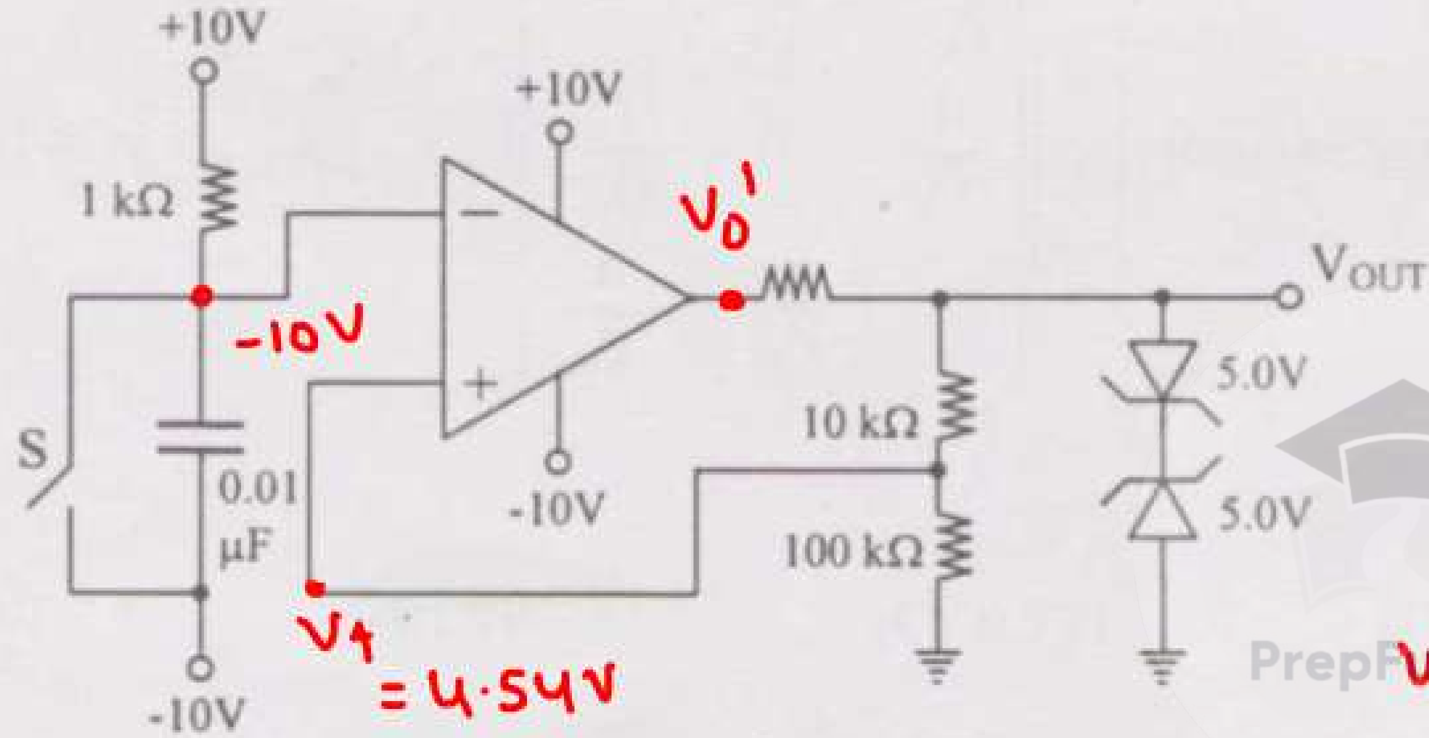
$$v_c(t) = -12 + 18 e^{-t/R_2 C}$$

$$-10 = -12 + 18 e^{-t_2/R_2 C}$$

$$\boxed{t_2 = R_2 C \ln(9)}$$

$$\boxed{\text{Time period } T = t_1 + t_2 = R_1 C \ln\left(\frac{22}{6}\right) + R_2 C \ln(9)}$$

The switch S in the circuit of the figure is initially closed. It is opened at time $t = 0$. You may neglect the Zener diode forward voltage drops. What is the behaviour of V_{OUT} for $t > 0$?



$v_-(0^+) = -10V$

$v_-(\infty) = +10V$

(A) It makes a transition from -5 V to +5 V at $t = 12.98$ µs

(B) It makes a transition from -5 V to +5 V at $t = 2.57$ µs

(C) It makes a transition from +5 V to -5 V at $t = 12.98$ µs

(D) It makes a transition from +5 V to -5 V at $t = 2.57$ µs

@ $t = 0^+$

$v_- = 10V$

Assuming $v_o' = +10V$

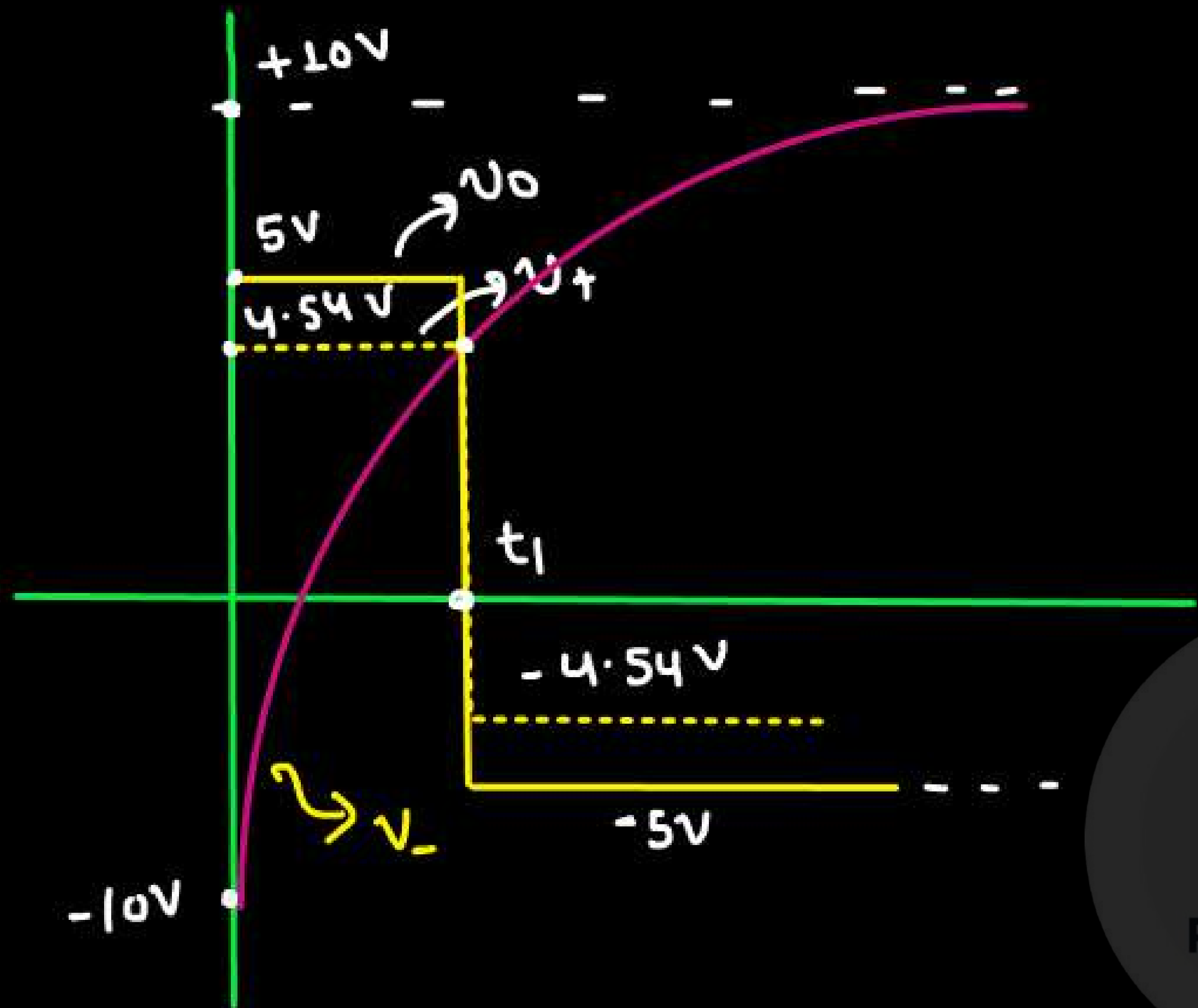
$v_o = +5V$

$$v_+ = \frac{5 \times 100}{110} = 4.54V$$

Assumption correct

$$\boxed{v_o(0^+) = 5V}$$

$$\boxed{v_+(0^+) = 4.54V}$$



$v_-(t_1^+) > 4.54\,V$

$v_+(t_1^+) < v_-(t_1^+)$

$\Downarrow$

$v_o(t_1^+) = -5V$

$v_+(t_1^+) = -4.54\,V$

always $v_- > v_+$ $(t > t_1)$

$v_o = -5V$

$v_-(0^+) = -10$

$v_-(\infty) = +10$

$v_-(t) = 10 - 20e^{-t/RC}$

at $t = t_1 \Rightarrow$ Transition in o/p

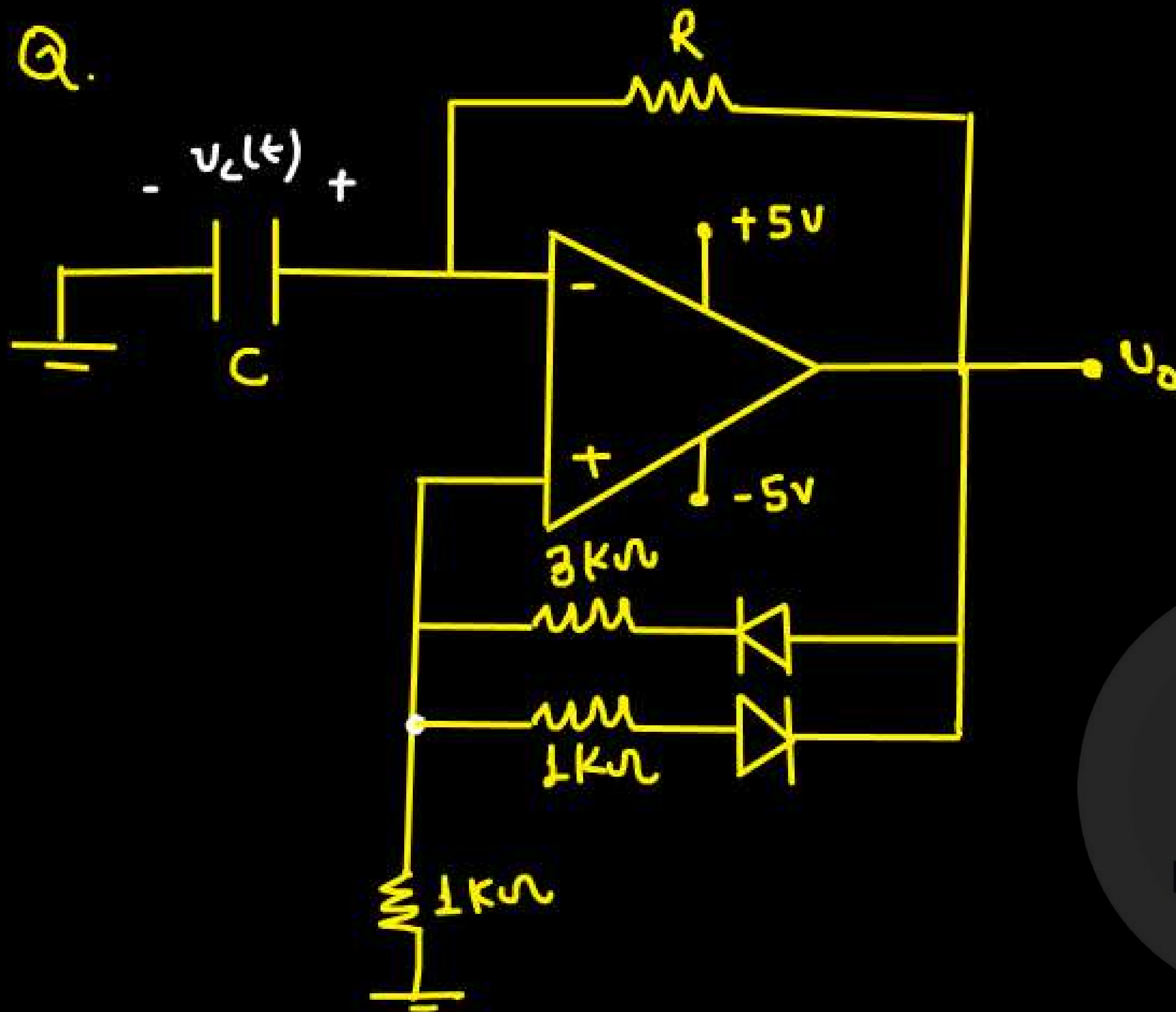
$v_-(t_1) = 4.54\,V$

$\Rightarrow$

$4.54 = 10 - 20e^{-t_1/RC}$

$\boxed{t_1 = 12.98\,\mu s}$

Q.

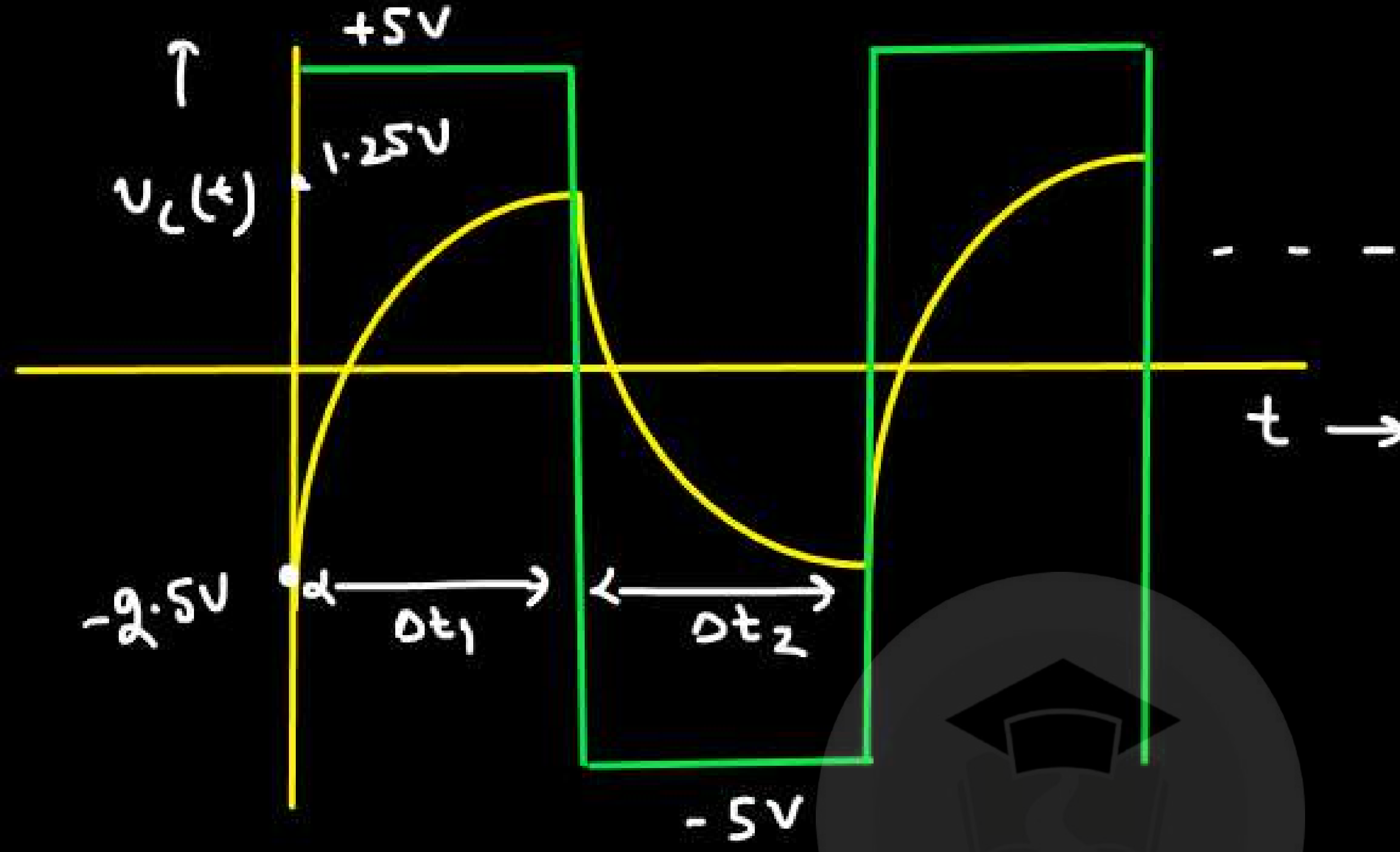


the time duration for +ve part of cycle is Δt_1 and for -ve part of cycle is Δt_2.

Find the value of $\exp\left(\frac{\Delta t_1 - \Delta t_2}{RC}\right)$.

→ if $v_o = +5V$, $v_+ = 1.25V$

if $v_o = -5V$, $v_+ = -2.5V$



$$1.25 = 5 - 7.5\, e^{-\Delta t_1/RC}$$

$$e^{-\Delta t_1/RC} = 0.5 \longrightarrow (1)$$

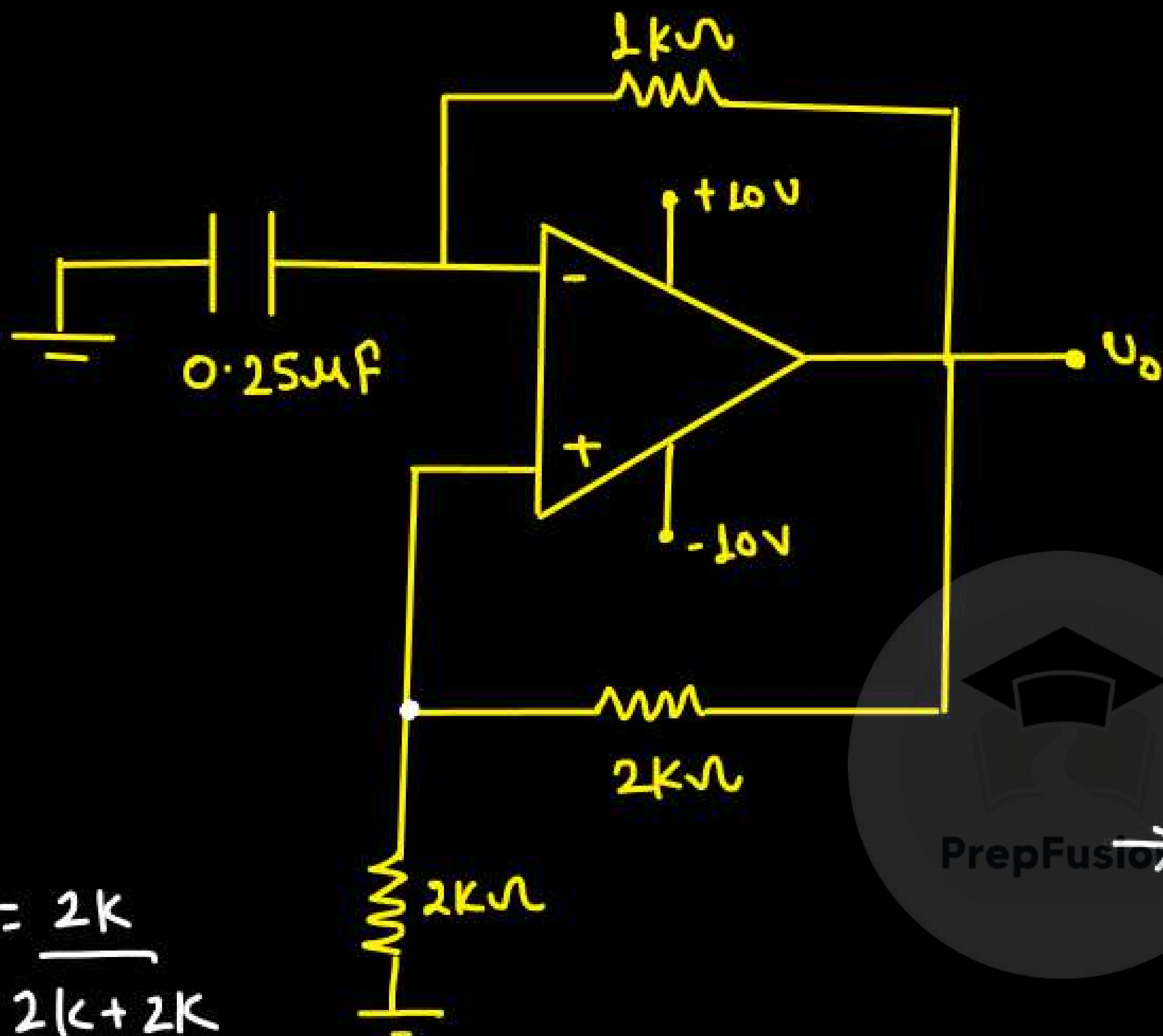
$$-2.5 = -5 + 6.25\, e^{-\Delta t_2/RC}$$

$$e^{-\Delta t_2/RC} = 0.4 \longrightarrow (2)$$

$$\text{eq } (2) \div \text{eq}^n\ (1) \Rightarrow e^{(\Delta t_1 - \Delta t_2)/RC} = \frac{0.4}{0.5} = \underline{0.8}$$

Ans.

Q.



Time period of o/p waveform?

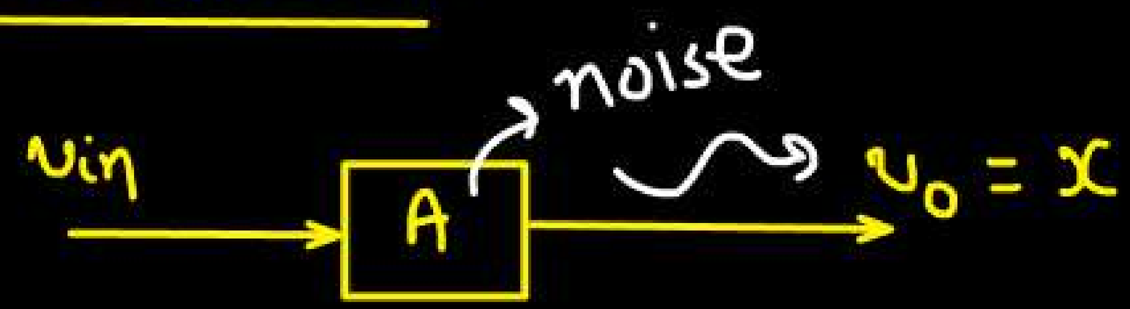
$$\beta = \frac{2K}{2K+2K} = \frac{1}{2}$$

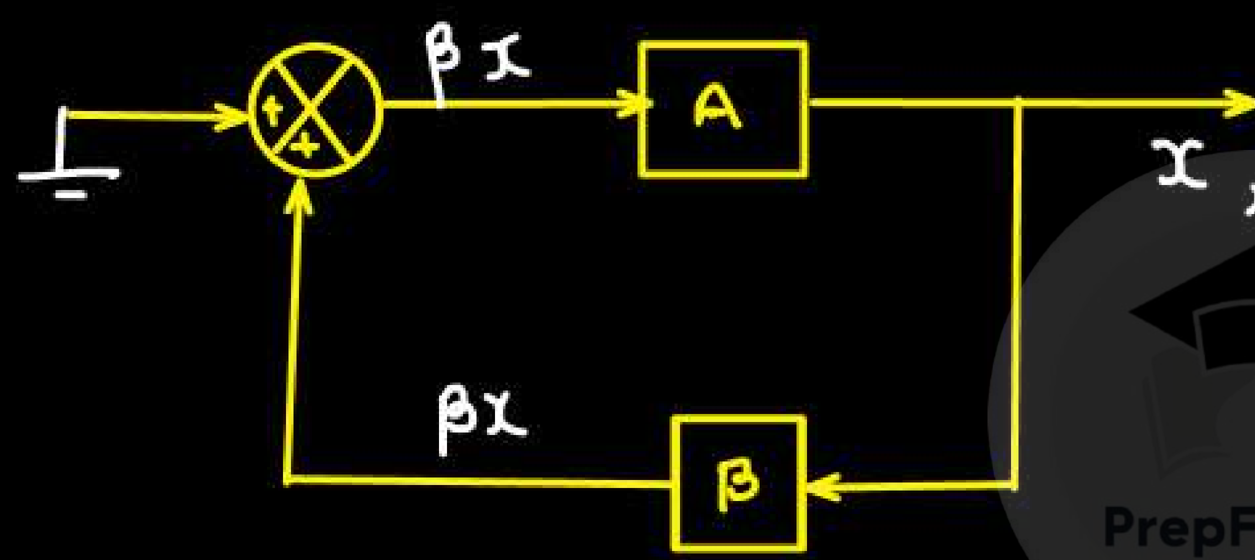
$$\rightarrow T = RC \ln\left(\frac{1+\beta}{1-\beta}\right)$$

$$= 0.25m \ln\left(\frac{3/2}{1/2}\right)$$

$$\boxed{T = 0.274 \text{ ms}}$$

⇒ Concept of oscillators :-



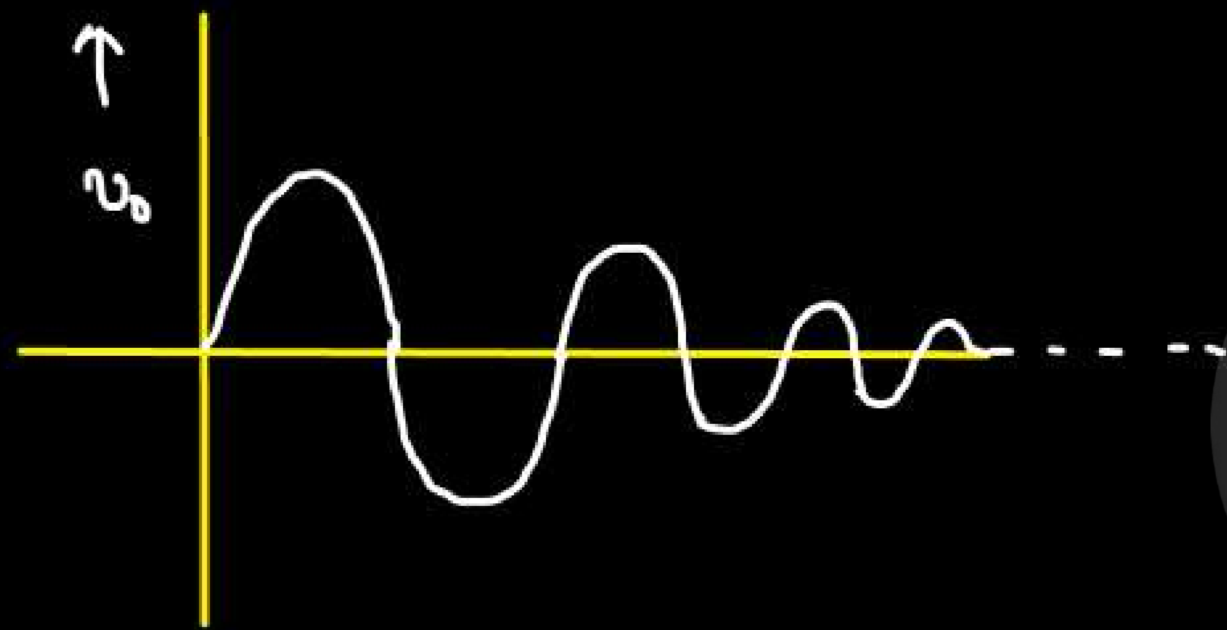


$x, A\beta x, (A\beta)^2 x, (A\beta)^3 x \ldots (A\beta)^n x$

$$\boxed{v_o = (A\beta)^n x}$$

Case 1 :- $A\beta < 1$ $\{\text{let } A\beta = 0.5\}$

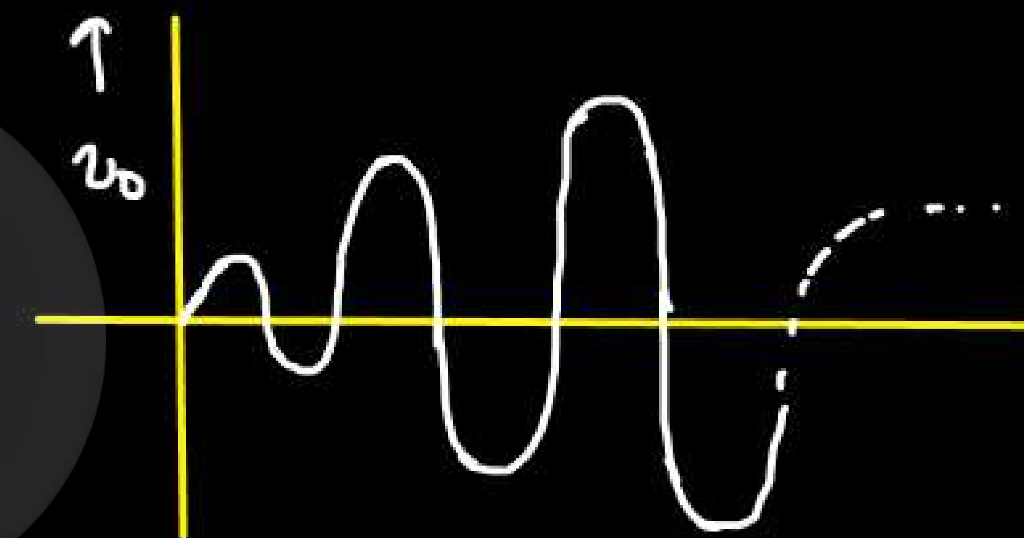
$$v_o = (0.5)^n x \Rightarrow \{0.5x, (0.5)^2 x, (0.5)^3 x \ldots\}$$



Case-2 :- $A\beta > 1$

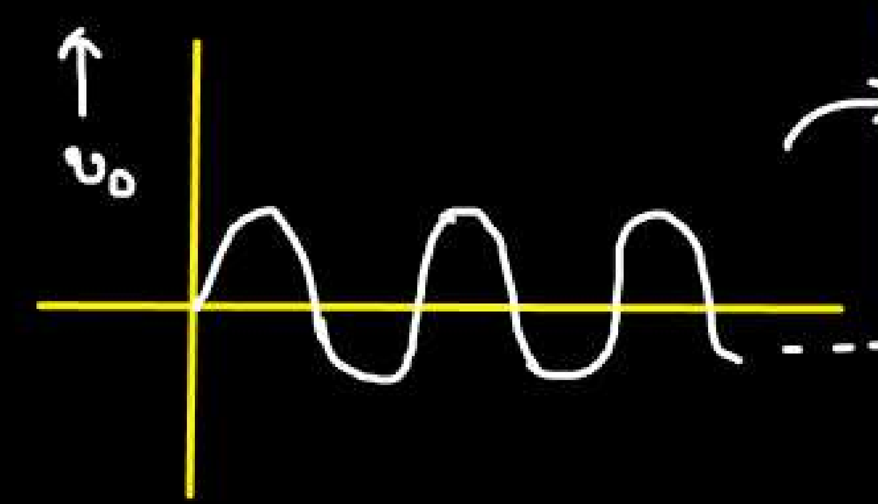
$\{\text{let } A\beta = 2\}$

$$v_o = (2)^n x \Rightarrow \{2x, 4x, 8x \ldots\}$$



Case-3 :- $A\beta = 1$

$$v_o = x$$



sustained oscillations

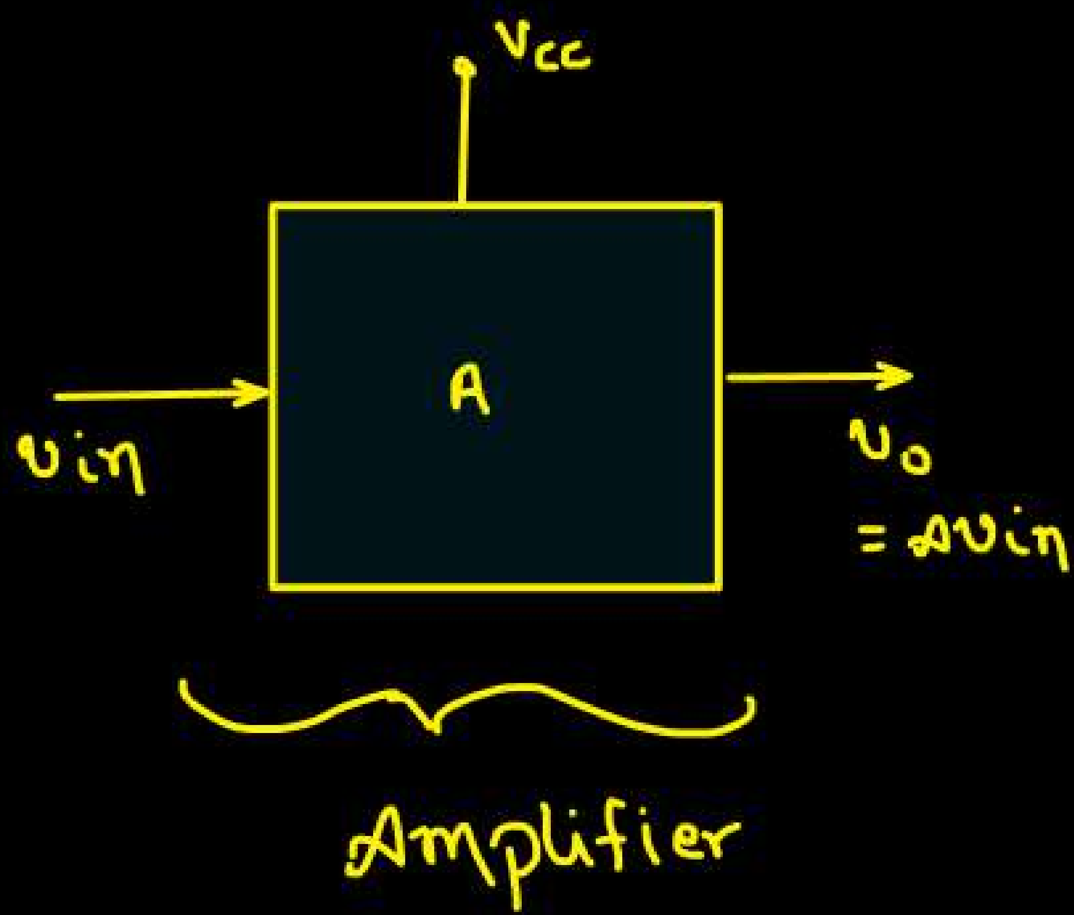
** For sustained oscillation:-

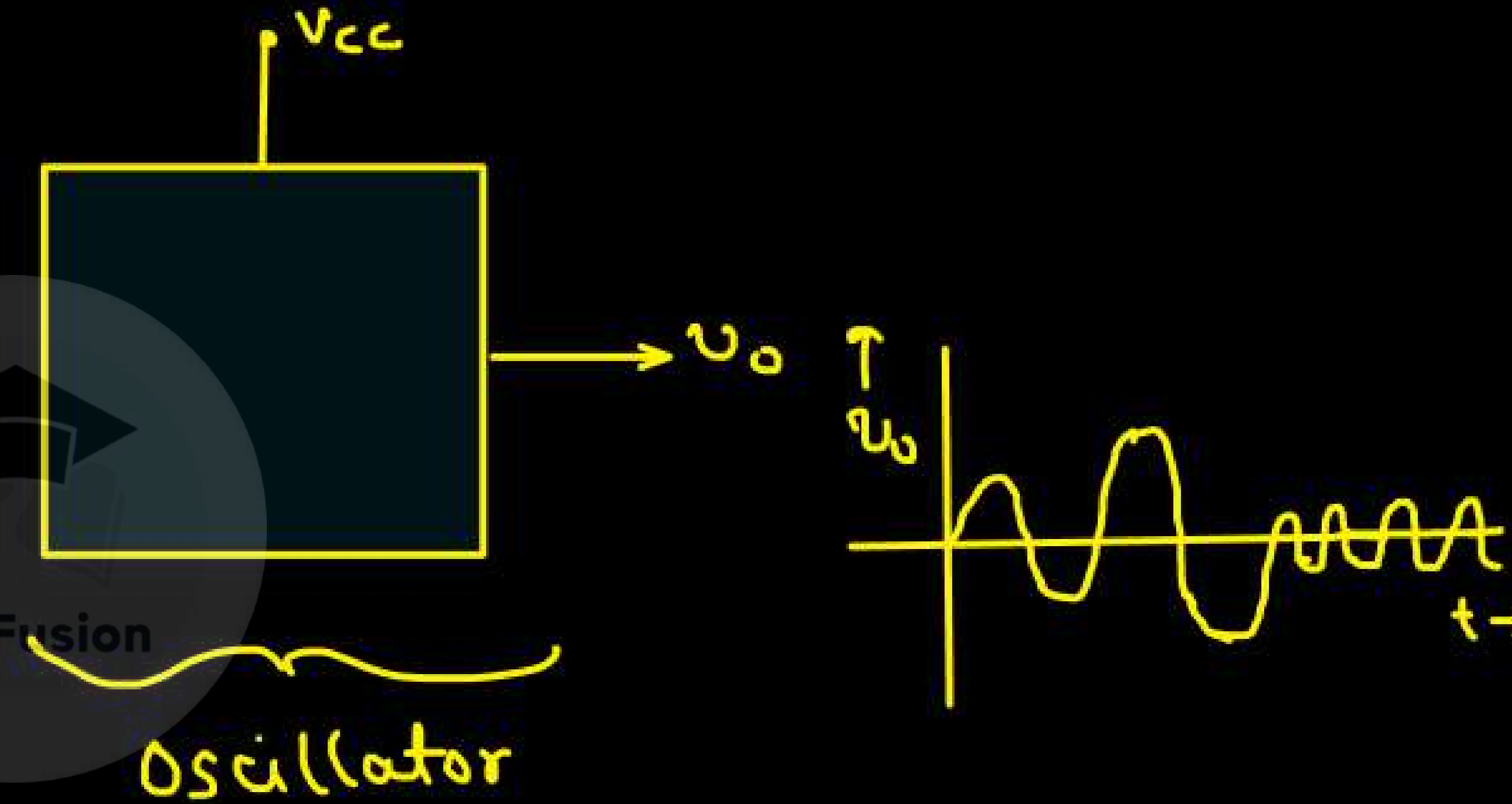
(i) $|A\beta| = 1 \Rightarrow$ loop gain should be 1. [Magnitude]

(ii) $\angle A\beta = 0^\circ, 360^\circ, 720^\circ \, --- \, 2n\pi$ {where, $n = 0, 1, 2 ...$}

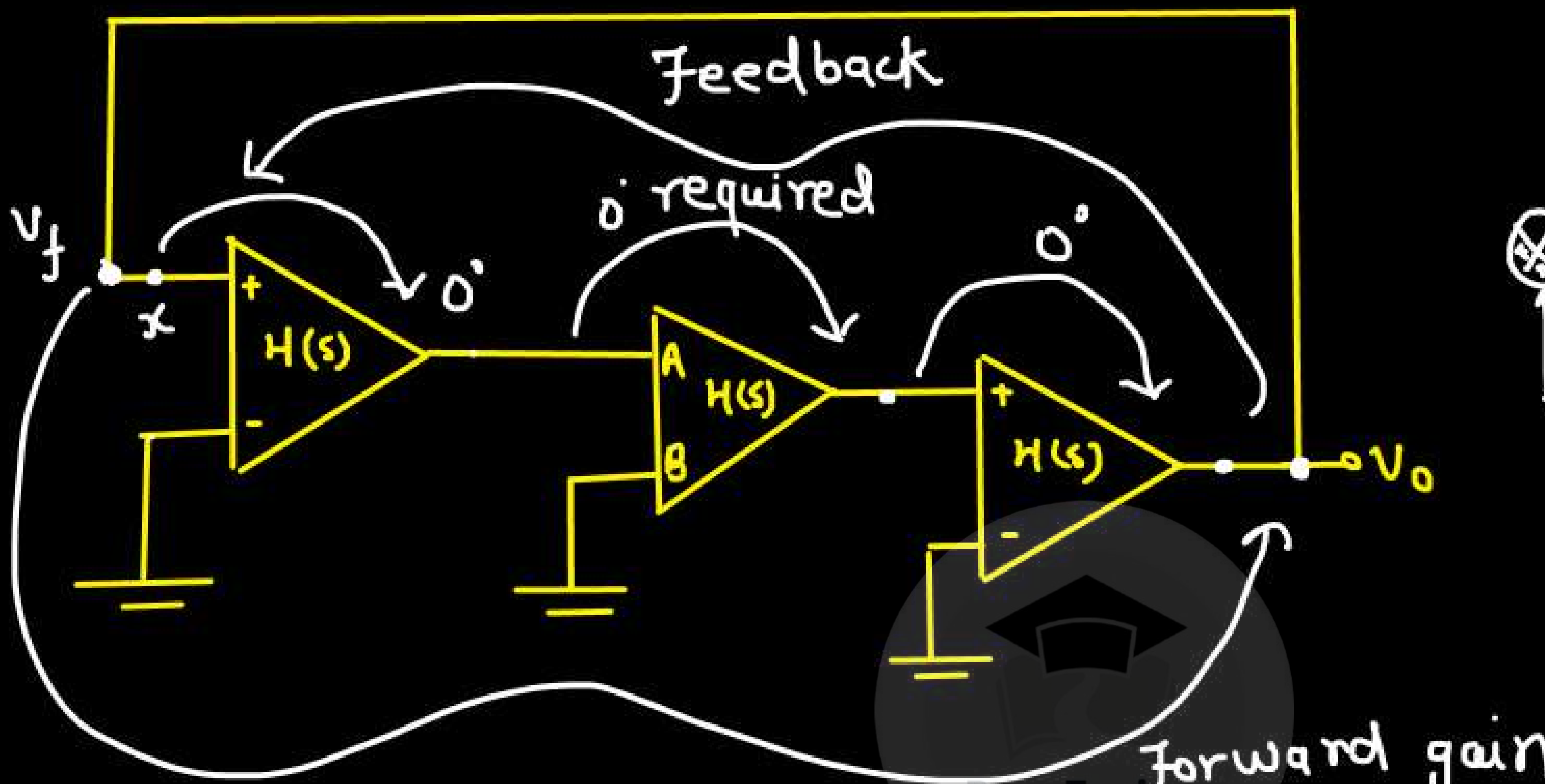
Phase shift around the feedback loop must be zero / multiple of 2π.

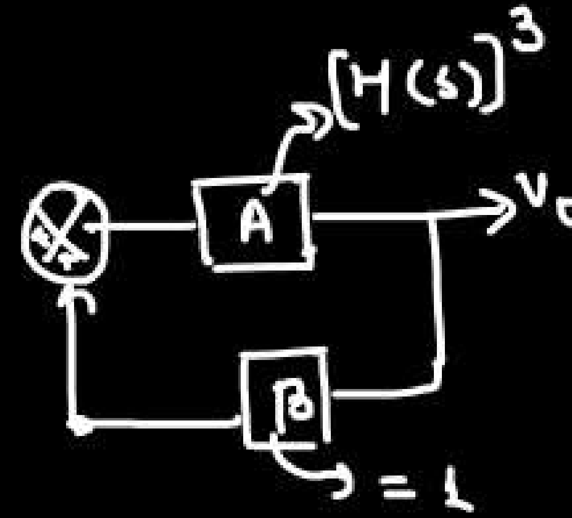
⇒ Amplifiers v/s Oscillators:-





Q.





$$H(s) = \frac{2}{1 + s/10^6}$$

(a) For sustained Oscillations, what should be sign of A and B ?

(b) What will be the frequency of oscillations?

(a) Here $\quad V_f = V_0$

$\boxed{\beta = 1} \Rightarrow$ phase shift in f/b path $= 0^\circ$

$\angle \beta = 0^\circ$

required :- $\angle A = 0^\circ \Rightarrow$ forward path phase shift $= 0^\circ$

$\boxed{A = +ve, \quad \beta = -ve}$ ✗ $\quad \boxed{A = -ve \quad , \quad \beta = +ve}$ ✓

(b) $\quad \beta = 1$

$$A = -[H(s)]^3 = \frac{-(2)^3}{\left(1 + \frac{s}{10^5}\right)^3}$$

$$A\beta = \frac{-8}{\left(1+\frac{s}{10^6}\right)^3}$$

$$A\beta = \frac{-8}{1+\frac{s^3}{(10^6)^3}+\frac{3s^2}{(10^6)^2}+\frac{3s}{10^6}} = \frac{-8}{1-\frac{j\omega^3}{(10^6)^3}-\frac{3\omega^2}{(10^6)^2}+\frac{3j\omega}{10^6}}$$

$$= \frac{-8}{1-\frac{3\omega^2}{(10^6)^2}+j\left[\frac{3\omega}{10^6}-\frac{\omega^3}{(10^6)^3}\right]}$$

$\boxed{\angle A\beta = 0^\circ}$ → required

$$\text{img.}[A\beta] = 0$$

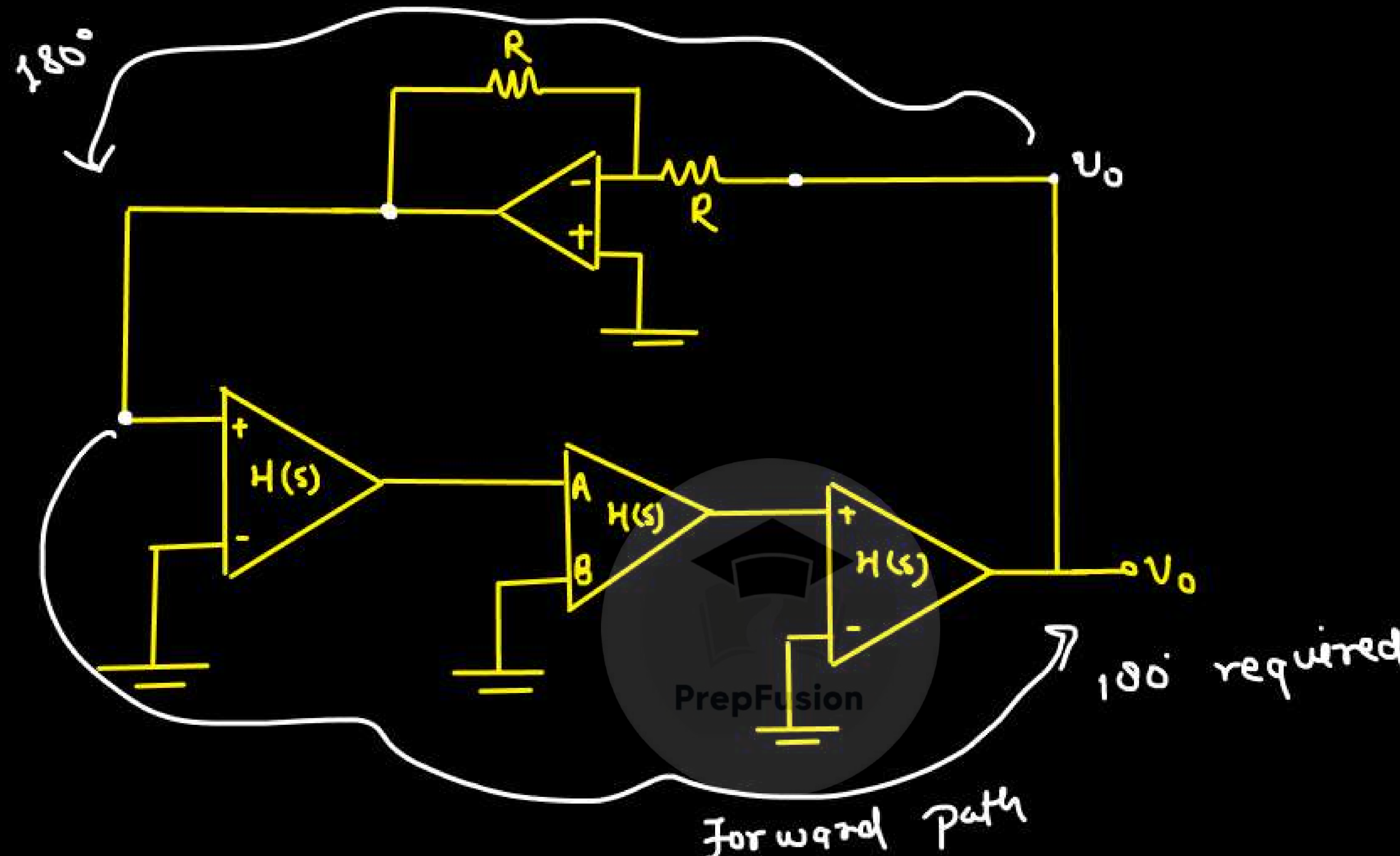
$$\frac{3\omega}{10^6} = \frac{\omega^3}{(10^6)^3}$$

$\boxed{\omega = \sqrt{3}\times 10^6 \text{ rad/sec.}}$ ⇝ Freq. of oscillation

$$A\beta\left[\text{at } \omega=\sqrt{3}\times10^6\right] = \frac{-8}{1-\frac{3\times3\times(10)^6}{10^6}} = 1$$

Here $\boxed{\angle A\beta = 0^\circ}$

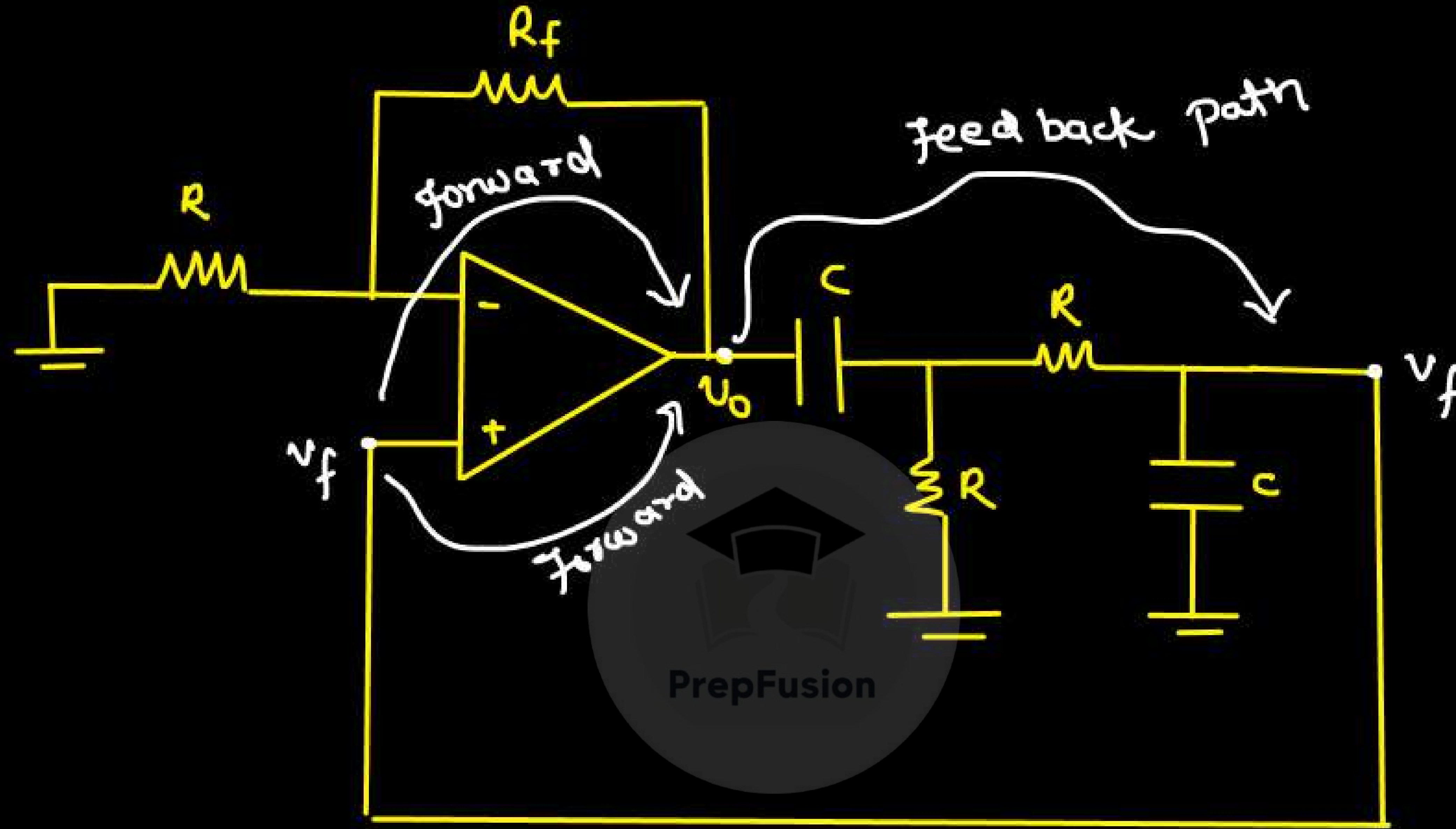
Q.



(a) For sustained Oscillations, what should be sign of A and B ?

→ $A = +ve$, $B = -ve$

Q.

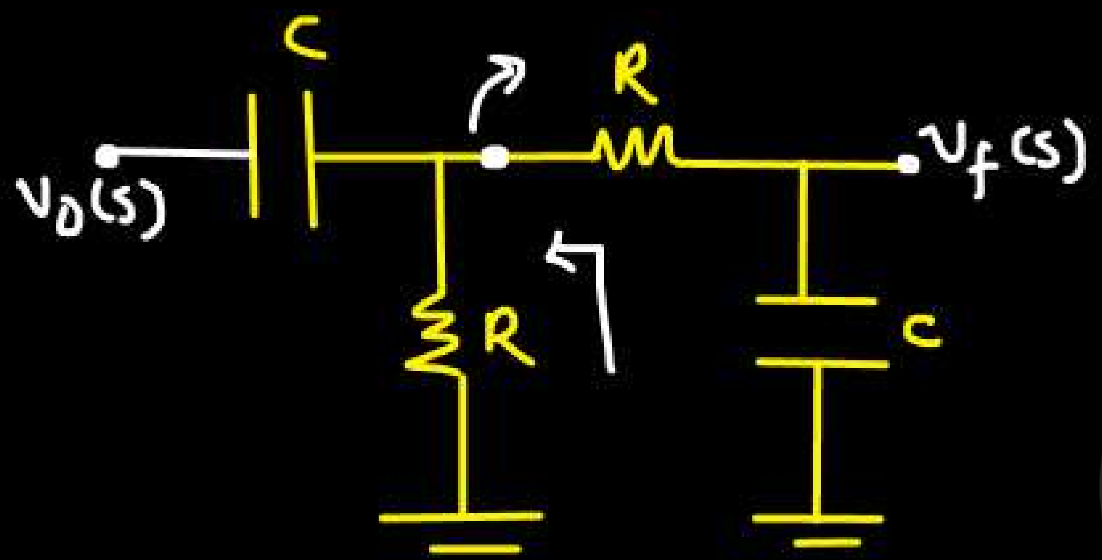


(a) Find the freq. of sustained oscillations.

(b) Find the ratio $\frac{R_f}{R}$ for sustained oscillations.

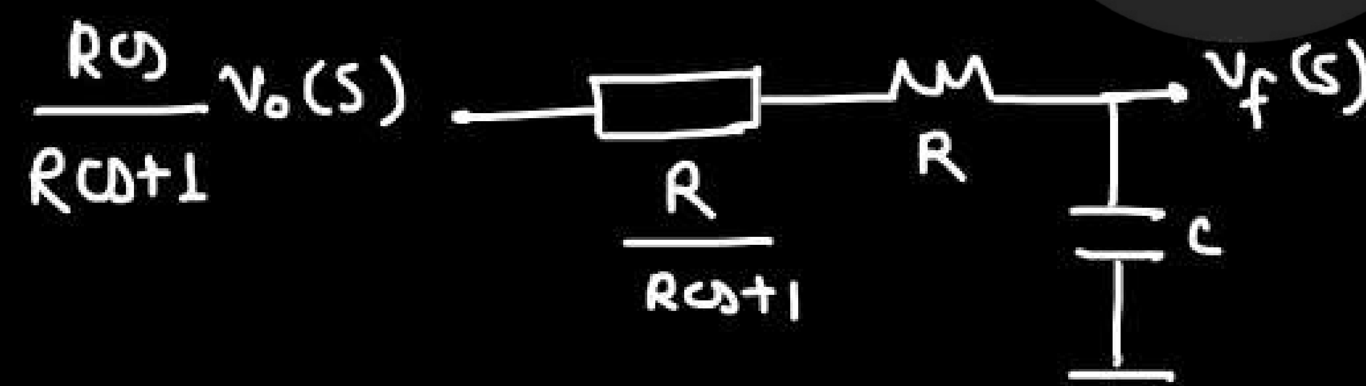
→ Forward path is non-inverting amp. ⇒

$$A = 1 + \frac{R_f}{R}, \quad \angle A = 0^\circ$$



$$V_f(s) = \beta\, v_o(s)$$

$$\boxed{\beta = \frac{v_f(s)}{v_o(s)}}$$



$$V_f(s) = \frac{1/Cs}{\frac{RCs+1}{Cs} + \frac{R}{RCs+1}} \times \frac{RCs}{RCs+1} v_o(s)$$

$$\boxed{\frac{V_f(s)}{v_o(s)} = \frac{RCs}{1 + 3RCs + (RCs)^2}}$$

$$\beta = \frac{j\omega RC}{1 + 3j\omega RC - \omega^2 R^2 C^2} = \frac{j\omega RC}{[1-\omega^2 R^2 C^2] + 3j\omega RC}$$

$\boxed{\angle \beta = 0^\circ} \rightarrow$ required

$\Downarrow$

β has to be real

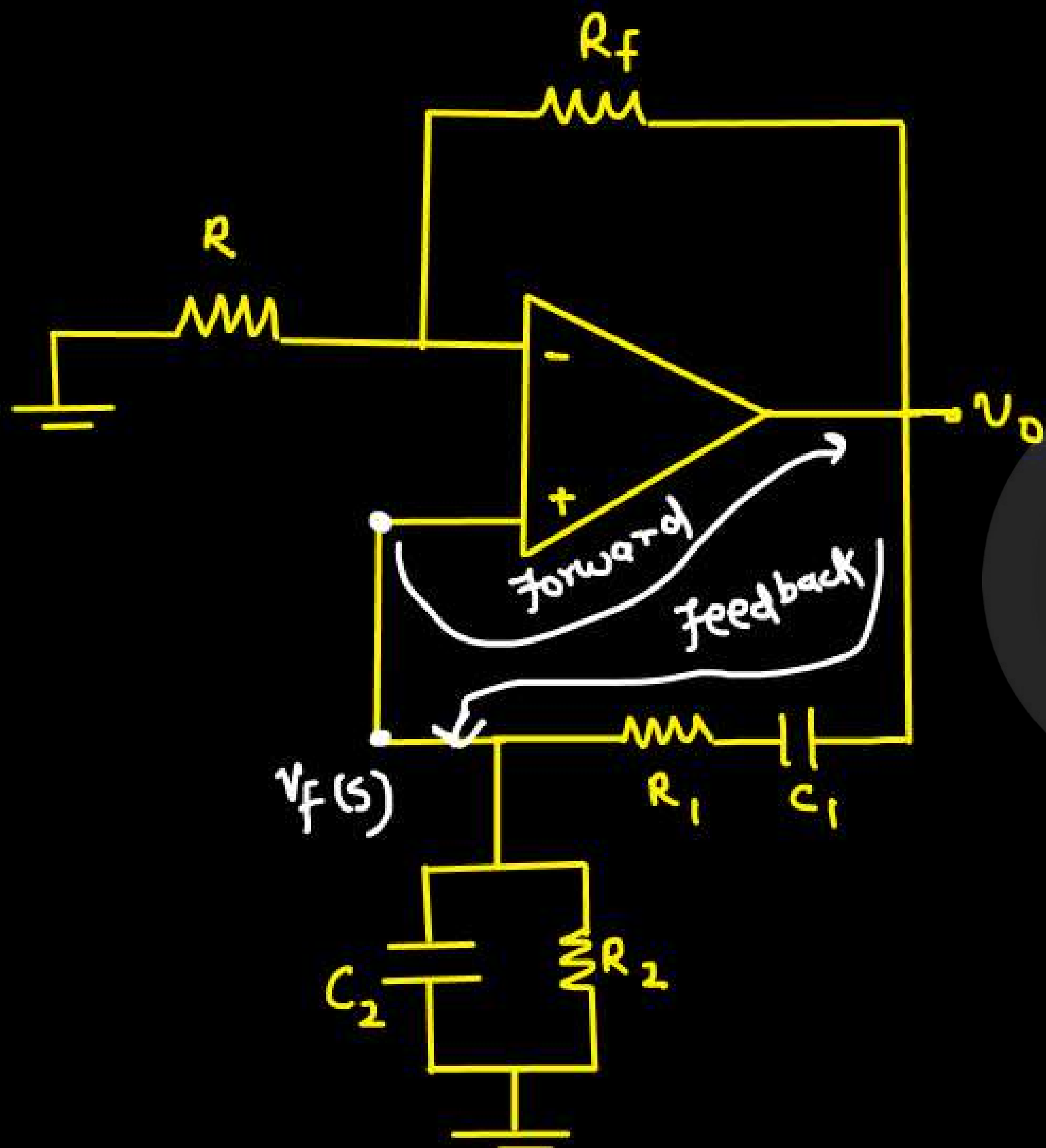
if $1 - \omega^2 R^2 C^2 = 0 \Rightarrow \beta$ will be real

$\boxed{\omega = \frac{1}{RC}} \Rightarrow$ Frequency of Oscillation

$\boxed{\beta\left(@\, \omega = 1/RC\right) = 1/3} \Rightarrow \angle\beta = 0^\circ,\ \angle A = 0^\circ$

$|A\beta| = 1 \Rightarrow A = 3 \Rightarrow 1 + \frac{R_f}{R} = 3 \Rightarrow \boxed{R_f = 2R}$

* Wein bridge oscillator:-



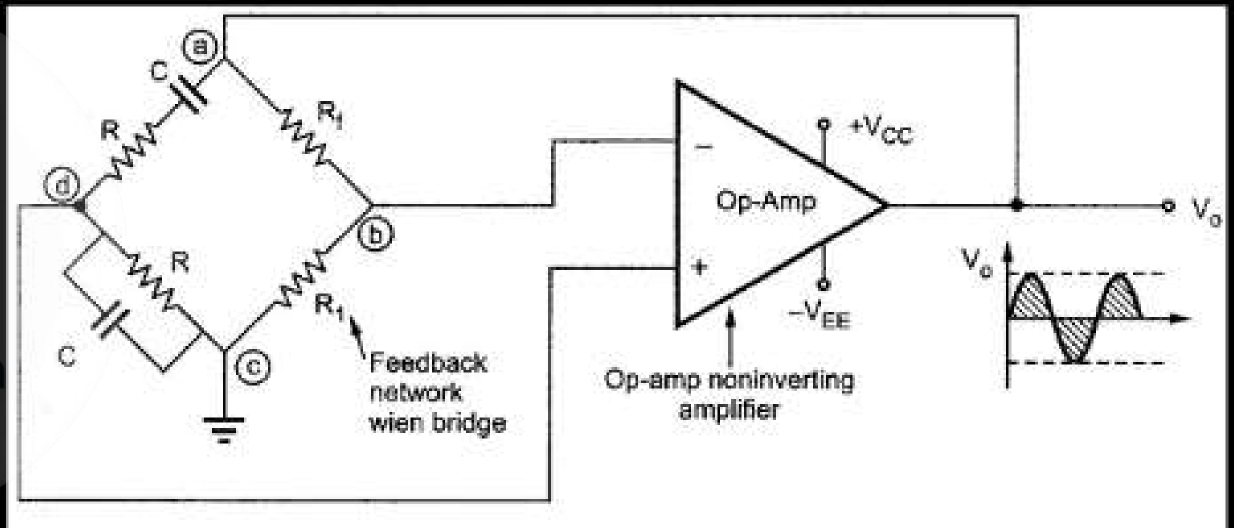
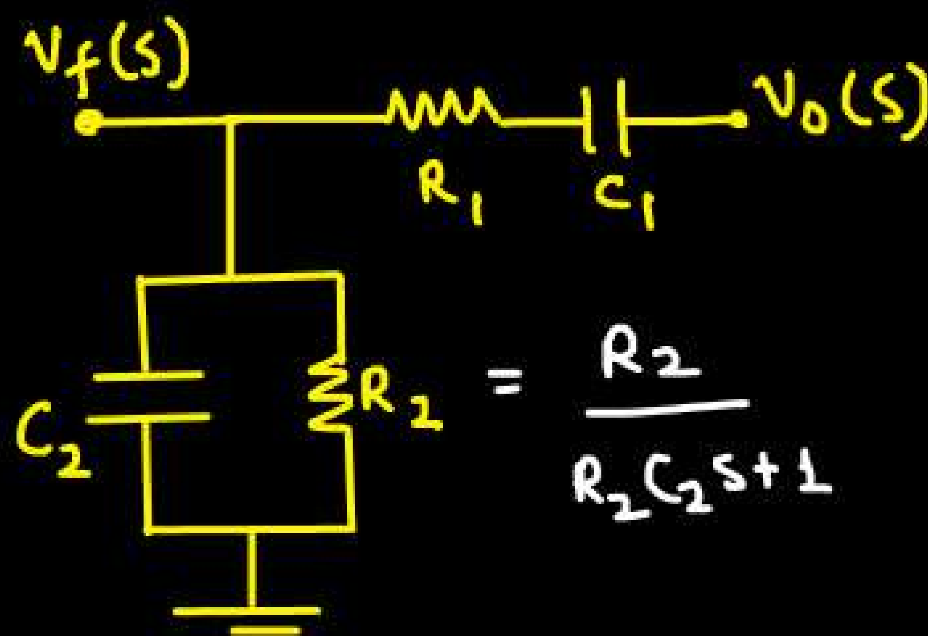


Fig. 2.95

[Pic from eeeguide.com]



$$= \frac{R_2}{R_2C_2s+1}$$

$$\boxed{\begin{gathered} A = 1 + \frac{R_f}{R} \\ \angle A = 0^\circ \end{gathered}}$$

$$V_f(s) = \frac{\dfrac{R_2}{R_2C_2s+1}}{\dfrac{R_2}{R_2C_2s+1} + \dfrac{R_1C_1s+1}{C_1s}} = \frac{R_2C_1s}{R_2C_1s + R_1R_2C_1C_2s^2 + R_2C_2s + R_1C_1s + 1} V_o(s)$$

$$\beta = \frac{j\omega R_2C_1}{1 - \omega^2R_1R_2C_1C_2 + j\omega[R_2C_1 + R_2C_2 + R_1C_1]}$$

$\boxed{\angle\beta = 0^\circ} \rightarrow$ required

$\Downarrow$

β has to be real

$$1 - \omega^2 R_1 R_2 C_1 C_2 = 0$$

$$\boxed{\omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}} \rightarrow \text{freq. of Oscillations}$$

$$\beta\left[@\ \omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}\right] = \frac{R_2 C_1}{R_2 C_1 + R_2 C_2 + R_1 C_1}$$

$$\star\ \boxed{\beta = \frac{1}{1 + \frac{C_2}{C_1} + \frac{R_1}{R_2}}} \rightarrow \angle \beta = 0^\circ$$

$$|A\beta| = 1 \Rightarrow A = 1/\beta \Rightarrow 1 + \frac{R_f}{R} = 1 + \frac{C_2}{C_1} + \frac{R_1}{R_2}$$

$$\star\ \boxed{\frac{R_f}{R} = \frac{C_2}{C_1} + \frac{R_1}{R_2}}$$

if $R_1 = R_2 = R$

$C_1 = C_2 = C$

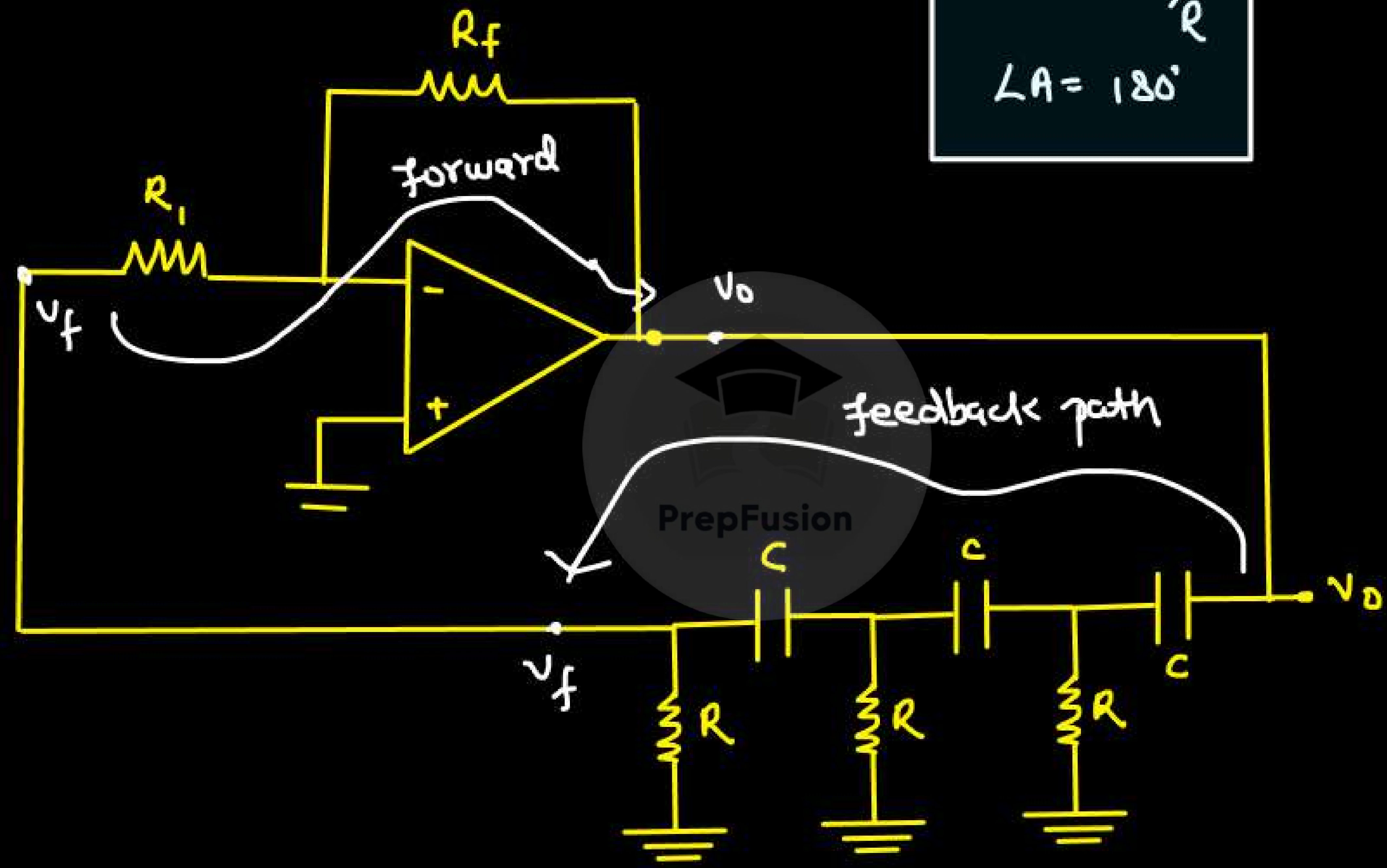
$$\boxed{\omega = \frac{1}{\sqrt{R^2C^2}} = \frac{1}{RC}}$$

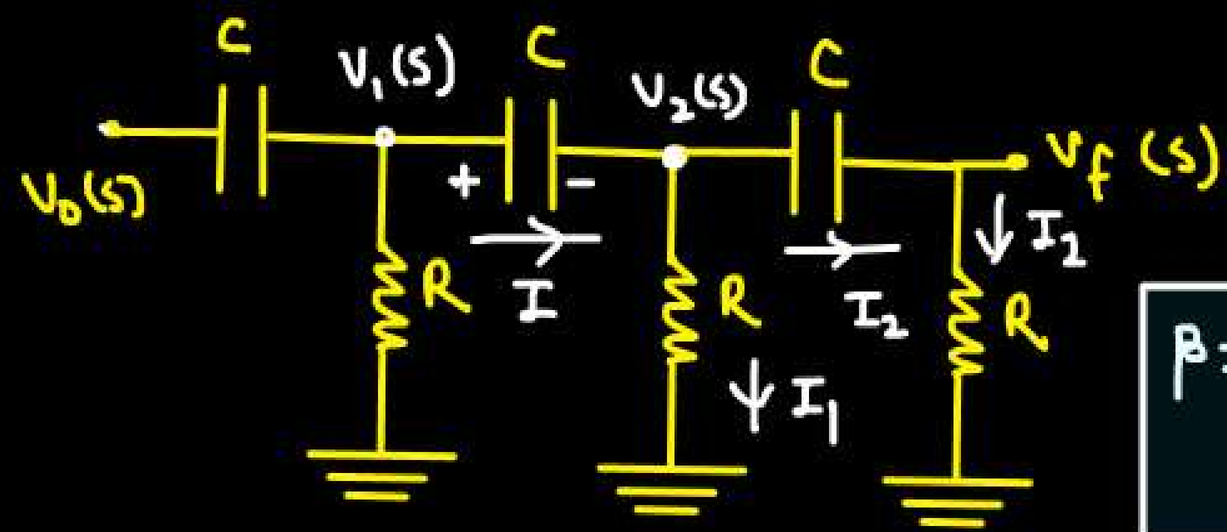
$$\boxed{\frac{R_f}{R} = 2}$$

✲ RC Phase Shift Oscillators:-

$$A = -R_f/R$$

$$\angle A = 180^\circ$$





$$\boxed{\beta = \frac{V_f(s)}{V_0(s)}}$$

$$V_f(s) = \frac{RCs}{RCs+1} V_2(s)$$

$$V_2(s) = \frac{RCs+1}{RCs} V_f(s) \quad \text{— (1)}$$

$$I = I_1 + I_2$$

$$** \quad I = \frac{V_2(s)}{R} + \frac{V_f(s)}{R}$$

By eq^n (1)

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

$$I = \frac{V_f(s)}{R}\left[\frac{1+2RCs}{RCs}\right] \quad \text{— (2)}$$

$$V_1(s) = I \times \frac{1}{Cs} + V_2(s)$$

$$= \frac{V_f(s)}{RCs}\left[\frac{1+2RCs}{RCs}\right] + \frac{V_f(s)}{RCs}\left[RCs+1\right]$$

{By eq^n (1) & (2)}

$$V_1(s) = \frac{V_f(s)}{RCs}\left[\frac{1+2RCs+(RCs)^2+RCs}{RCs}\right] \quad \text{— (3)}$$

$$[V_0(s) - V_1(s)]\,Cs = \frac{V_1(s)}{R} + I$$

$$V_0(s) = V_1(s)\left[\frac{RCs+1}{RCs}\right] + \frac{I}{Cs}$$

By eq^n (2) and (3)

$$V_0(s) = \frac{V_f(s)}{(RCs)^3}\left[1+3RCs+(RCs)^2\right]\left[RCs+1\right] + \frac{V_f(s)}{(RCs)^2}\left[1+2RCs\right]$$

★★ $$V_0(s) = \frac{V_f(s)}{(RCs)^3}\left[(RCs)^3+6(RCs)^2+5RCs+1\right]$$

$$\beta = \frac{V_f(s)}{V_o(s)} = \frac{(RCs)^3}{(RCs)^3 + 6(RCs)^2 + 5RCs + 1}$$

$$\boxed{\beta = \frac{-j\omega^3 R^3 C^3}{-j\omega^3 R^3 C^3 - 6\omega^2 R^2 C^2 + 5j\omega RC + 1}}$$

$\boxed{\angle\beta = 180^\circ}$ → required

⇓

$\beta = \text{real}$

For β real

$$1 - 6\omega^2 R^2 C^2 = 0$$

$\boxed{\omega = \frac{1}{RC\sqrt{6}}}$ ⤳ Frequency of oscillation

$$\beta\left[@\,\omega = \frac{1}{RC\sqrt{6}}\right] = \frac{-\frac{1}{6\sqrt{6}} \times \frac{1}{R^3C^3} \times R^3C^3}{-\frac{1}{6\sqrt{6}} \times \frac{1}{R^3C^3} \times R^3C^3 + 5\frac{1}{\sqrt{6}RC} \times RC} = \frac{-\frac{1}{6\sqrt{6}}}{\frac{-1}{6\sqrt{6}} + \frac{5}{\sqrt{6}}}$$

$$\boxed{\beta = \frac{-1}{29}} \rightarrow \boxed{\angle\beta = 180^\circ}$$ ✓

$$\boxed{\angle A = 180^\circ}$$ ✓

$$\Rightarrow \boxed{\angle A\beta = 0^\circ}$$

$$|\alpha\beta| = 1$$

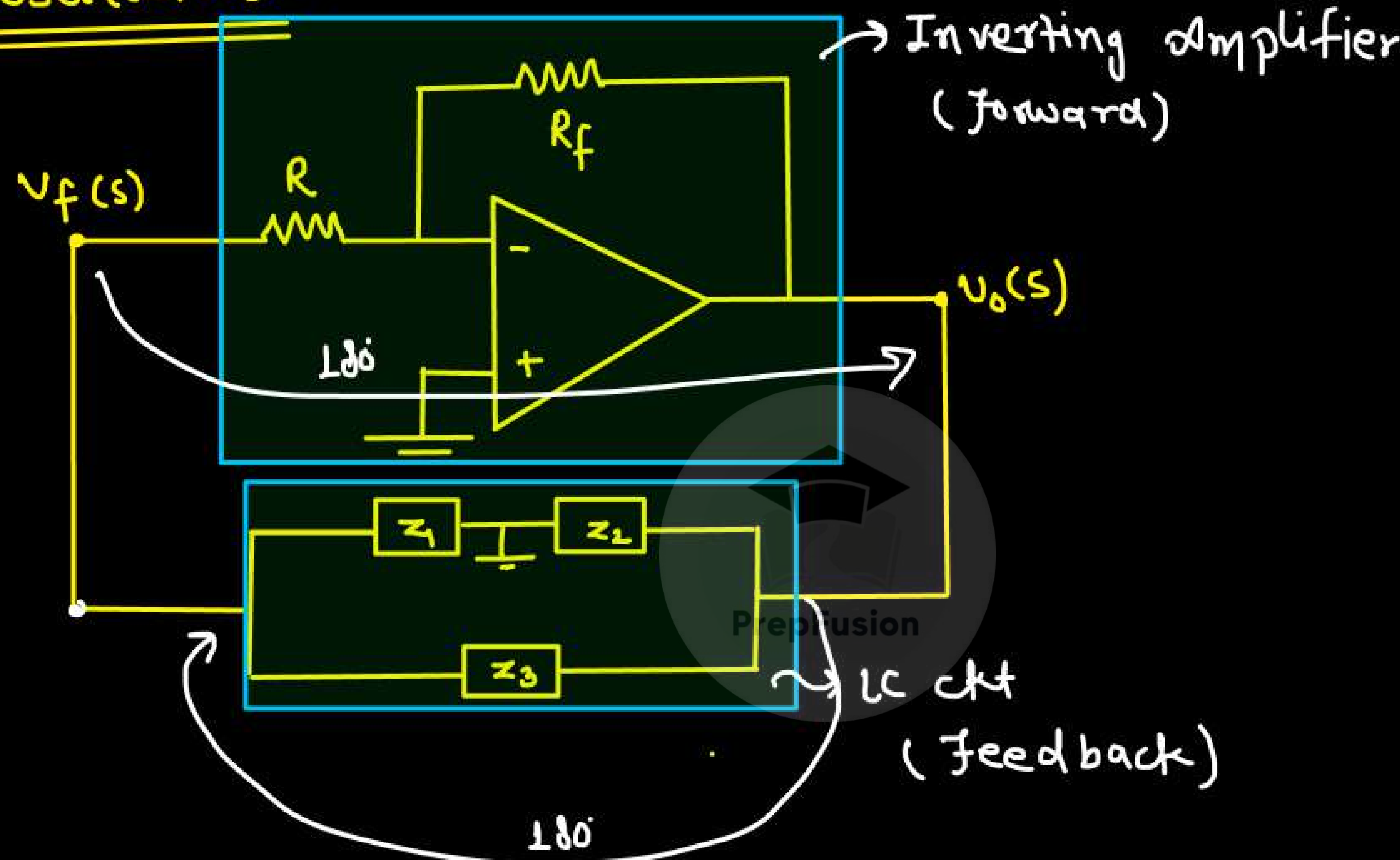
$$\Rightarrow |A| = \frac{1}{|\beta|} = 29 \Rightarrow |A| = \frac{R_f}{R} = 29$$

$$** \quad \boxed{R_f = 29R}$$

$$** \quad \boxed{\omega = \frac{1}{\sqrt{6} \times RC}} \Rightarrow \text{Freq. of Oscillation}$$

$$= \frac{1}{\sqrt{2N} \times RC} \qquad N \Rightarrow \text{no of CR ckts}$$

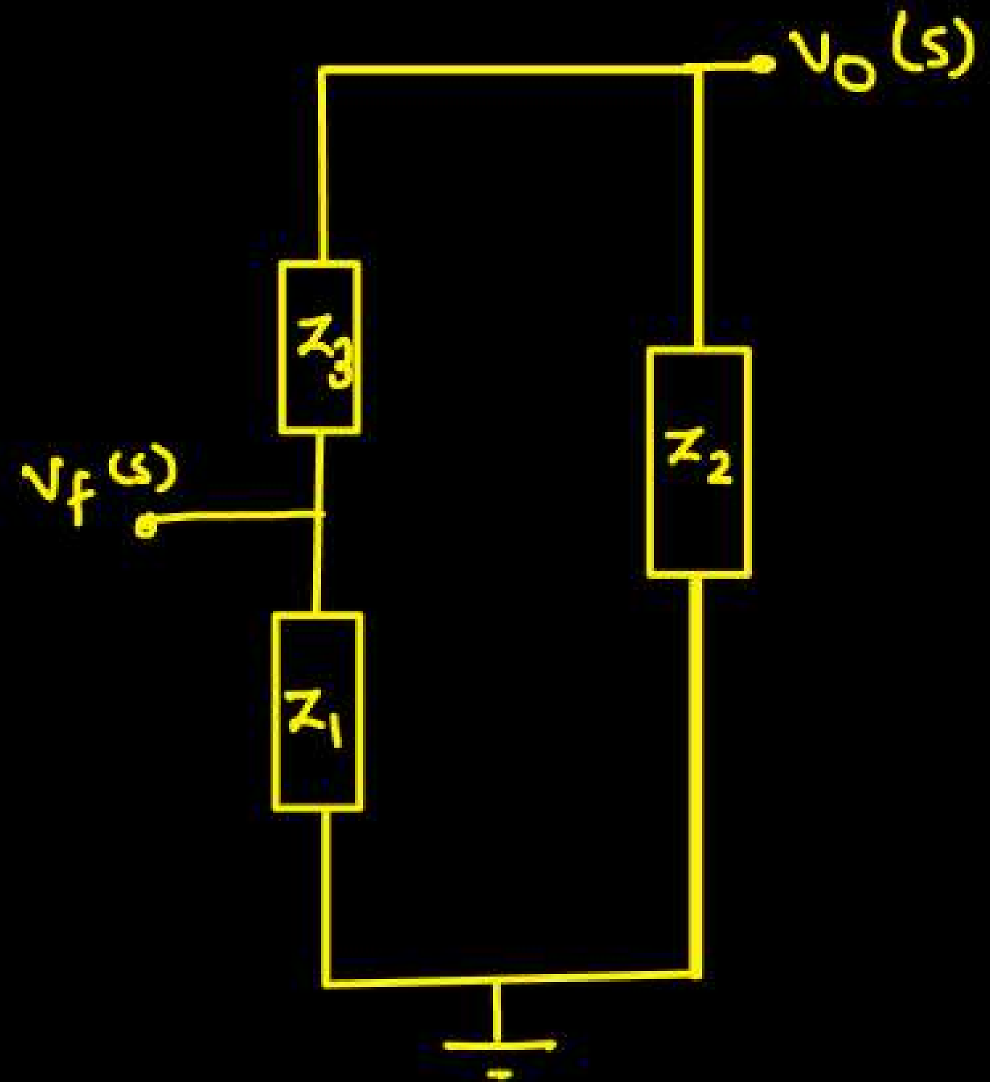
✱ LC Oscillators :-



(a) Forward gain (A) :-

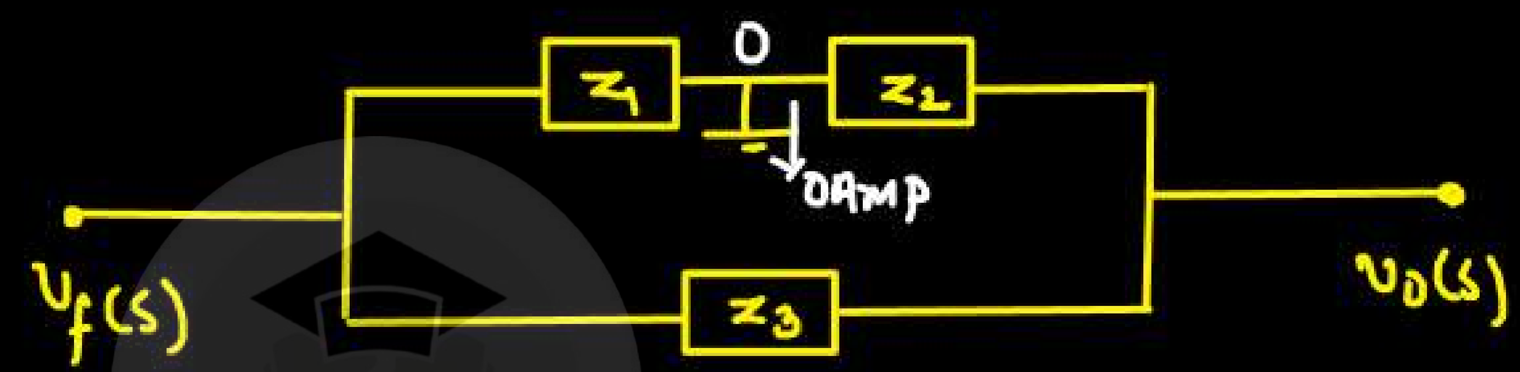
$$\boxed{A = \frac{-R_f}{R}}$$

$$\boxed{|A| = R_f/R}$$



$$v_f(s) \approx \frac{Z_1}{Z_1+Z_3} v_o(s)$$

$$\boxed{\beta(s) \approx \frac{Z_1}{Z_1+Z_3}}$$



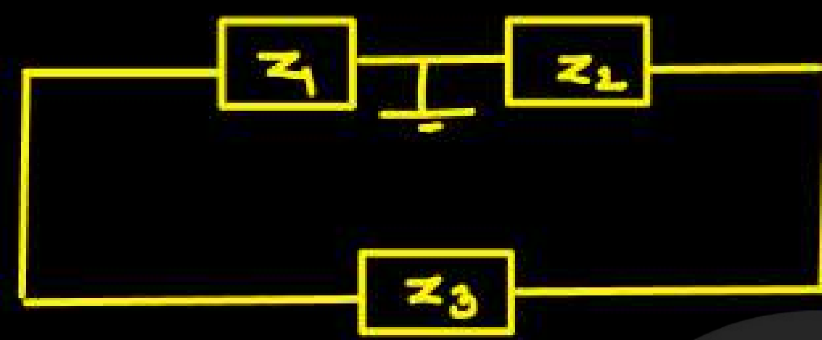
$$\frac{-v_f(s)}{Z_1(s)} - \frac{v_o(s)}{Z_2(s)} = 0$$

$$\boxed{\frac{v_f(s)}{v_o(s)} = -\frac{Z_1(s)}{Z_2(s)}}$$

Remember This one ★★★

$$\boxed{|\beta| = \frac{Z_1(s)}{Z_2(s)}}$$

For Finding Freq. of Oscillations:-



$$\boxed{Z_1 + Z_2 + Z_3 = 0}$$

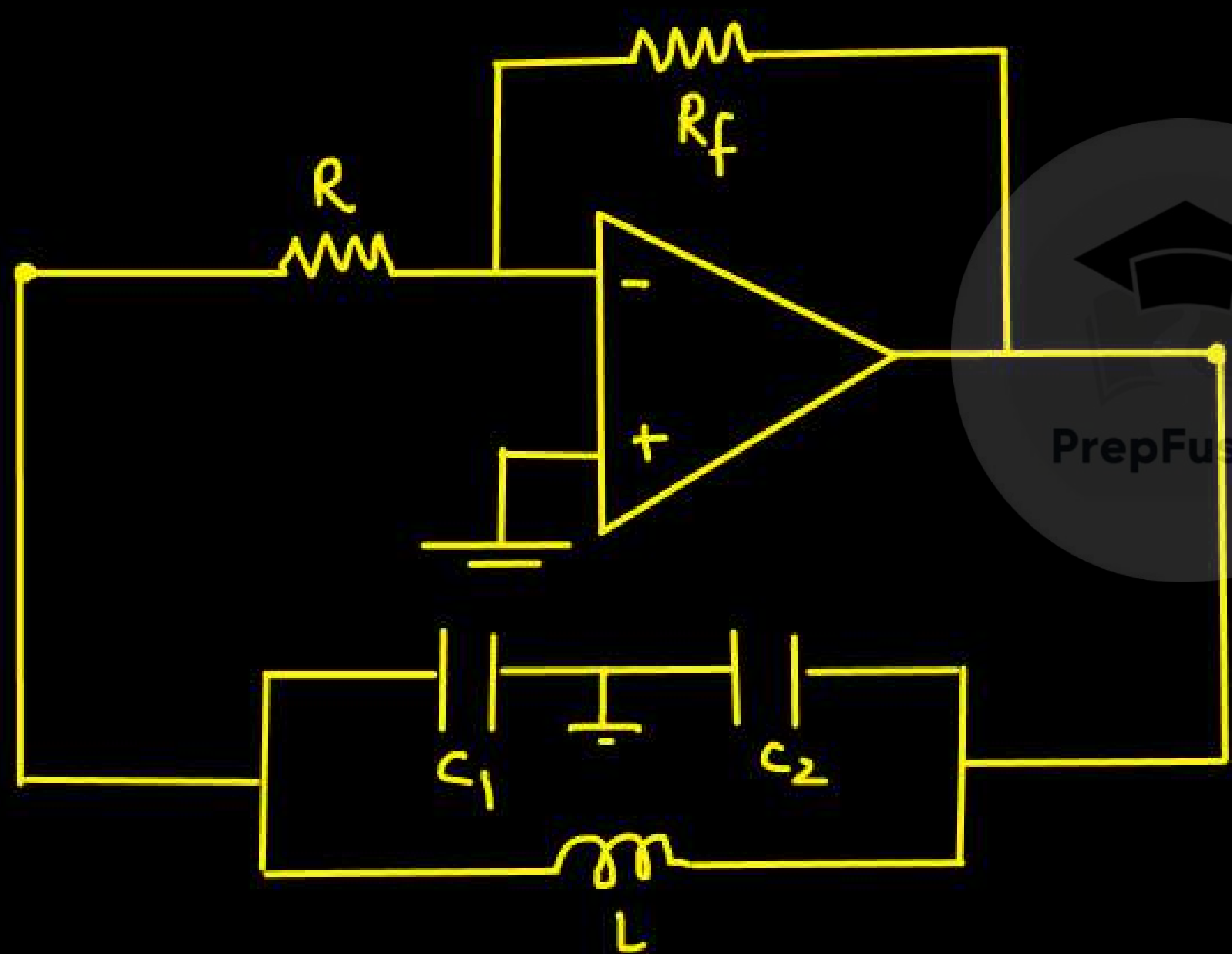
↓ From Here you will get ω value

1. $Z_1, Z_2 \rightarrow$ cap., $Z_3 \rightarrow$ inductor $\Rightarrow$ Colpitt's oscillator
2. $Z_1, Z_2 \rightarrow$ Ind., $Z_3 \rightarrow$ cap $\Rightarrow$ Hartley oscillator

Colpitt's Oscillator :-

Z_1 , Z_2 → Capacitor

Z_3 → Inductor



LC circuits

(a) Forward gain (A) :-

$$A = -\frac{R_f}{R} \quad , \quad |A| = \frac{R_f}{R} \quad , \quad \angle A = 180^\circ$$

(b) Frequency of Oscillations :-

$$\frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} + j\omega L = 0$$

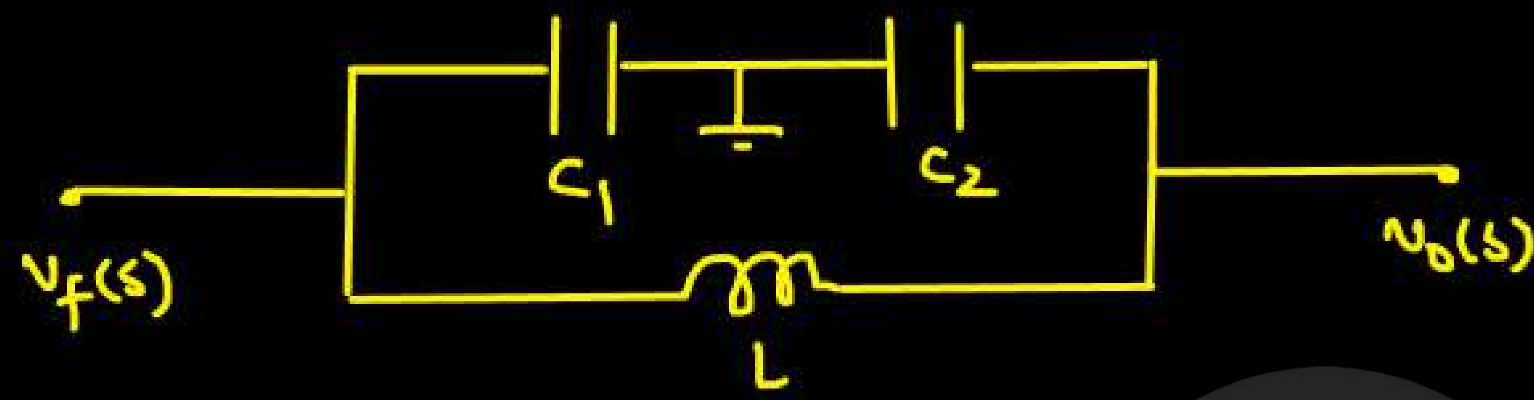
$$j\left[\frac{-1}{\omega C_1} - \frac{1}{\omega C_2} + \omega L\right] = 0$$

$$\omega L = \frac{1}{\omega}\left[\frac{1}{C_1} + \frac{1}{C_2}\right]$$

$$\omega = \frac{1}{\sqrt{L\left(\frac{1}{C_1} + \frac{1}{C_2}\right)}}$$

$$\boxed{\omega = \frac{1}{\sqrt{L\frac{C_1 C_2}{C_1 + C_2}}}}$$

(c) Feedback factor (β):-



$$-V_f(s) \times C_1 s - V_o(s)\, C_2 s = 0$$

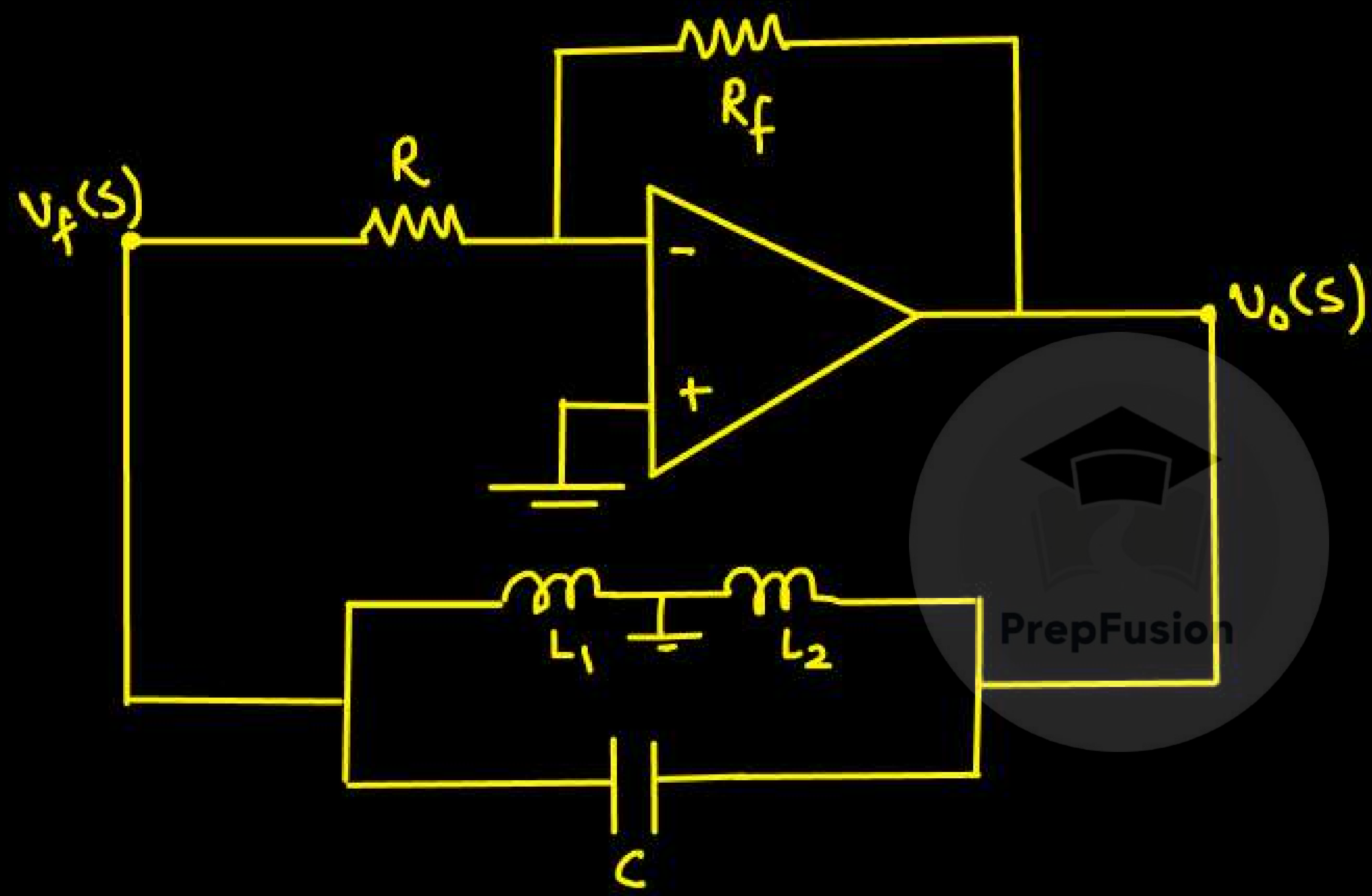
$$\frac{V_f(s)}{V_o(s)} = -\frac{C_2}{C_1}$$

$$\boxed{|\beta| = \frac{C_2}{C_1}}$$

For sustained oscillations; $|A\beta| > 1$

$$\boxed{\frac{R_f}{R} \times \frac{C_2}{C_1} > 1}$$

Hartley Oscillator:-



(a) Forward gain (A) :-

$$A = \frac{-R_f}{R}, \quad |A| = \frac{R_f}{R}, \quad \angle A = 180^\circ$$

(b) Frequency of Oscillation (ω) :-

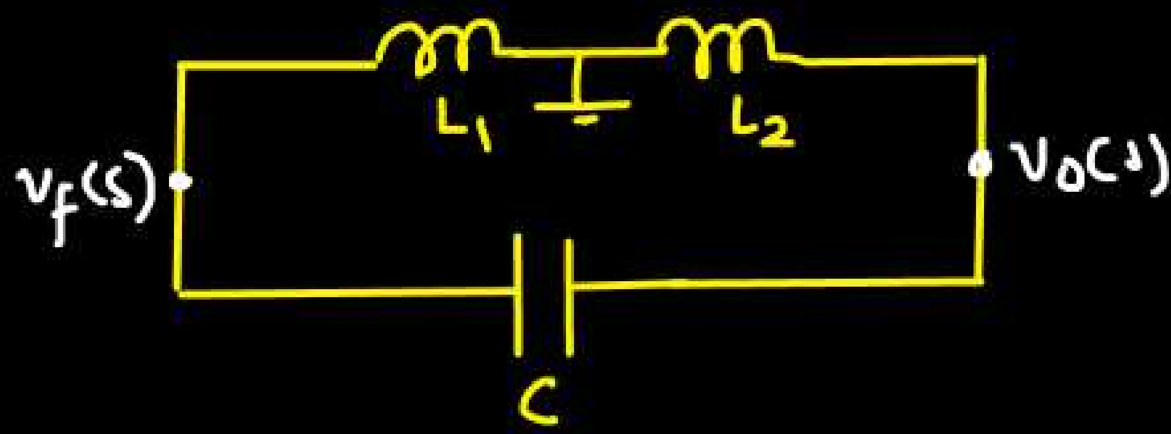
$$j\omega L_1 + j\omega L_2 + \frac{1}{j\omega C} = 0$$

$$\omega L_1 + \omega L_2 - \frac{1}{\omega C} = 0$$

$$\omega (L_1 + L_2) = \frac{1}{\omega C}$$

$$\boxed{\omega = \frac{1}{\sqrt{(L_1+L_2)C}}}$$

Feedback Factor:-



$$-\frac{V_f(s)}{L_1 s} - \frac{V_0(s)}{L_2(s)} = 0$$

$$\frac{V_f(s)}{V_0(s)} = \beta(s) = -\frac{L_1}{L_2}$$

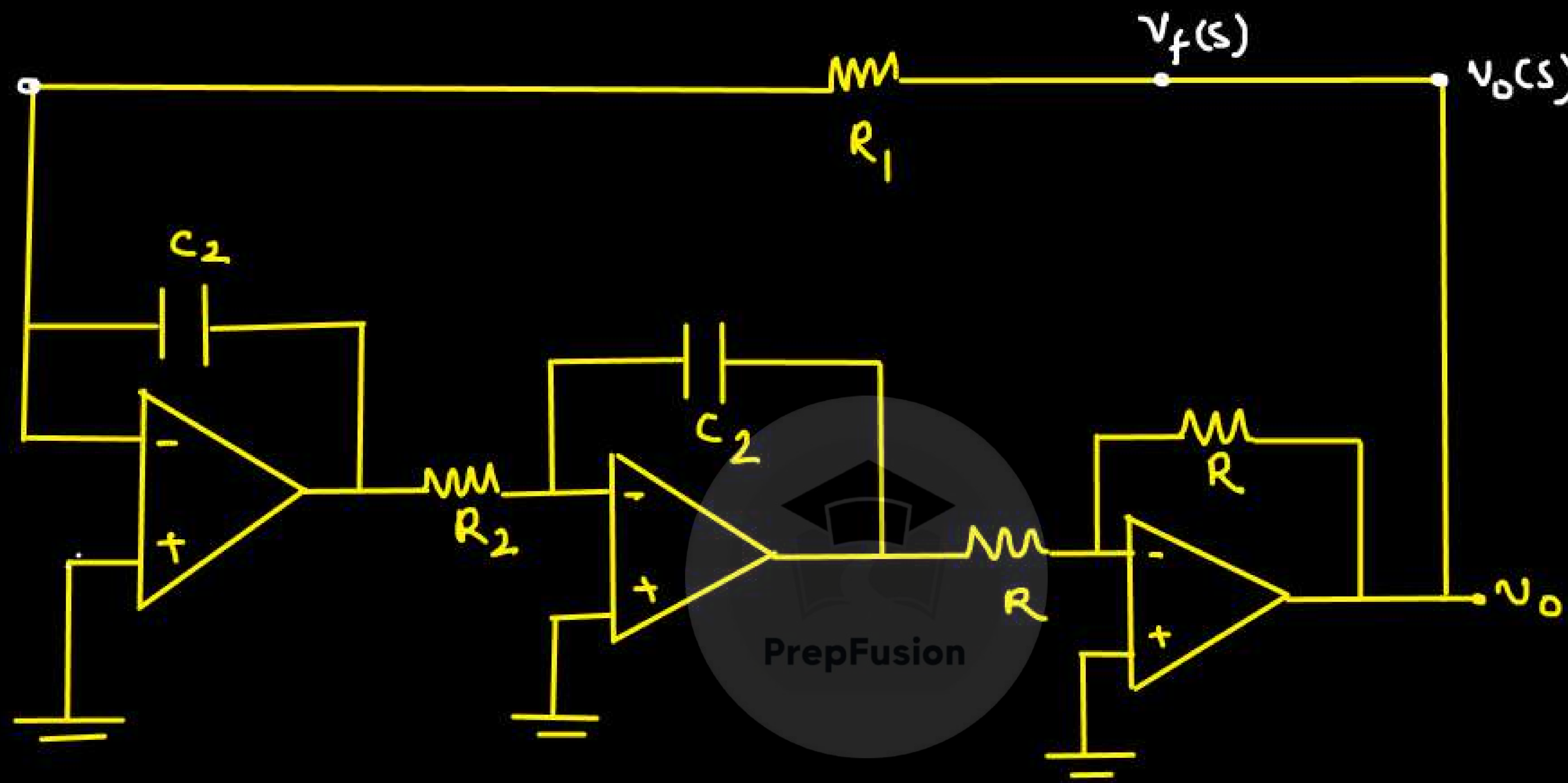
$$\boxed{|\beta| = \frac{L_1}{L_2}}$$

<u>For sustained oscillations:-</u>

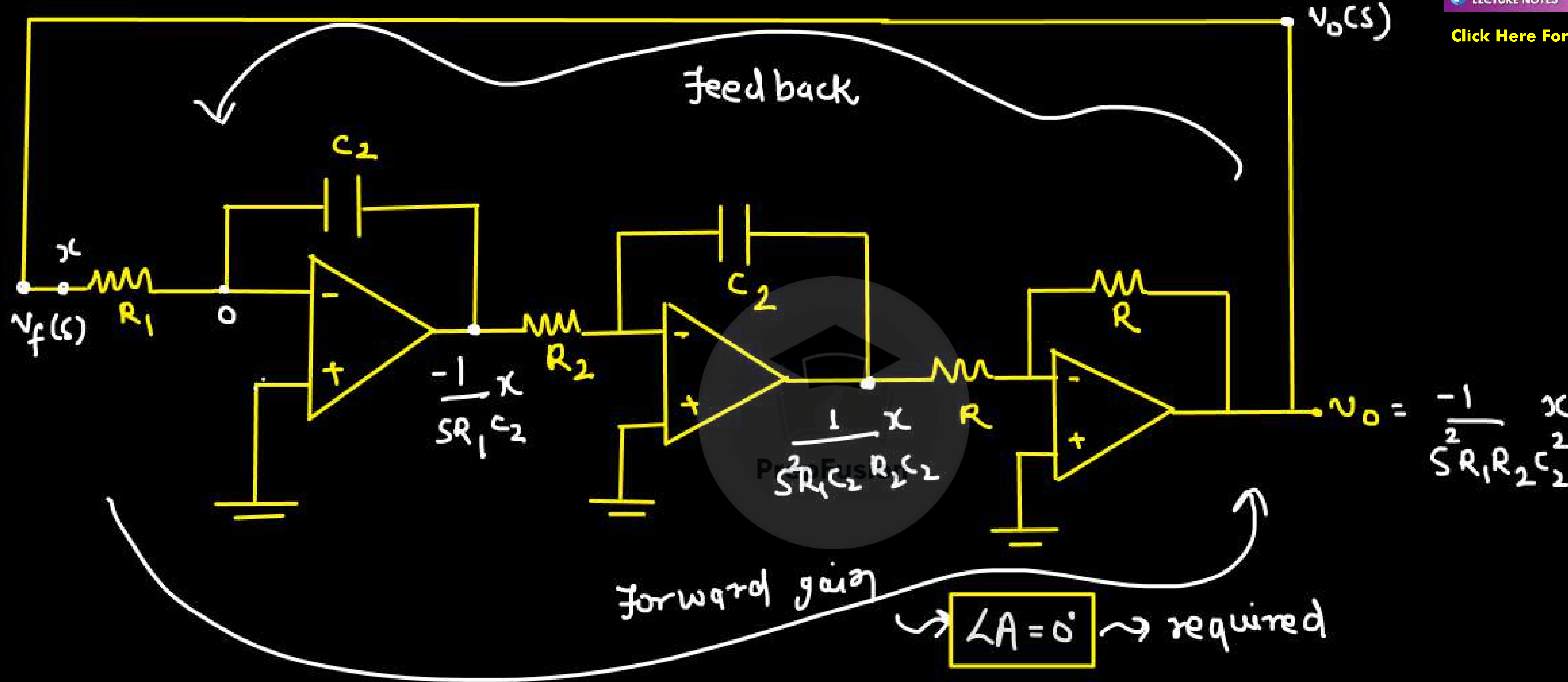
$$|\alpha\beta| = 1$$

$$\boxed{\frac{R_f}{R} \times \frac{L_1}{L_2} = 1}$$

Q.



Find the frequency of Sustained oscillations.



$\boxed{\beta = 1}$ $\angle\beta = 0^\circ$

Forward gain $A = \dfrac{-1}{s^2 R_1 R_2 C_2^2} = \dfrac{-1}{-\omega^2 R_1 R_2 C_2^2}$

$$= \frac{1}{\omega^2 R_1 R_2 C_2^2} \qquad \angle A = 0^\circ$$

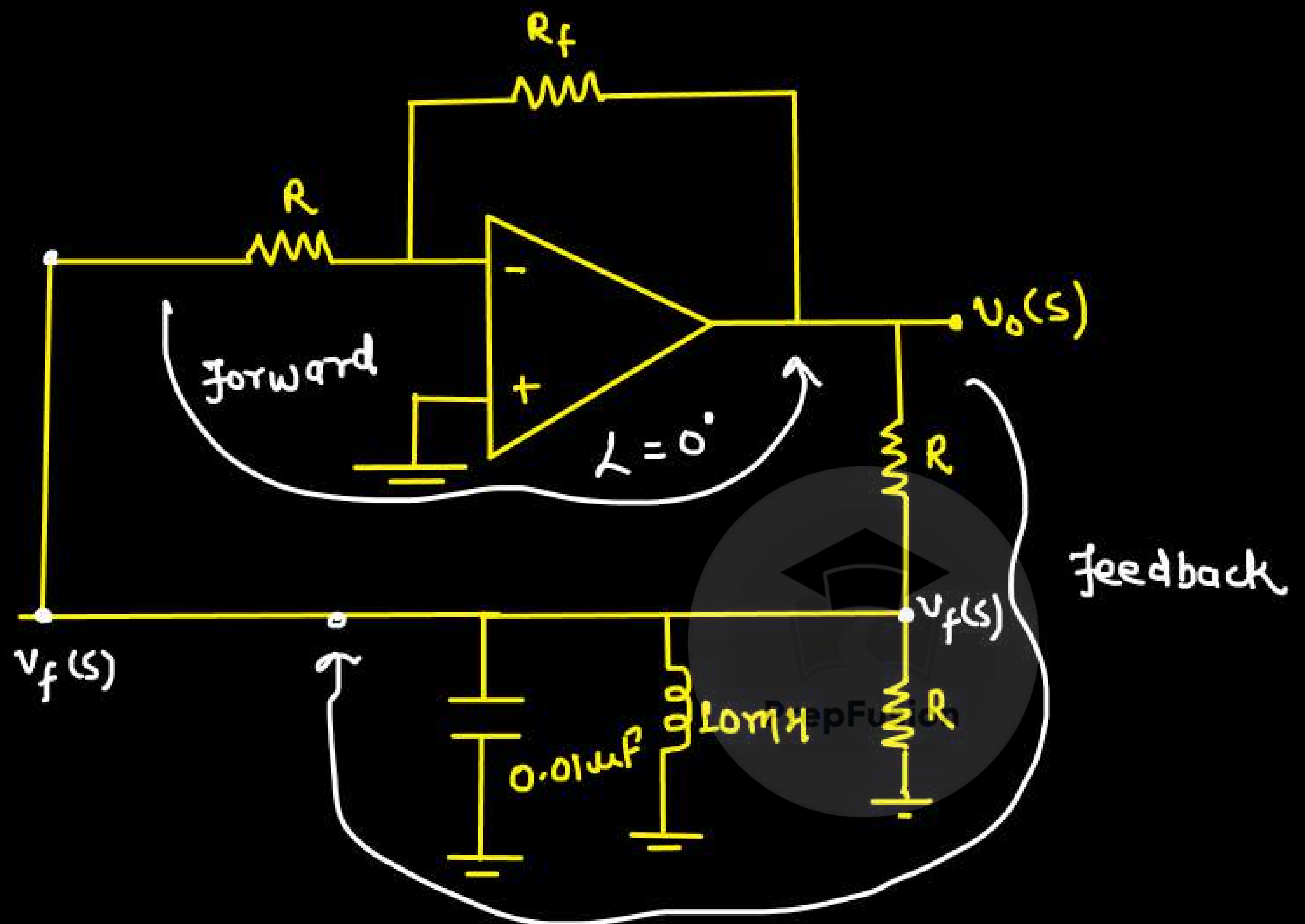
For sustained oscillation :-

$$|A\beta| = 1$$

$$\frac{1}{\omega^2 R_1 R_2 C_2^2} = 1$$

$$\boxed{\omega = \frac{1}{C_2\sqrt{R_1 R_2}}} \rightsquigarrow \text{Frequency of oscillations}$$

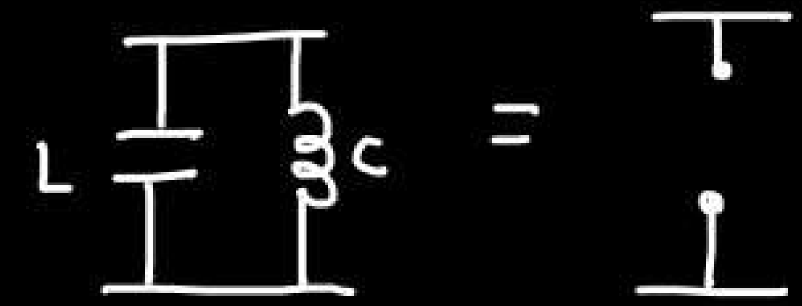
Q.



(a) Find the frequency of sustained oscillations?

(b) The ratio of R_f/R for sustained oscillations?

→ required $\angle\beta = 0^\circ$

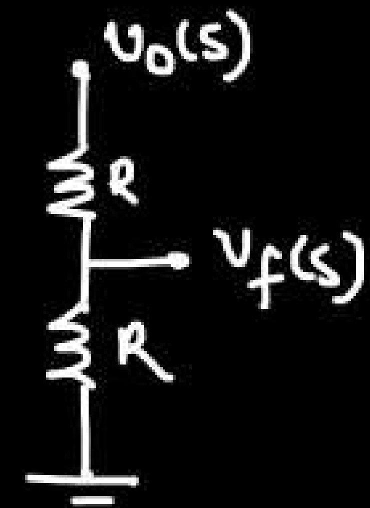


$$Ls \,||\, \frac{1}{Cs} = \infty$$

$$\Rightarrow Ls + \frac{1}{Cs} = 0$$

$$j\omega L - \frac{j}{\omega C} = 0$$

$$\boxed{\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{10^{-8} \times 10^{-2}}} = 10^5 \text{ rad/sec.}}$$



$$v_f(s) = \frac{1}{2} v_o(s)$$

$$\boxed{\beta = 1/2} \qquad \angle\beta = 0^\circ$$

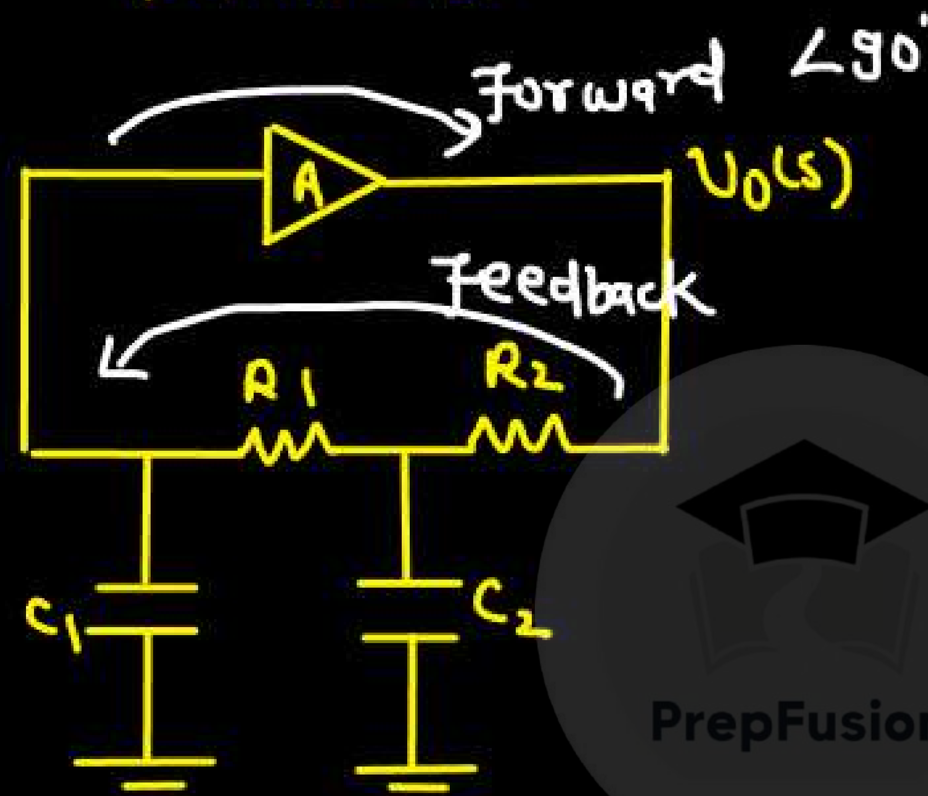
↳ $|A\beta| = 1$

$$\left(1+\frac{R_f}{R}\right)\left(\frac{1}{2}\right) = 1$$

$$\boxed{\frac{R_f}{R} = 1}$$

Q. The forward gain A can be written as

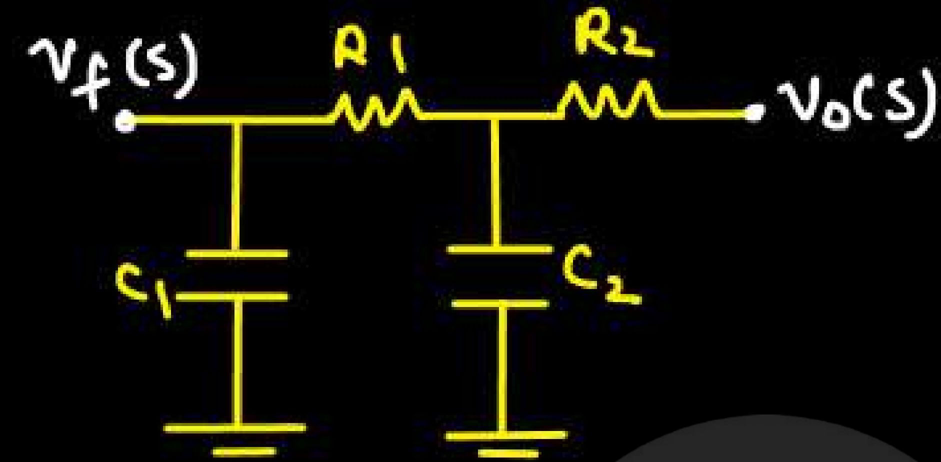
$$A = |A| \angle 90^\circ$$



For sustained oscillations, find the magnitude of A and the freq. at which the circuit oscillates.

→

$\boxed{\angle\beta = -90^\circ} \rightarrow$ required



$$\frac{v_f(s)}{v_0(s)} = \frac{1}{s^2C^2R^2 + 3RCs + 1}$$

$$\beta = \frac{1}{-\omega^2R^2C^2 + 3j\omega RC + 1}$$

For $\angle\beta = -90^\circ$, $\quad 1 - \omega^2R^2C^2 = 0$

$$\boxed{\omega = \frac{1}{RC}} \rightarrow \text{Freq. of Oscillations}$$

Ans

$$\beta\left(\text{at } \omega = \frac{1}{RC}\right) = \frac{1}{3j \times \frac{1}{RC} \times RC} = \frac{-j}{3}$$

$$\boxed{\angle\beta = -90^\circ}$$

$$|\beta| = 1/3$$

↳ $|A\beta| = 1$

$$\boxed{|A| = 3}$$ Ans.

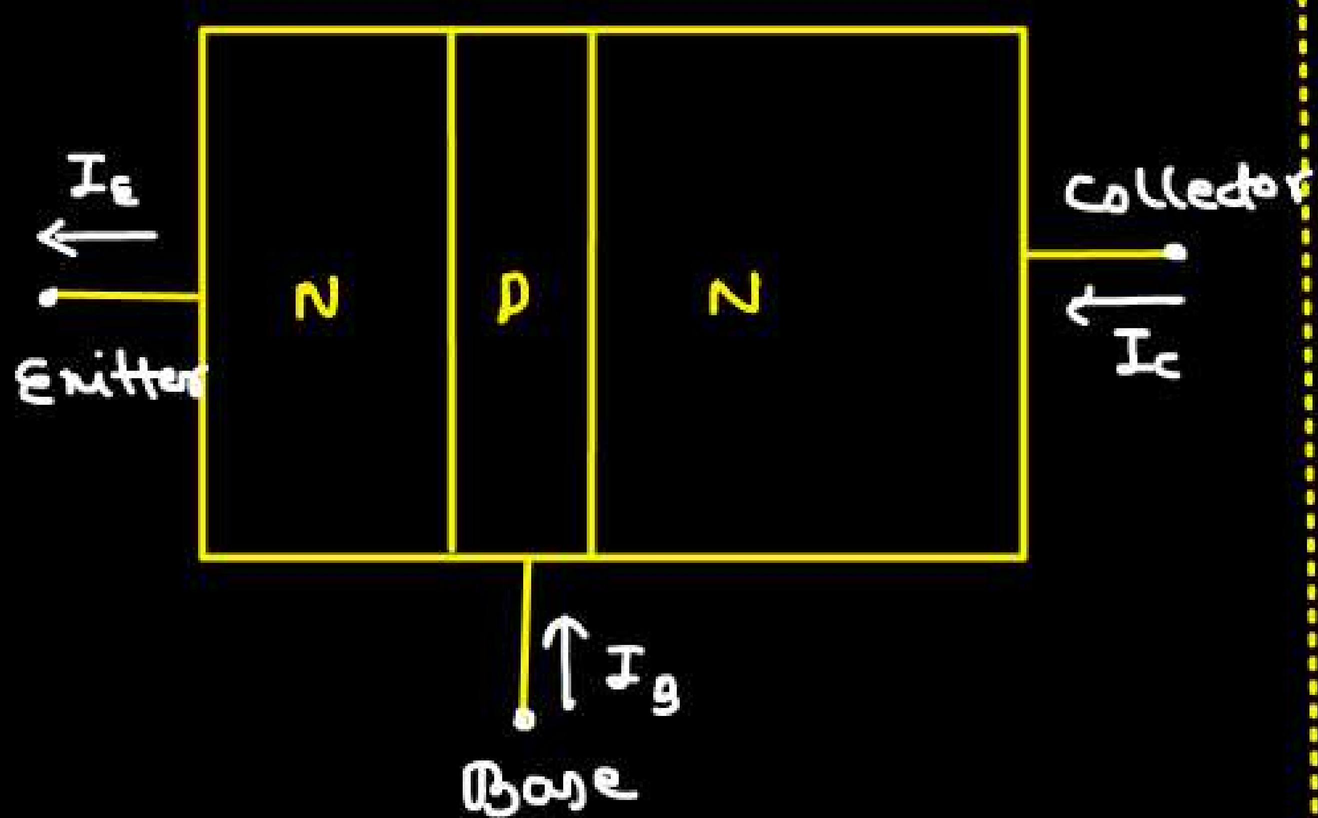
Bipolar Junction Transistors

Two charge carrier [$e^{\ominus}$, holes] (BJTs)

BJT [NPN, PNP]

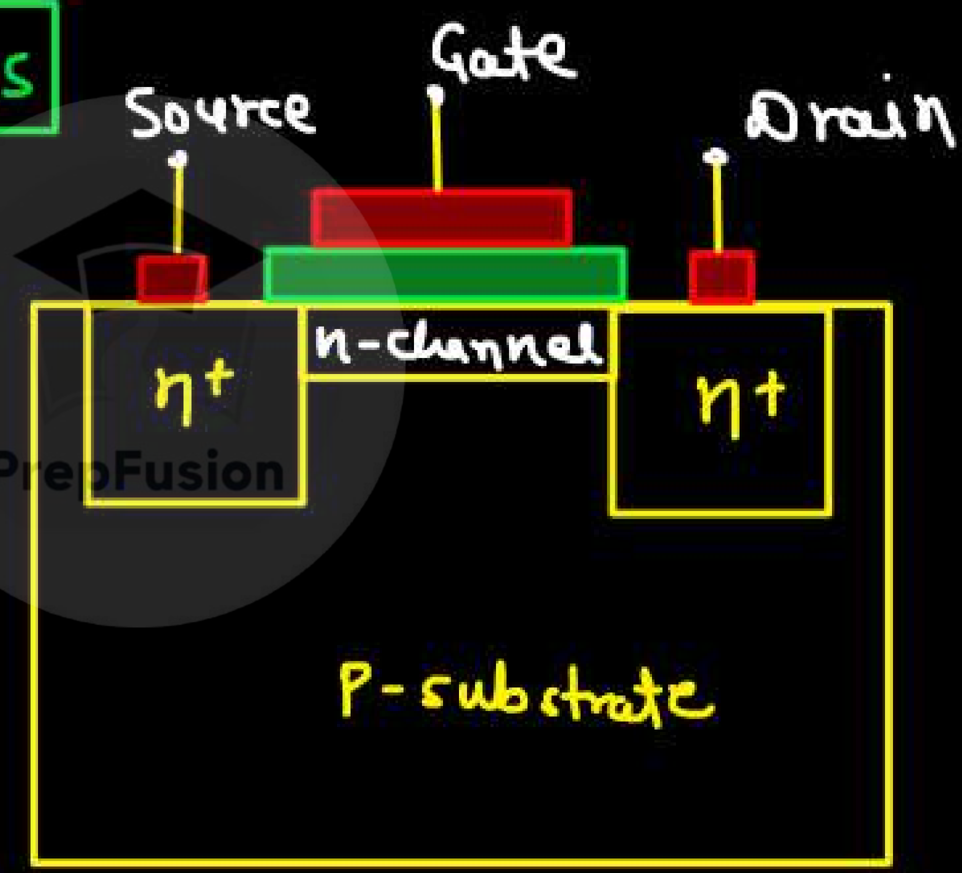
MOS [NMOS, PMOS]

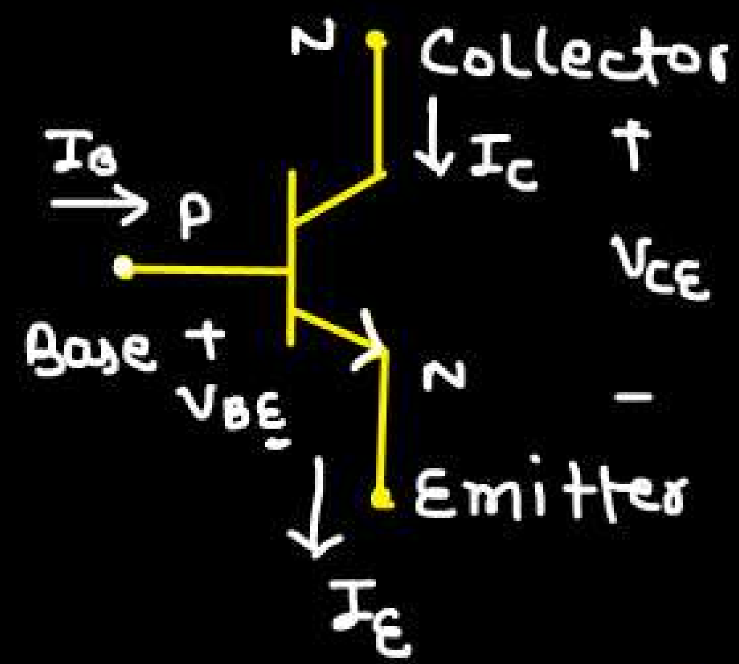
NPN



$A_C > A_E > A_B$

NMOS





$$\boxed{I_C \approx I_S \exp\left(\frac{V_{BE}}{\eta V_T}\right)} \quad (V_{CE}) > (V_{CE})_{sat}$$

I_S = Reverse sat-current

$$\boxed{I_E = I_C + I_B}$$

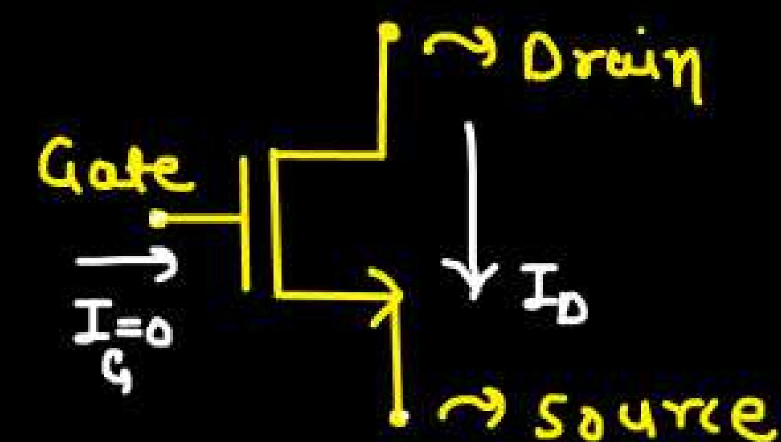
$V_T \rightarrow$ Thermal voltage

$V_A \rightarrow$ Early voltage

$$\boxed{V_T \propto T}$$

$V_T = 25\,mV$ @ $300K$

$$\boxed{I_C = I_S \exp\left(\frac{V_{BE}}{\eta V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)}$$



$$\boxed{I_D = \frac{\mu_n C_{ox} W}{2L}\left[(V_{GS} - V_T)^2\right]} \; ; \quad \boxed{V_{DS} > V_{GS} - V_T}$$

$$I_D = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_T)^2(1 + \lambda V_{DS})$$

☆ $\boxed{I_E = I_C + I_B}$ — ①

☆ $\boxed{I_C = \beta I_B}$ — ② $\beta \rightarrow$ Common Emitter current gain

[β is typically High]

$$I_B = \frac{I_C}{\beta}$$

☆ if $\beta = \infty$

$\boxed{I_B = 0 \text{ Amp}}$

By eq^n ① and ②

$$I_E = \beta I_B + I_B$$

☆ $\boxed{I_E = (\beta + 1) I_B}$ — ③

$$\boxed{I_C = \alpha I_E} \quad \text{— (4)}$$

α = common Base current gain

(3) $\div$ (2)

$$\frac{I_E}{I_C} = \frac{(\beta+1) I_B}{\beta I_B}$$

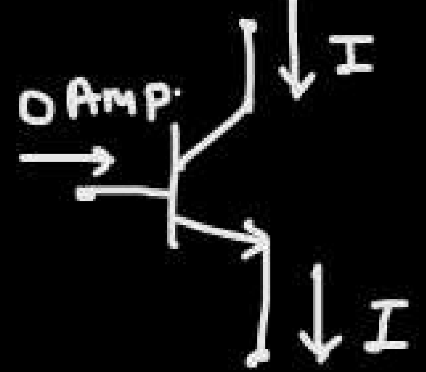
$$\boxed{I_E = \left(\frac{\beta+1}{\beta}\right) I_C} \quad \text{— (5)}$$

From (4) and (5)

$$\boxed{\alpha = \frac{\beta}{\beta+1}}$$

$\{ \alpha \approx 1$ or $\alpha < 1 \}$

$$\boxed{\begin{matrix}\text{if } \beta = \infty \\ \alpha = 1\end{matrix}}$$



For $\beta = \infty$

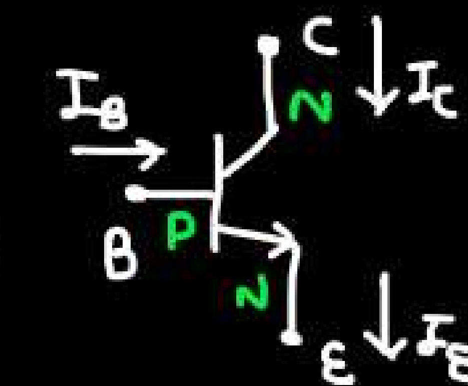
$I_C = I_E = I$

$I_E = I_C + I_B$

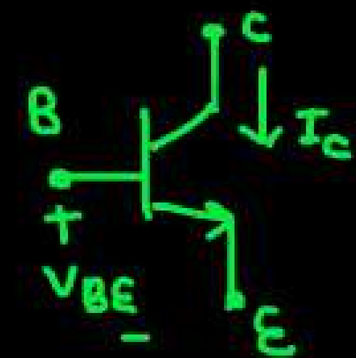
$I_C = \beta I_B$

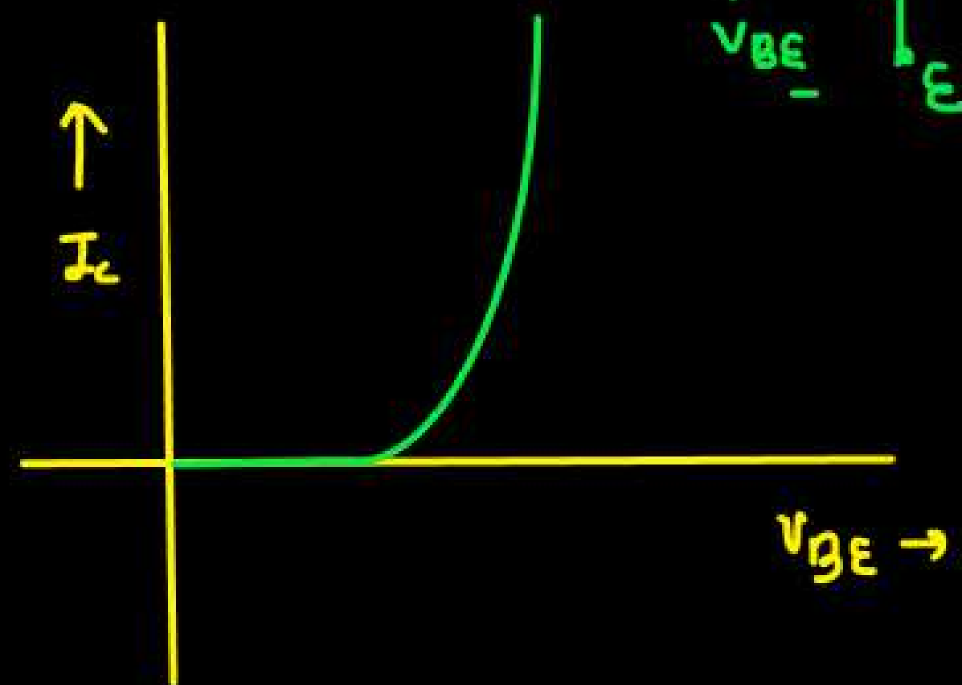
$I_E = (\beta+1) I_B$

$\alpha = \frac{\beta}{\beta+1}$



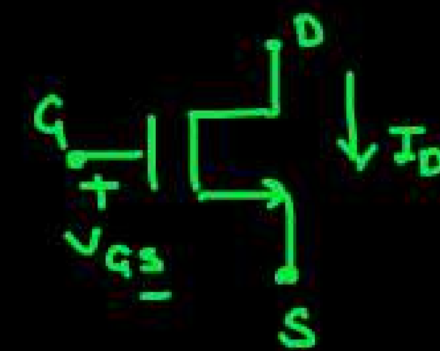
I_C v/s V_{BE}

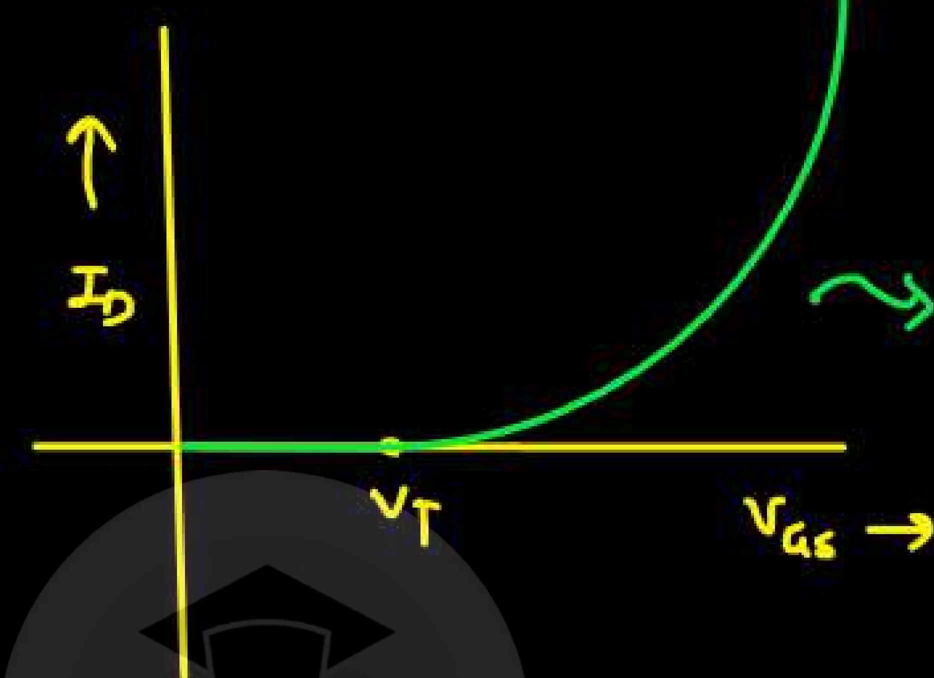




$$\boxed{I_C = I_S \exp\left(\frac{V_{BE}}{\eta V_T}\right)}$$

I_D v/s V_{GS}





→ parabolic

Q. For 10X increase in I_C, find change in V_{BE}. ($V_T = 25mV$), $\eta = 1$

→

$$I_C = I_S \exp\left(\frac{V_{BE_1}}{V_T}\right) \quad \text{— (1)}$$

$$10 I_C = I_S \exp\left(\frac{V_{BE_2}}{V_T}\right) \quad \text{— (2)}$$

2 ÷ 1

$$10 = \frac{\exp\left(\frac{V_{BE2}}{V_T}\right)}{\exp\left(\frac{V_{BE1}}{V_T}\right)}$$

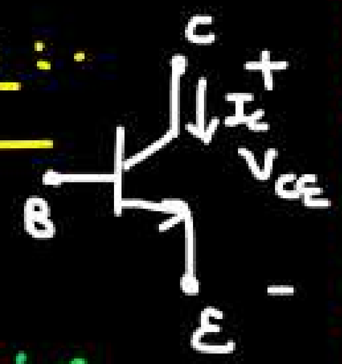
$$10 = \exp\left(\frac{V_{BE2} - V_{BE1}}{V_T}\right)$$

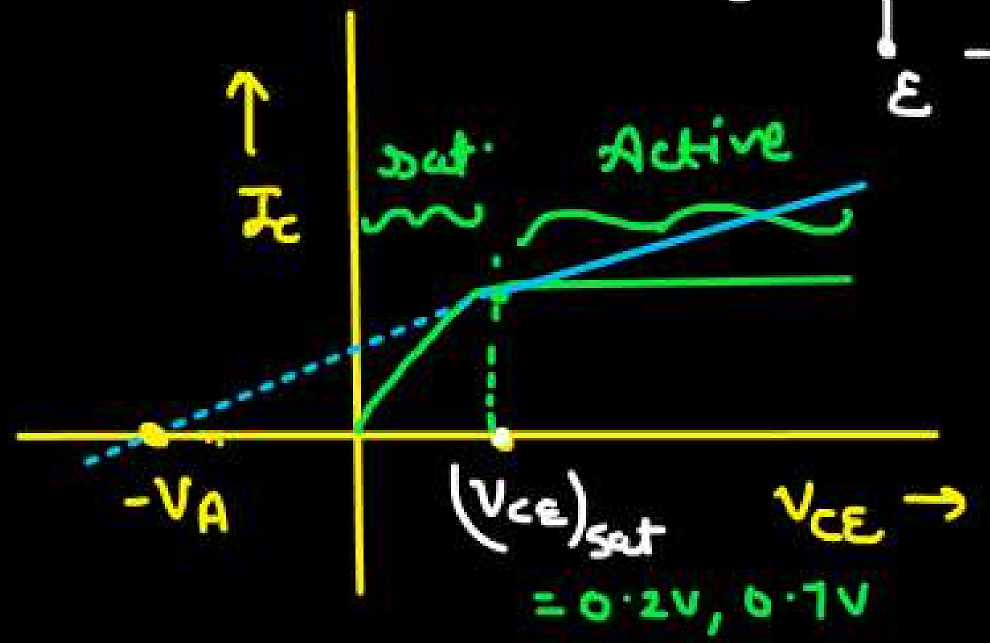
$$V_{BE2} - V_{BE1} = V_T \ln(10)$$

$$\boxed{\Delta V_{BE} = 57\,mV}$$

↳ in the question, Typically $\boxed{V_{BE} = 0.7V}$

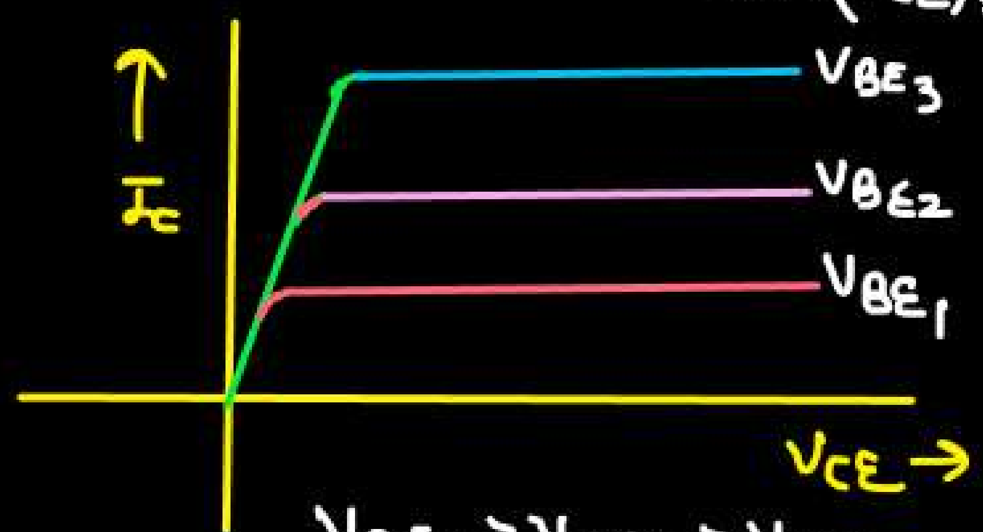
I_C v/s V_{CE} curve :





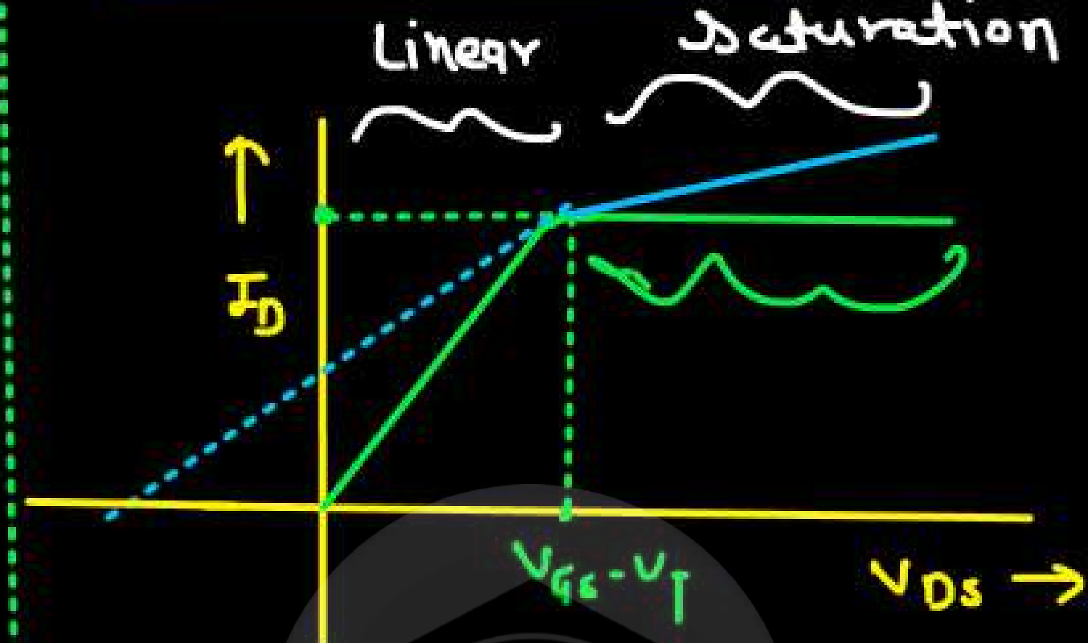
$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)\left(1+\frac{V_{CE}}{V_A}\right)$$

$V_{CE} > (V_{CE})_{sat}$

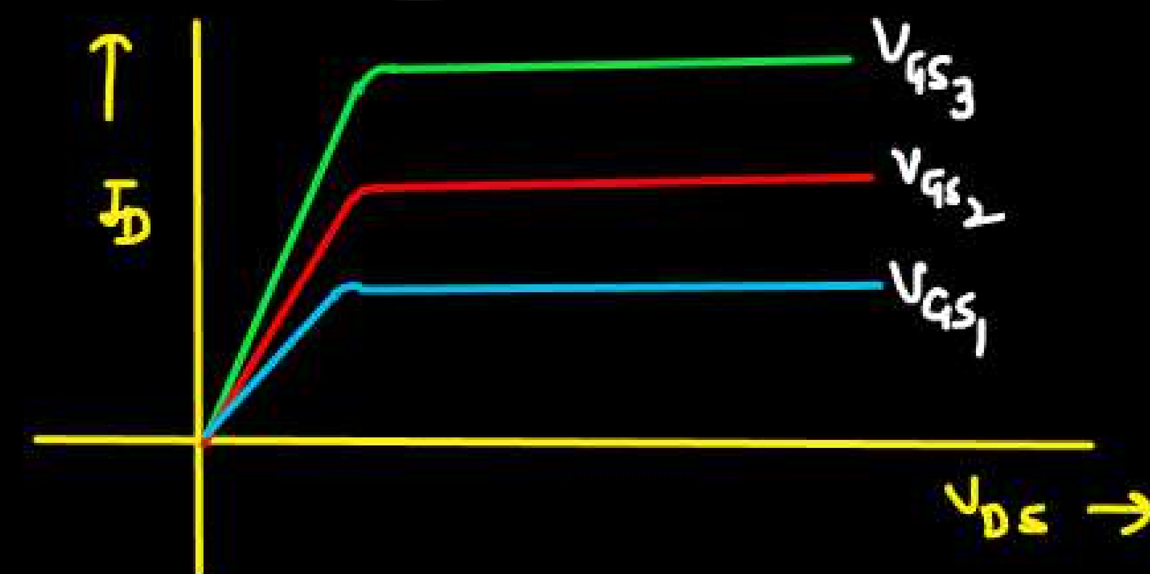


$V_{BE_3} > V_{BE_2} > V_{BE_1}$

I_D v/s V_{DS} curve

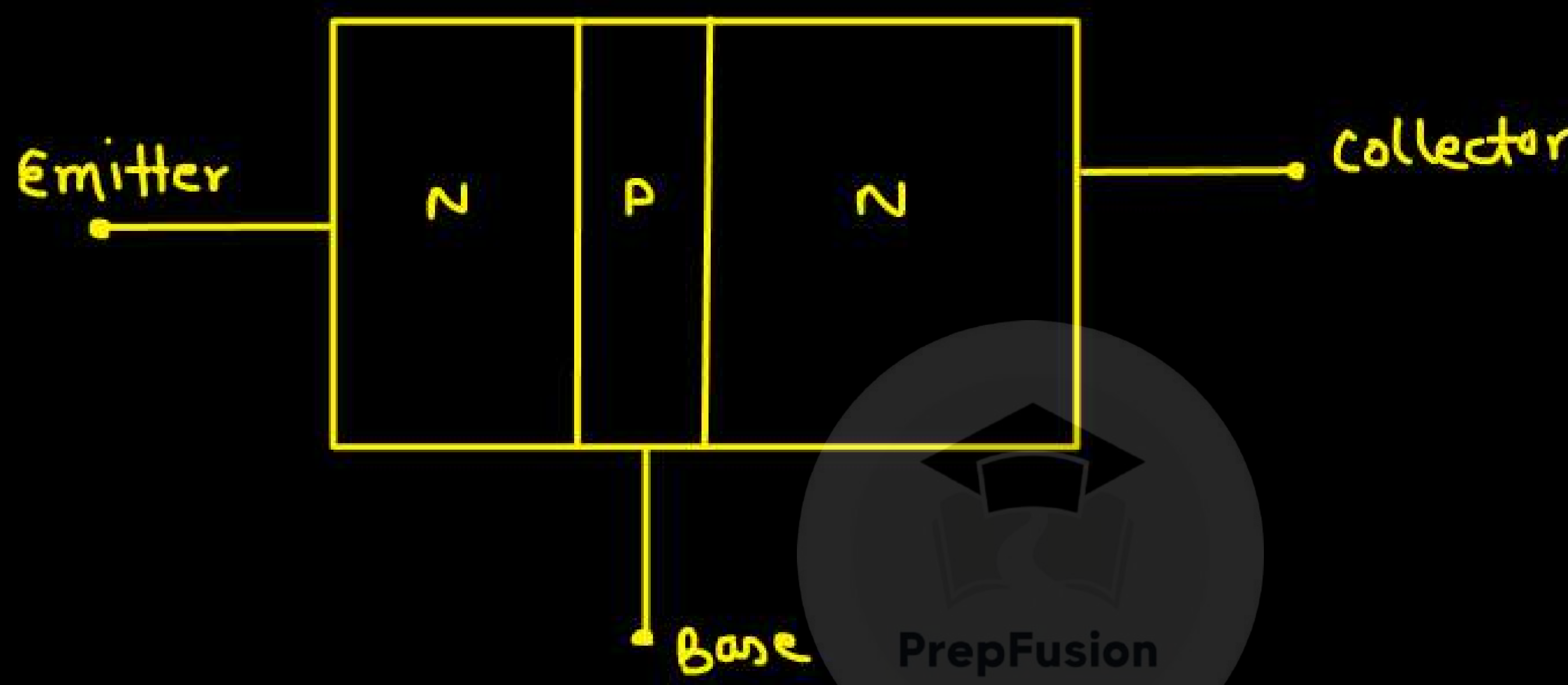


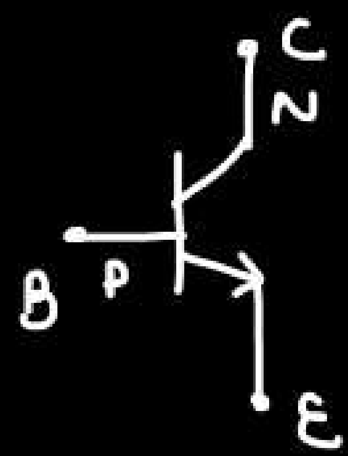
$$I_D = \frac{\mu_n C_{ox} W}{2L}(V_{GS}-V_T)^2(1+\lambda V_{DS}) \quad \{V_{DS} > V_{GS}-V_T\}$$



$$\boxed{V_{GS_3} > V_{GS_2} > V_{GS_1}}$$

Region of Operations in BJTs:-





Emitter - Base → Emitter Junction (J_E)

Collector Base → Collector Junction (J_C)

Region of Operation	J_E	J_C
1 Cut-off	RB	RB
2 Saturation	FB	FB
[Active] 3 Forward Active	FB	RB
4 Reverse Active	RB	FB

Active region of operation:-

$$\boxed{\begin{array}{l} J_E \to FB \\ J_C \to RB \end{array}}$$

$I_E = I_C + I_B$ ✓

$I_C = \beta I_B$ ✓

$I_C = \alpha I_E$ ✓

$V_{BE} = 0.7V$ [or given] ✓

$V_{CE} > (V_{CE})_{sat}$

$I_C \to max^m$

Saturation Region:-

$$\boxed{\begin{array}{l} J_E \to FB \\ J_C \to FB \end{array}}$$

$I_E = I_C + I_B$ ✓

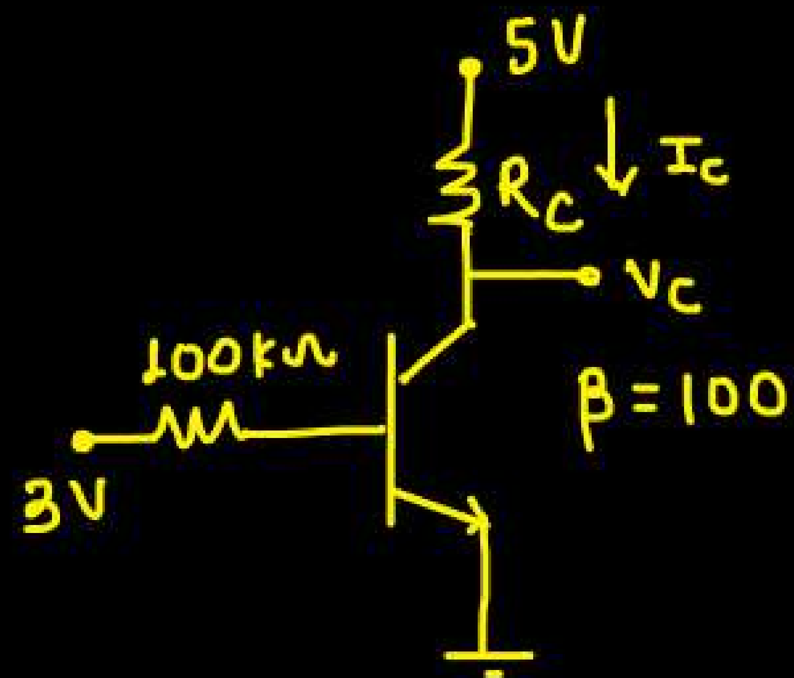
$$\boxed{\begin{array}{l} I_C = \beta I_B \quad \times \\ I_C = \alpha I_E \quad \times \end{array}}$$

$V_{BE} = 0.7V$ [or given] ✓

$V_{CE} = (V_{CE})_{sat} = 0.2V$ [or given] ✓

$I_C \to min^n$

Q.



$V_{BE} = 0.7V$

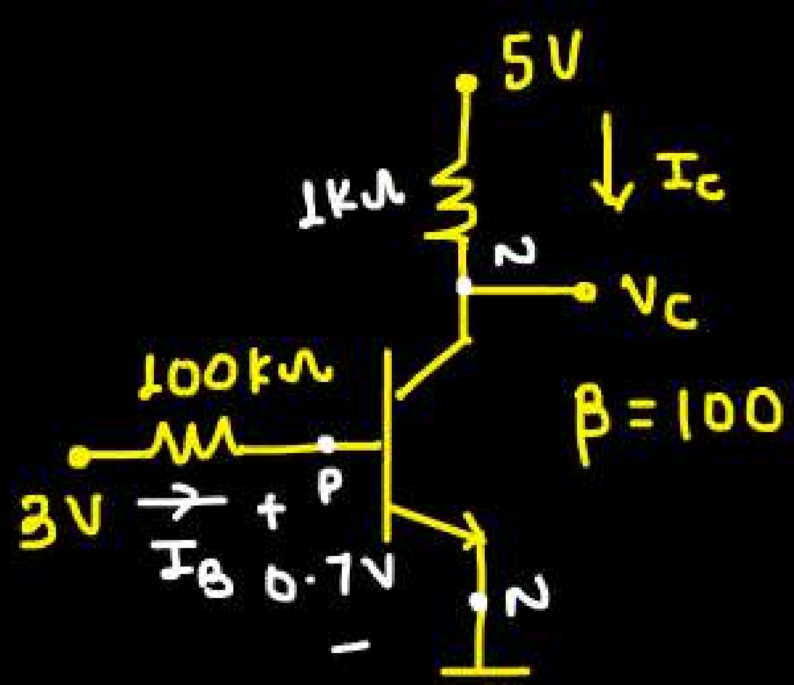
$(V_{CE})_{sat} = 0.2V$

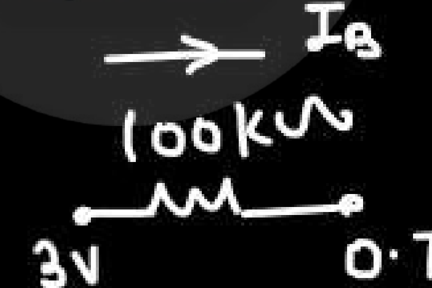
Find the value of V_{CE} and I_C for

(a) $R_C = 1k\Omega$

(b) $R_C = 10k\Omega$

→

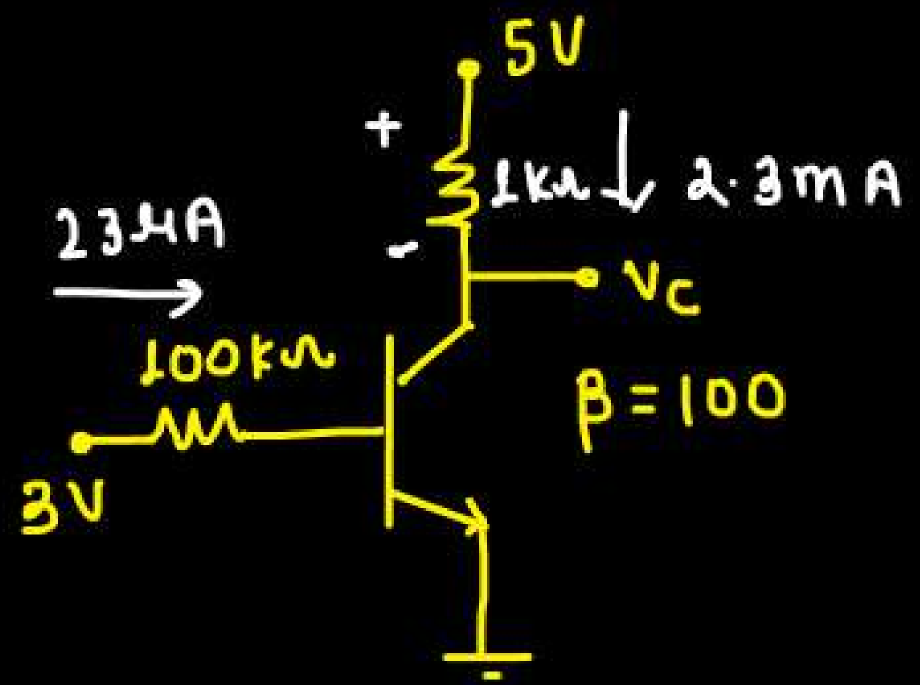




$$I_B = \frac{2.3}{100k}$$

$$\boxed{I_B = 23\mu A}$$

Assuming BJT in active region



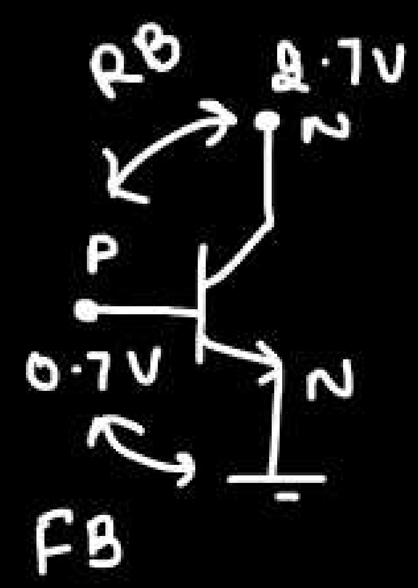
$I_C = \beta I_B$

$I_C = 100 \times 23 \times 10^{-6}$ Amp

$\boxed{I_C = 2.3\,\text{mAmp.}}$ ✓

$V_C = 5 - (1k)(2.3\,\text{mA})$

$\boxed{V_C = 2.7\,V}$ ✓

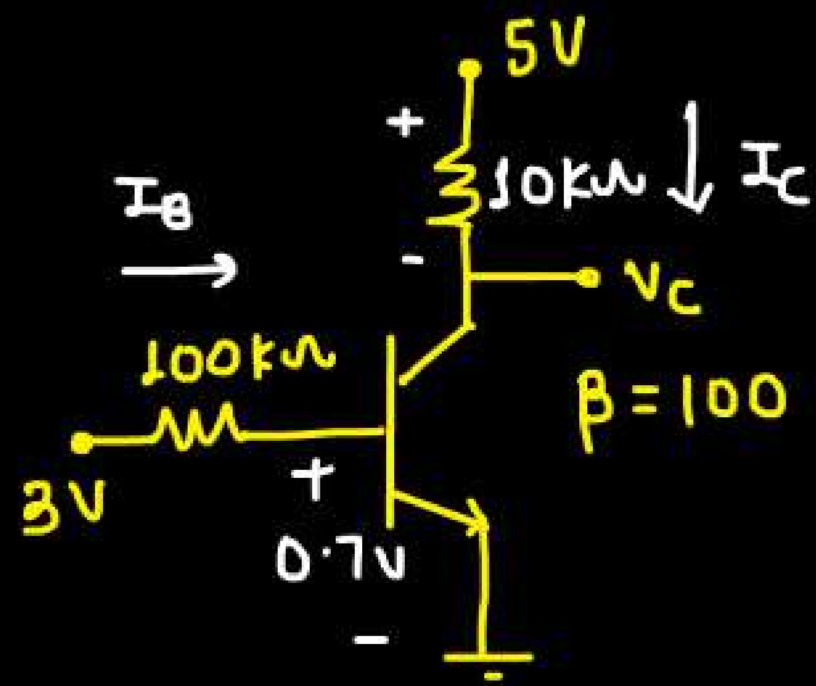


$\Rightarrow$ BJT is in active region

Assumption correct

$\boxed{I_E = (\beta+1) I_B = 101 \times 23\mu = 2.323\,\text{mA}}$

(b)

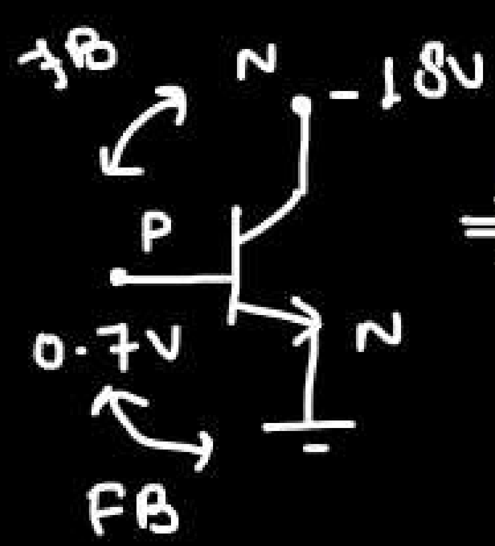


$$I_B = \frac{2.3}{100k} = 23\,\mu A$$

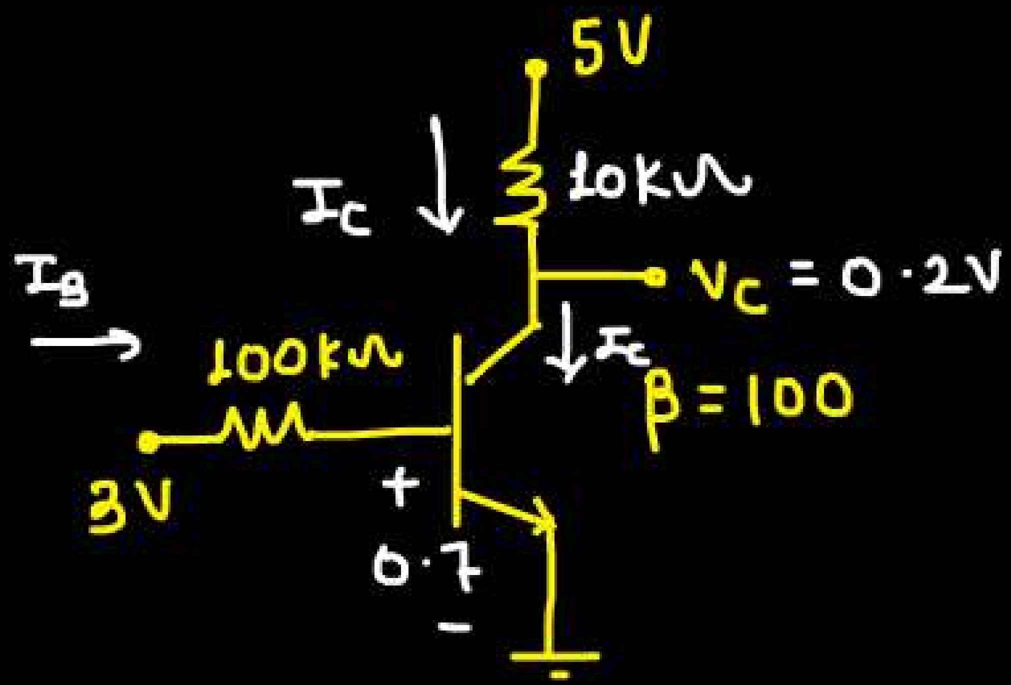
Assuming, BJT in active

$$I_C = \beta I_B$$
$$= 100 \times 23\mu$$
$$= 2.3\,mA \quad \times$$

$$V_c = 5 - 10K \times I_c$$
$$= 5 - 10k \times 2.3$$
$$= 5 - 23$$
$$V_c = -18V \quad \times$$



$\Rightarrow$ $\boxed{\text{sat. region} \Downarrow \text{Assumption wrong}}$



Given, if BJT is in sat.

$\Rightarrow V_{ce} = (V_{CE})_{sat} = 0.2V$

$$\boxed{I_C = \frac{5-0.2}{10K} = 0.48mA}$$

$$\boxed{V_C = 0.2V}$$

$I_B = ?$

$$\boxed{I_B = I_C/\beta = ?}$$ X

$$I_B = \frac{2.3}{100k}$$

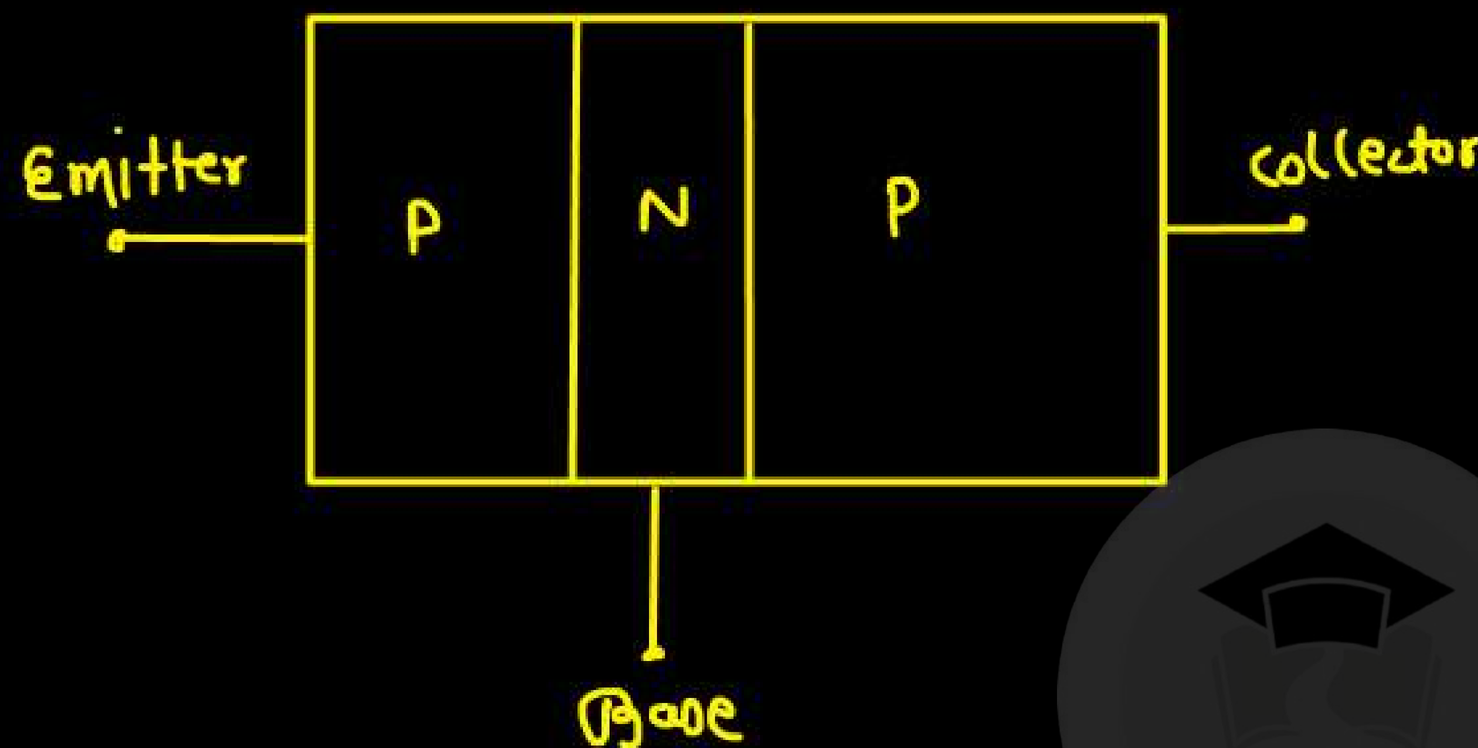
$$\boxed{I_B = 23\mu Amp}$$

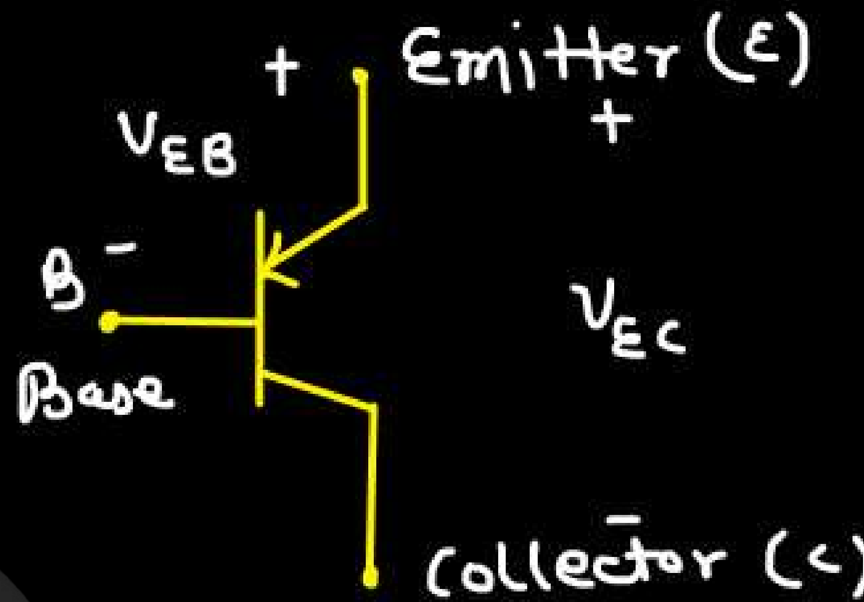
$$I_E = I_C + I_B$$

$$= 480 + 23$$

$$\boxed{I_E = 503\mu A}$$

PNP Transistor:-





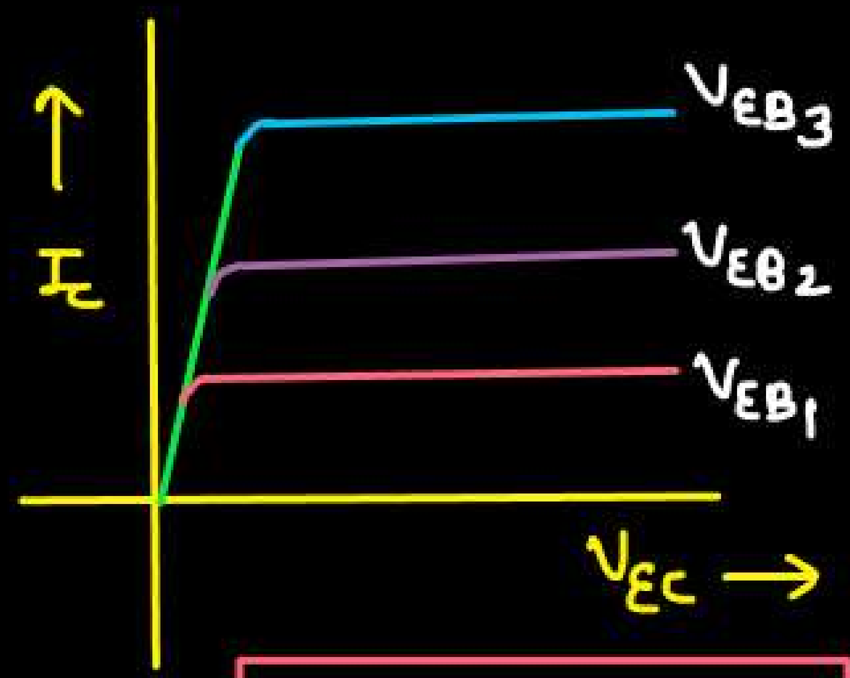
$$\boxed{I_C = I_S \exp\left(\frac{V_{EB}}{nV_T}\right)\left(1+\frac{V_{EC}}{V_A}\right)} \; ; \; \boxed{V_{EC} > (V_{EC})_{sat}}$$

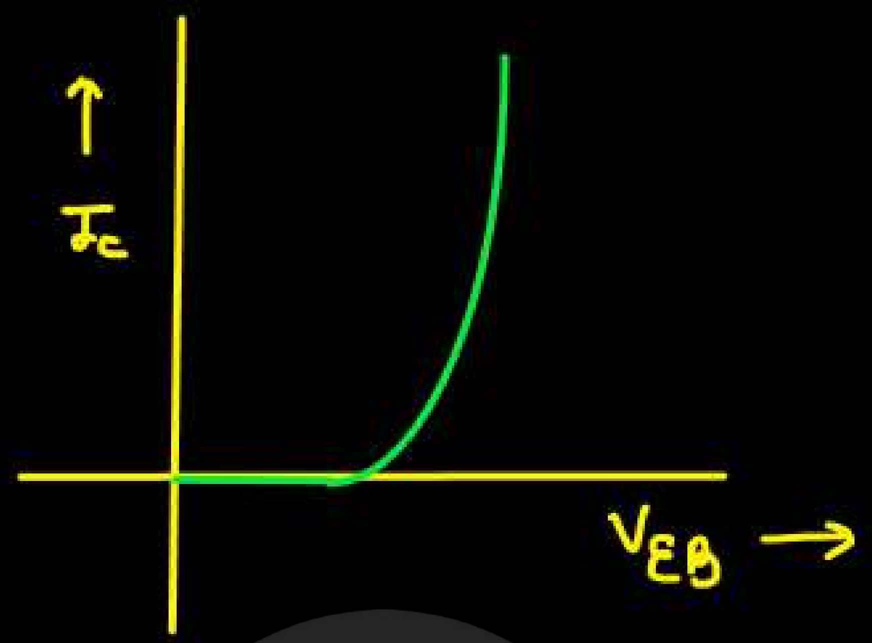
Active region

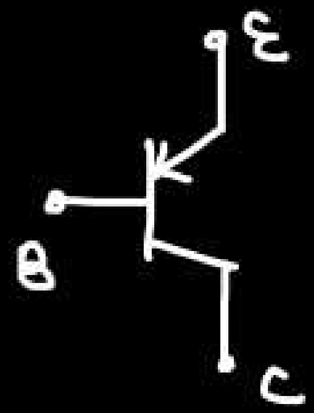
$$\boxed{I_E = I_C + I_B}$$

$$I_C = \beta I_B$$

$$I_E = (\beta+1) I_B$$







$$\boxed{V_{EB_3} > V_{EB_2} > V_{EB_1}}$$

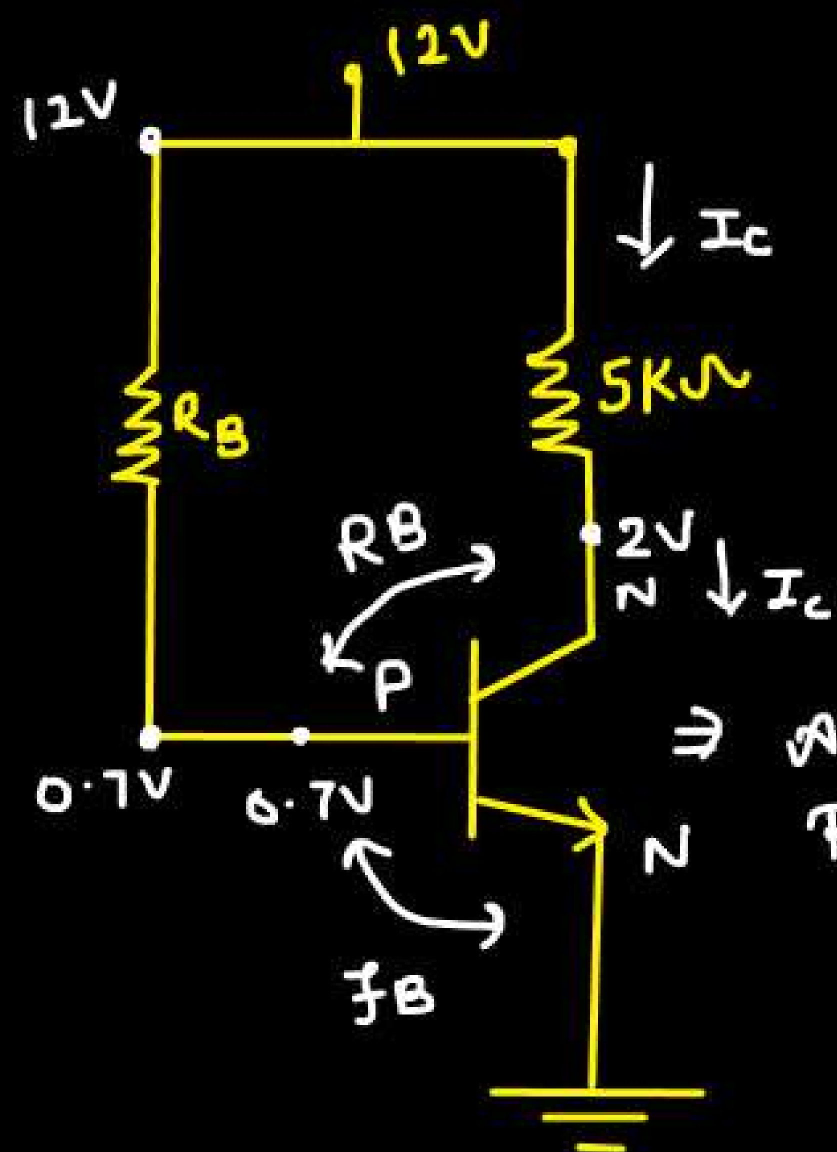
Region of operation:-

$$\left.\begin{array}{llll} \text{Active} & \equiv & J_E \rightarrow FB, & J_C \rightarrow RB \\ \text{Sat.} & \equiv & J_E \rightarrow FB, & J_C \rightarrow FB \end{array}\right\}$$

$$\begin{array}{llll} \text{Cutoff} & \equiv & J_E \rightarrow RB, & J_C \rightarrow RB \\ \text{Reverse Active} & \equiv & J_E \rightarrow RB, & J_C \rightarrow FB \end{array}$$

Assignment-18

Q.



$\Rightarrow$ Active Region

$V_{CE} = 2V$

$V_{BE} = 0.7V$

$\beta = 50$

Find R_B.

$$I_c = \frac{10}{5K} = 2mA$$

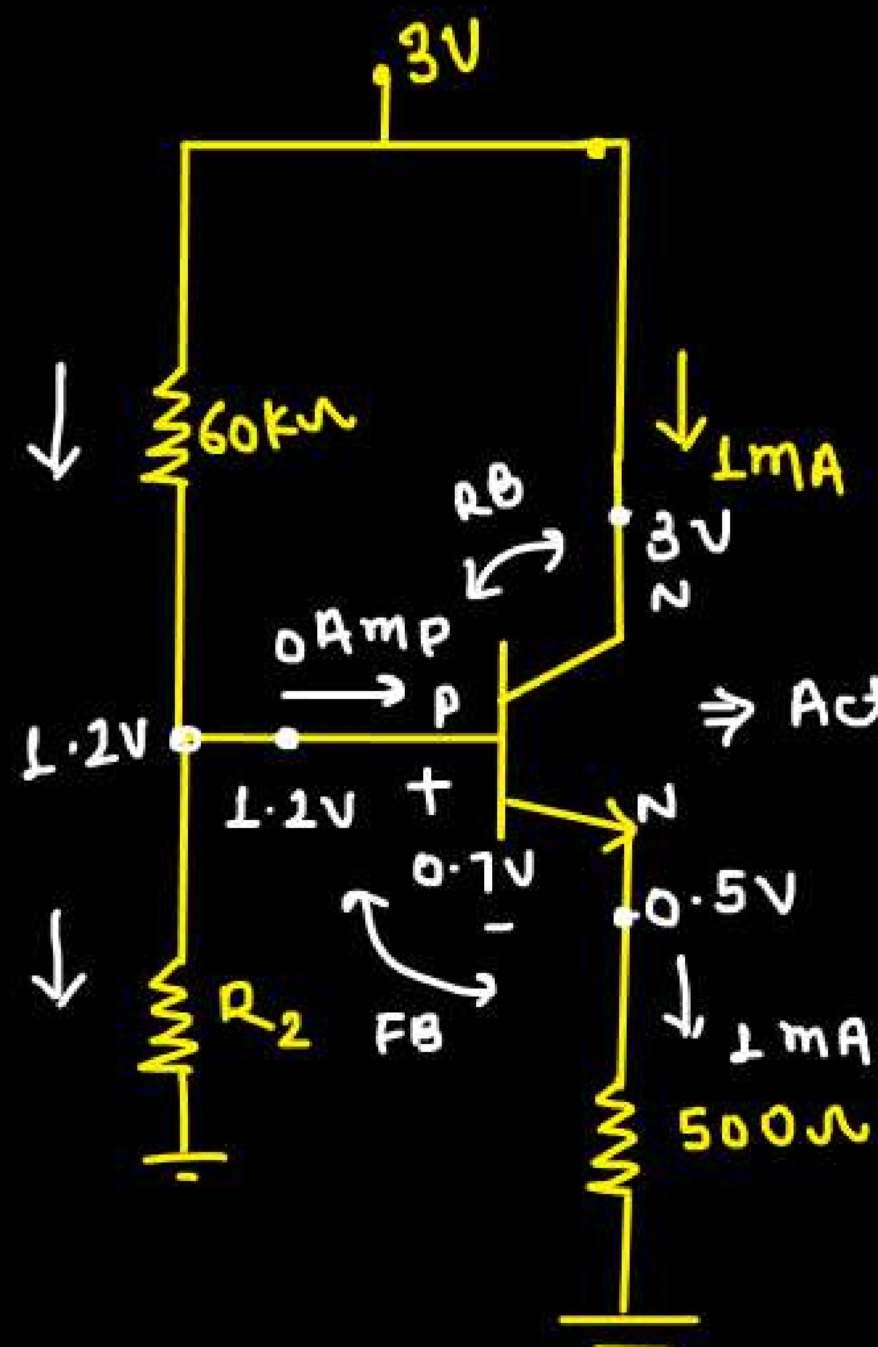
$$I_B = \frac{11.3}{R_B}$$

$$I_c = \beta I_B$$

$$2mA = \frac{50 \times 11.3}{R_B}$$

$$\boxed{R_B = 282.5\Omega}$$

Q.



$I_C = 1mA$

$\boxed{\beta = \infty}$

Find R_2.

$V_{BE} = 0.7$

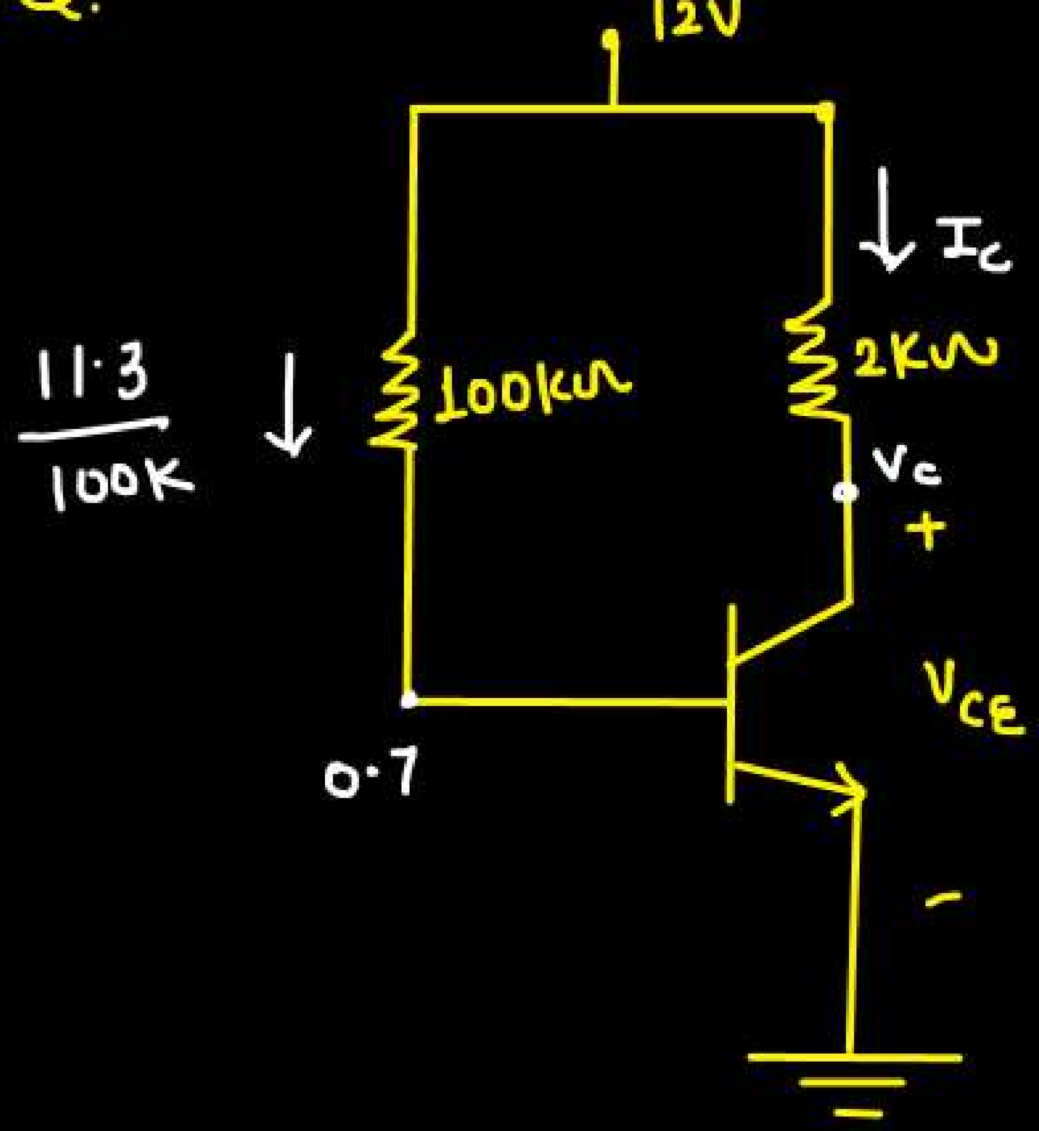
$\Rightarrow$ Active $\rightarrow$ $\beta = 0 \Rightarrow I_C = I_E = 1mA, \quad I_B = 0$

$$\frac{3-1.2}{60} = \frac{1.2}{R_2} \quad \{R_2 \text{ in } k\Omega\}$$

$$R_2 = 40 \{\text{in } k\Omega\}$$

$$\Rightarrow \boxed{R_2 = 40\,k\Omega}$$

Q.



if $\beta = 80$, $V_{BE} = 0.7V$

Find V_{CE}?

(a) $-6.08V$

(b) $0.2V$

(c) $1.2V$

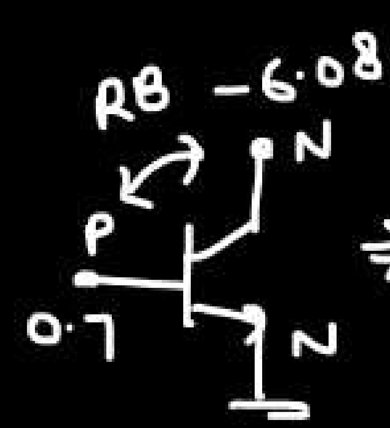
(d) $6.08V$

$\boxed{I_B = 113\,\mu Amp}$

Active → assume

$I_C = \beta I_B = 80 \times 113\mu = 9.04\,mA$

$V_{CE} = 12 - 2K(9.04m) = -6.08V$



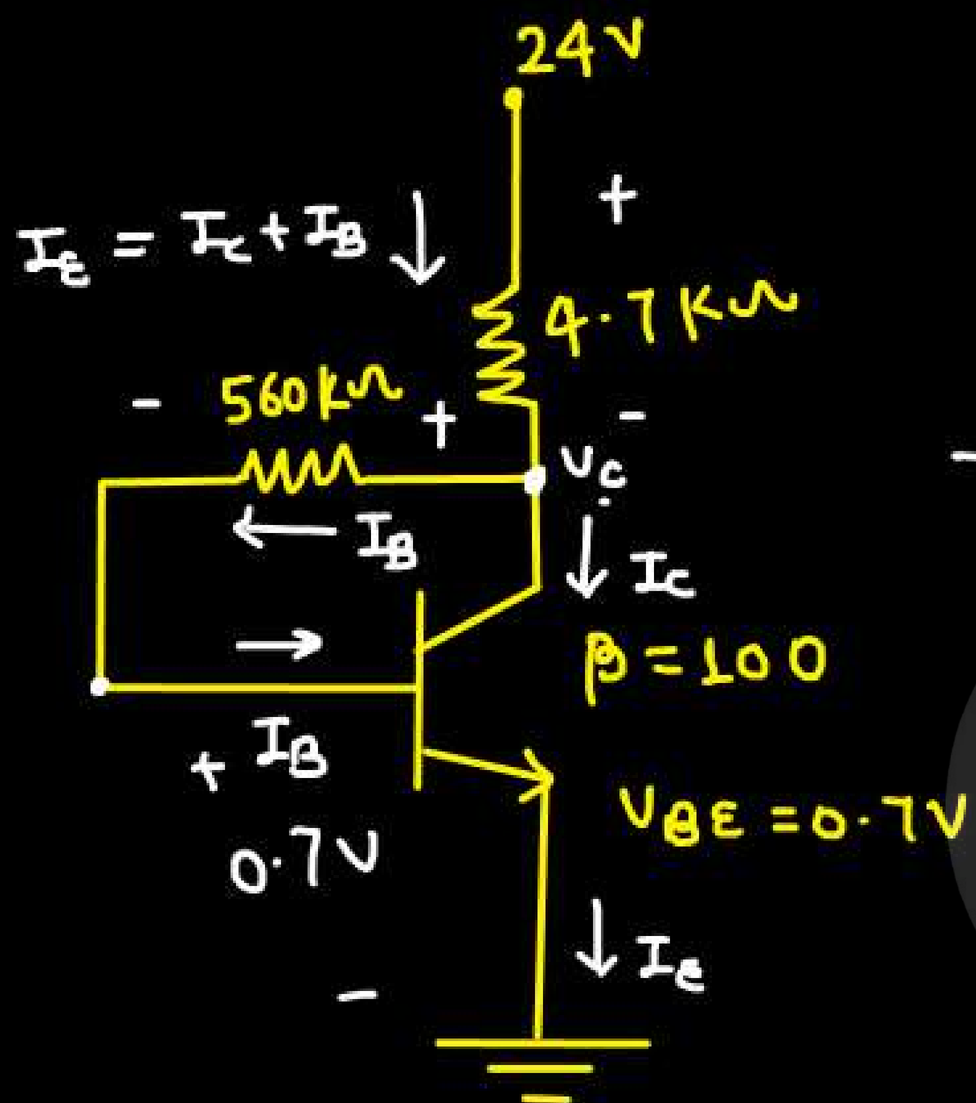
⇒ Saturation

$\boxed{(V_{CE})_{sat} = 0.2V} = V_{CE}$

Q.

$I_E = (\beta + 1) I_B$

Find collector current.



$\rightarrow$ $24 = (4.7K \times I_E) + (560K \times I_B) + 0.7$

$\boxed{\text{Assuming} \rightarrow \text{Active}}$

$24 = 4.7(101) I_B + 560 I_B + 0.7$ $\{I_B, I_E \text{ in mA}\}$

$I_B = 0.0225 \{\text{in mA}\}$

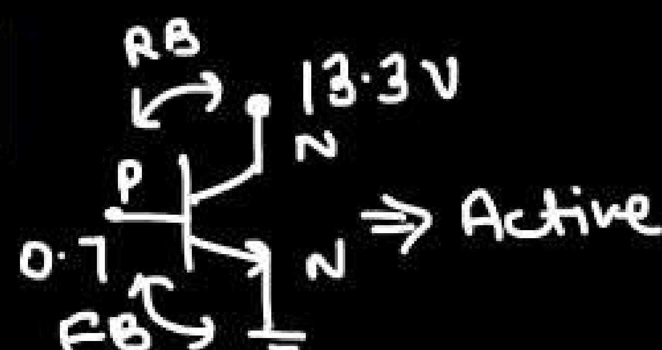
$I_B = 0.0225\ mA = 22.5\ \mu A$

$\boxed{I_C = \beta I_B = 2.25\ mA}$ ANS.

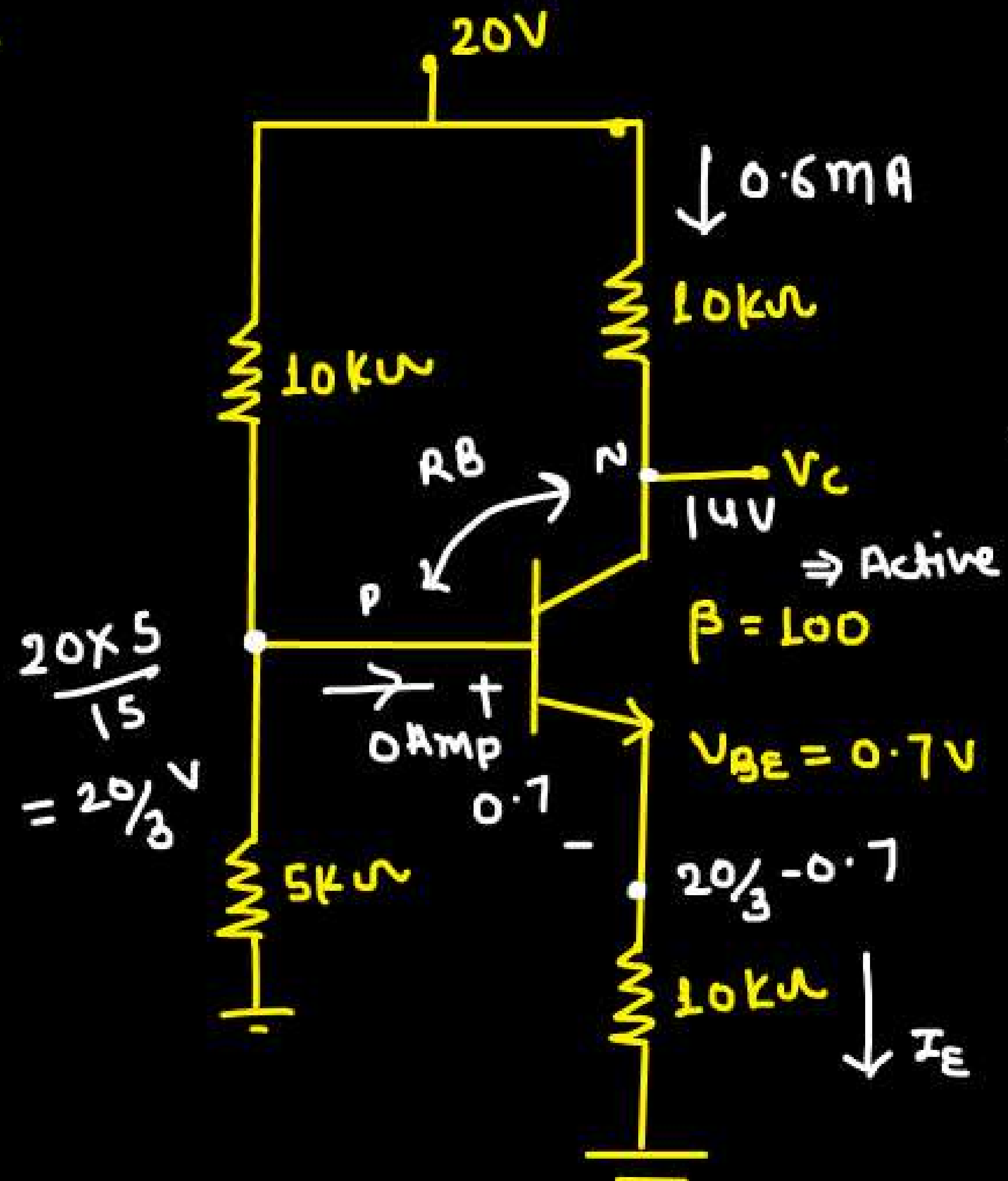
$I_E = 2.27\ mA$

$\rightarrow$ $V_C = 24 - 4.7K \times 2.27M$

$\boxed{V_C = 13.3V}$



Q.



Find V_c.

(a) $20/3\,V = 6.66V$

(b) $10V$

✓(c) $14V$

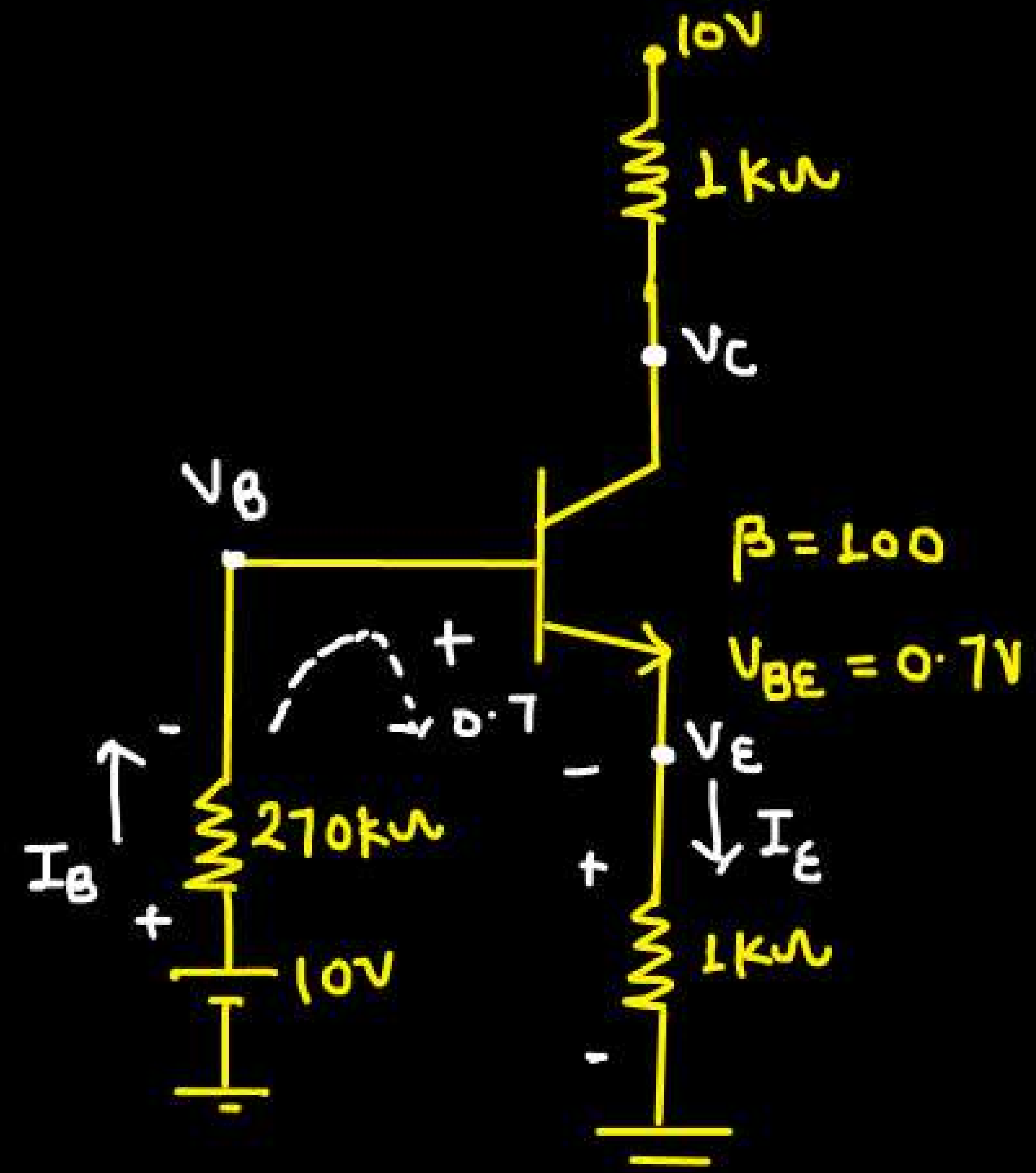
(d) $20V$

→ since, options are far from each other we are taking $\beta \to \infty$ for ease of calculation

$$I_E = \frac{6.66 - 0.7}{10k} = 0.6\,mA \approx I_C$$

$$\boxed{V_c = 20 - 10 \times (0.6) = 14V}$$

Q.



Find the region of operation.

→

$$10 = 270 I_B + 0.7 + I_E$$

Assuming → active

$$10 = 270 I_B + 0.7 + 101 I_B$$

$$\boxed{I_B = 0.025 \text{ mA}}$$

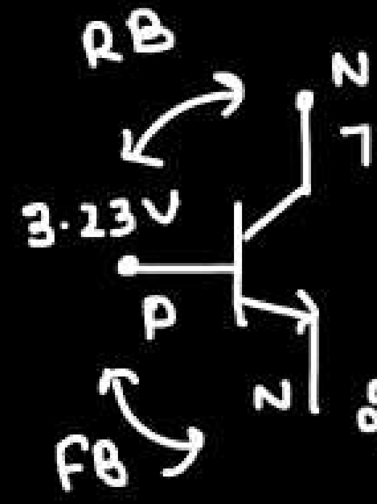
$I_E = 2.53$ mA

$I_C = 2.5$ mA

$V_c = 10 - 2.5 = 7.5V$

$V_e = 2.53V$

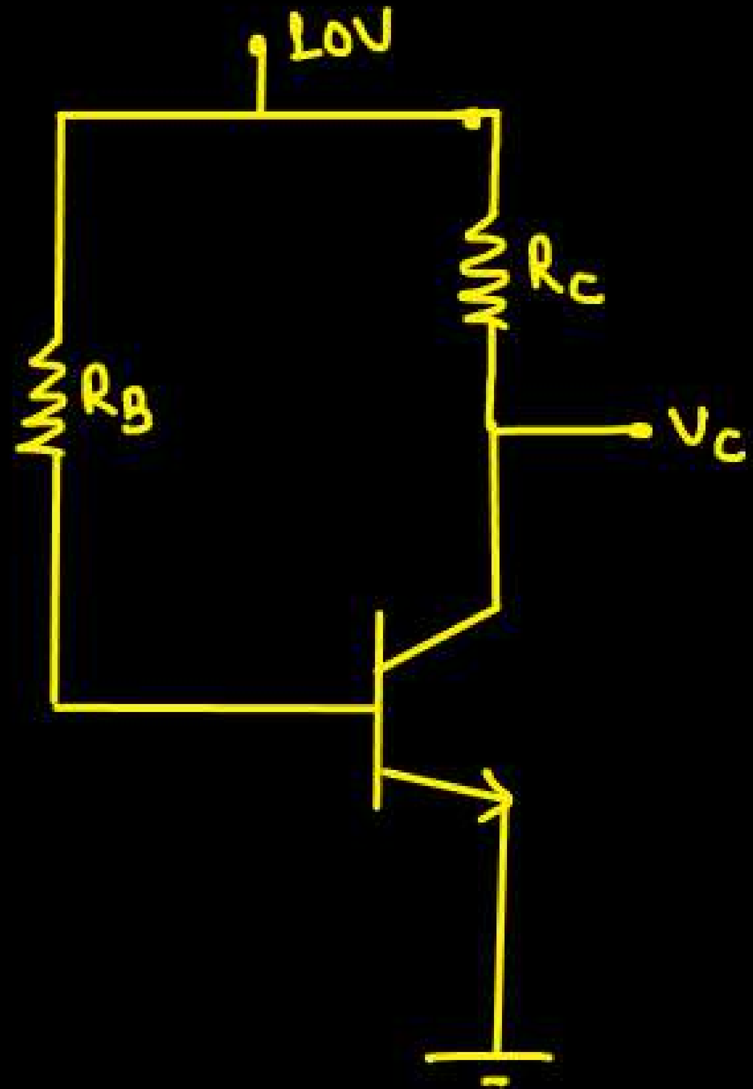
$$\boxed{V_B = 2.53 + 0.7 = 3.23V}$$



⇒ $\boxed{\text{Active}}$

ANS

Q.



Transistor is working in active mode.

When $V_C = 2V$, $R_C = R_{C_1}$

when $V_C = 4V$, $R_C = R_{C_2}$

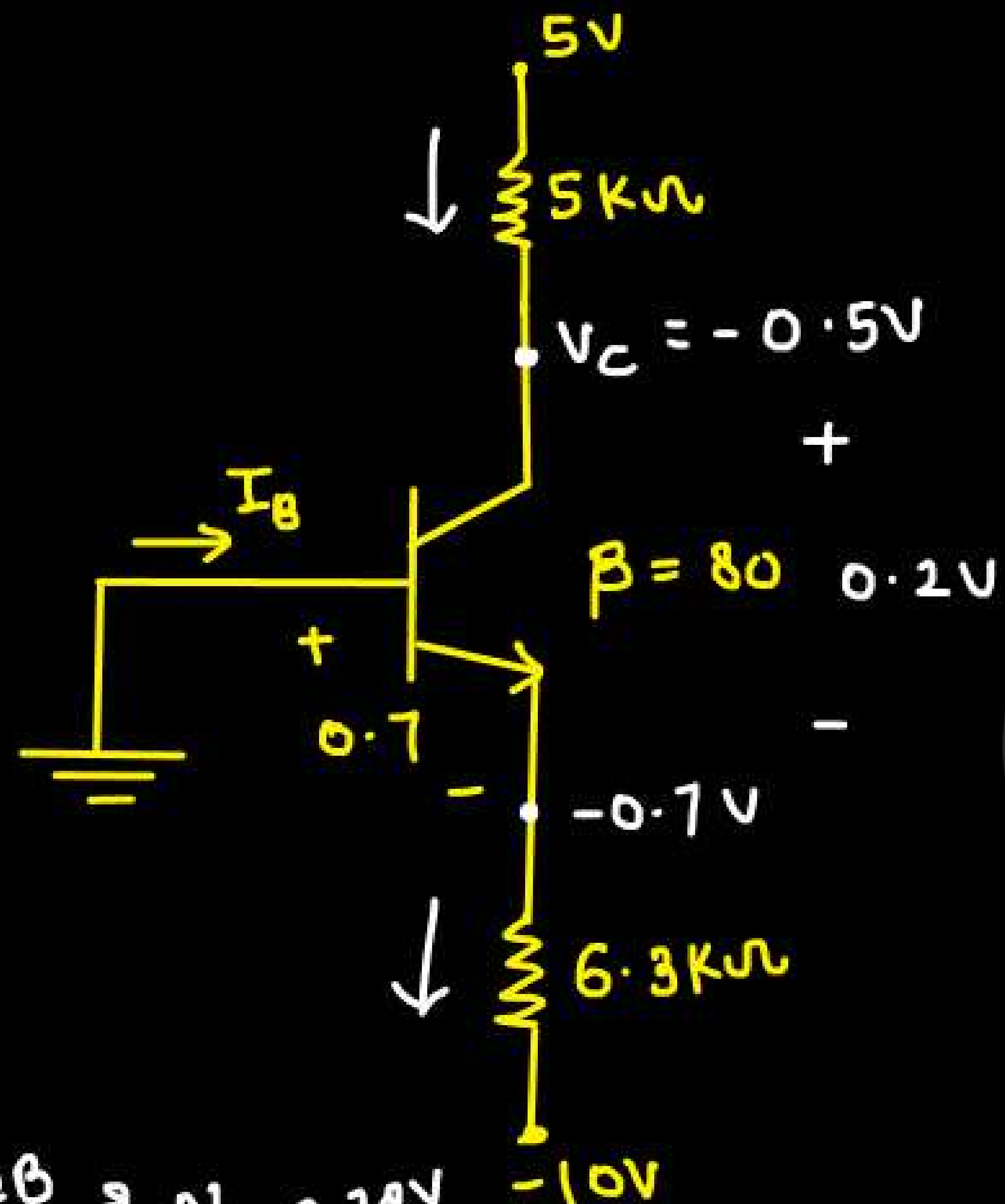
Find the ratio $\frac{R_{C_2}}{R_{C_1}} = ?$

$$\boxed{I_C \neq f(V_{CE})}$$

Even if V_{CE} is changing, I_C will be same.

$$\frac{10-2}{R_{C_1}} = \frac{10-4}{R_{C_2}} \Rightarrow \boxed{\frac{R_{C_2}}{R_{C_1}} = 0.75}$$

Q.



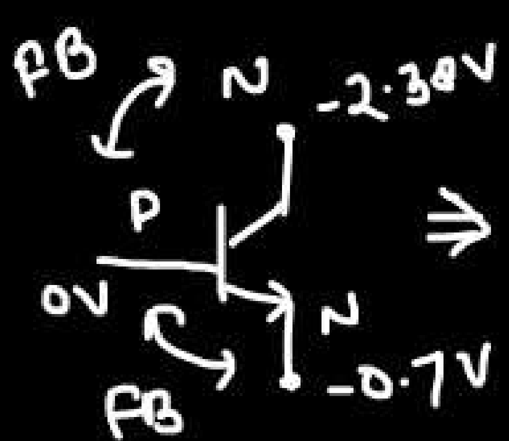
Find I_B, $(V_{CE})_{sat} = 0.2V$

$$\boxed{I_E = \frac{-0.7+10}{6.3k} = 1.48mA}$$

× $$\boxed{I_B = \frac{1.48}{81} = 18.2\,\mu Amp}$$ {Assuming → Active}

$I_C \approx 1.48mA$

$V_C = 5 - (1.48 \times 5) = -2.38V$



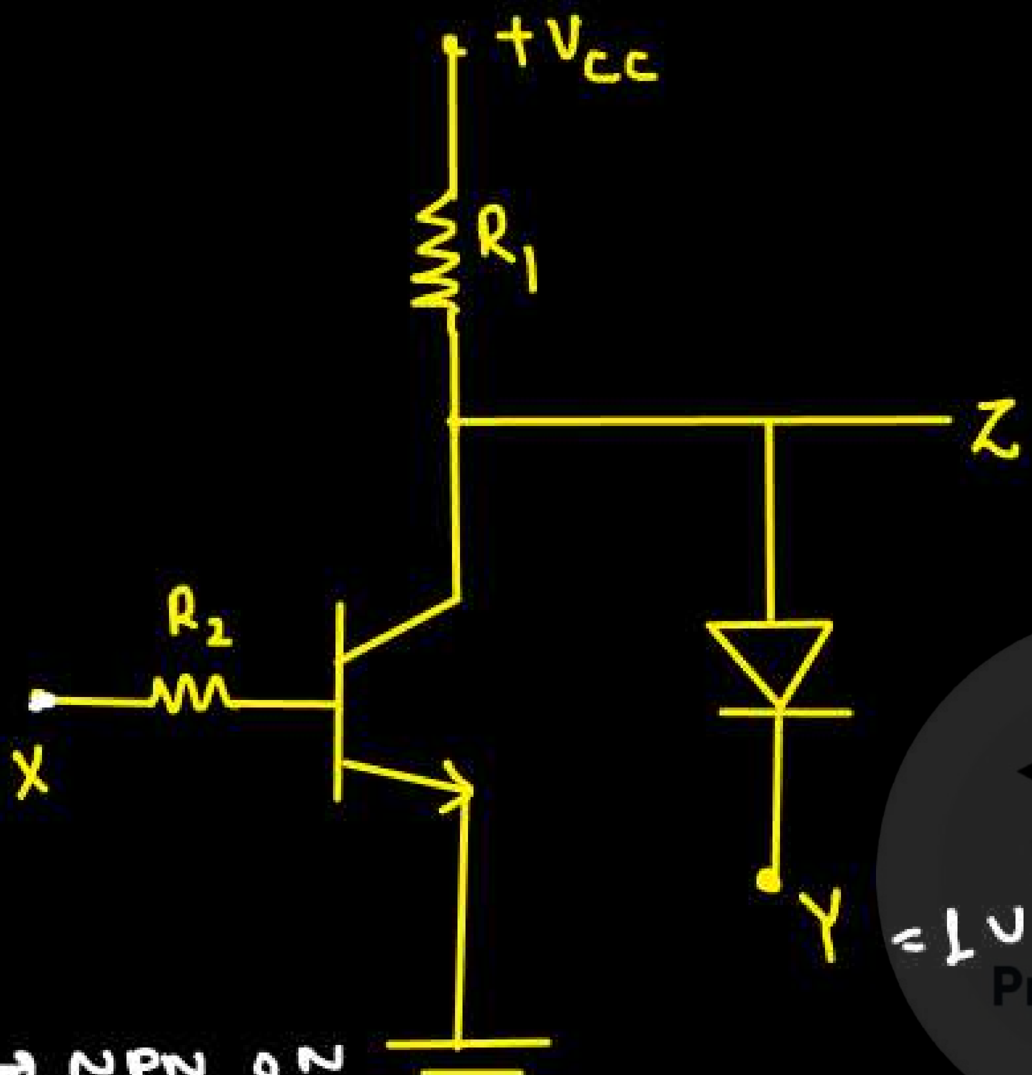
⇒ sat. = {Assumption wrong}

$$\boxed{I_C = \frac{5.5}{5K} = 1.1mA}$$

Ans.

$$\boxed{I_B = 1.48 - 1.1 = 0.38mA}$$

Q.



1 → Vcc

0 → Ground

Boolean Expression for Z ?

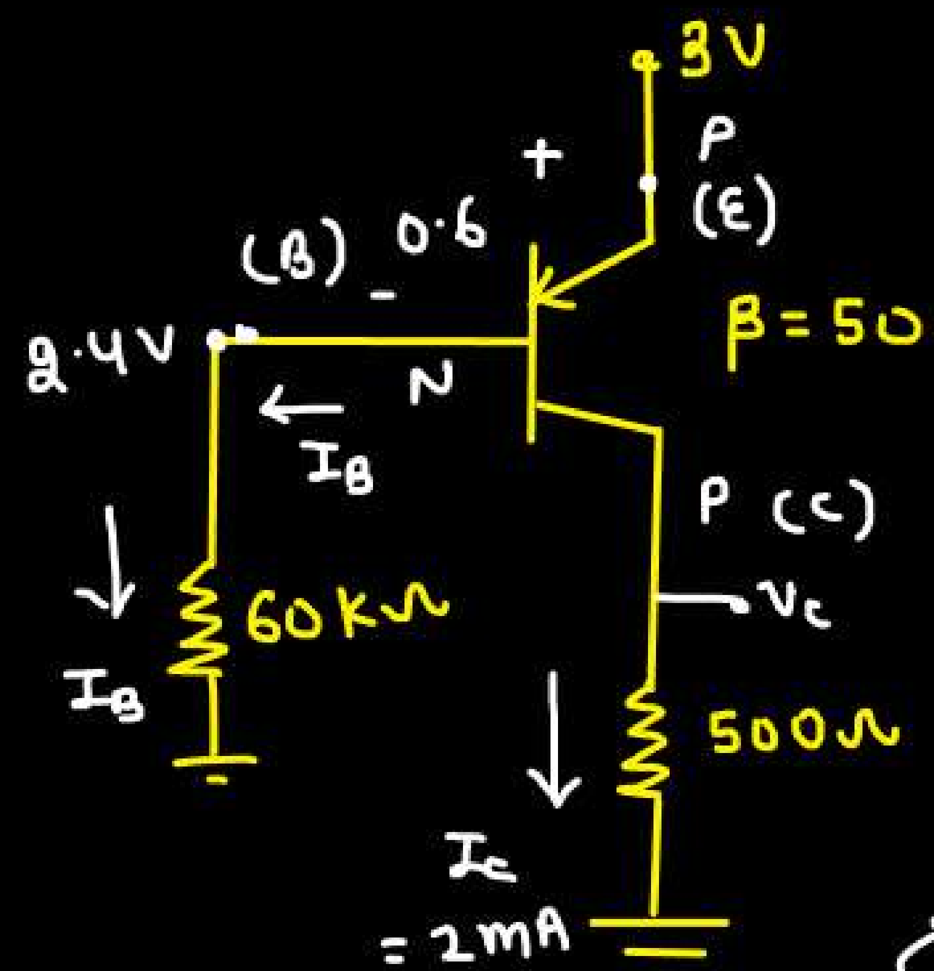
X → High → NPN ON

X → low ⇒ NPN = OFF

X	Y	Z
0	0	0
0	1	1
1	0	0
1	1	0

$\boxed{Z = \bar{X}Y}$

Q. $V_{EB} = 0.6V$



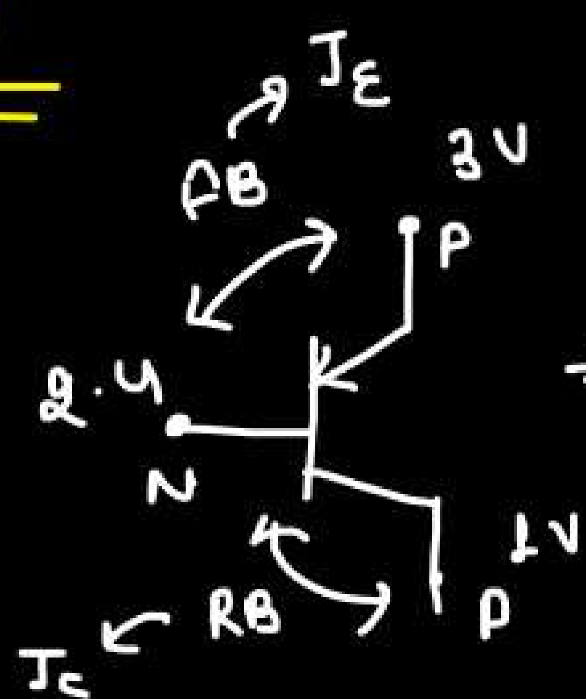
Find V_{EC} ?

$I_B = \frac{2.4}{60K} = 0.04mA$

Assuming → Active

$I_c = 0.04 \times 50 = 2mA$

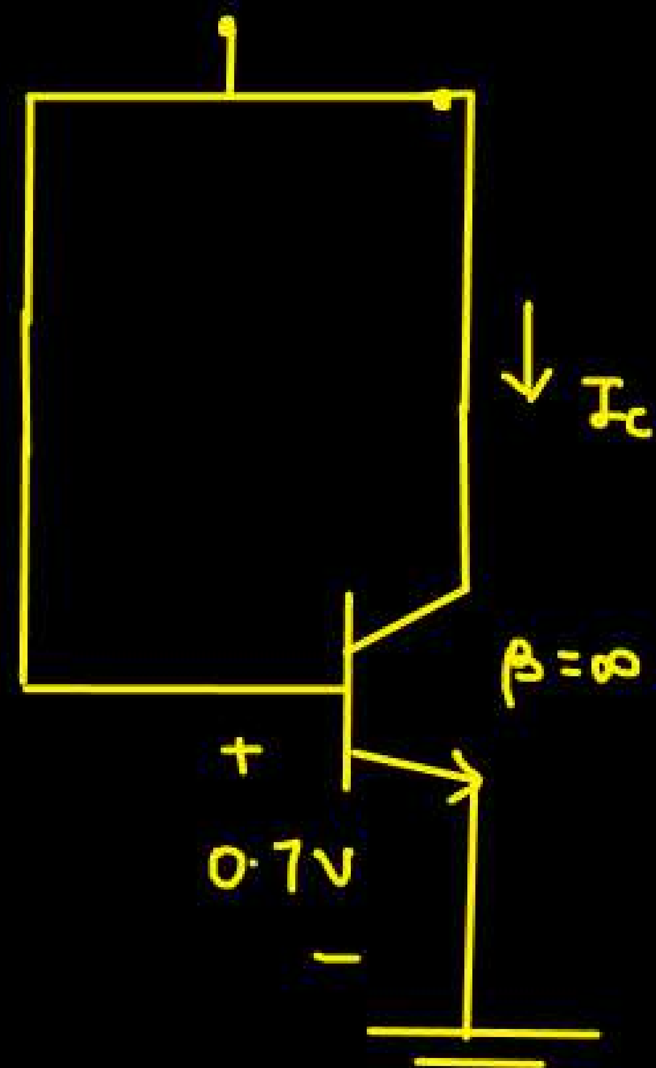
$$\boxed{V_c = 500 \times 2m = 1V}$$



⇒ Active

$$\boxed{V_{EC} = 3 - 1 = 2V}$$

Q.



$V_{BE} = 0.7V$

Reverse saturation current = 10^{-13} Amp

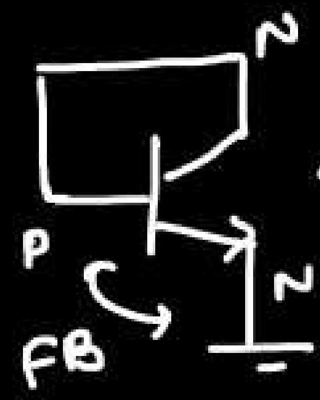
$V_T = 26\,mV$

Emitter current = ?

$\rightarrow I_c = I_E = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \rightarrow$ Active region

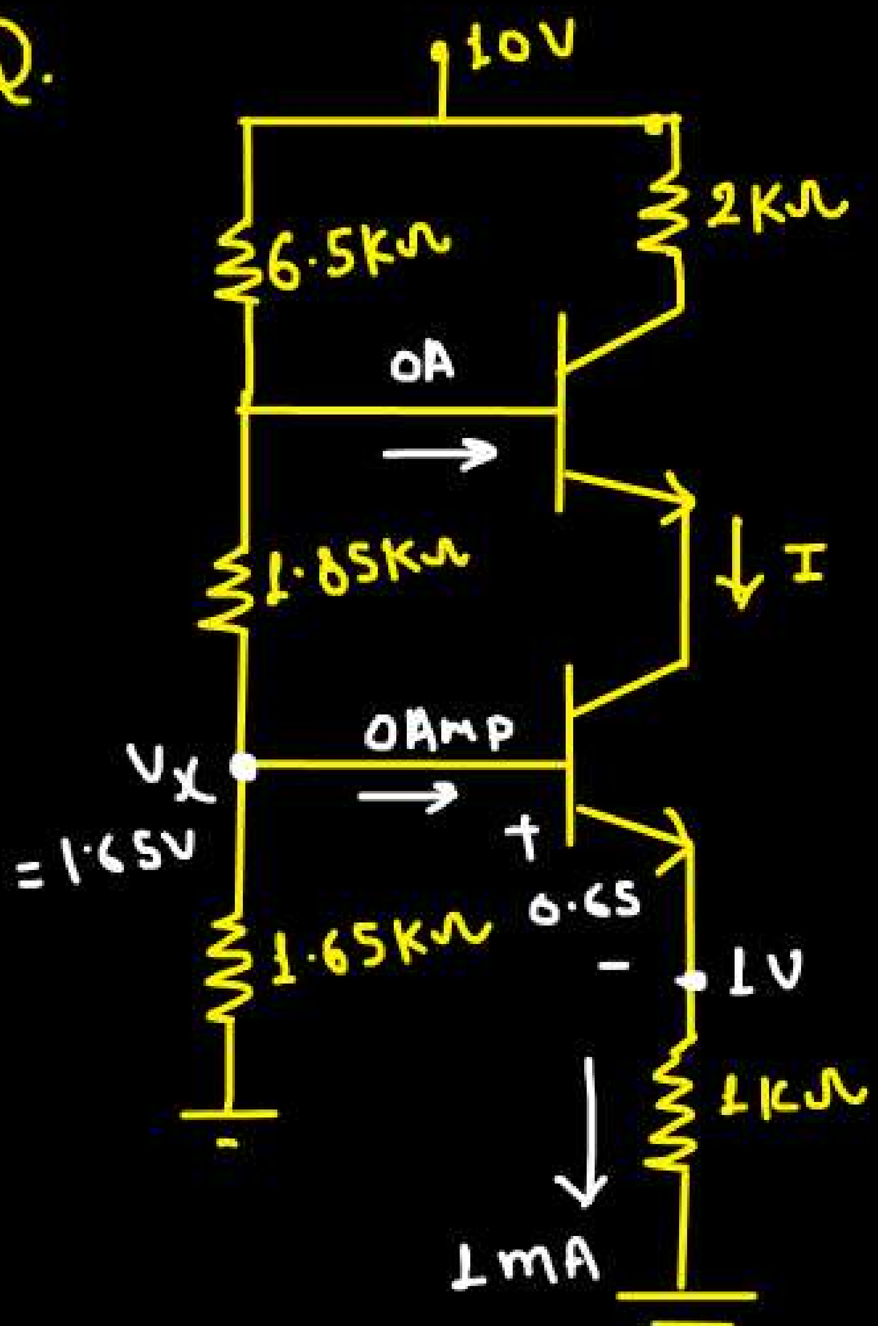
$= 10^{-13} \exp\left(\frac{0.7}{0.025}\right)$

$$\boxed{I_c = 49.2\,mA}$$



→ diode connected

Q.



$V_{BE} = 0.65$

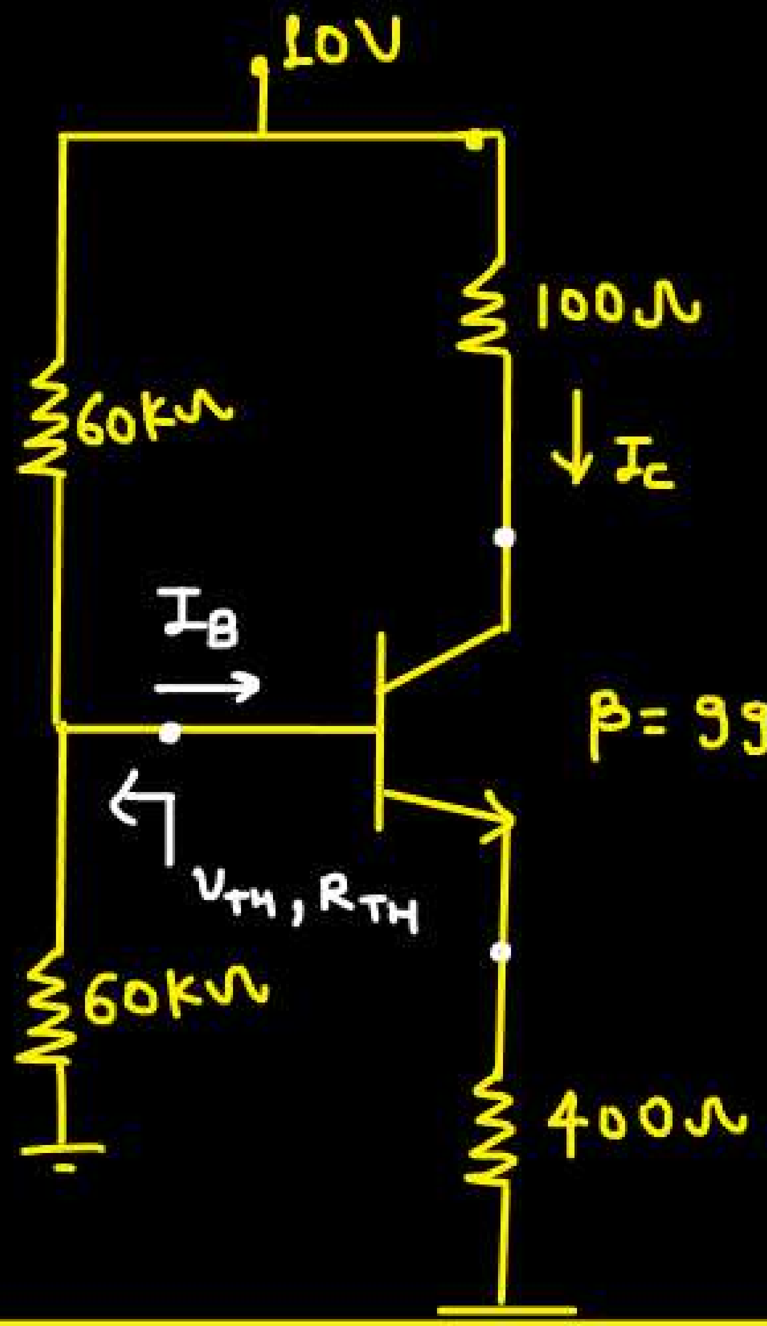
$\beta = \infty \rightarrow$ Active region

Find I ?

$$V_x = \frac{1.65}{1.65 + 1.85 + 6.5} \times 10 = 1.65V$$

$$\boxed{I = 1mA}$$

Q.

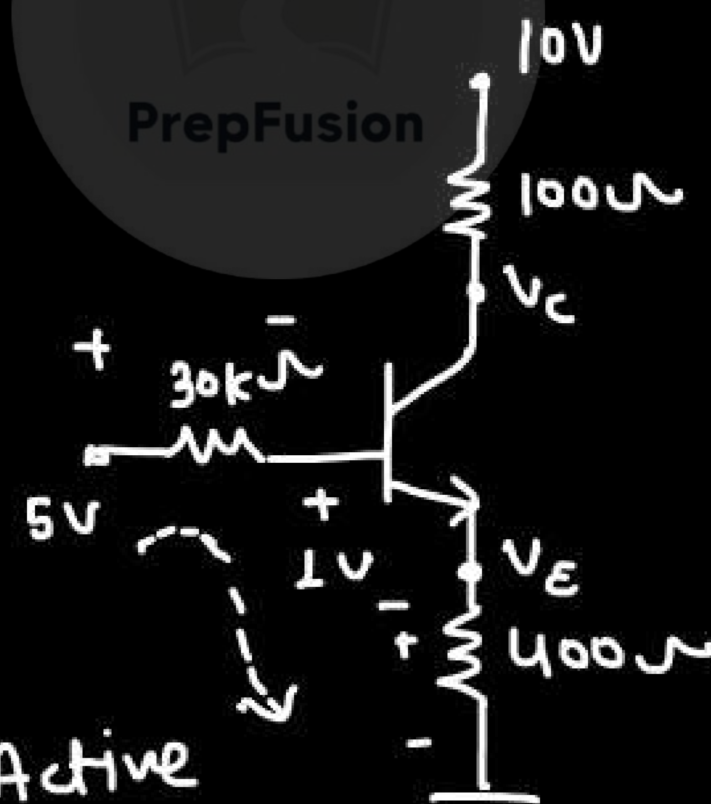


$V_{BE} = 1V$

Find I_C ?

→ $V_{TH} = \frac{10 \times 60}{120} = 5V$

$R_{TH} = 30k\Omega$



Assuming → Active

$\Rightarrow 5 = 30 I_B + 1 + 0.4(100) I_B$

$4 = 70 I_B$

$\boxed{I_B = 0.057 \text{ mA}}$

$\boxed{I_C = 5.65 \text{ mA}}$ → ANS

$\boxed{I_E = 5.7 \text{ mA}}$

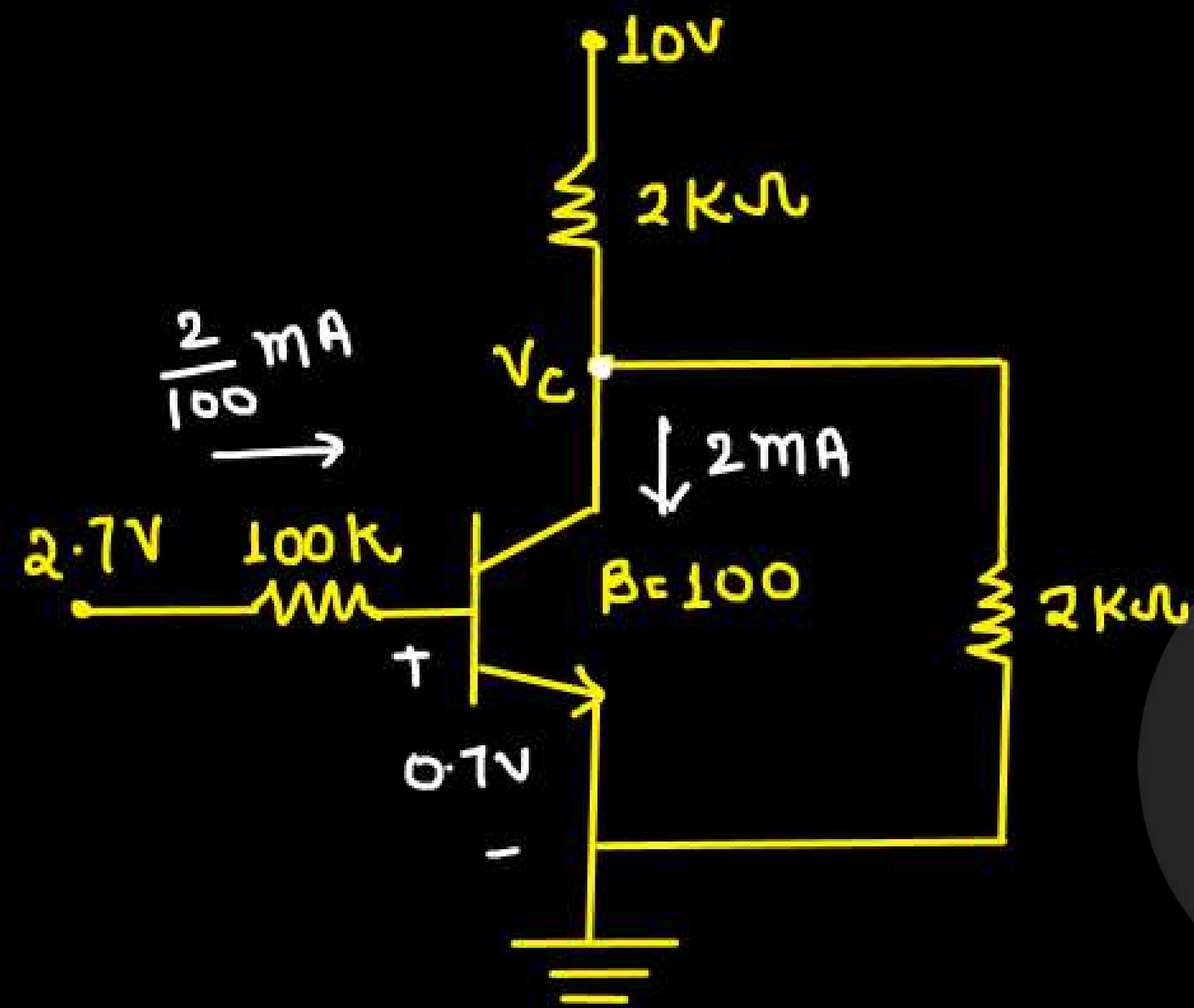
$V_E = 0.4 \times 5.7 = 2.28V$

$V_C = 10 - (0.1 \times 5.65) = 9.43V$

$V_B = 3.28V$

⟹ Active

Q.



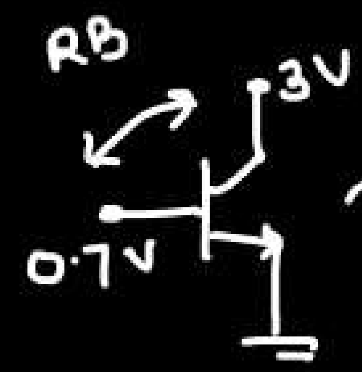
$V_{BE} = 0.7V$

Find V_C.

$$\frac{V_C - 10}{2K} + \frac{V_C}{2K} + 2m = 0$$

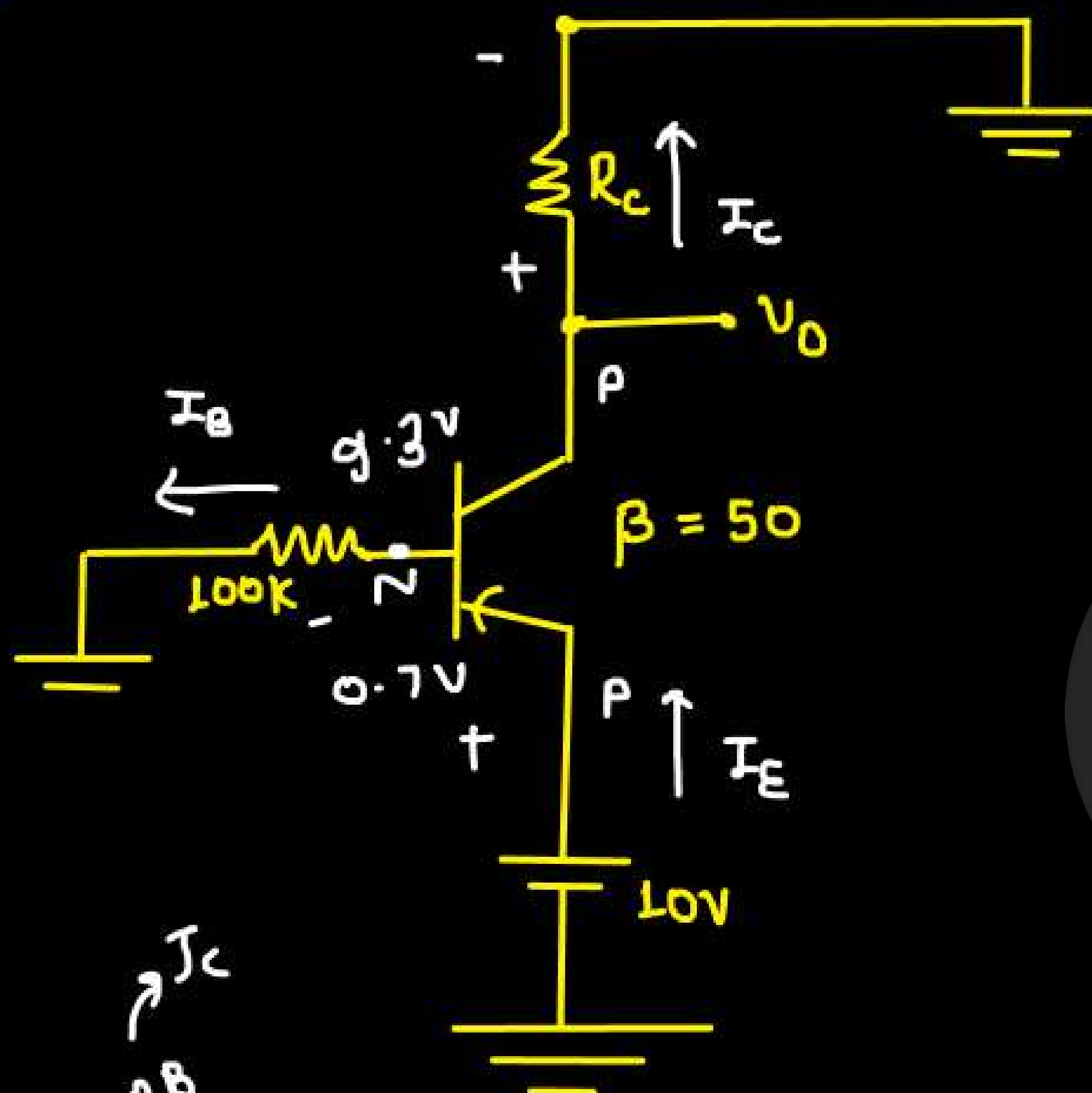
$$2V_C - 10 + 4 = 0$$

$$\boxed{V_C = 3 \text{ volt}}$$



→ Active

Q.



$|V_{BE}| = 0.7V$

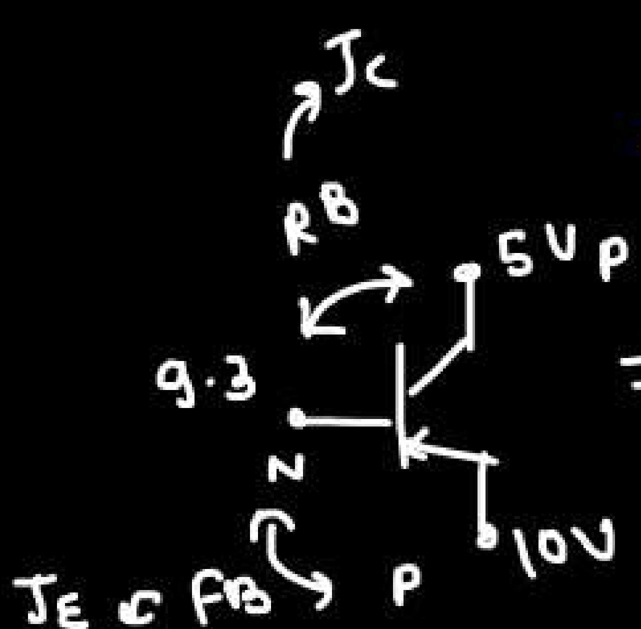
For V_o to be 5V, the value of R_C (in kΩ) is ____.

$$I_B = \frac{9.3}{100K} = 93\,\mu A \quad , \quad I_C = 4.65\,mA$$

$$V_o = I_C \times R_C$$

$$5 = 4.65m \times R_C$$

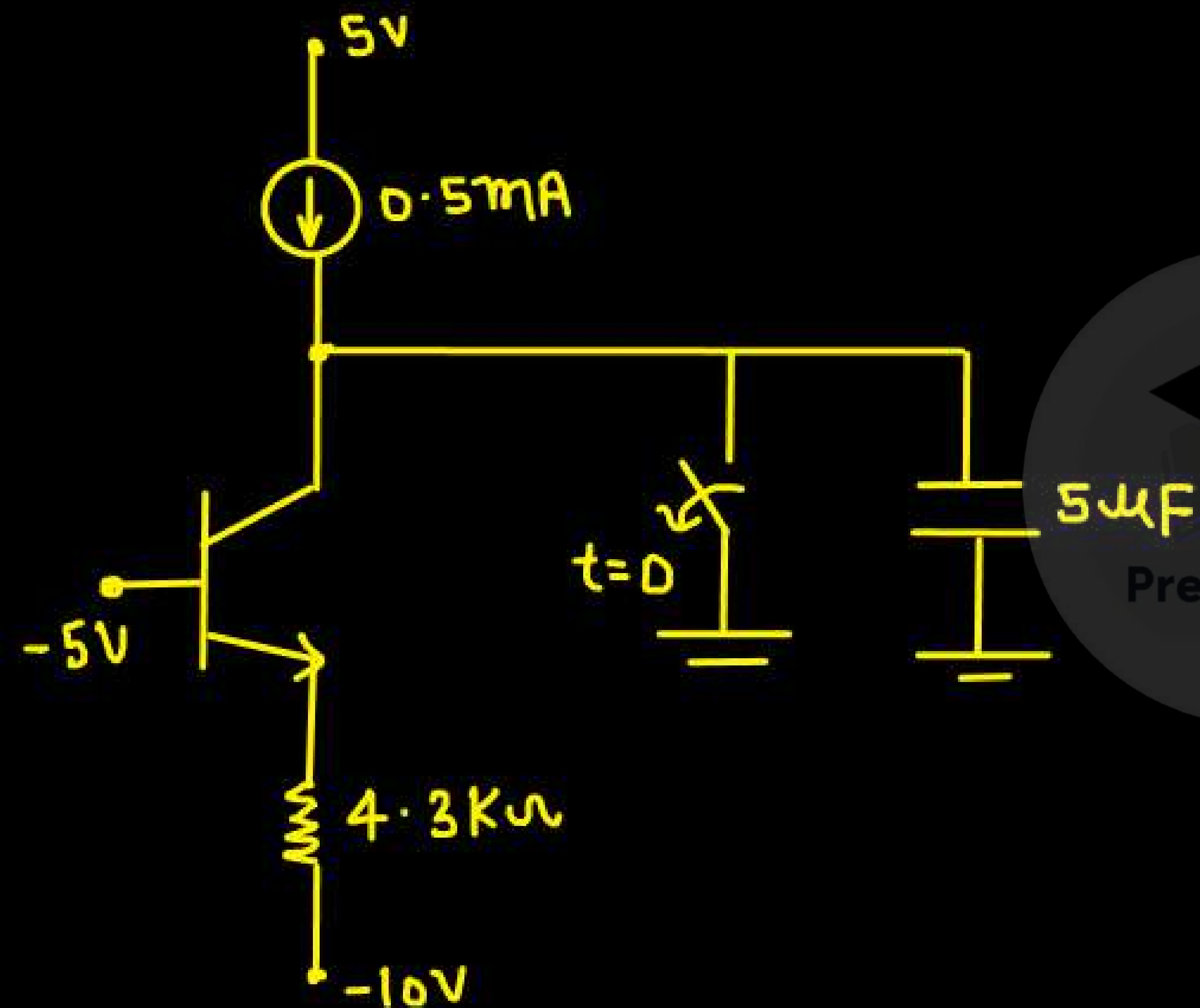
$$\boxed{R_C = 1.07\,k\Omega}$$



$\Rightarrow$ Active

Assignment - 19

Q.



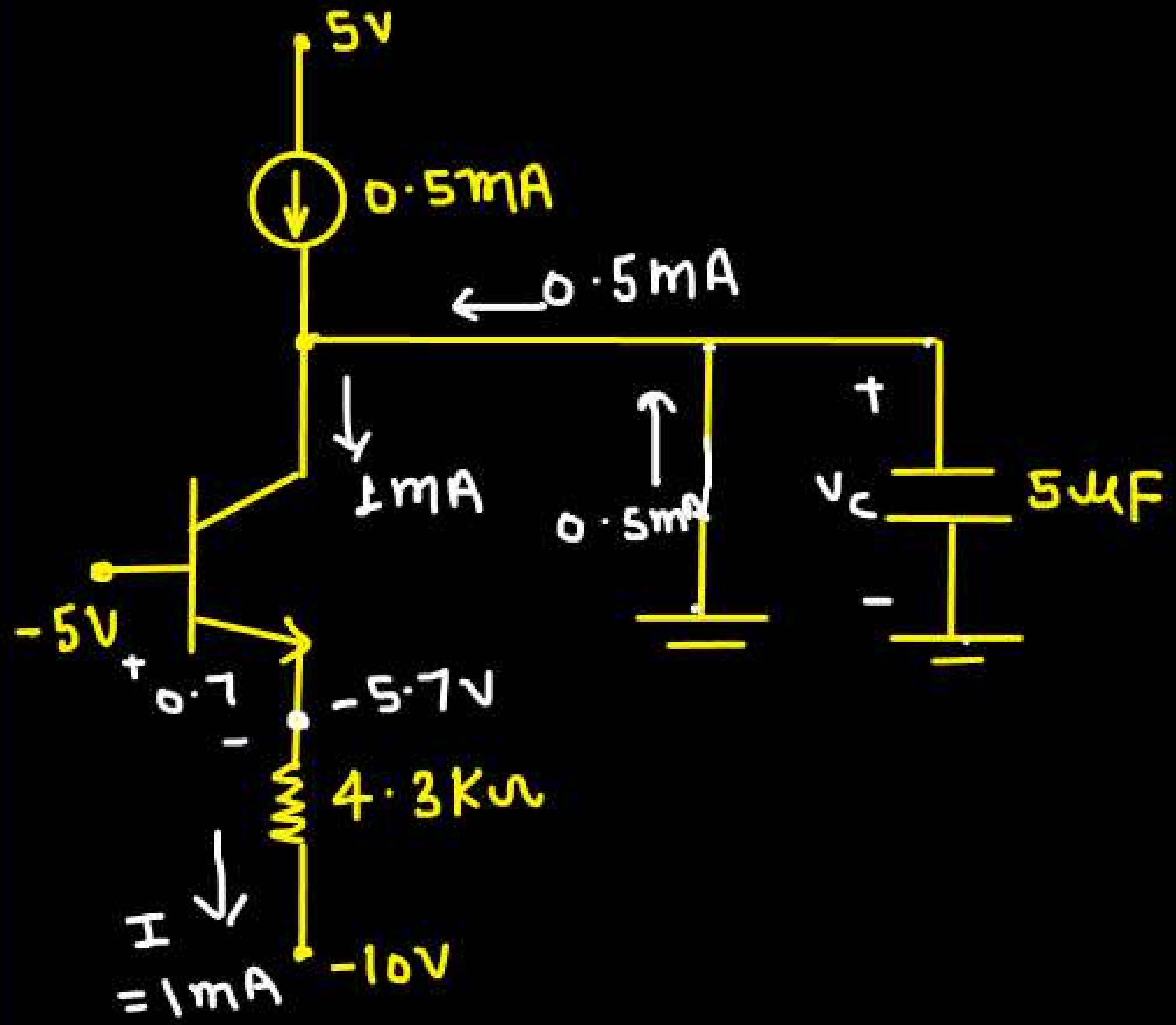
$\beta = \infty$

$(V_{BE})_{ON} = 0.7V$

$(V_{CE})_{sat} = 0.7V$

The switch s is initially closed. At time t=0, switch is opened. The time t at which Transistor leaves the active region.

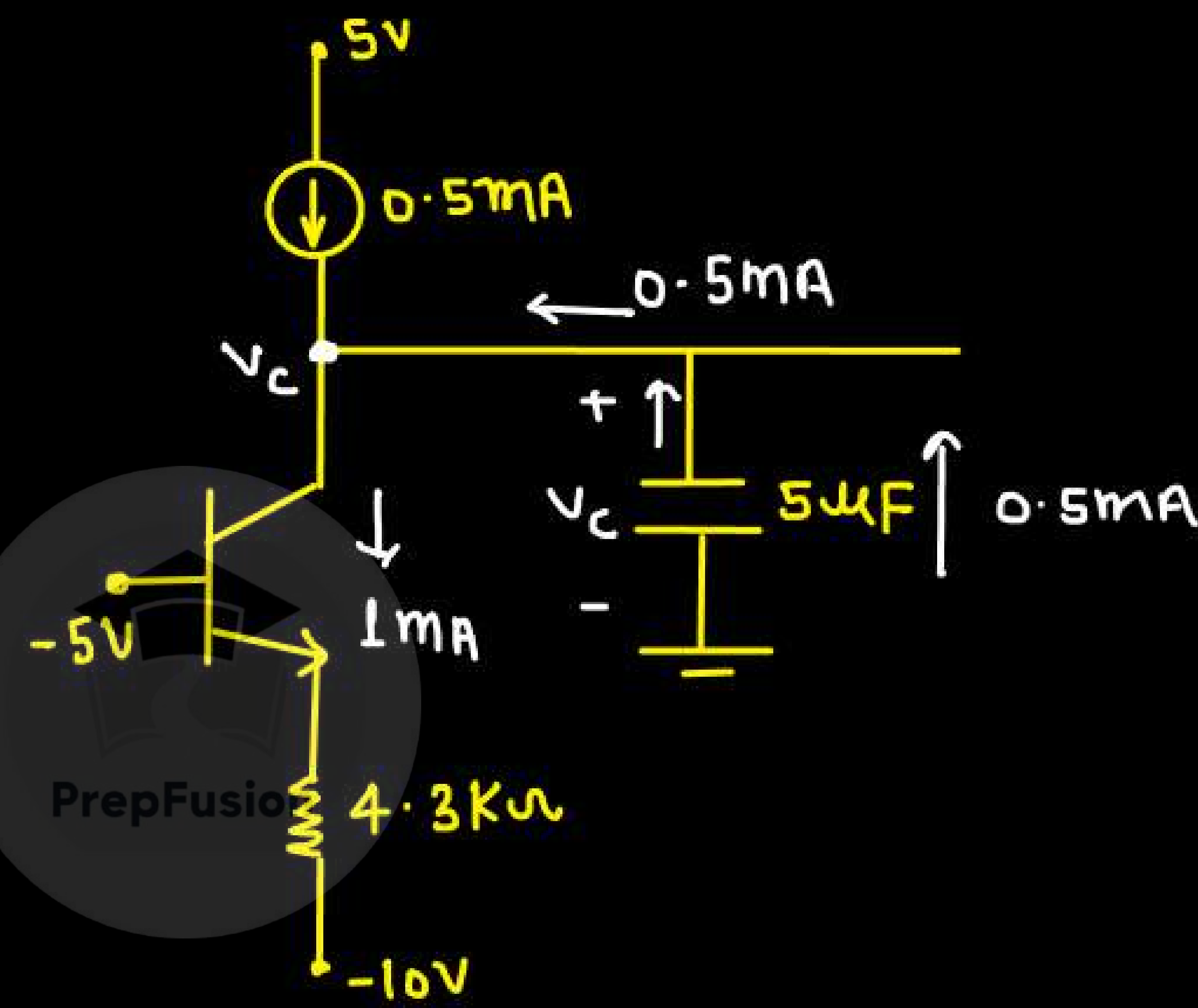
For t<0 :-



$$I = \frac{-5.7+10}{4.3k} = 1mA$$

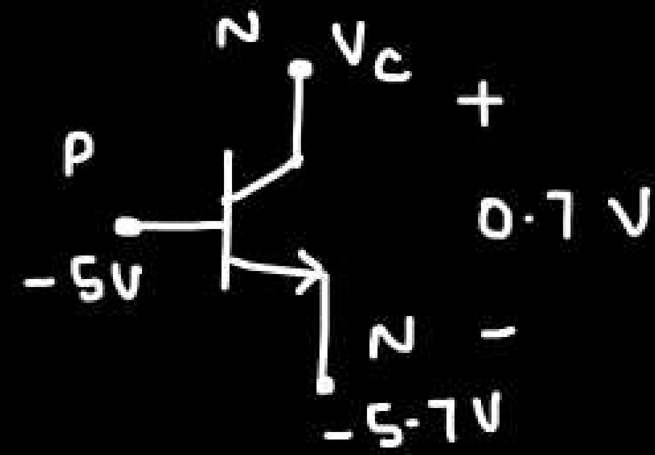
$$\boxed{v_c(0^-) = 0V}$$

For t>0 :-



$$v_c(t) = \frac{-1}{5\mu}\int_0^t 0.5m \cdot dt$$

$$\boxed{v_c(t) = -100t}$$



$V_c(0^+) = 0V$

↳ Active region of Tr

V_c is going down.

⇓

Tr moving Towards saturation

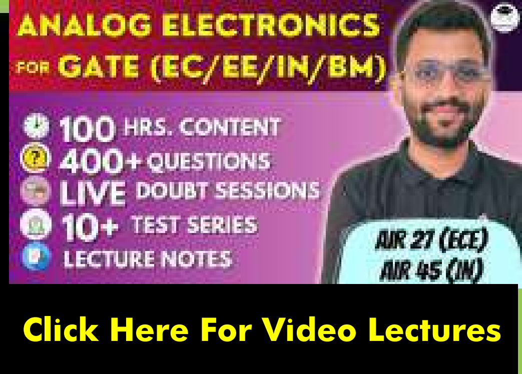
Given, $(V_{CE})_{sat} = 0.7V$

$\Rightarrow V_c - (-5.7) = 0.7$

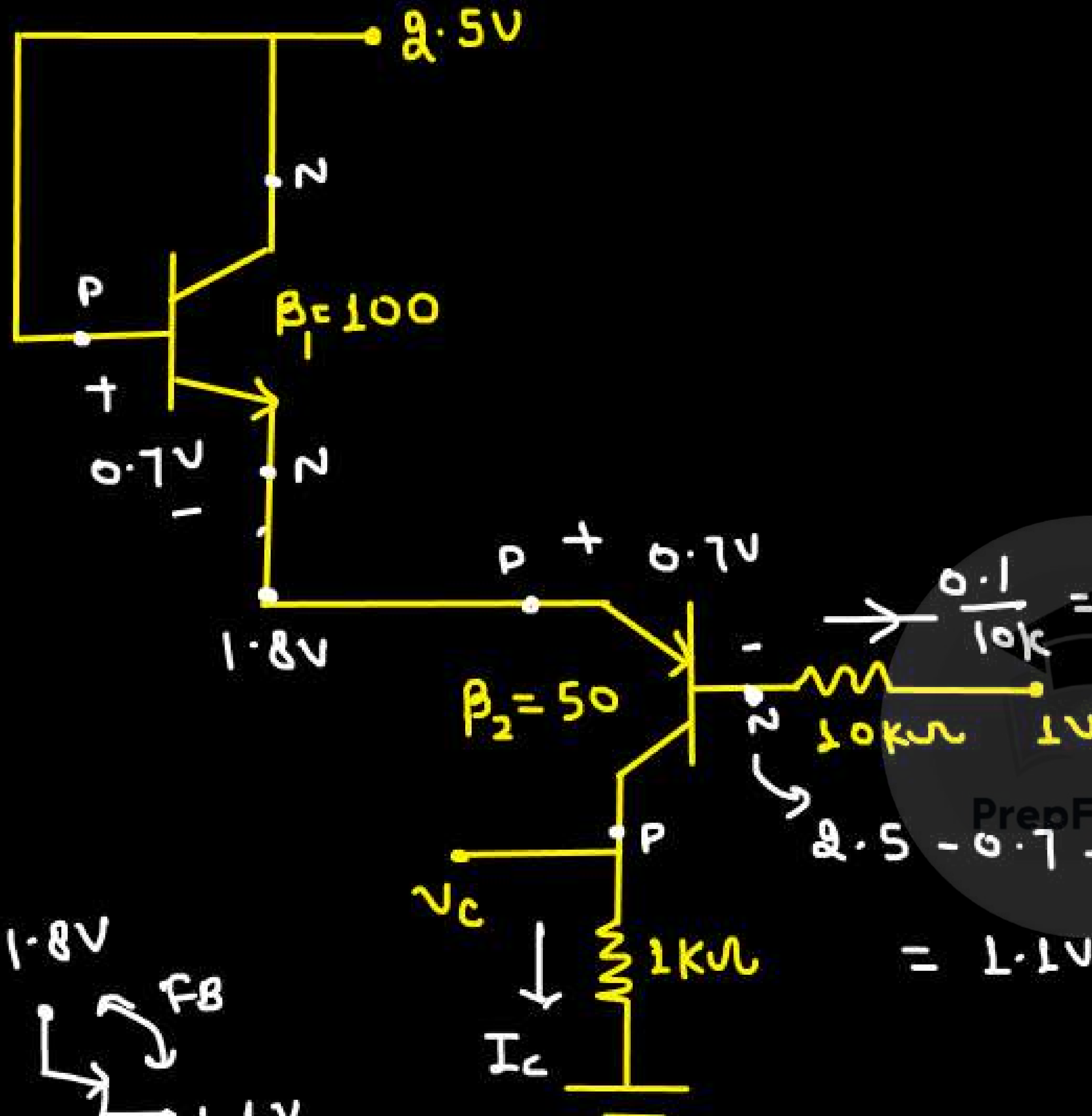
$\boxed{V_c = -5V} \rightarrow$ sat. condⁿ ✓

$-100t = -5$

$\boxed{t = 50\,msec}$ ✓



Q.



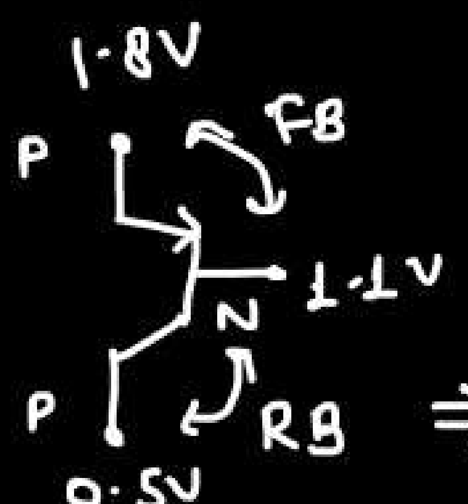
$|V_{BE}| = 0.7V$

Find V_c.

$\frac{0.1}{10k} = I_B$

$2.5 - 0.7 - 0.7$

$= 1.1V$



$\Rightarrow$ Active

$I_B = \frac{0.1}{10K}$

$I_B = 0.01mA$

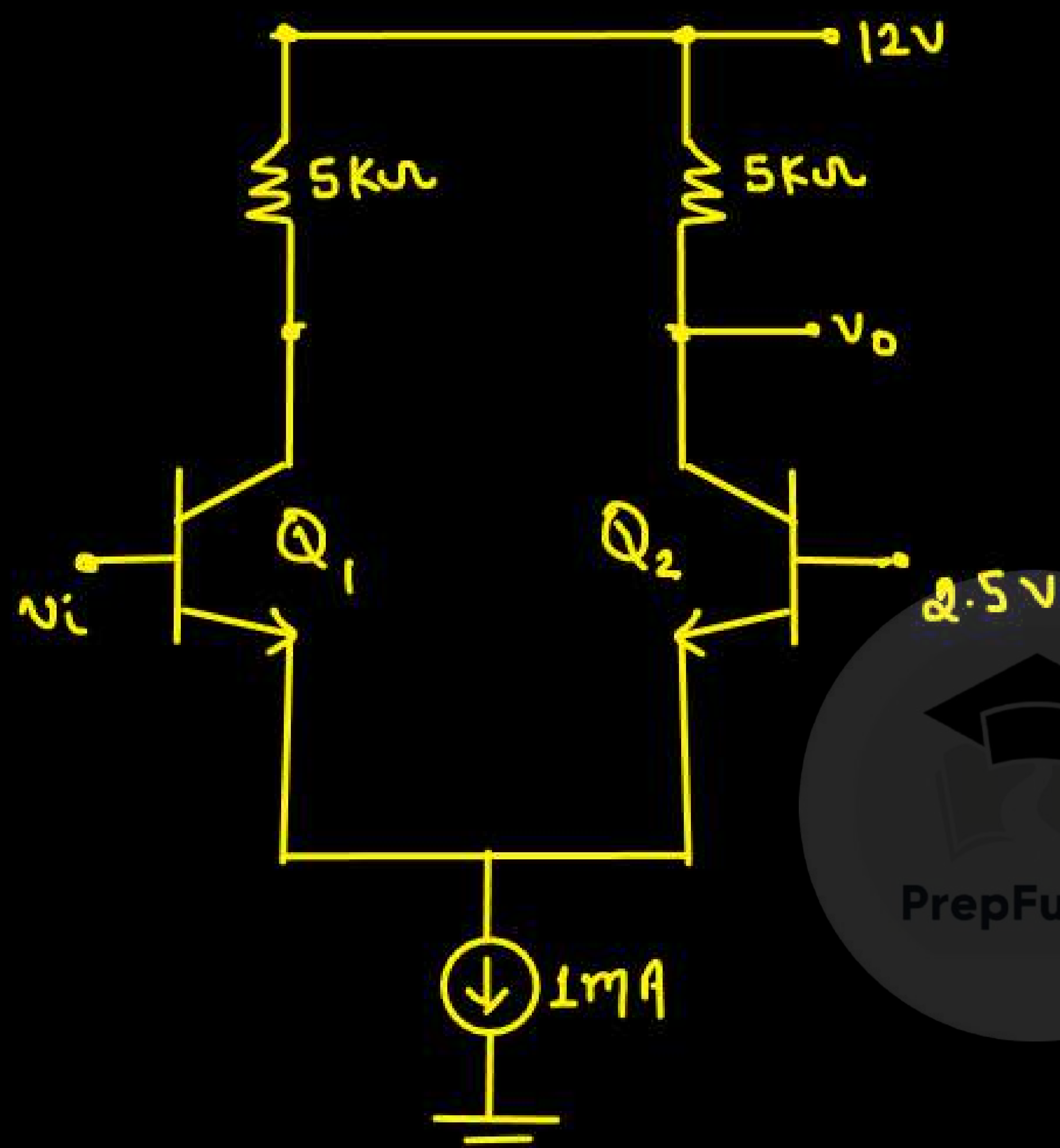
↳ Assuming active

$V_c = I_c \times 1k\Omega$

$= 50 \times 0.01m \times 1K$

$\boxed{V_c = 0.5V}$ ANS.

Q.



Reverse sat. current is same.

Both Transistors are $\boxed{\text{matched.}}$

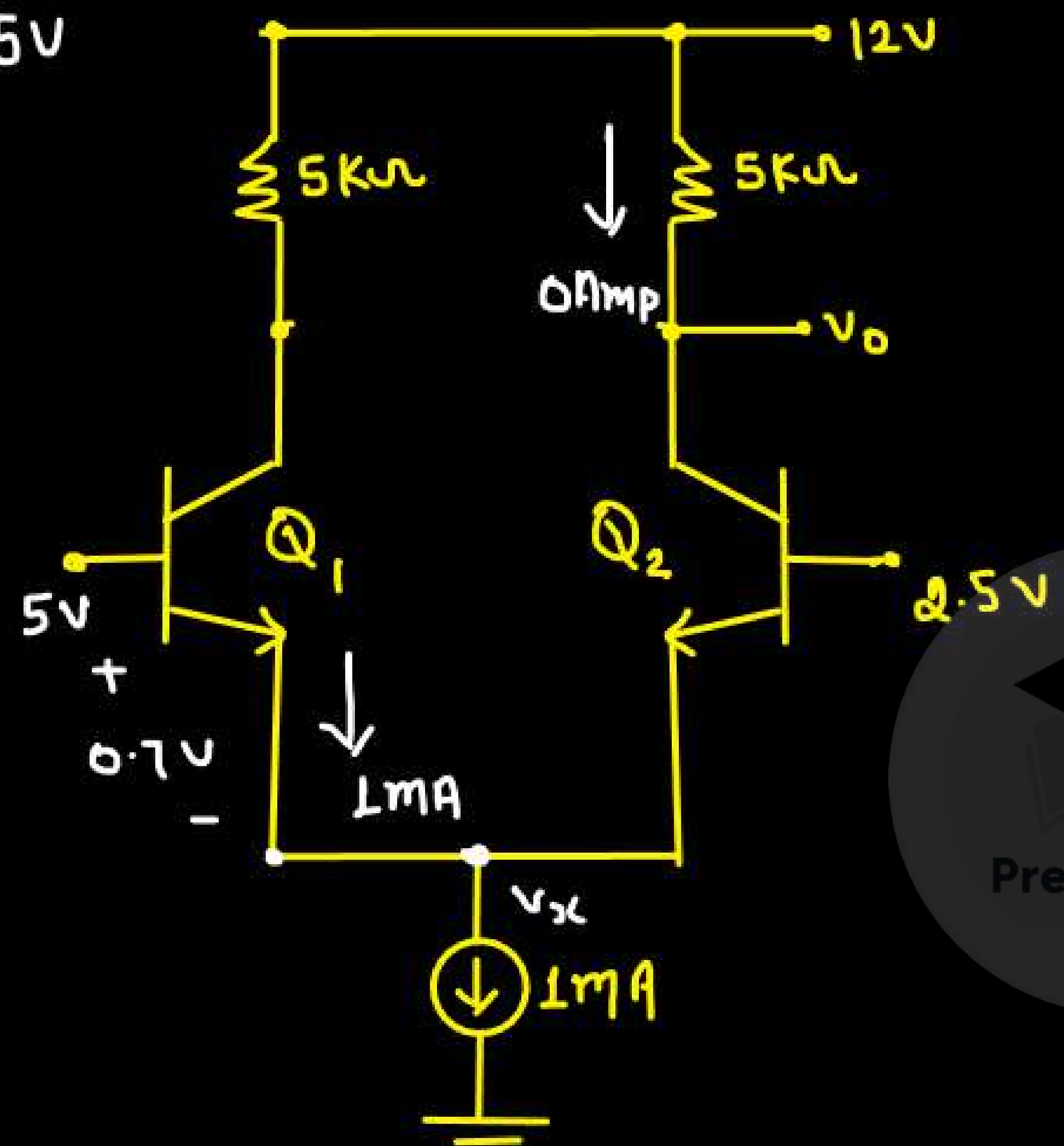
$(V_{BE})_{ON} = 0.7V, \quad \beta = 100$

Find v_o when

(a) $v_i = 5V$

(b) $v_i = 0V$

(a) $v_i = 5V$



① Q_1, Q_2 both ON → ✗

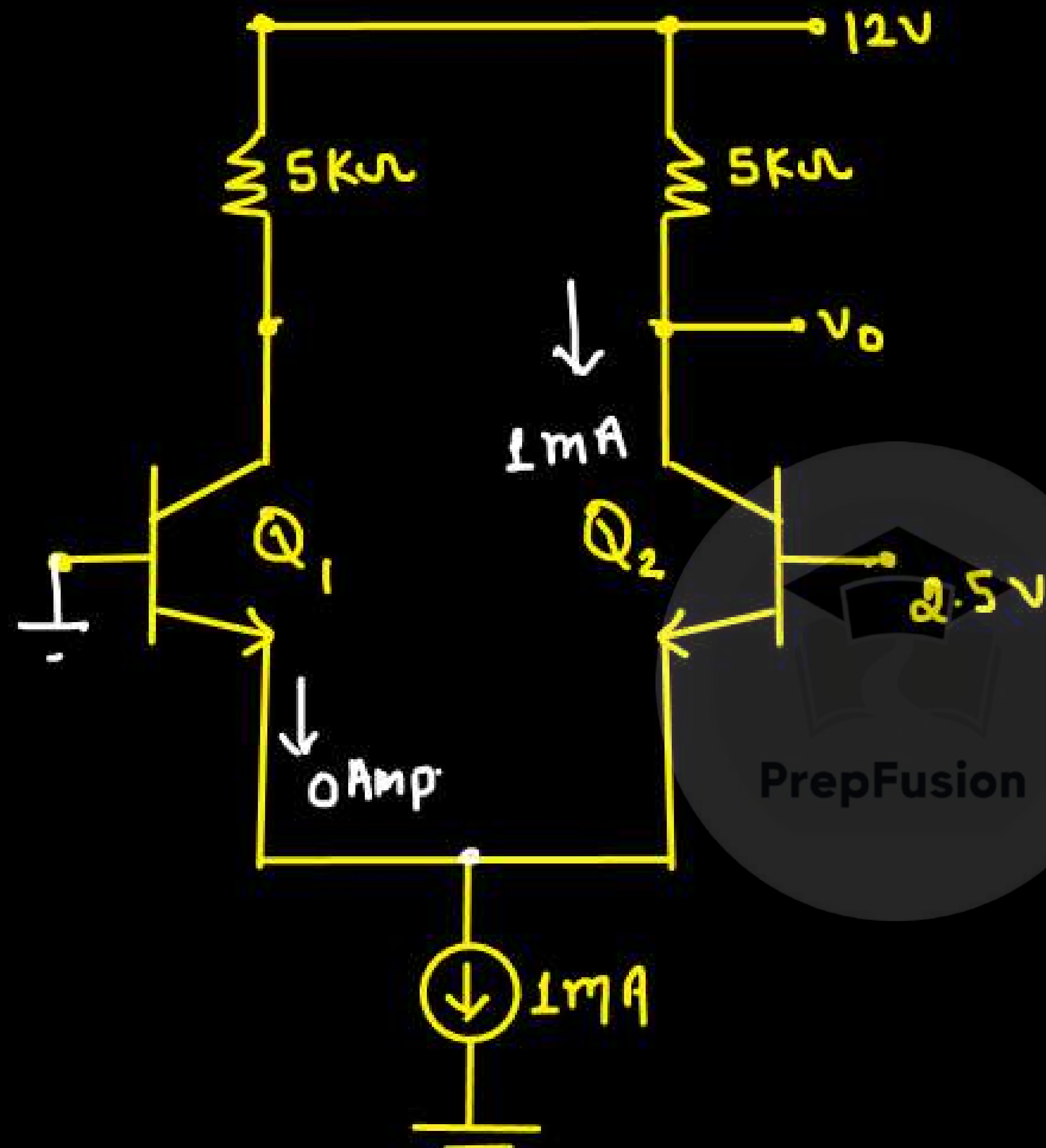
② Q_2 ON, Q_1 OFF } → ✗

③ Q_1 ON, Q_2 OFF } ✓

$\Rightarrow Q_1$ ON, Q_2 OFF

$$\boxed{V_o = 12V}$$

(b)



Q_2 ON

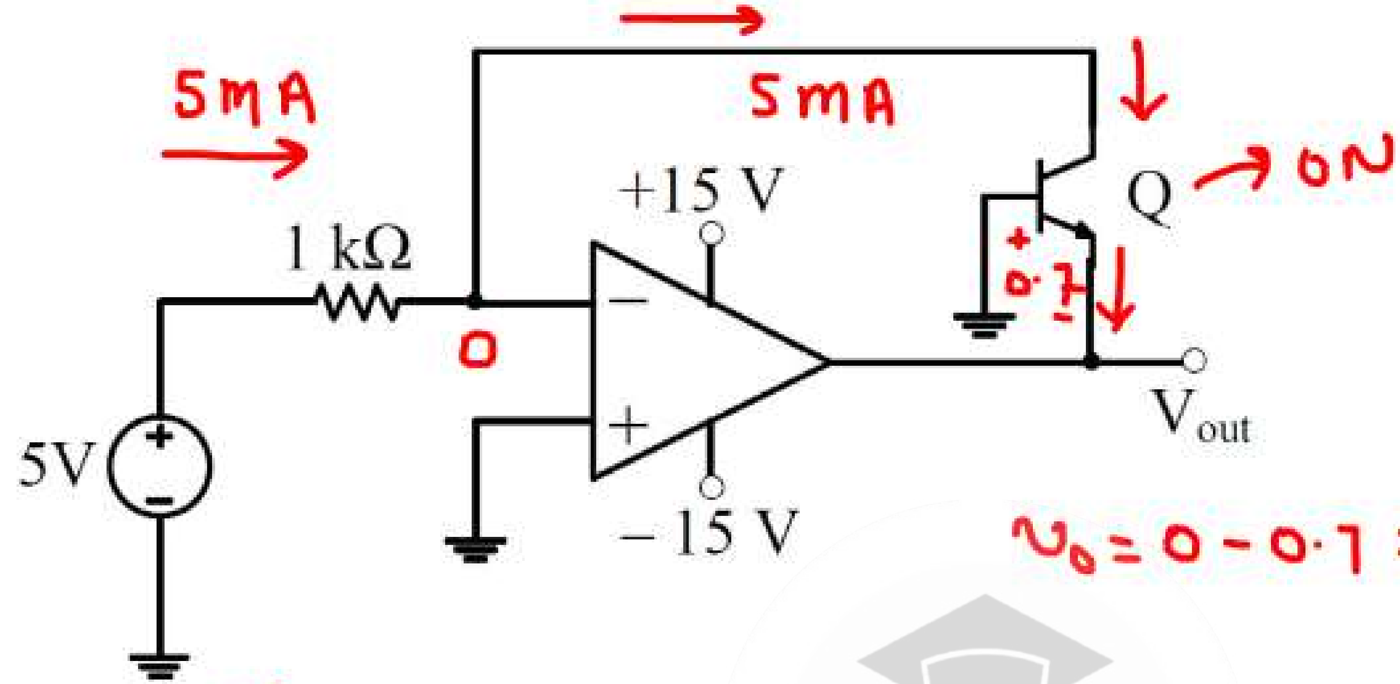
Q_1 OFF

$V_0 = 12 - 5 \times 1$

$$\boxed{V_0 = 7\text{ V}}$$

Q.

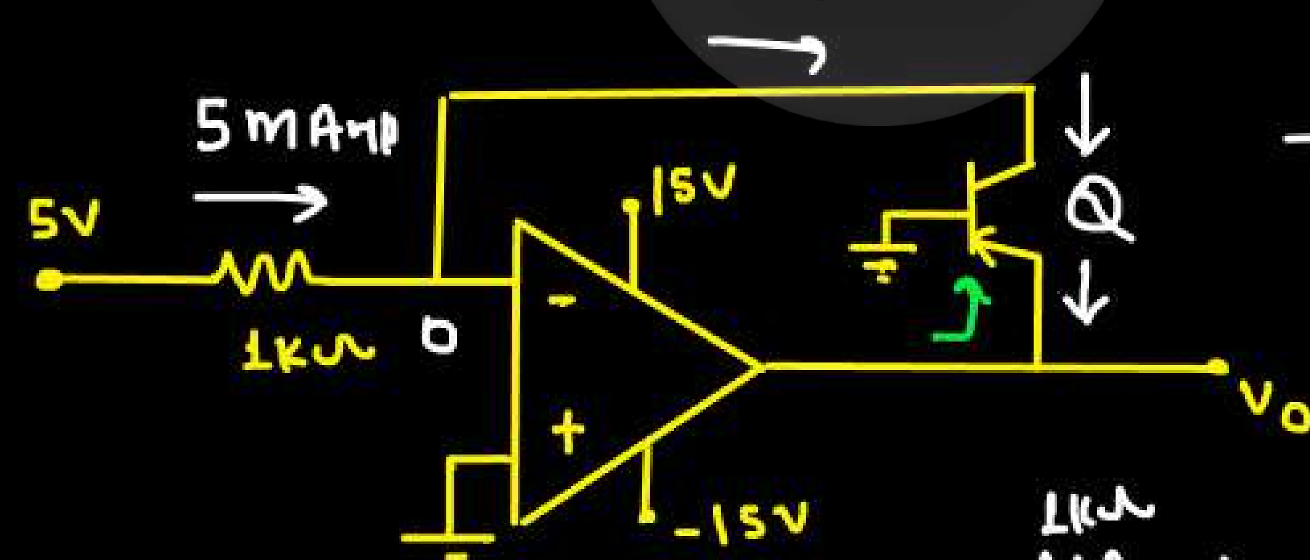
In the circuit shown below what is the output voltage (V_{out}) if a silicon transistor Q and an ideal op-amp are used?



$v_0 = 0 - 0.7 = -0.7V$

(A) −15 V (B) −0.7 V (C) +0.7 V (D) +15 V

Q.



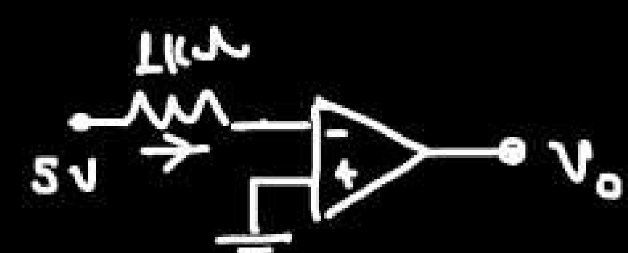
→ Assume Q ⇒ ON

⇓

Q is actually off

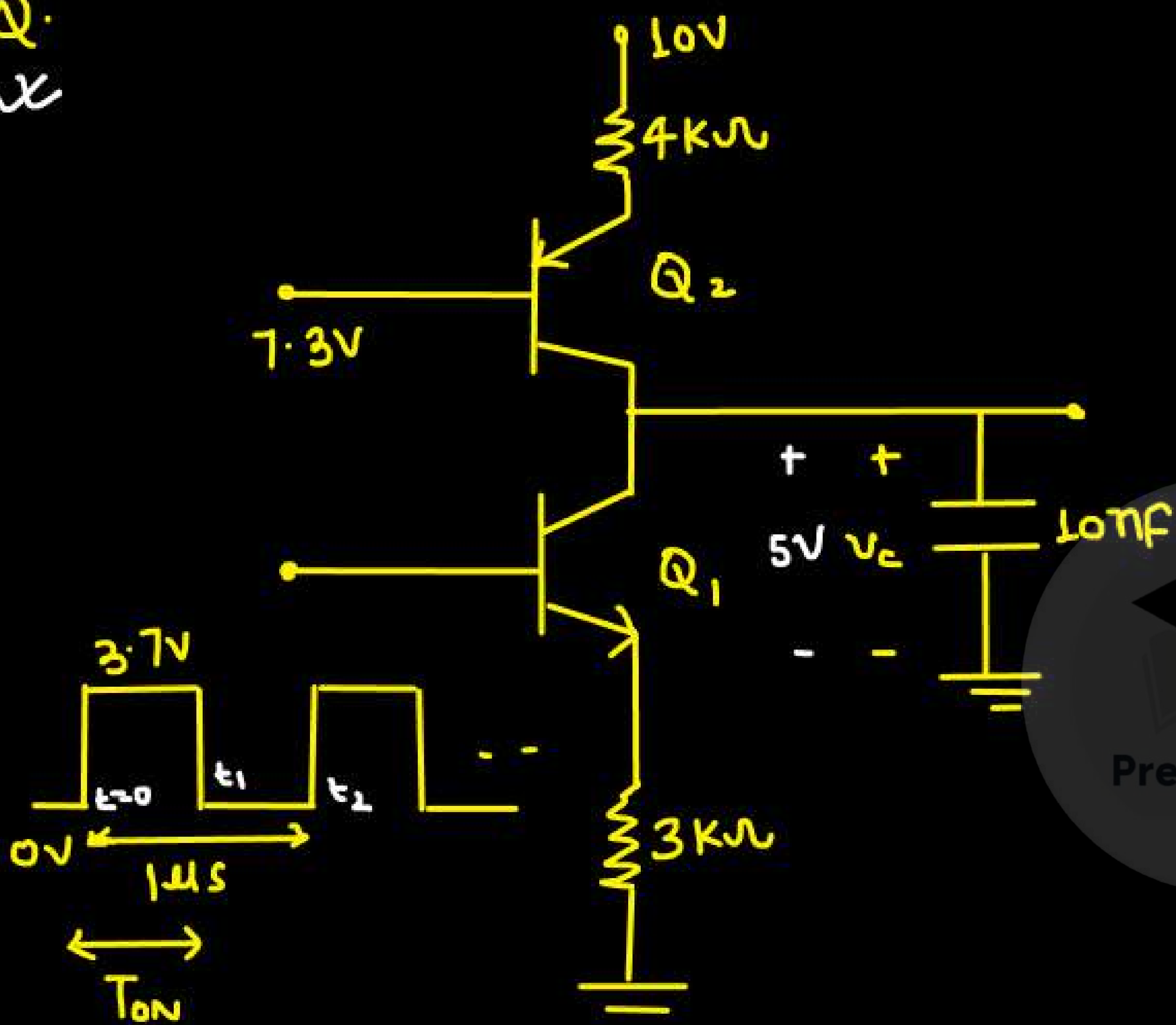
⇓

No f/b



← $\boxed{V_0 = -15V}$ ANS

Q.



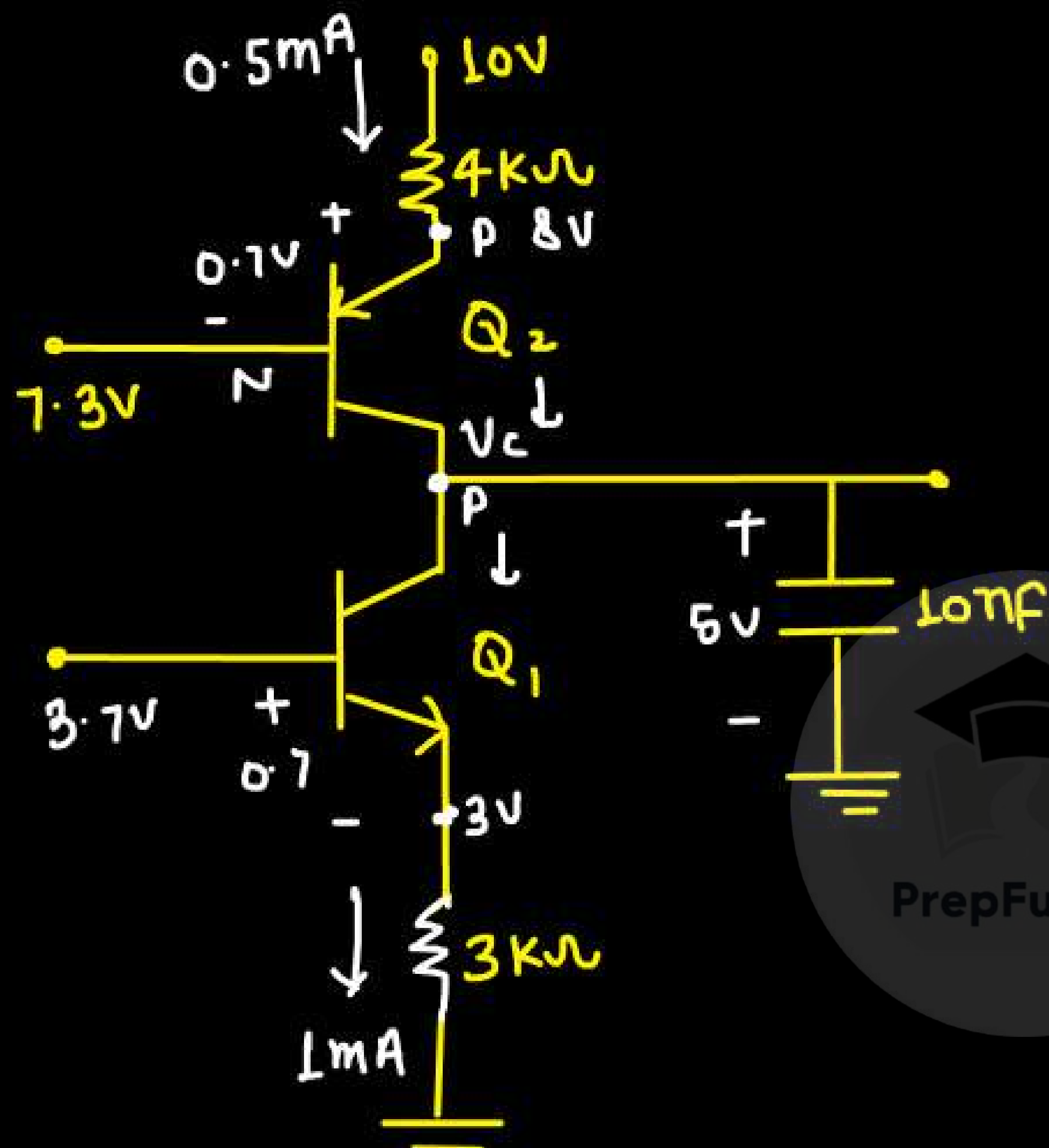
$|V_{EB}| = 0.7V$

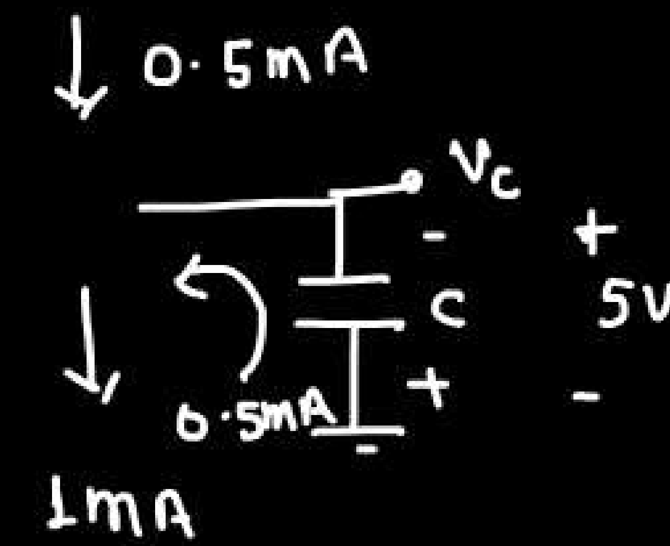
Capacitor is initially charged to 5V.

The input to Q_1 Transistor is shown.

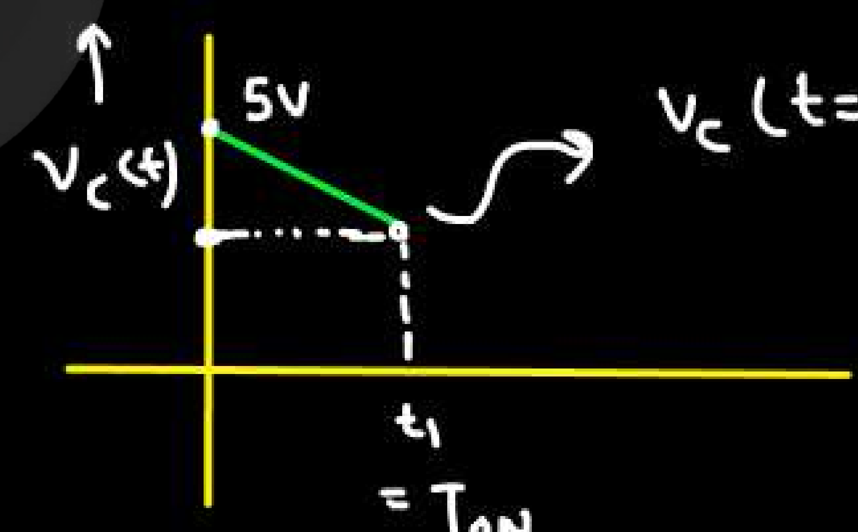
Determine T_{ON} such that Tr. $\boxed{\text{never enter into saturation}}$ even after arbitraily long time.

@ $t = 0^+$

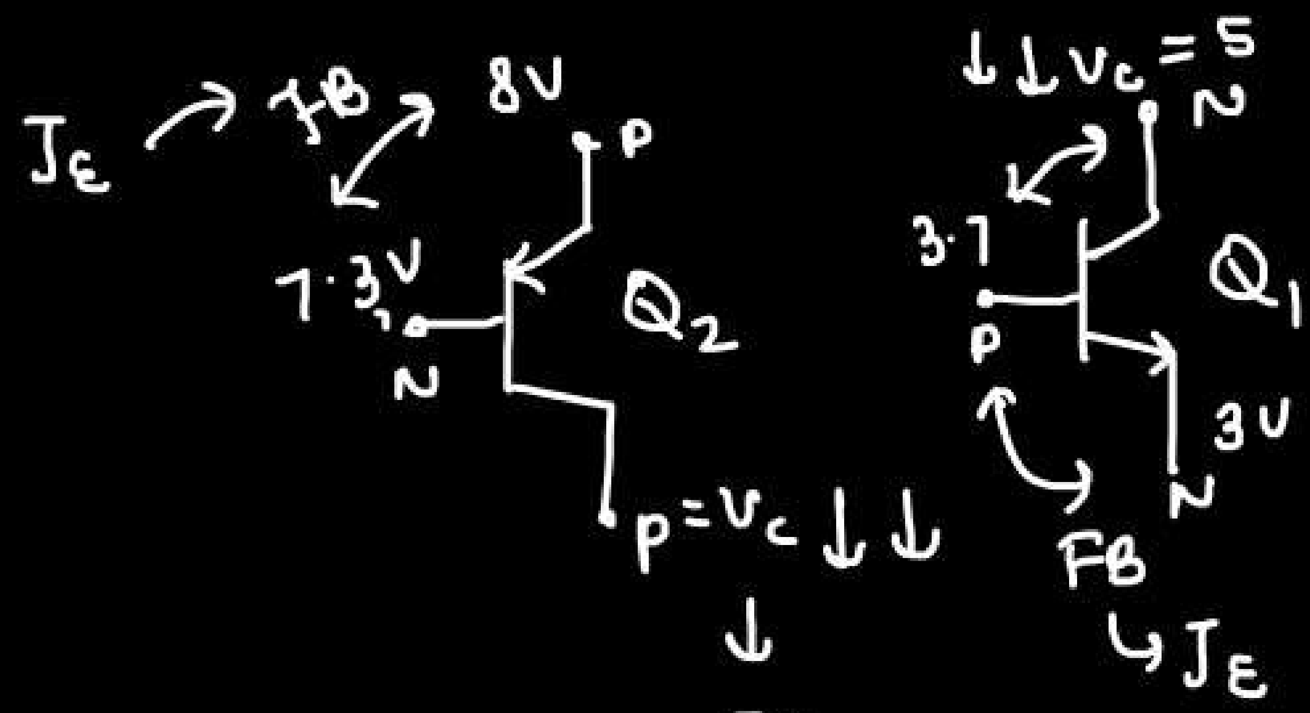




$$V_c(t) = 5 - \frac{0.5m\,[t]}{10n}$$



$$V_c(t = T_{ON}) = 5 - 5\times10^{4}\,T_{ON}$$



Active → J_C → R.B.

V_C going down

↓

5V

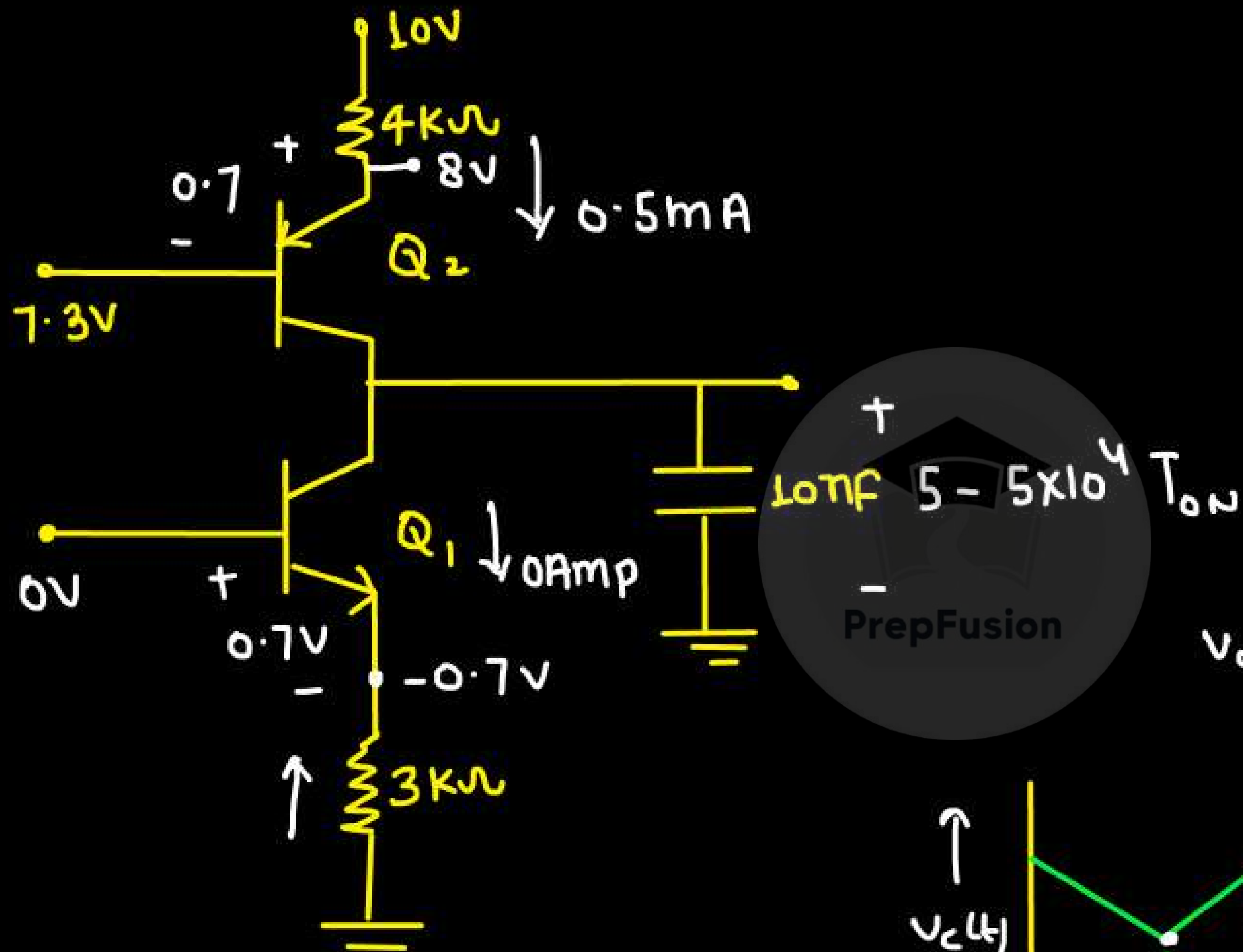
⇓

Q_2 stays in active

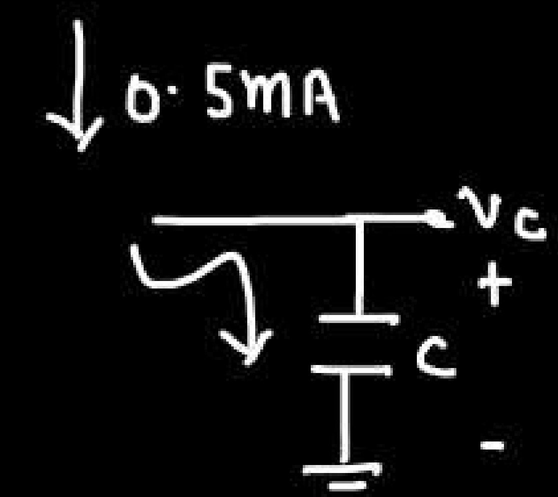
⇓

Q_1 moves toward sat.

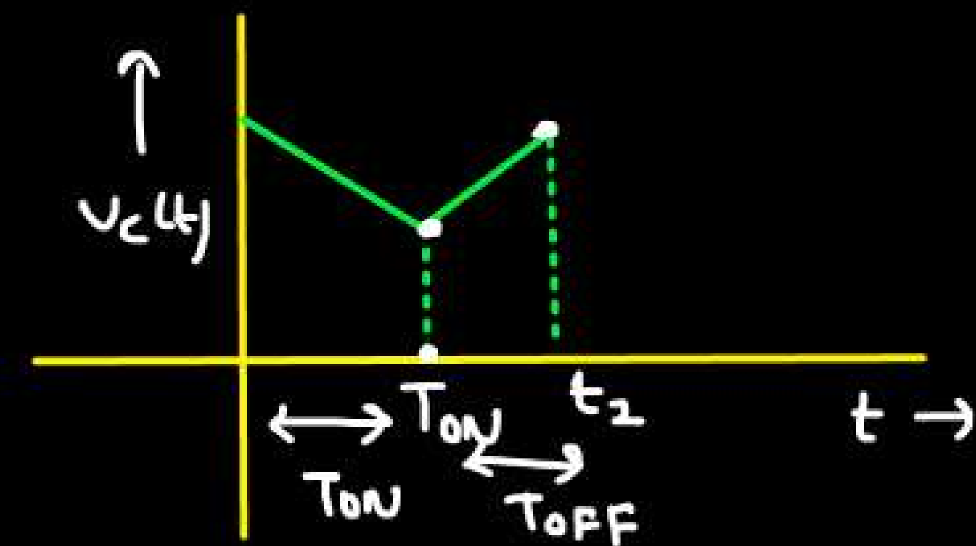
@ $t = t_1^+$

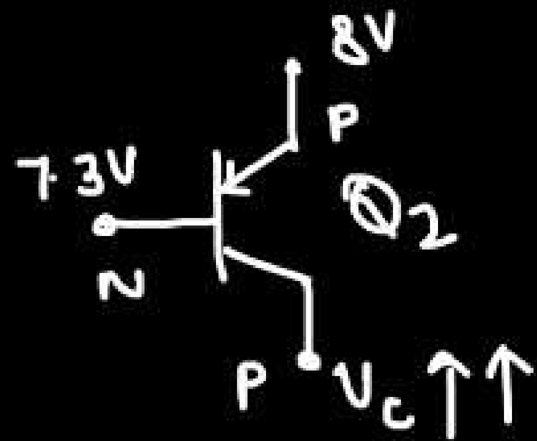


Q₁ is OFF.



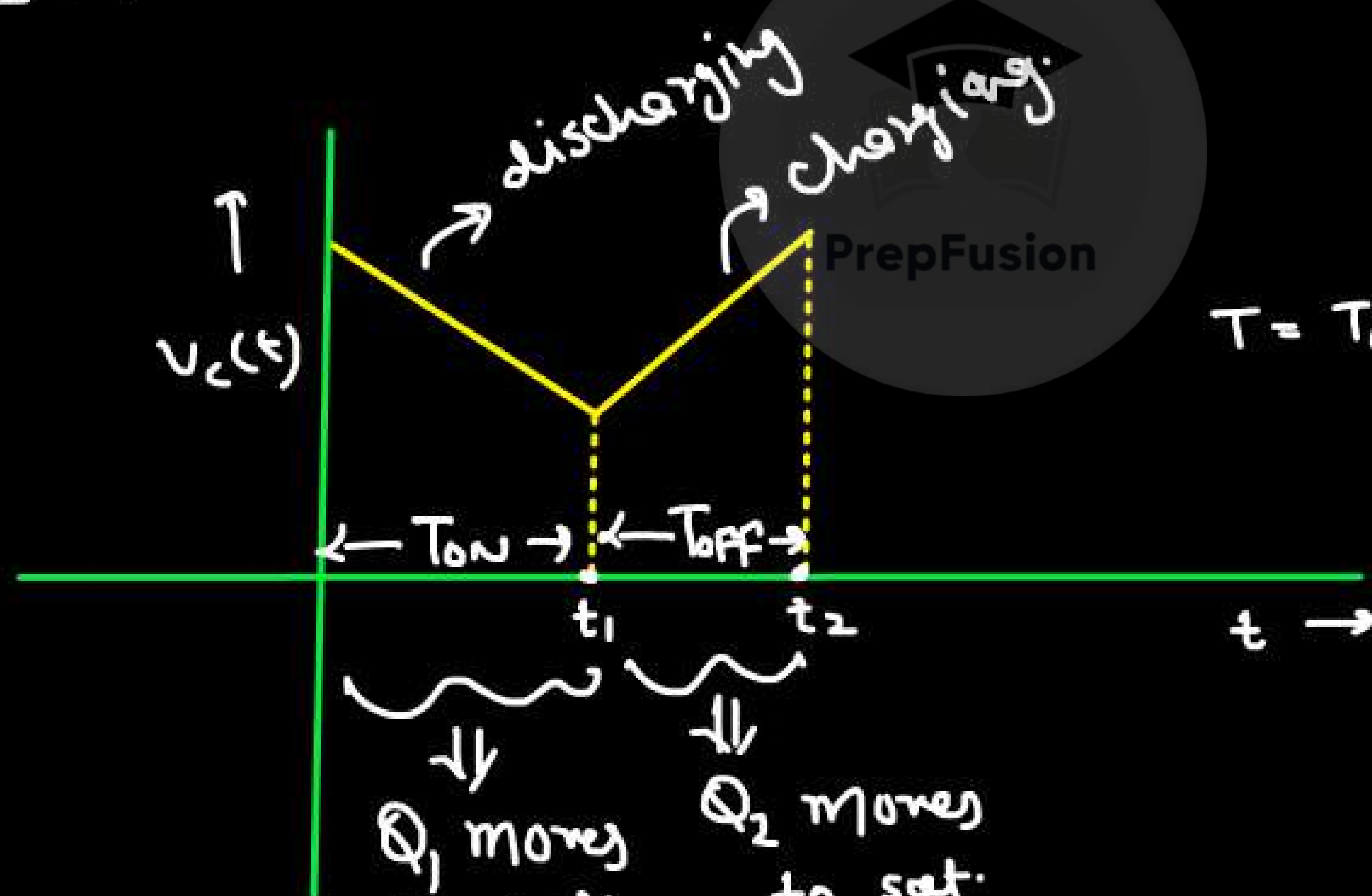
$$v_c(t) = 5 - 5\times10^4\, T_{ON} + \frac{0.5m}{10n}(t - t_1)$$





$\Downarrow$

Q_2 moves towards sat.

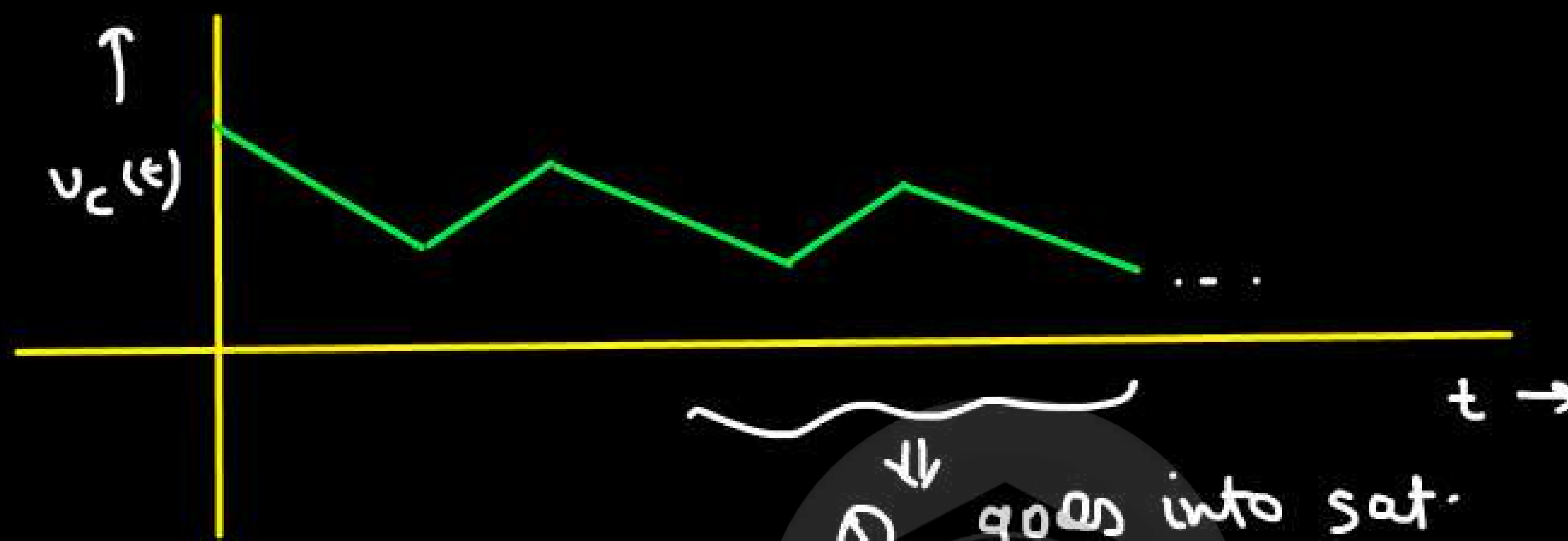


$T = T_{ON} + T_{OFF}$

$\Downarrow$ Q_1 moves to sat

$\Downarrow$ Q_2 moves to sat.

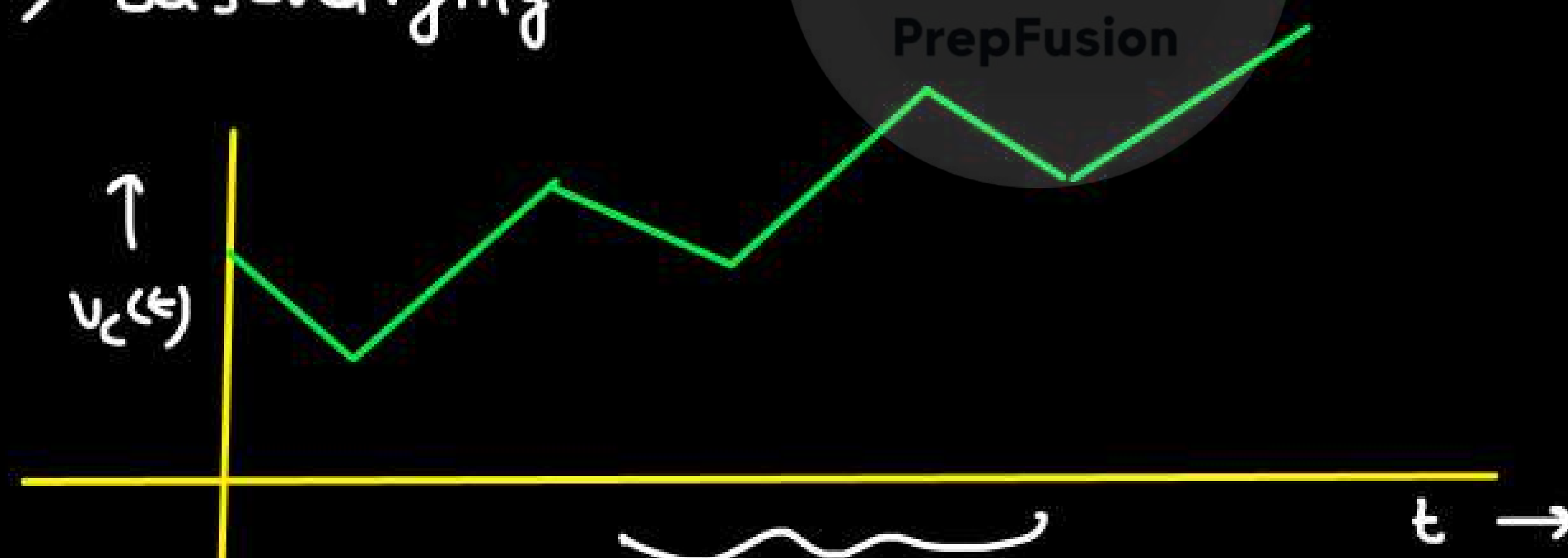
(i) discharging > charging



$\Downarrow$

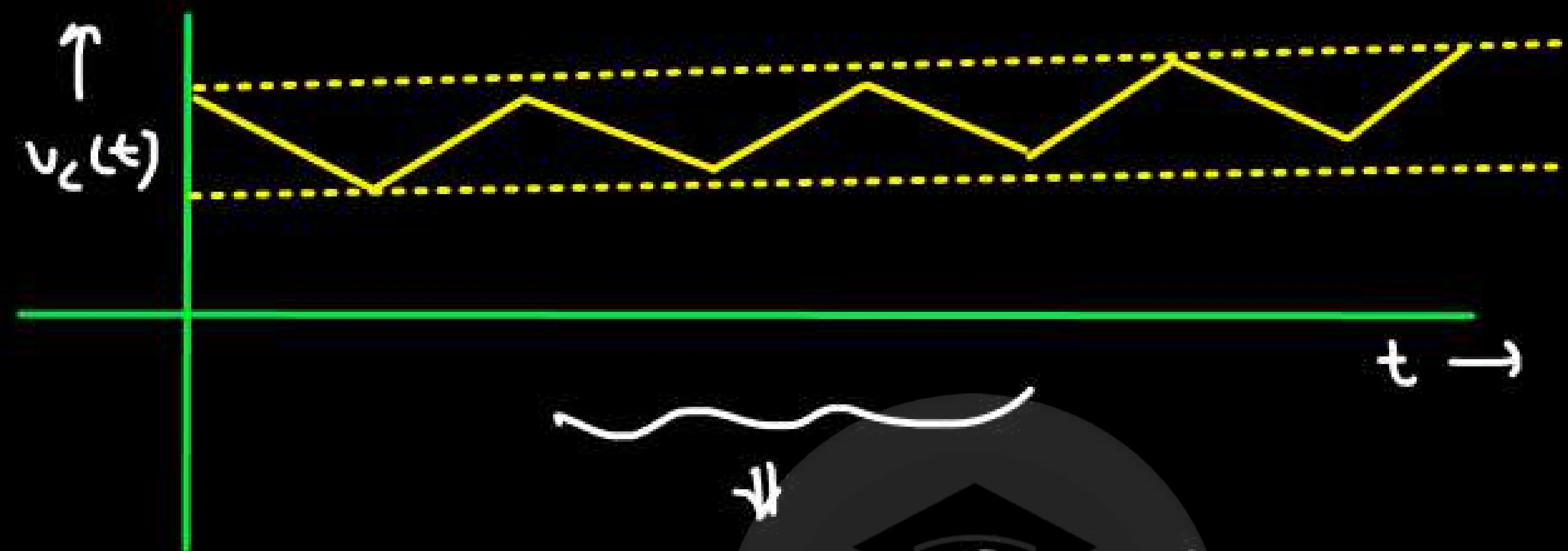
Q_1 goes into sat.

(ii) charging > discharging



Q_2 goes into sat.

(iii) charging = discharging



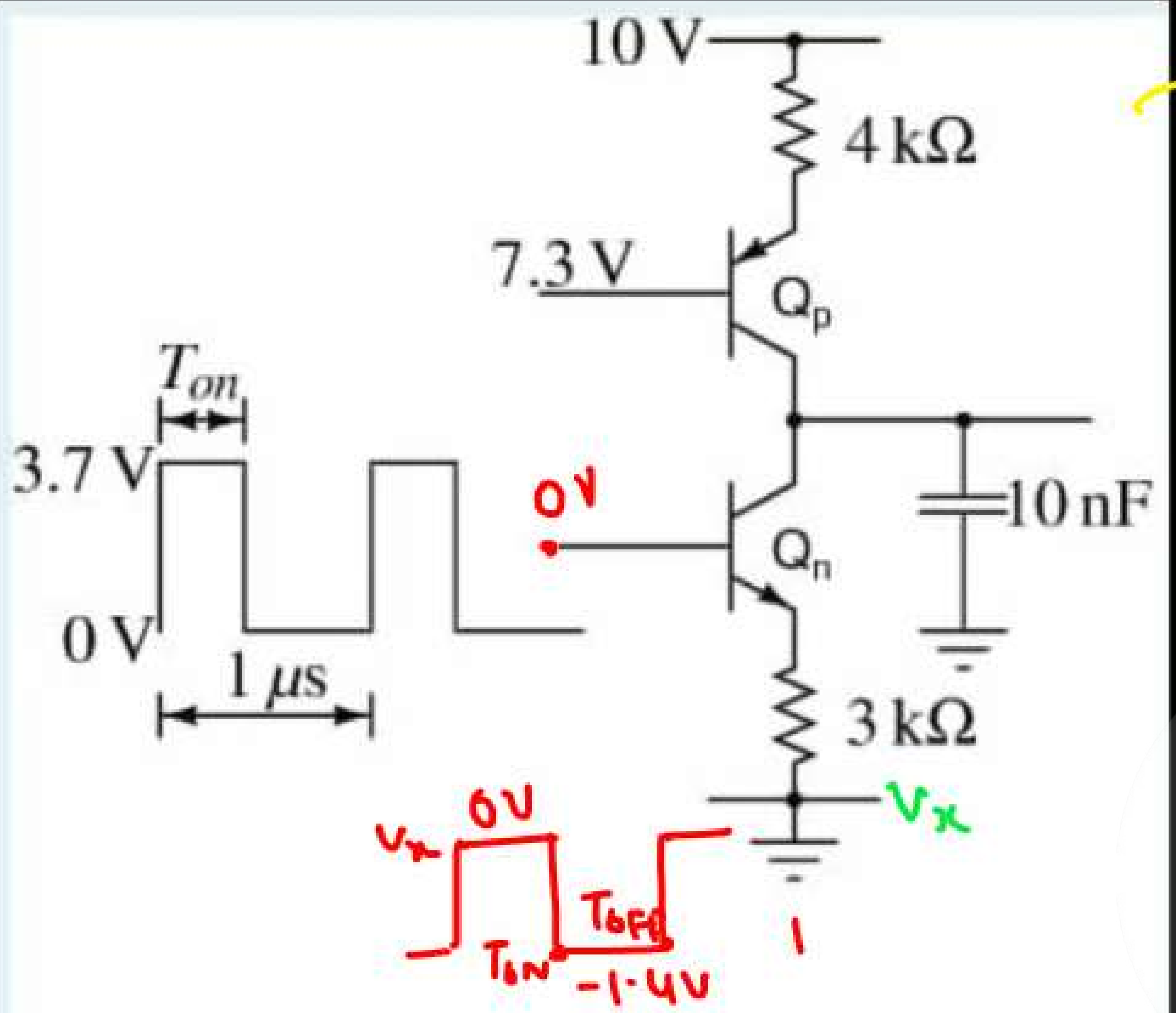
$\Downarrow$

Q_1 and Q_2 both never enter into sat.

$$\frac{0.5m \times T_{off}}{c} = \frac{0.5m \times T_{ON}}{c} \Rightarrow T_{ON} = T_{off}$$

$T = 1\mu s$

$$\boxed{T_{ON} = \tfrac{1}{2}\mu s}$$

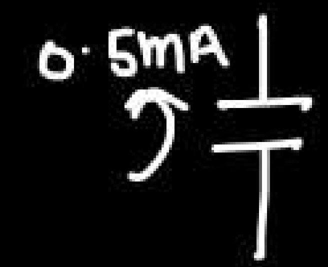


In this circuit, the 10 nF capacitor is initially charged to 5V. The NPN transistor is driven with a 1 μs period rectangular wave going from 0 to 3.7 V and an ON duration of T_{on}. Determine T_{on} so that the transistors never leave the active region even after an arbitrarily long time. NPN and PNP transistors are active with $V_{BE} = 0.7$ V and $V_{EB} = 0.7$ V, respectively.

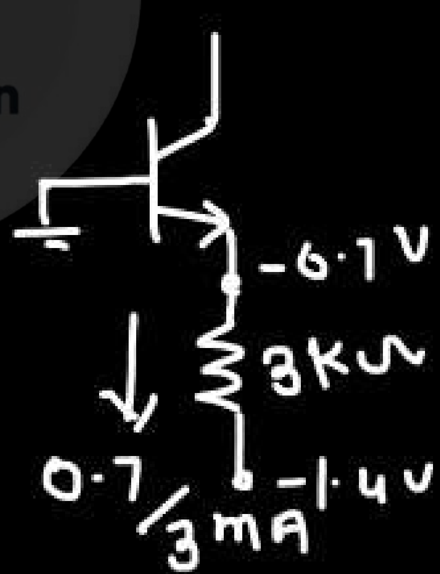
(The answer must be in **micro-seconds** [μs]. Round off fractional answers to two decimal places.)

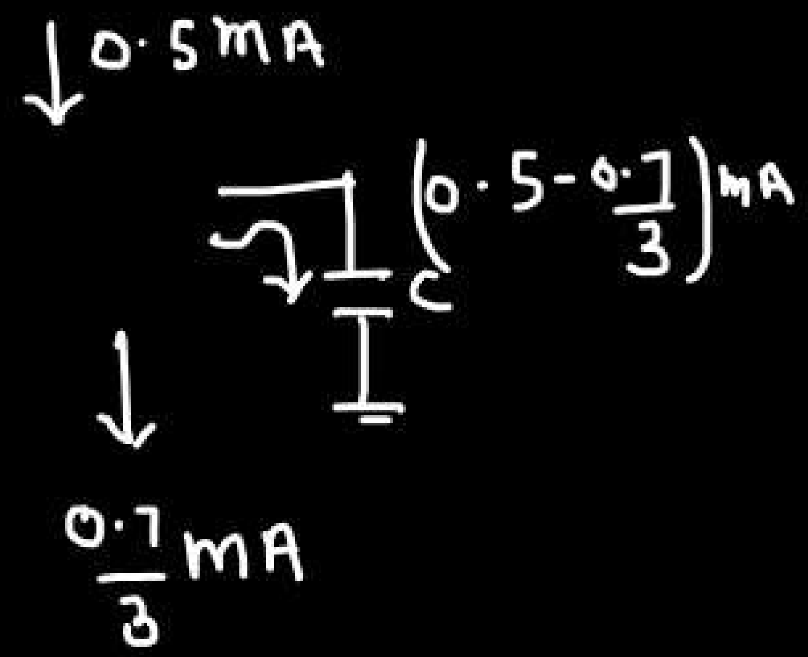
Asked in written Test

→ $v_i = 3.7V$



$v_i = 0V$





$$\frac{0.5mA \times T_{ON}}{C} = \frac{0.8mA}{3} \times \frac{T_{OFF}}{C}$$

$$\frac{1.5}{0.8} T_{ON} = T_{OFF}$$

$$T = 1\mu$$

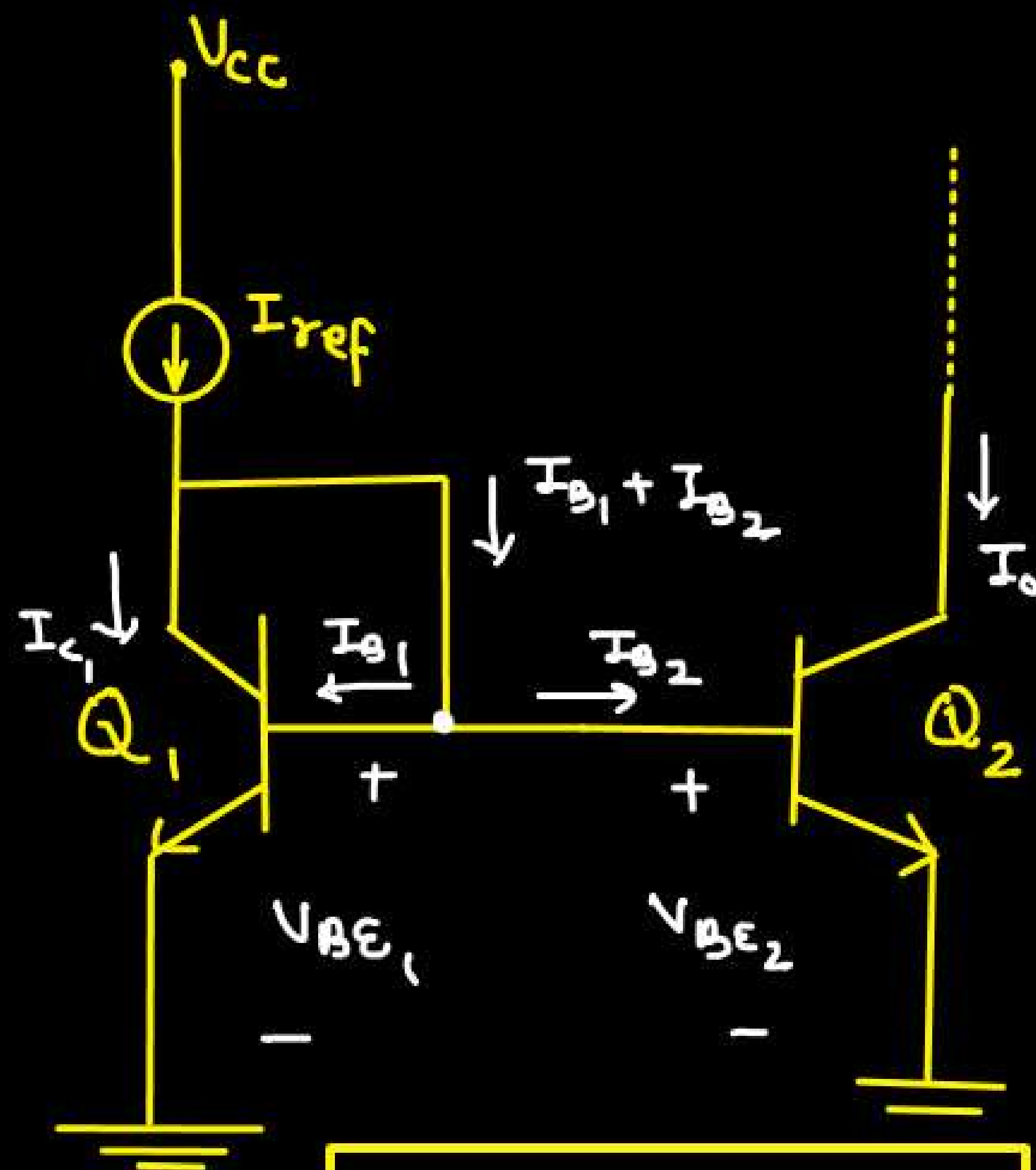
$$T_{ON} + \frac{15}{8} T_{ON} = 1\mu$$

$$T_{ON} = \frac{8}{23}\mu$$

$$\boxed{T_{ON} = 0.347\,\mu sec.}$$

Current Mirror Circuits

[Copying Current]



$$\boxed{V_{BE_1} = V_{BE_2} = V_{BE}}$$

$I_{S_1} = I_{S_2} = I_S$

$\beta_1 = \beta_2 = \beta$

Both Q_1 and Q_2 $\boxed{\text{are matched.}}$

Both Q_1 and Q_2 are in $\boxed{\text{active region}}$

$\{V_A = \infty\}$

$$I_{C_1} = I_{S_1} \exp\left(\frac{V_{BE_1}}{\eta V_T}\right)$$

$$I_{C_2} = I_{out} = I_{S_2} \exp\left(\frac{V_{BE_2}}{\eta V_T}\right)$$

Here $I_{S_1} = I_{S_2}$, $V_{BE_1} = V_{BE}$

$$\boxed{I_{C_1} = I_{C_2} = I_{out}}$$

$$I_{out} = I_{C_1} \quad \text{--- (1)}$$

$$I_{ref} = I_{C_1} + I_{B_1} + I_{B_2} \quad \text{--- (2)}$$

$$I_{B_1} = \frac{I_{C_1}}{\beta_1}$$

$$I_{B_2} = \frac{I_{C_2}}{\beta_2}$$

↳ Here, we know $I_{C_1} = I_{C_2}$, $\beta_1 = \beta_2 = \beta$

$$\Rightarrow I_{B_1} = I_{B_2} = I_B$$

$$I_{ref} = I_{C_1} + 2 I_{B_1}$$

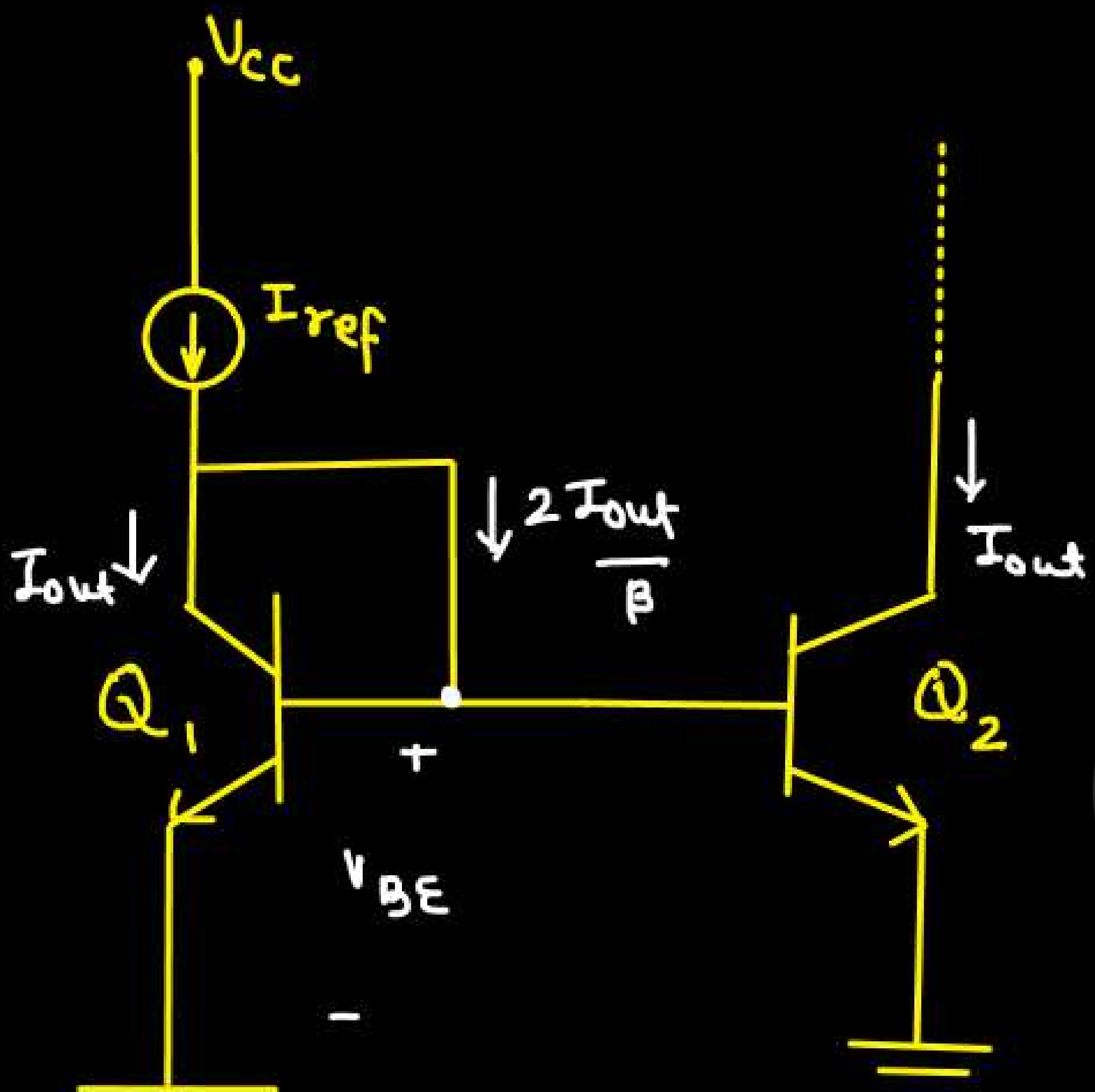
$$I_{ref} = I_{C_1} + \frac{2 I_{C_1}}{\beta}$$

$$I_{ref} = \left(1 + \frac{2}{\beta}\right) I_{out}$$

$$\frac{I_{out}}{I_{ref}} = \frac{\beta}{\beta + 2}$$

**

$$\boxed{I_{out} = \left(\frac{\beta}{\beta+2}\right) I_{ref}}$$



β = same

I_s = same

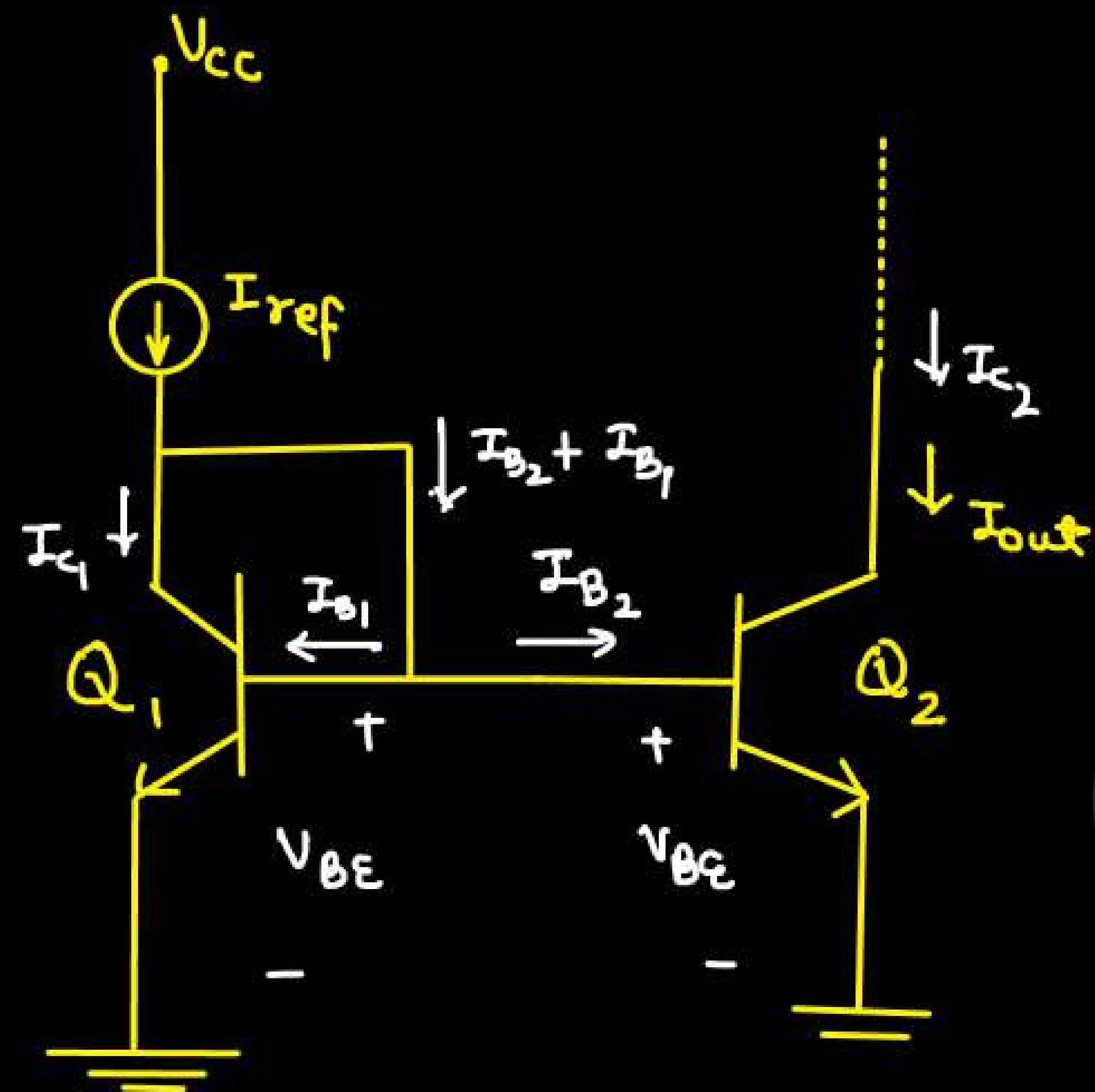
both active, $r_A = \infty$

$\left.\beta, I_s, V_{BE} \text{ same}\right\} \Rightarrow I_C, I_B$ same

$$I_{ref} = I_{out} + \frac{2I_{out}}{\beta}$$

$$\boxed{I_{out} = \frac{\beta}{\beta+2} I_{ref}}$$

V_{BE}



$$\boxed{I_S \propto A_Q}$$

Q. Both Tr. Q_1 and Q_2 have β values of 10 and 20 respectively.

Tr Q_1 and Q_2 have cross-section area of A_{Q_1} and A_{Q_2}.

Given $\boxed{\dfrac{A_{Q_2}}{A_{Q_1}} = 2 \ , \ \beta_1 = 10, \ \beta_2 = 20}$

Find $\dfrac{I_{out}}{I_{ref}} = ?$

$$\frac{I_{S_2}}{I_{S_1}} = 2 \quad , \quad \beta_1 = 10 \quad , \quad \beta_2 = 20$$

$$I_{C_1} = I_{S_1} \exp\left(\frac{V_{BE}}{\eta V_T}\right) \quad \text{—} (1)$$

$$I_{C_2} = I_{S_2} \exp\left(\frac{V_{BE}}{\eta V_T}\right) \quad \text{—} (2)$$

$$(2) \div (1)$$

$$\frac{I_{C_2}}{I_{C_1}} = 2 \Rightarrow \boxed{I_{C_2} = 2 I_{C_1}} \qquad \boxed{I_{out} = 2 I_{C_1}}$$

$$\Rightarrow I_{ref} = I_{C_1} + I_{B_2} + I_{B_1}$$

$$I_{ref} = I_{C_1} + \frac{I_{C_2}}{\beta_2} + \frac{I_{C_1}}{\beta_1}$$

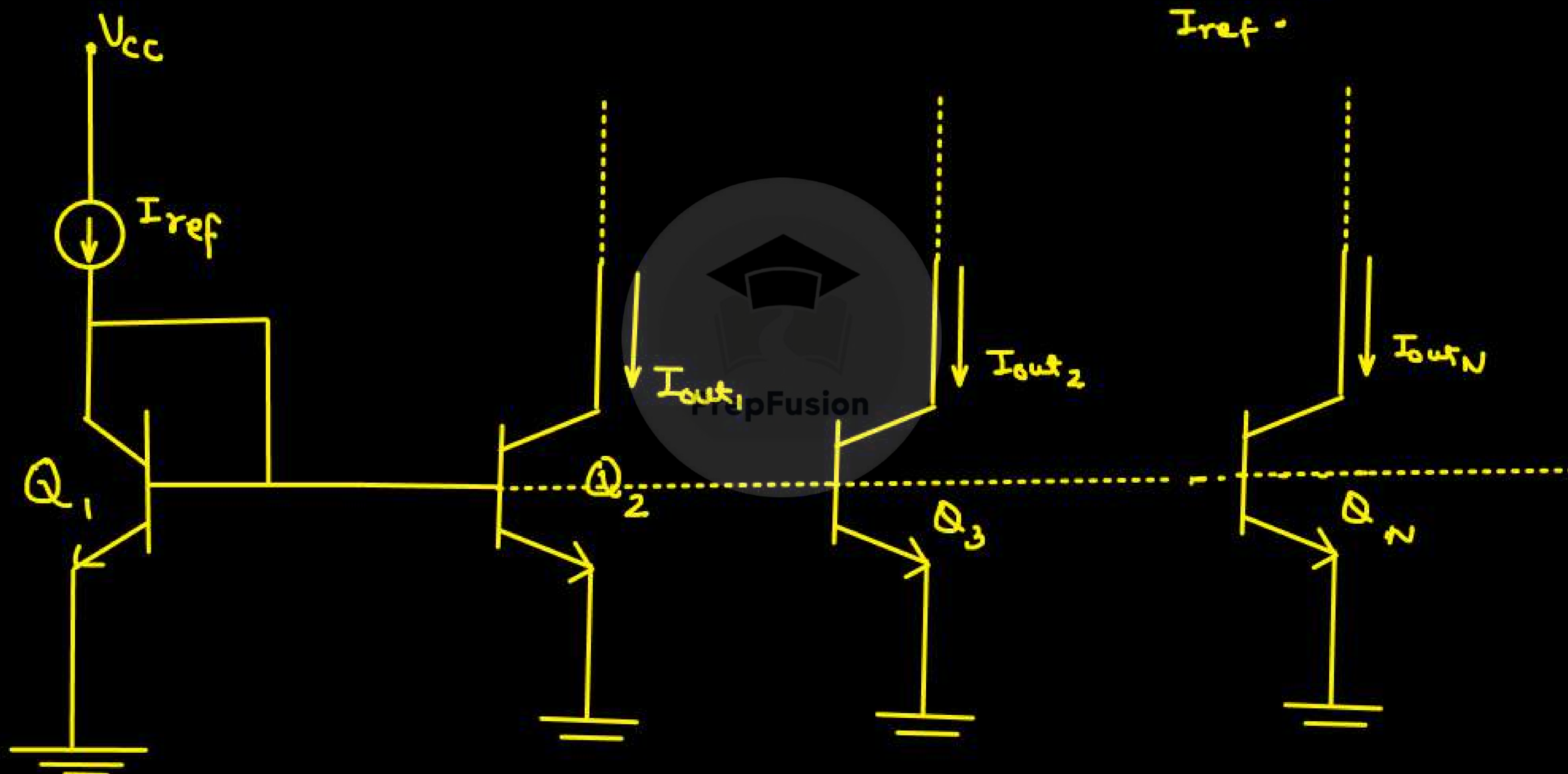
$$I_{ref} = \frac{I_{out}}{2} + \frac{I_{out}}{\beta_2} + \frac{I_{out}}{2\beta_1}$$

$$I_{ref} = \frac{I_{out}}{2} + \frac{I_{out}}{20} + \frac{I_{out}}{20}$$

$$I_{ref} = \frac{6}{10} I_{out}$$

$$\boxed{\frac{I_{out}}{I_{ref}} = \frac{10}{6} = 1.67}$$

Q. All the N Transistors are matched and have same β value. Find I_{out_1}, I_{out_2} --- I_{out_N} in terms of I_{ref}.

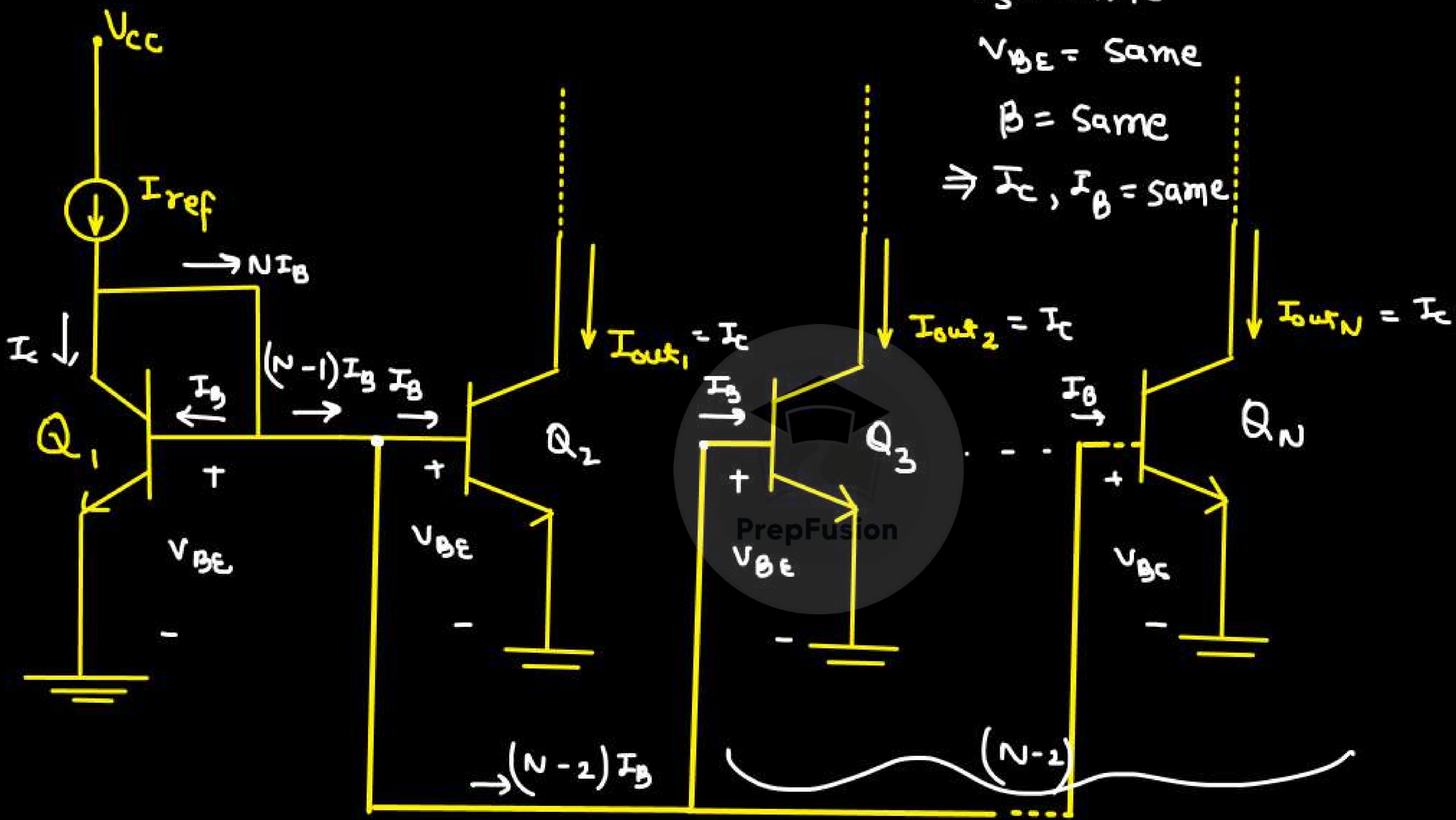


I_S = same

V_{BE} = same

β = same

$\Rightarrow I_C, I_B$ = same



$$I_{c_1} = I_{out_1} = I_{out_2} = I_{out_3} = \cdots\ I_{out_N} = I_c = I_{out}$$

$$I_{ref} = I_C + N I_B$$

$$I_{ref} = I_C + \frac{N I_C}{\beta}$$

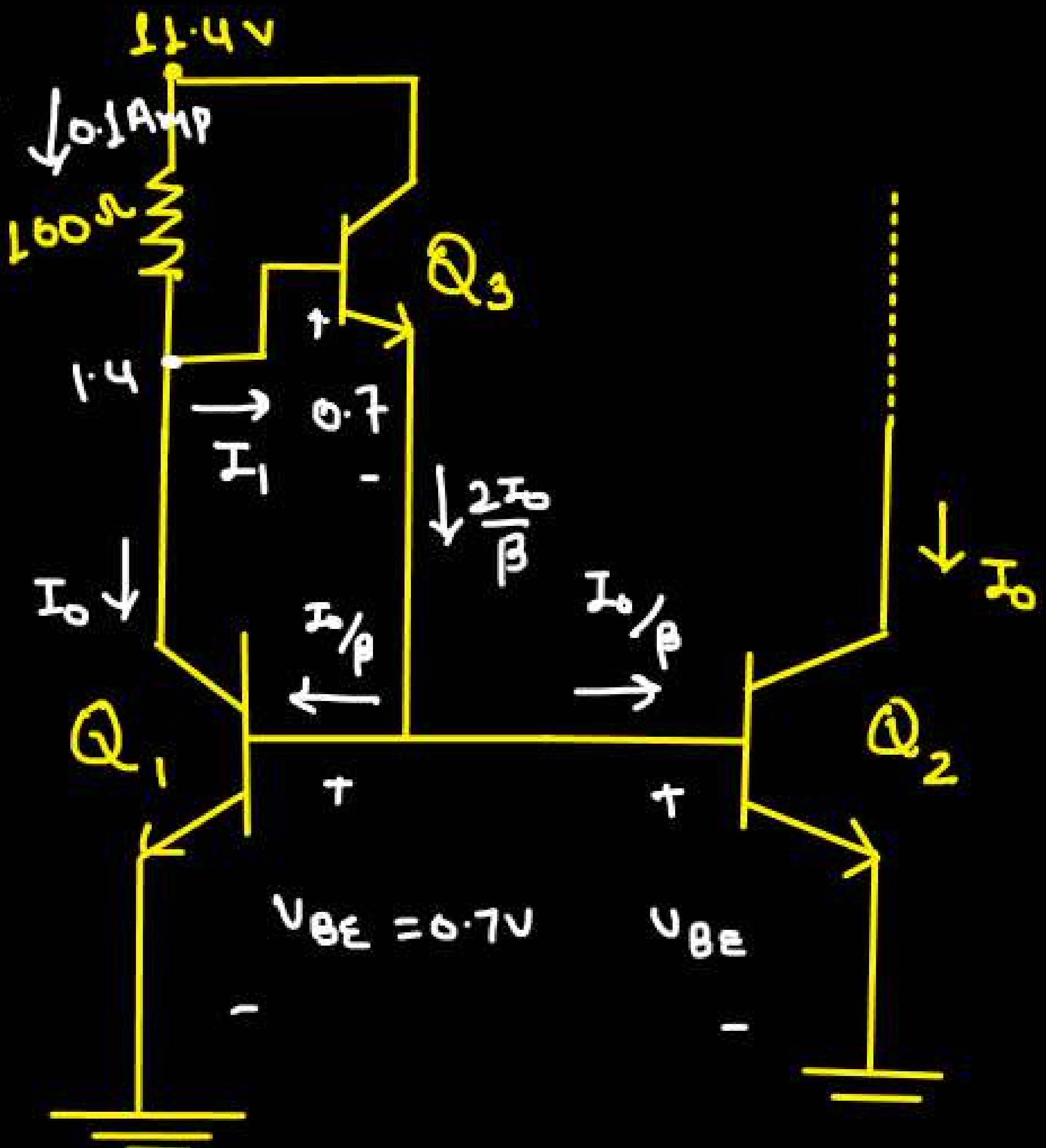
$$I_{ref} = I_{out} + \frac{N I_{out}}{\beta}$$

$$\boxed{I_{out} = I_{ref}\left(\frac{\beta}{\beta+N}\right)} \;\; ** = I_{out_1} = I_{out_2} = \text{----} \; I_{out_N}$$

$$\boxed{\text{if } \beta = \infty}$$

$$\boxed{I_{out} = I_{ref} = I_{out_1} = I_{out_2} = \text{---} \; I_{out_N}}$$

Q.



Tr. Q_1 and Q_2 are matched.

All Tr. are working in active mode.

$\boxed{\beta_1 = \beta_2 = 100}$; $\beta_3 = 99$

$(V_{BE})_{ON} = 0.7$

Find $I_o = ?$

↳ For Q_1 and Q_2

V_{BE} same, I_s same, β same

$\Rightarrow$ I_C, I_B same

$I_{C_1} = I_{C_2} = I_C$

$I_{B_1} = I_{B_2} = I_B$

$$I_1 = I_{B_3} = \frac{I_{E_3}}{\beta_3 + 1} = \frac{2I_o}{\beta(\beta_3+1)} \quad \text{—(1)}$$

$\beta_1 = \beta_2 = \beta = 100$

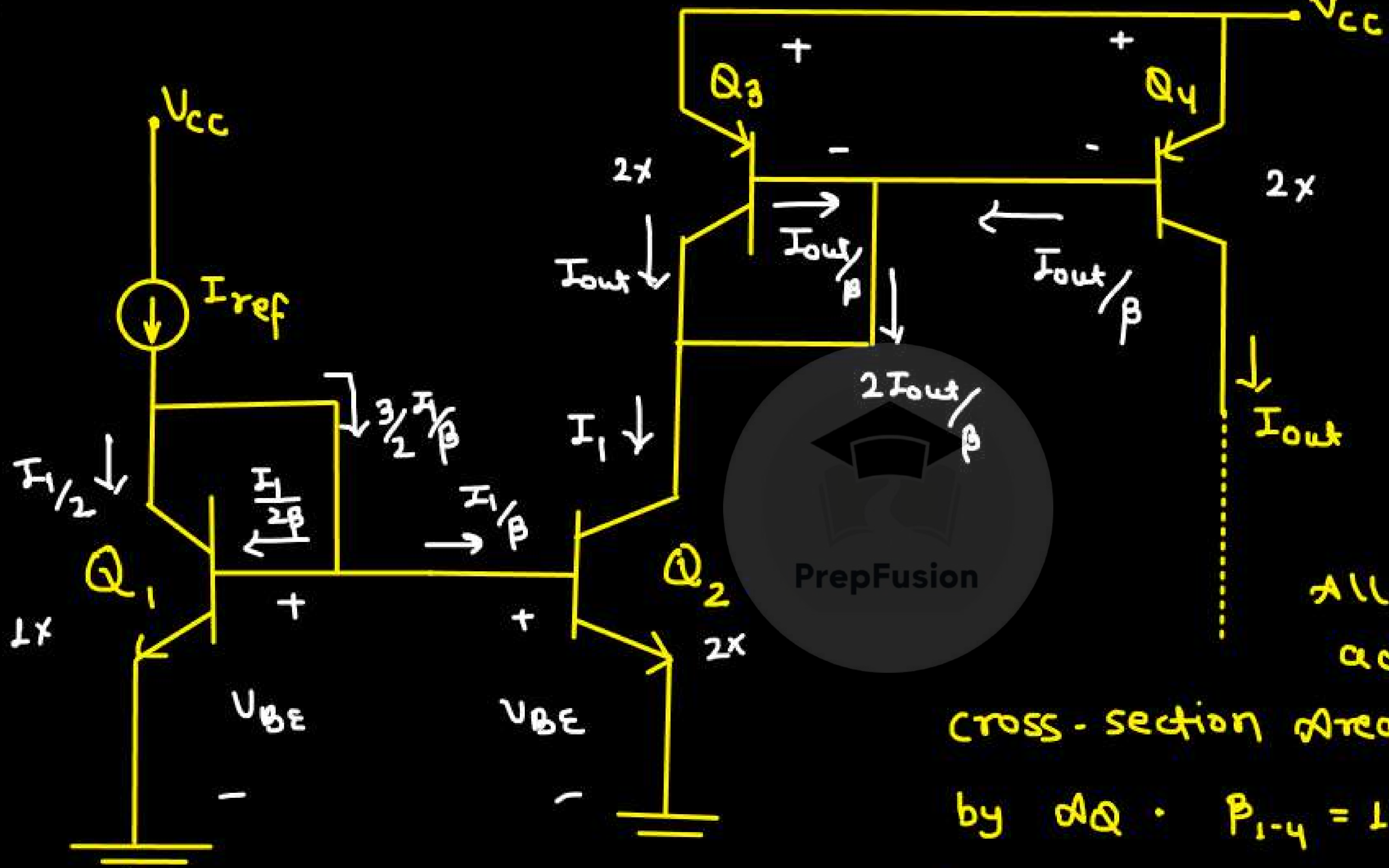
$$0.1\,\text{Amp} = I_0 + I_1$$

$$0.1 = I_0 + \frac{2I_0}{\beta(\beta_3+1)}$$

$$0.1 = I_0\left[1 + \frac{2}{100\times100}\right]$$

$$\boxed{I_0 = 99.98\,\text{mAmp}}$$

Q.



All Tr. are working in active mode of operation.

cross-section area of Tr is shown by AQ. $\beta_{1-4} = 100$

$AQ_2 = 2AQ_1$, $AQ_3 = AQ_2 = AQ_4$

Find I_{out}/I_{ref}.

For Q_3 and Q_4

$$A_{Q_3} = A_{Q_4} \Rightarrow I_{S_3} = I_{S_4}$$

$$V_{EB_3} = V_{EB_4}$$

$$\beta_3 = \beta_4$$

$$\left.\begin{aligned} \Rightarrow I_{C_3} = I_{C_4} = I_{out} \\ I_{B_3} = I_{B_4} = I_{out}/\beta \end{aligned}\right\} - (1)$$

$$\Rightarrow \quad I_1 = I_{out} + \frac{2 I_{out}}{\beta} \quad - (2)$$

4 $\quad I_1 = I_{C_2} = I_{S_2} \exp\left(V_{BE}/V_T\right)$

$$I_{C_1} = I_{S_1} \exp\left(V_{BE}/V_T\right)$$

$$\frac{A_{Q_2}}{A_{Q_1}} = 2 = \frac{I_{S_2}}{I_{S_1}}$$

$$\frac{I_{c_2}}{I_{c_1}} = 2$$

$$I_1 = 2I_{c_1}$$

$$\boxed{I_4 = I_1/2}$$

$$I_{ref} = \frac{I_1}{2} + \frac{3}{2}\frac{I_1}{\beta}$$

$$I_{ref} = \left(\frac{1}{2} + \frac{3}{2\beta}\right)\left(I_{out} + \frac{2 I_{out}}{\beta}\right) \quad \{\text{By eq}^n \text{ ② }\}$$

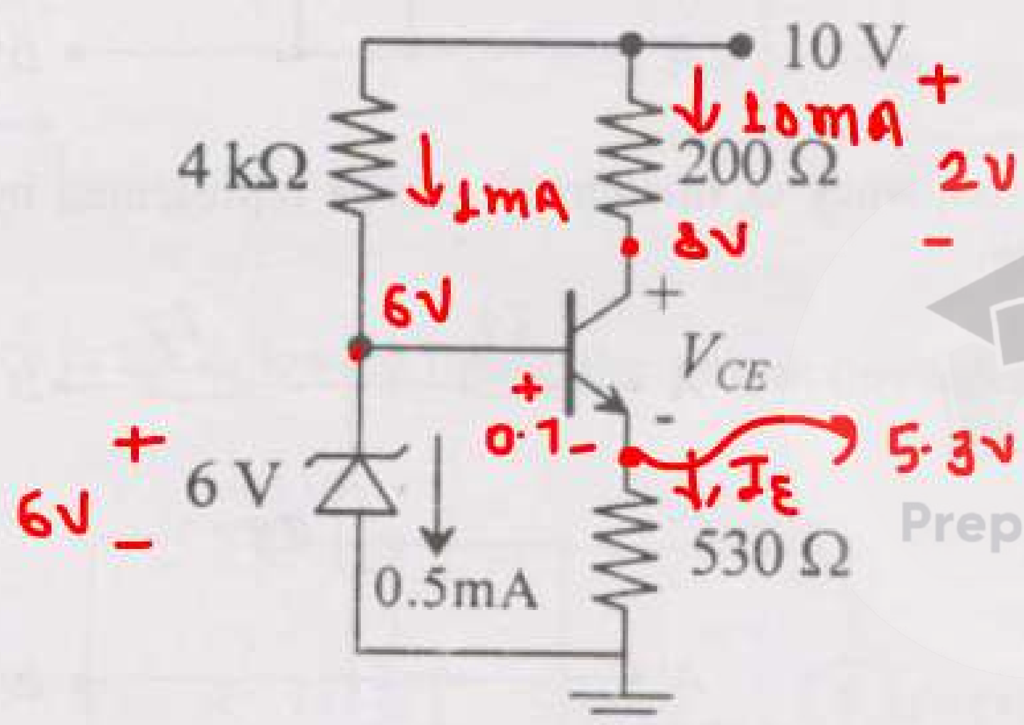
$$I_{ref} = \left[\frac{\beta+3}{2\beta}\right)\left(\frac{\beta+2}{\beta}\right) I_{out}$$

$$I_{ref} = \frac{103}{200} \times \frac{102}{100} I_{out}$$

$$\boxed{\frac{I_{out}}{I_{ref}} = 1.90}$$

Assignment - 19

Q. In the circuit shown below, $V_{BE} = 0.7$ V.



The β of the transistor and V_{CE} are, respectively

(A) 19 and 2.8 V (B) 19 and 4.7 V (C) 38 and 2.8 V (D) 38 and 4.7 V

FB ✗
RB ✗
BD ✓

$$I_E = \frac{5.3}{530} = 10\,mA$$

$$I_B = 0.5\,mA$$

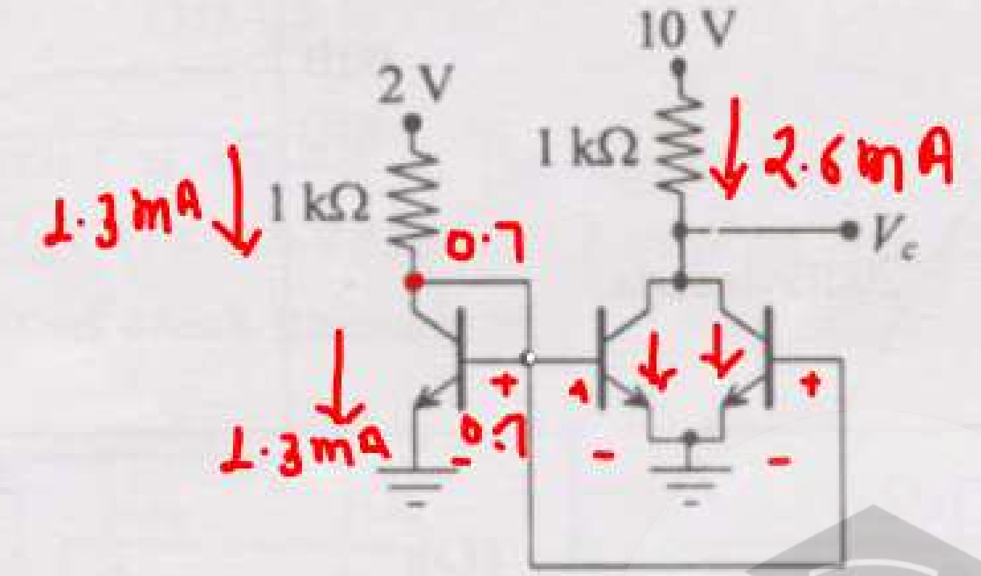
$$10 = (\beta+1)\,0.5$$

$$\boxed{\beta = 19}$$

$$V_{CE} = 8 - 5.3$$
$$= 2.7\,V$$

Q.

The three transistors in the circuit shown below are identical, with $V_{BE} = 0.7$ V and $\beta = 100$.



option → Far

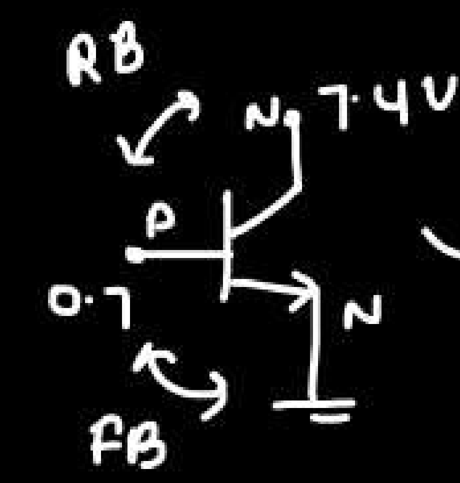
Take $\beta = \infty$

The voltage V_c is

(A) 0.2 V (B) 2 V (C) 7.4 V (D) 10 V

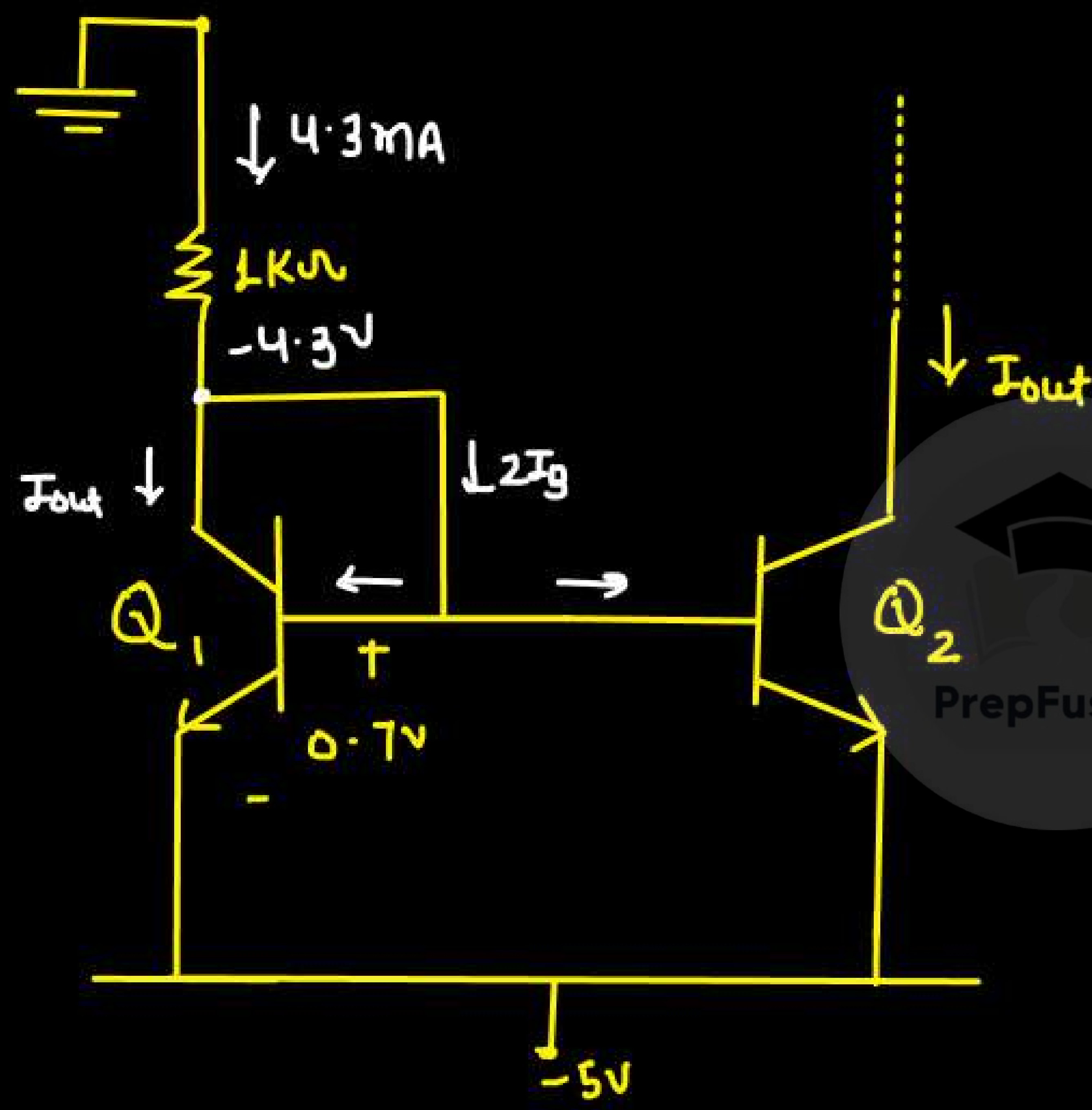
$$V_c = 10 - 2.6m\,(1k)$$

$$\boxed{V_c = 7.4\,V}$$



→ Active

Q.



Both Tr in active region.

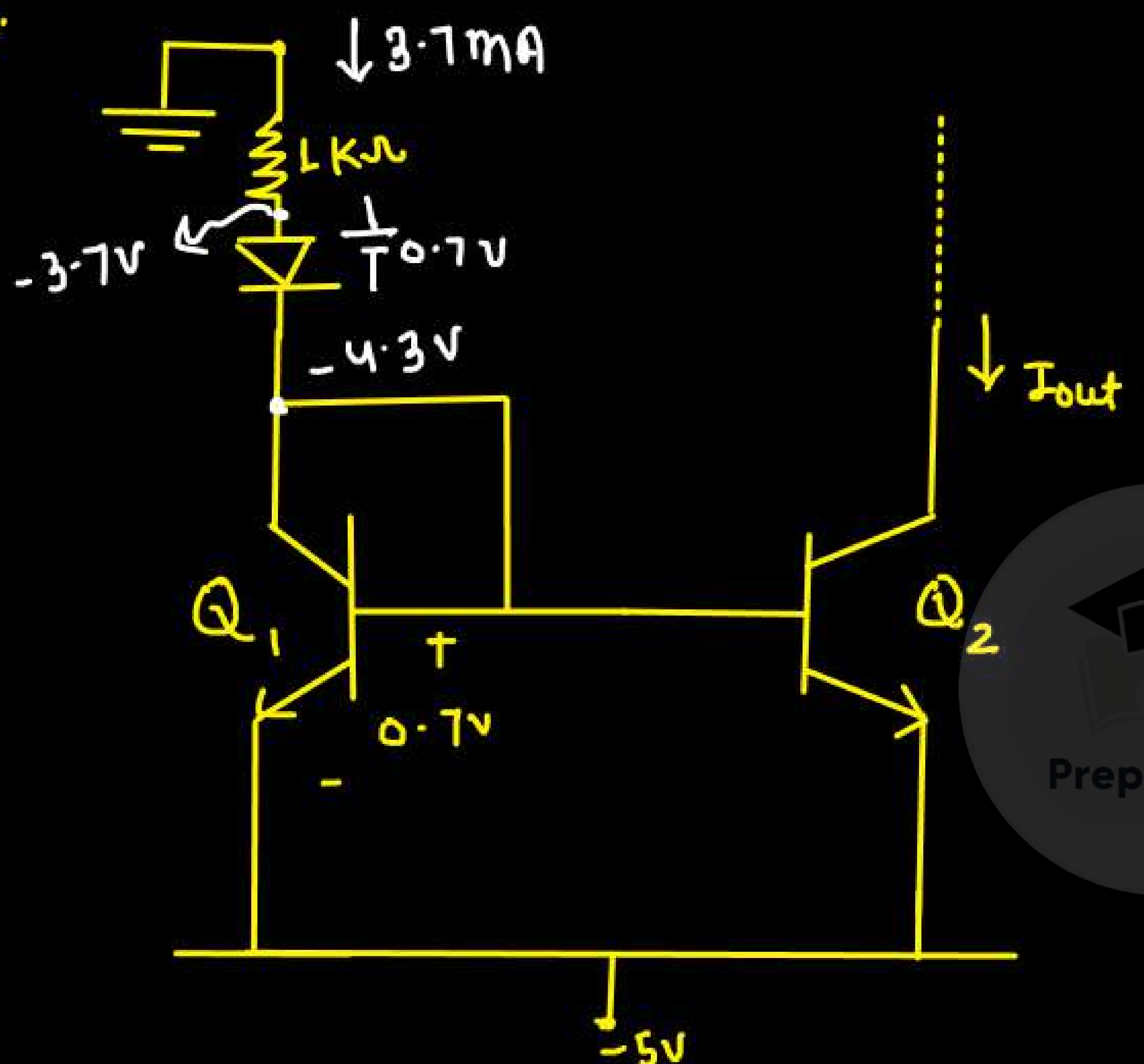
$\beta = 10$

Find I_{out}.

$$I_{out} = \left(\frac{10}{10+2}\right) 4.3\,mA$$

$$= 3.58\,mA$$

Q.



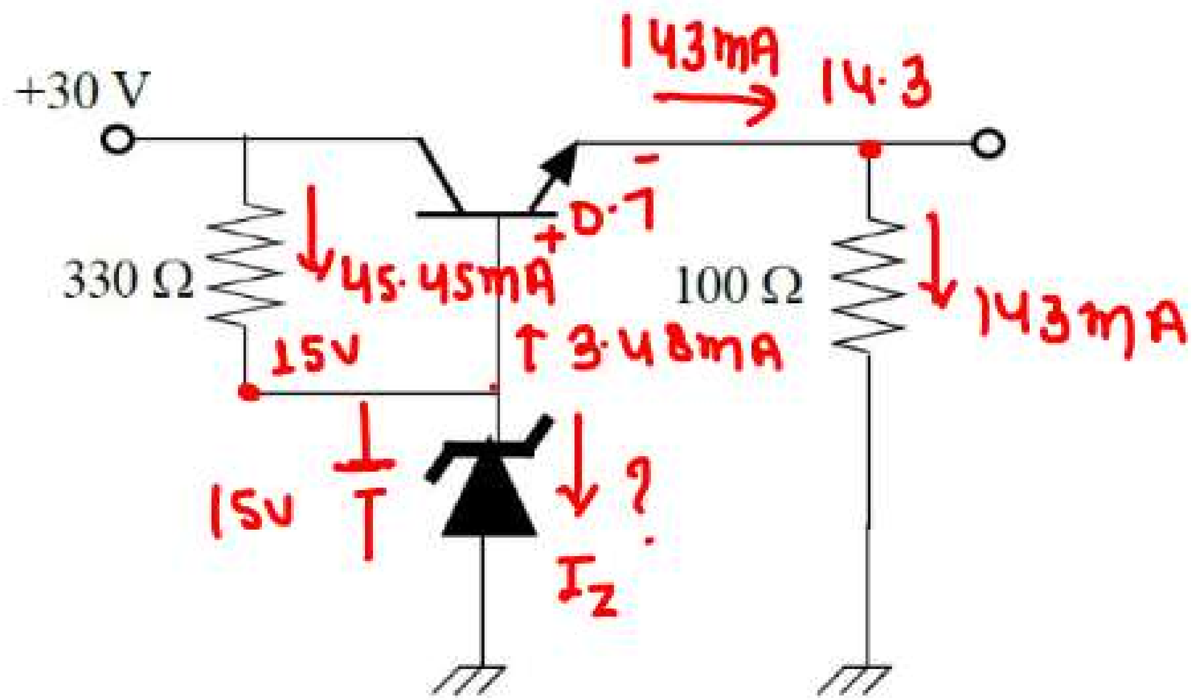
$\beta = \infty$

V_γ for diode = 0.7V

Find I_{out} ?

$\Rightarrow$ $\boxed{I_{out} = 3.7\,mA}$

For the circuit shown in the figure, the transistor has $\beta = 40$, $V_{BE} = 0.7$ V, and the voltage across the Zener diode is 15 V. The current (in mA) through the Zener diode is ____________.



FB
RB
BD

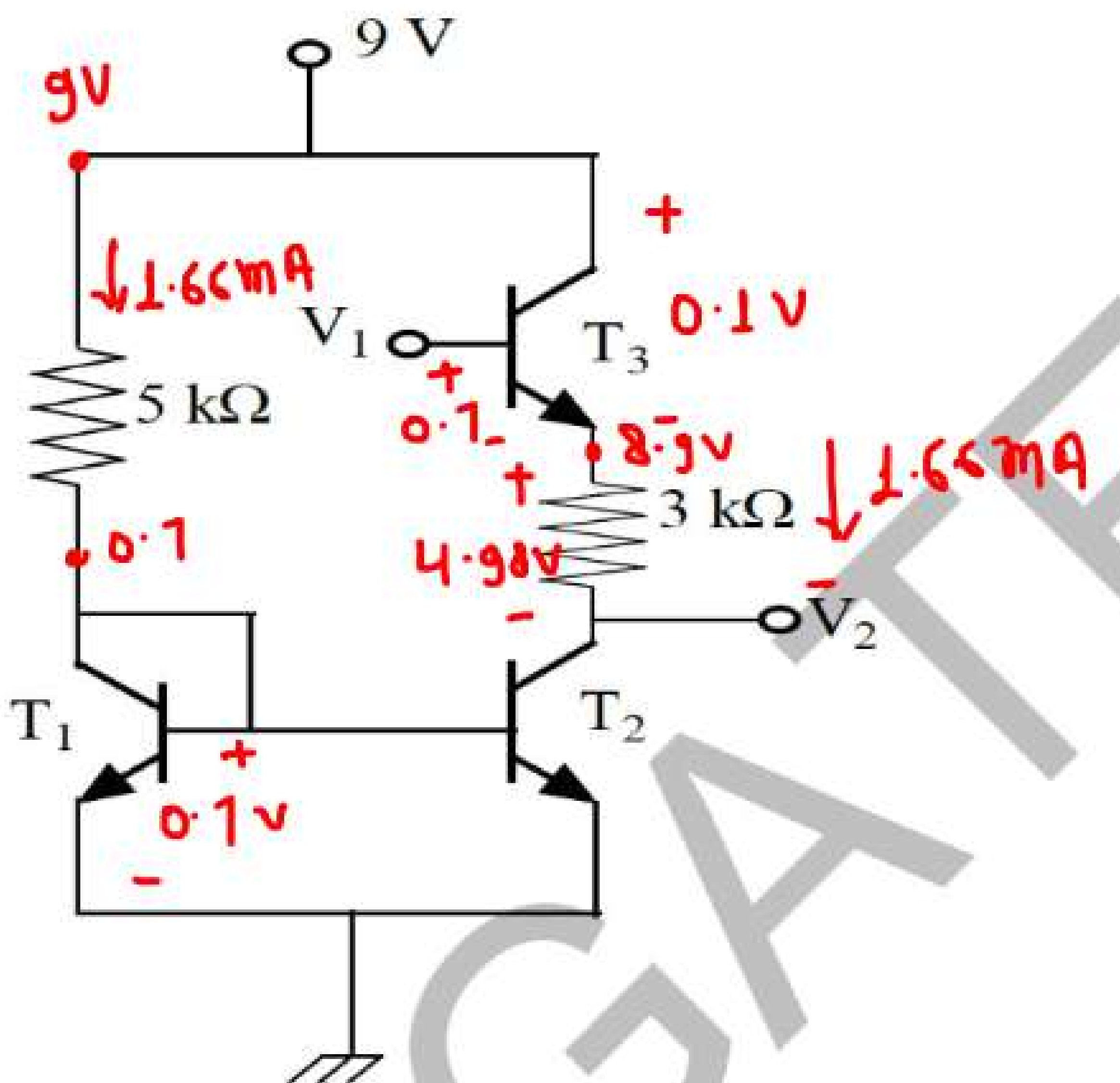
↳ zener probably will go into B.D. → assuming

$$I_E = 143\,mA$$

$$I_B = \frac{143}{41} = 3.48\,mA$$

$$\boxed{I_Z = 45.45 - 3.48 = 41.96\,mA}$$

In the figure, transistors T_1 and T_2 have identical characteristics. $V_{CE(sat)}$ of transistor T_3 is 0.1 V. The voltage V_1 is high enough to put T_3 in saturation. Voltage V_{BE} of transistors T_1, T_2 and T_3 is 0.7 V. The value of $(V_1 - V_2)$ in V is __________.

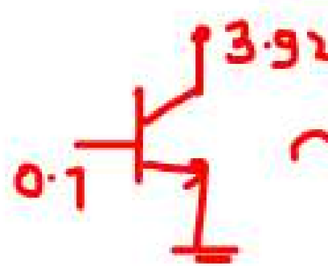


$\boxed{V_1 = 8.9 + 0.7 = 9.6V}$

Assuming →

T_2 in active ✓

$\boxed{V_2 = 3.92V}$

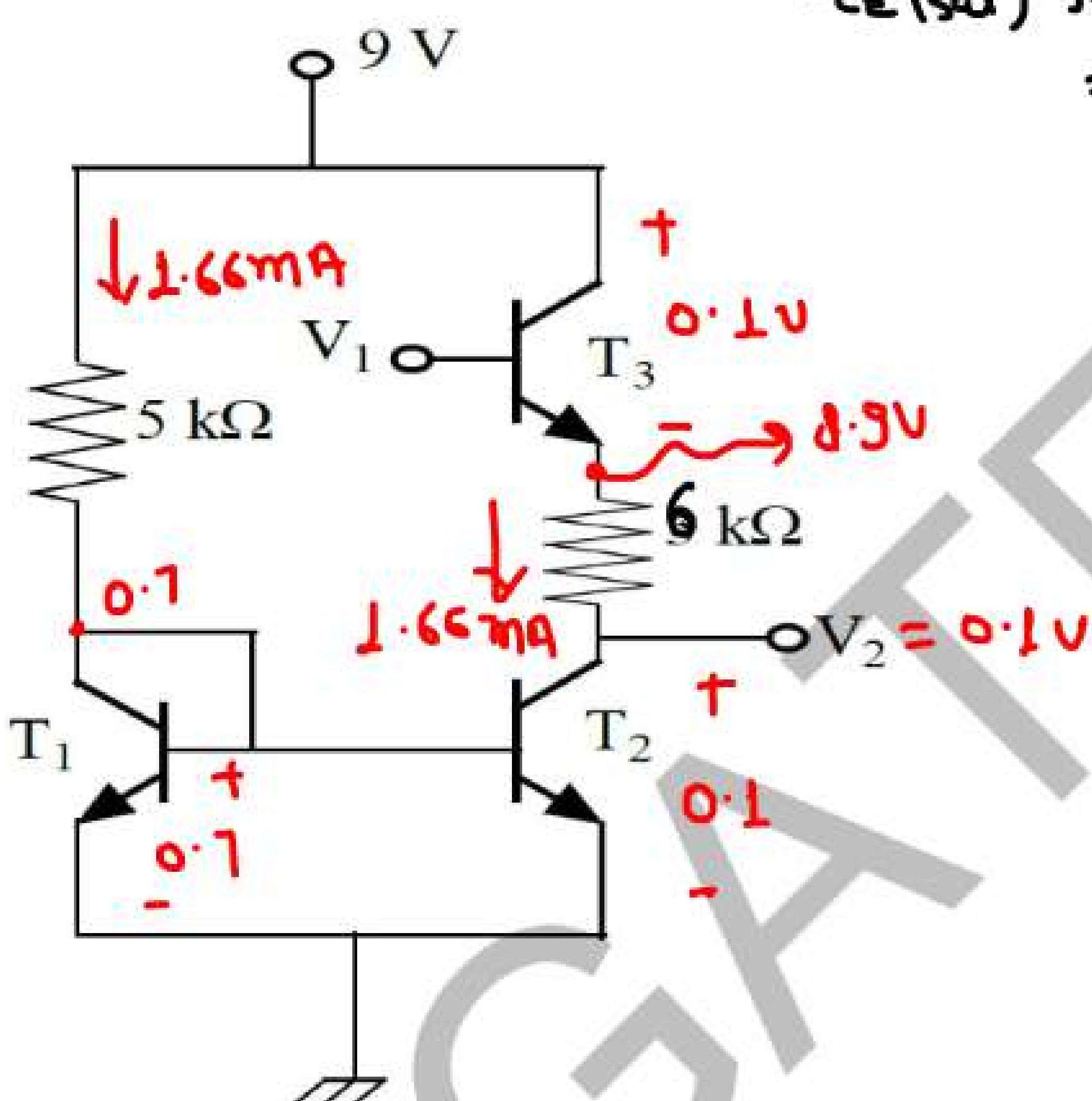


~> Active

$\boxed{V_1 - V_2 = 9.6 - 3.92 = 5.68V}$ ANS.

In the figure, transistors T_1 and T_2 have identical characteristics. $V_{CE(sat)}$ of transistor T_3 is 0.1 V. The voltage V_1 is high enough to put T_3 in saturation. Voltage V_{BE} of transistors T_1, T_2 and T_3 is 0.7 V. The value of $(V_1 - V_2)$ in V is ________.

$V_{CE(sat)}$ for T_2 (Given) $= 0.1V$



Assuming
$T_2 \rightarrow$ Active

$V_2 = 8.9 - 1.66(5)$
$= -1.06$

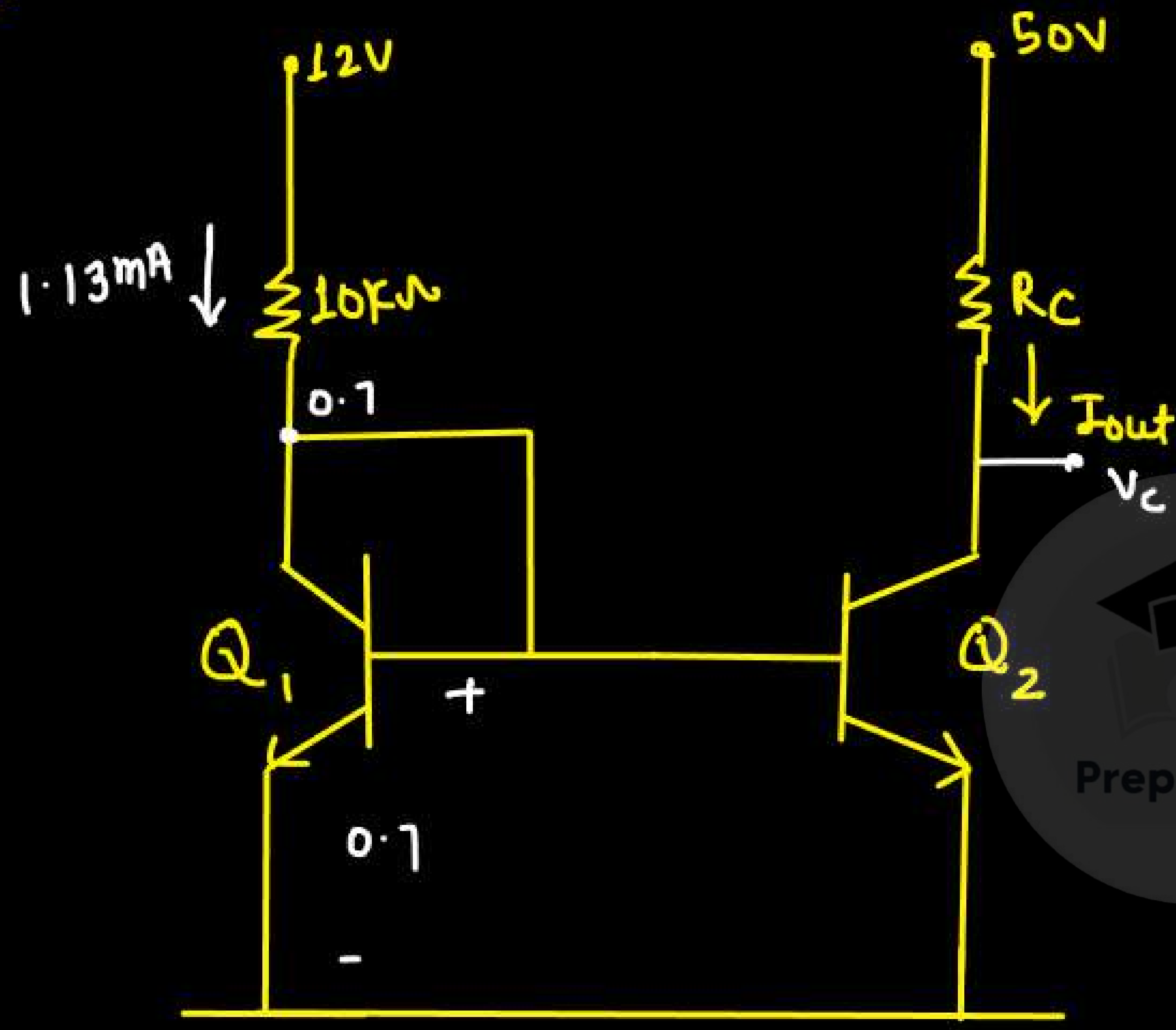
IB, −1.06, 0.7, IB → Sat

$V_2 = 0.1V$, $V_1 = 8.9 + 0.7 = 9.6V$

$$\boxed{\begin{aligned} V_1 - V_2 &= 9.6 - 0.1 \\ &= 9.5V \end{aligned}}$$

ANS =

Q.



$\beta = 100$

$V_{BE} = 0.7V$

$(V_{CE})_{sat} = 0.7V$

Find I_{out} for

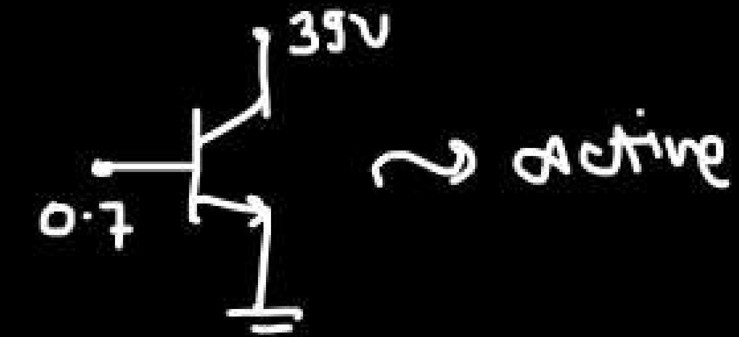
(a) $R_c = 10k\Omega$

(b) $R_c = 50k\Omega$

(a) $R_C = 10\,k\Omega$

$Q_2 \rightarrow$ Active (Assuming)

$$\boxed{I_{out} = \frac{100}{102} \times 1.13 = 1.1\ mA}$$ ANS.

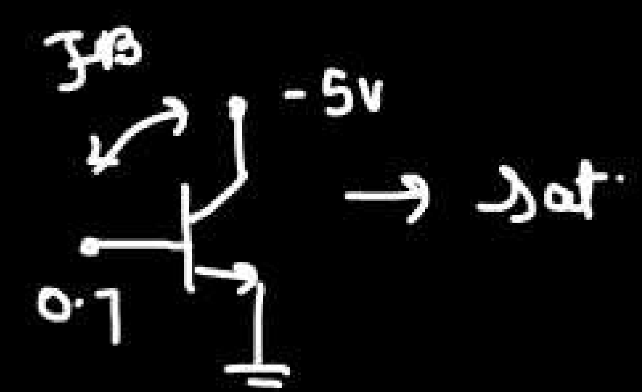


$$V_C = 50 - 1.1m \times 10K = 39V$$

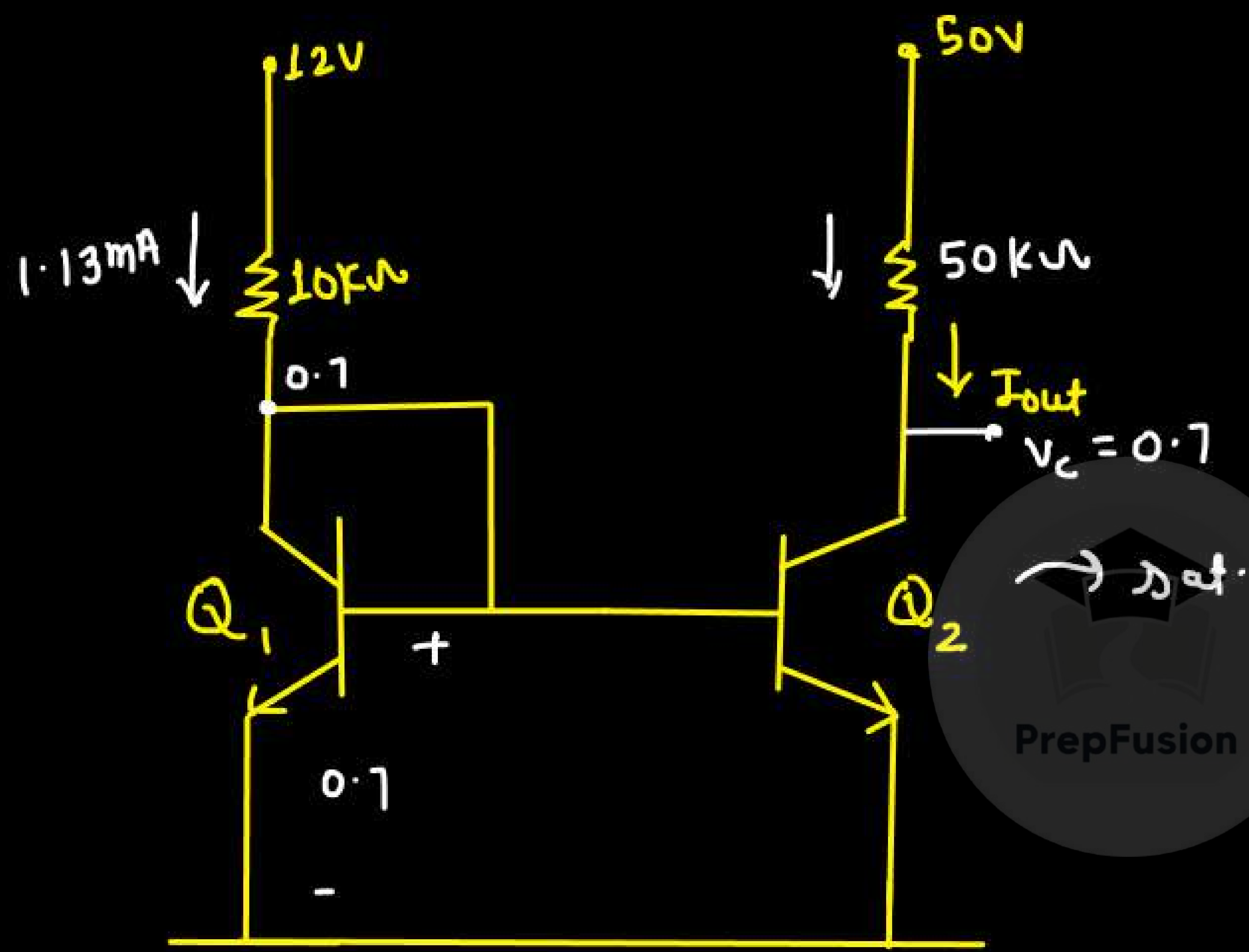
(b) $R_C = 50\,k\Omega$

$Q_2 \rightarrow$ active (Assuming)

$$\boxed{I_{out} = 1.1\ mA} \times$$



$$V_C = 50 - 1.1 \times 50 = -5V$$



$(V_{CE})_{sat} = 0.7\,V$

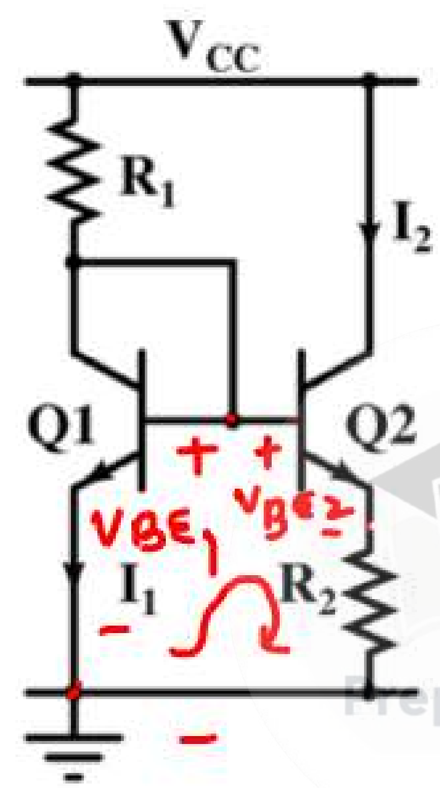
$$I_{out} = \frac{49.3}{50k}$$

$$\boxed{I_{out} = 0.98\,mA}$$

ANS

Standard

Resistor R_1 in the circuit below has been adjusted so that $I_1 = 1$ mA. The bipolar transistors Q1 and Q2 are perfectly matched and have very high current gain, so their base currents are negligible. The supply voltage V_{cc} is 6 V. The thermal voltage kT/q is 26 mV.



$\beta = \infty$

$\boxed{I_C = I_E}$

The value of R_2 (in Ω) for which I_2=100 μA is ________

$$I_1 = I_S \exp\left(\frac{V_{BE_1}}{V_T}\right) \longrightarrow (1)$$

$$I_2 = I_S \exp\left(\frac{V_{BE_2}}{V_T}\right) \longrightarrow (2)$$

$$\frac{0 + V_{BE_1} - V_{BE_2}}{R_2} = I_2$$

$$\frac{V_{BE_1} - V_{BE_2}}{I_2} = R_2 \quad \text{—} \quad (3)$$

(1) ÷ (2)

$$\frac{I_1}{I_2} = \frac{e^{(V_{BE_1}/V_T)}}{e^{(V_{BE_2}/V_T)}}$$

$$10 = \exp\left(\frac{V_{BE_1} - V_{BE_2}}{V_T}\right)$$

$$V_{BE_1} - V_{BE_2} = 26\,mV \times \ln(10)$$

$$V_{BE_1} - V_{BE_2} = 59.8\,mV$$

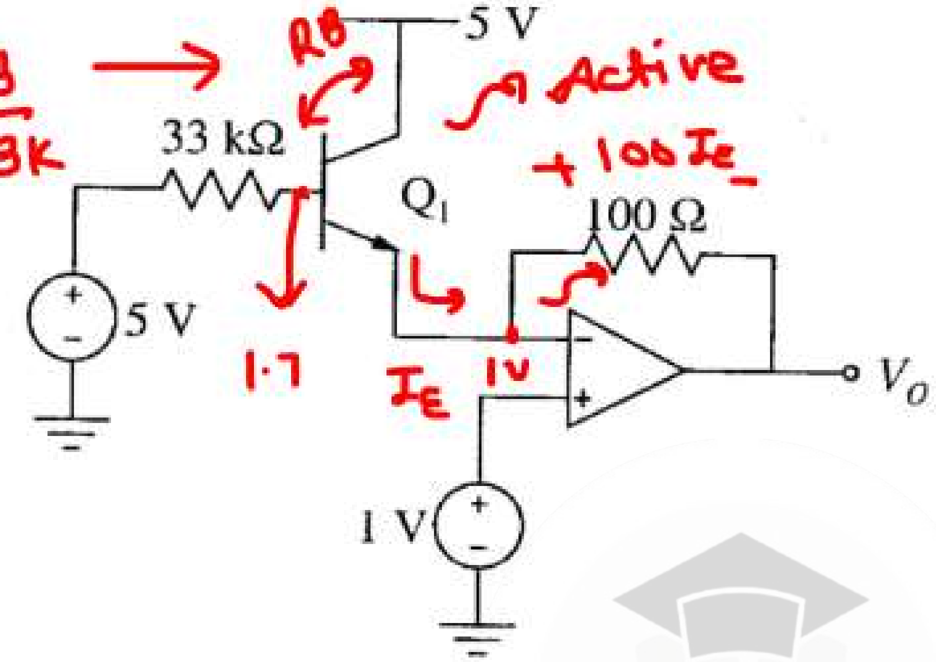
From eq^n (3)

$$R_2 = \frac{59.867\,mV}{0.1\,mA}$$

$$\boxed{R_2 = 598.67\,\Omega}$$

Q.36 Assuming base-emitter voltage of 0.7 V and $\beta = 99$ of transistor Q_1, the output voltage V_O in the ideal opamp circuit shown below is

$0.1mA = \frac{3.3}{33K}$



$I_E = (\beta+1) I_B$

$= 100 \times 0.1$

$= 10mA$

$V_O = 1 - 100 I_E$

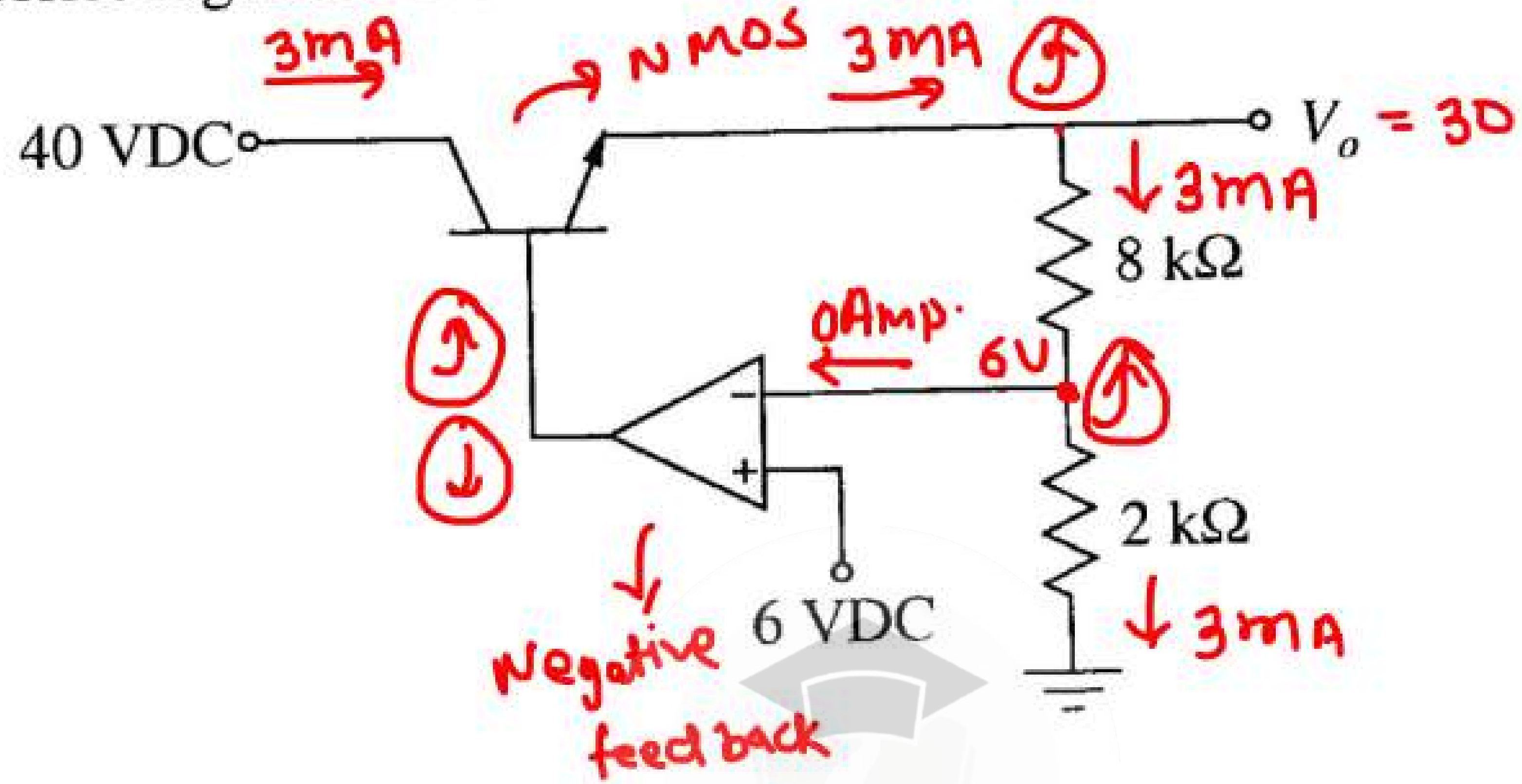
$= 1 - 100 \times 10m$

$= 0V$

(A) –1 V (B) –1/3.3 V (C) 0 V (D) 2 V

(a) The value of V_o of the series regulator shown below is

(b) Find power dissipated in BJT. ($\beta = \infty$)



(A) 24 V (B) 28 V (C) 30 V (D) 32 V

$6V = \frac{2V_o}{10}$

$\boxed{V_o = 30V}$ Ans.

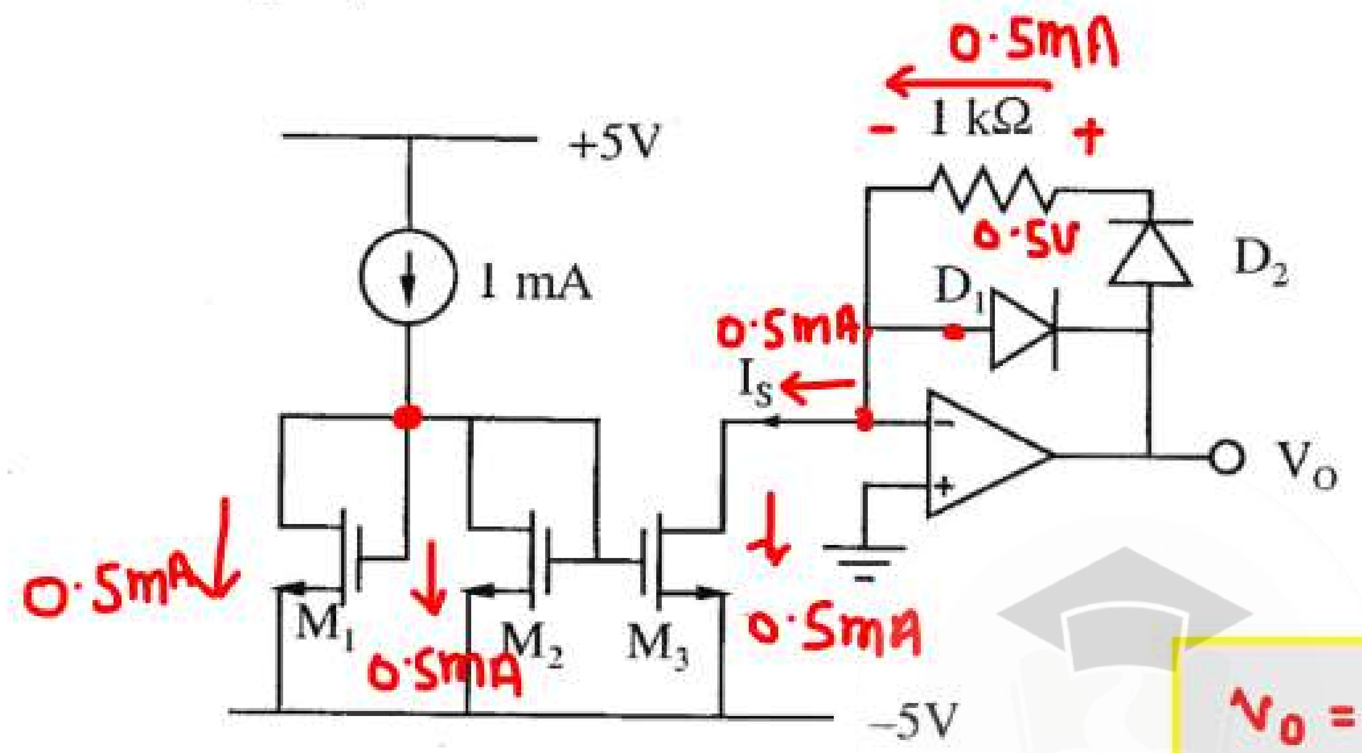
(b) power dissipated in BJT = $\boxed{V_{CE} \times I_C}$

$V_{CE} = 40 - 30 = 10V$

$I_c = 3mA$

$\boxed{P_d = 10 \times 3m = 30mW}$ Ans.

M1, M2 and M3 in the circuit shown below are matched N-channel enhancement mode MOSFETs operating in saturation mode, forward voltage drop of each diode is 0.7 V, reverse leakage current of each diode is negligible and the opamp is ideal.



$D_1, D_2 \to$ OFF ✗

D_1 ON, $D_2 \to$ OFF ✗

$D_1, D_2 \to$ ON ✗

D_2 ON, D_1 OFF

$\boxed{V_0 = 0 + 0.5 + 0.7 = 1.2V}$

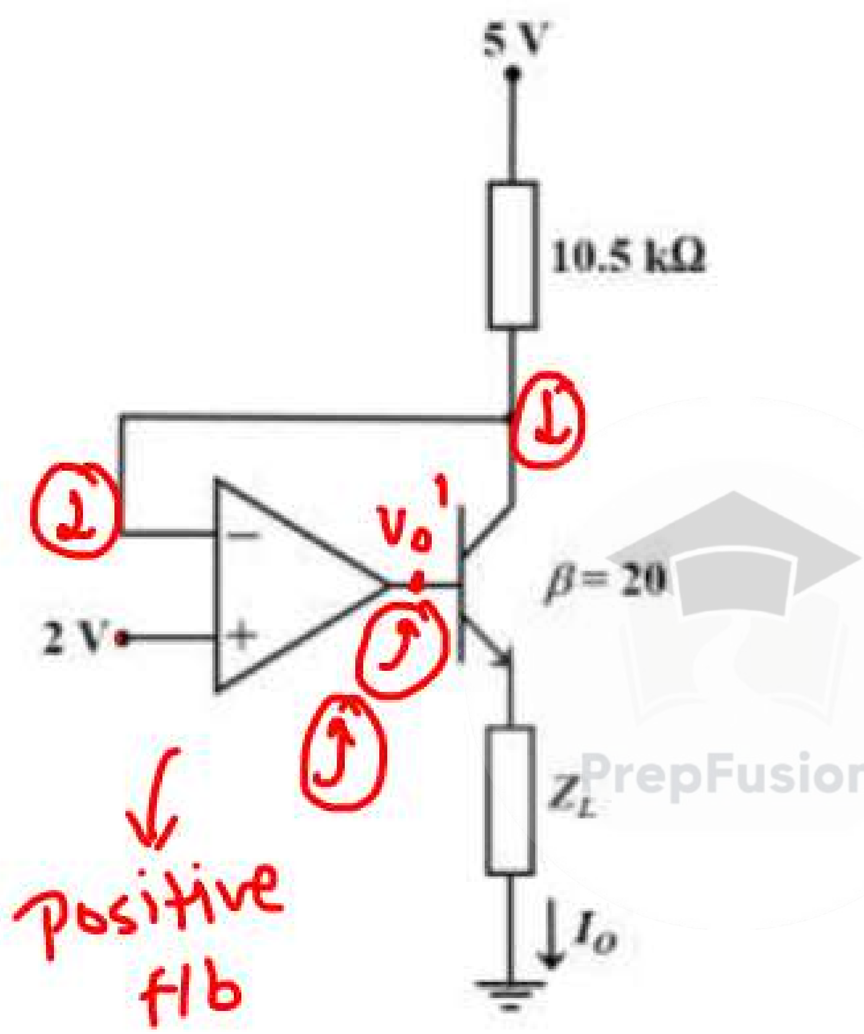
Q.54 The current I_S in the circuit is

(A) –1 mA (B) 0.5 mA (C) 1 mA (D) 2 mA

Q.55 For the computed value of current I_S, the output voltage V_O is

(A) 1.2 V (B) 0.7 V (C) 0.2 V (D) –0.7 V

In the given circuit, assume that the opamp is ideal and the transistor has a β of 20. The current I_o (in µA) flowing through the load Z_L is ____.

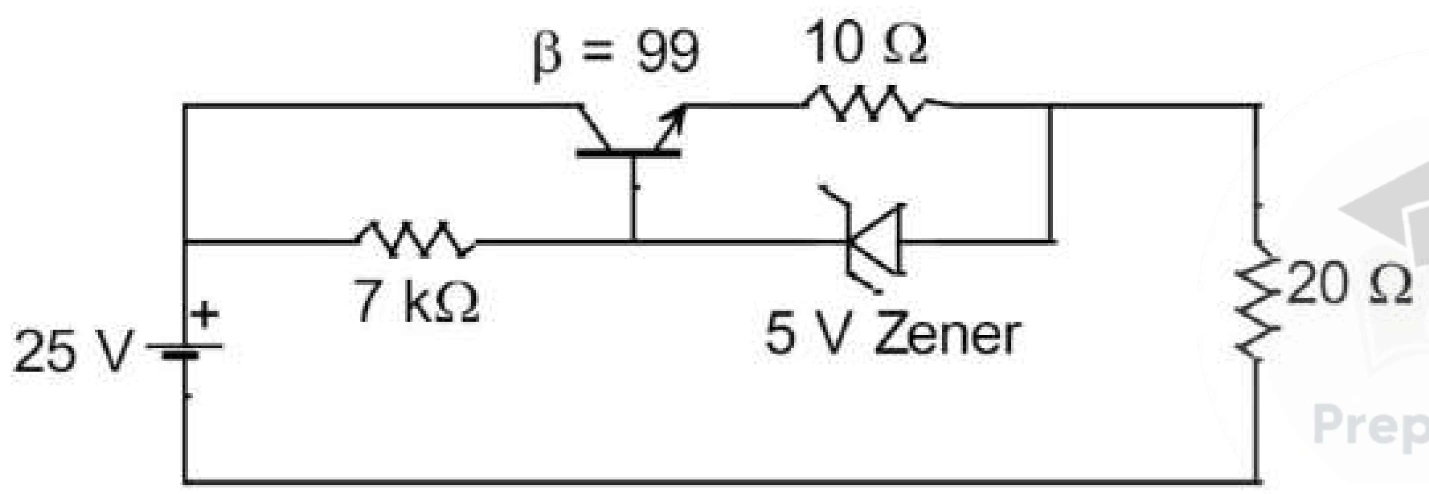


$V_o' = -V_{sat}$ or $+V_{sat}$

if $V_o' = +V_{sat} \Rightarrow$ BJT ON $\Rightarrow V_- = ? \Rightarrow$ can't determine $\Rightarrow$ No conclusion

✓ if $V_o' = -V_{sat} \Rightarrow$ BJT OFF $\Rightarrow V_- = 5V \Rightarrow V_o' = -V_{sat} \Rightarrow$ $\boxed{I_o = 0 \text{ Amp.}}$

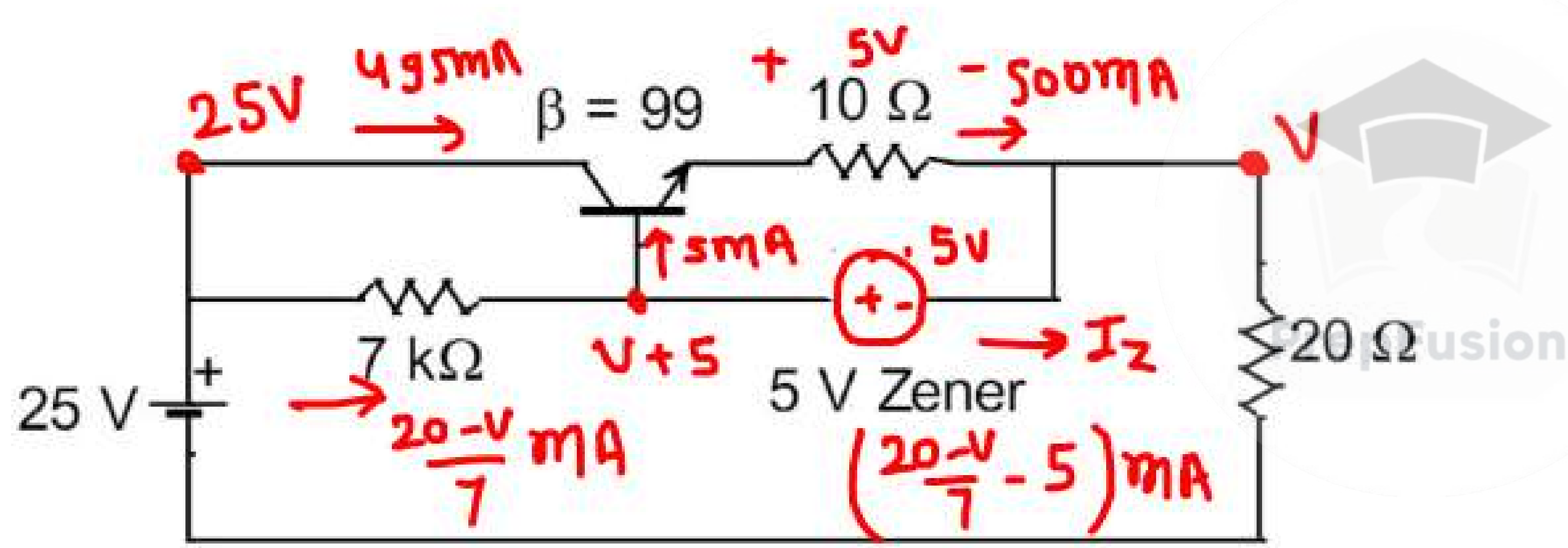
The Zener diode in circuit has a breakdown voltage of 5 V. The current gain β of the transistor in the active region in 99. Ignore base-emitter voltage drop V_{BE}. The current through the 20 Ω resistance in milliamperes is ________(Round off to 2 decimal places).



$\boxed{V_{BE} = 0\,V}$

Let zener goes into B.D.

The Zener diode in circuit has a breakdown voltage of 5 V. The current gain β of the transistor in the active region in 99. Ignore base-emitter voltage drop V_{BE}. The current through the 20 Ω resistance in milliamperes is ________(Round off to 2 decimal places).



$I_E = 0.5$ Amp

$I_B = \frac{0.5}{100} = 5$ mA

$$\frac{20}{7} - 5 - \frac{V}{7} + 500 = \frac{V}{20} \times 1000$$

$$497.8 = 50.14\,V$$

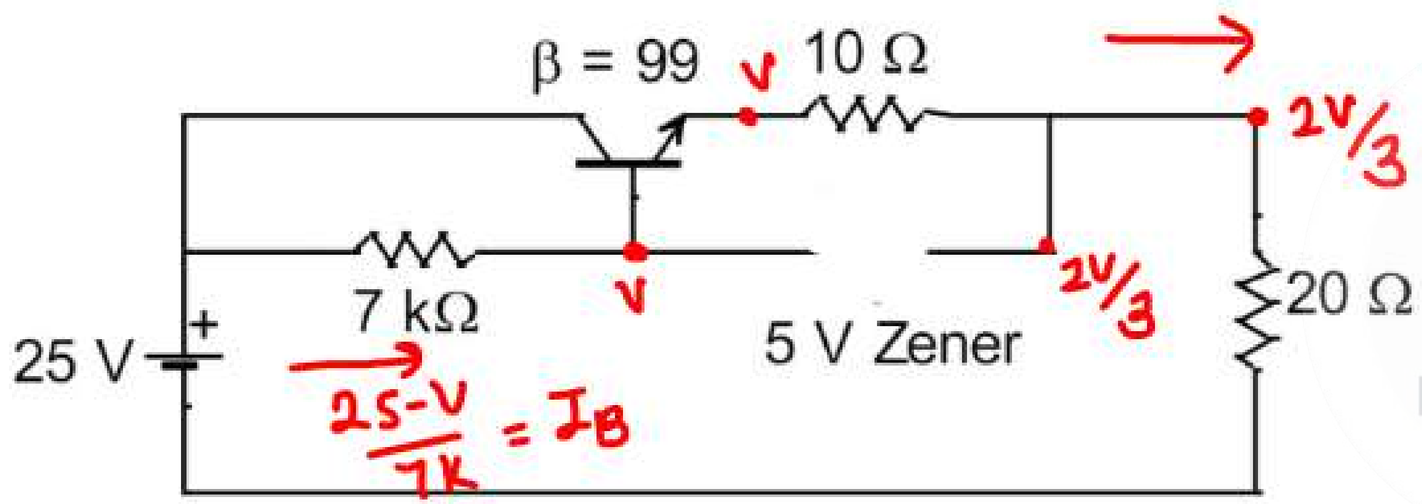
$$\Rightarrow \boxed{V = 9.92V}$$

$I_Z = -3.56$ mA

$\Downarrow$

Zener NOT in B.D.

The Zener diode in circuit has a breakdown voltage of 5 V. The current gain β of the transistor in the active region in 99. Ignore base-emitter voltage drop V_{BE}. The current through the 20 Ω resistance in milliamperes is ________(Round off to 2 decimal places).



$$\frac{25-V}{7K} = I_B$$

$$I_E = \frac{2V/3}{201} = \frac{V}{30}$$

$$I = \frac{2V/3}{20} = \frac{15}{60}$$

$$\boxed{I = 250\,mA}$$

$$\frac{25-V}{7000} \times 100 = \frac{V}{30}$$

$$75 - 3V = 7V \Rightarrow \boxed{V = 7.5\,V}$$

$V_Z = 5V$

7.5 — 5V

$+\,2.5\,-$

↳ R.B.

Q.

In the voltage reference circuit shown in the figure, the op-amp is ideal and the transistors Q_1, $Q_2, \ldots, Q_{32}$ are identical in all respects and have infinitely large values of common-emitter current gain (β). The collector current (I_c) of the transistors is related to their base-emitter voltage (V_{BE}) by the relation $I_C = I_S \exp(V_{BE}/V_T)$, where I_S is the saturation current. Assume that the voltage V_p shown in the figure is 0.7 V and the thermal voltage $V_T = 26$ mV.

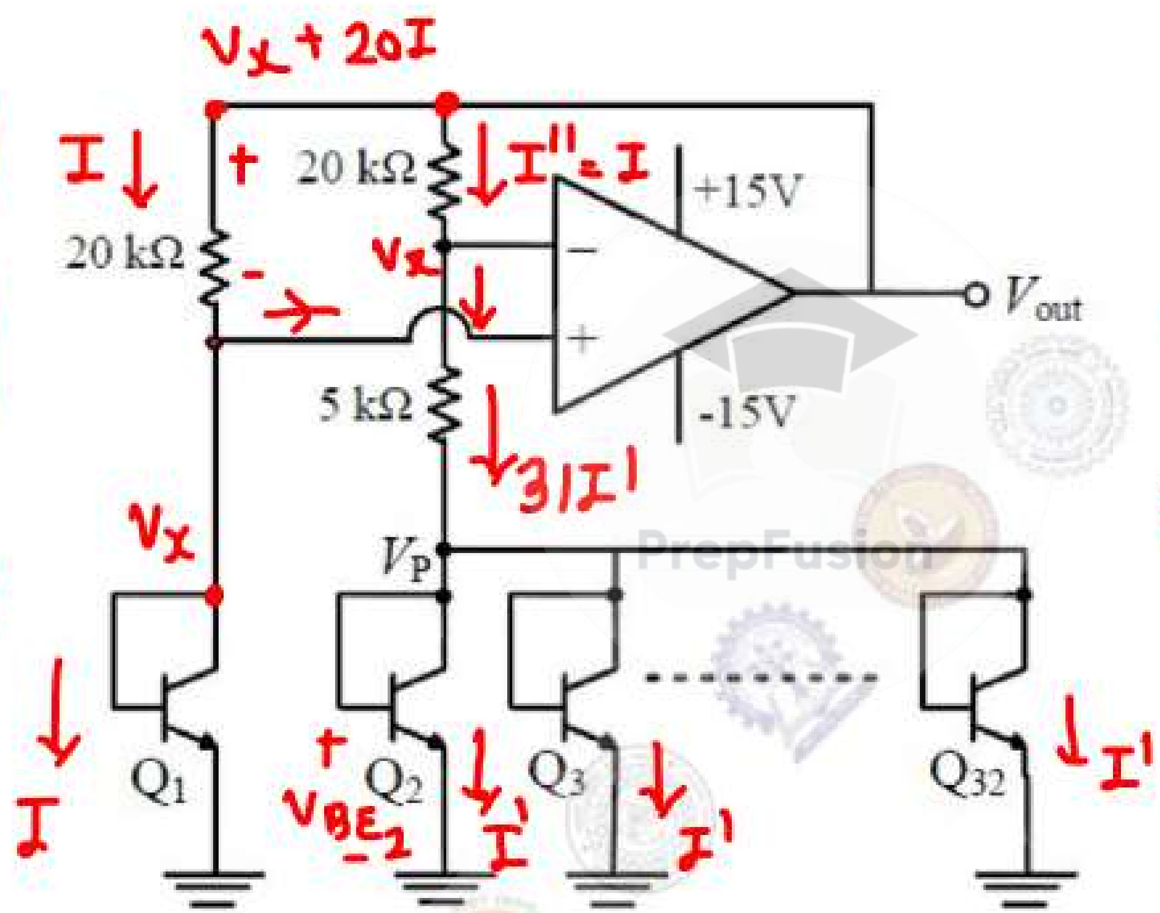
→ mA

$I = I_s \exp\left(\frac{V_x}{V_T}\right)$

$I' = I_s \exp\left(\frac{V_P}{V_T}\right)$

$I'' = \frac{V_x + 20I - V_x}{20}$

$= I$



matched

$V_{BE_1} = V_x$

$V_{BE_2} = V_{BE_3} = \cdots V_{BE_{32}} = V_p = 0.7$

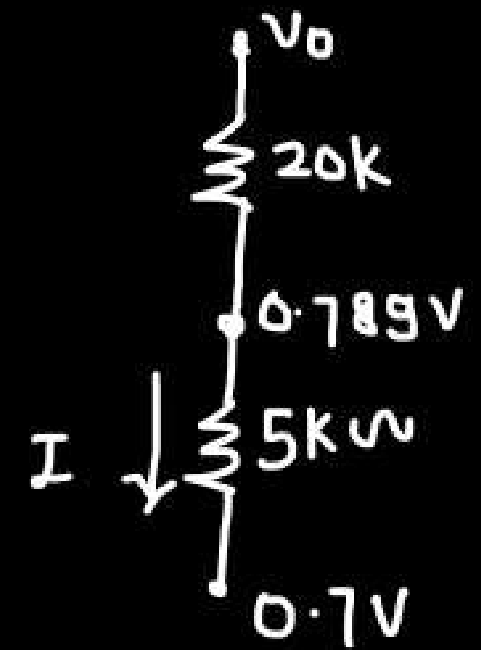
The output voltage V_{out} (in volts) is ________

$$I = 31 I'$$

$$I_s \exp\left(\frac{V_x}{V_T}\right) = 31 I_s \exp\left(\frac{0.7}{V_T}\right)$$

$$\exp\left(\frac{V_x - 0.7}{V_T}\right) = 31$$

$$\boxed{V_x = 0.789\,V}$$

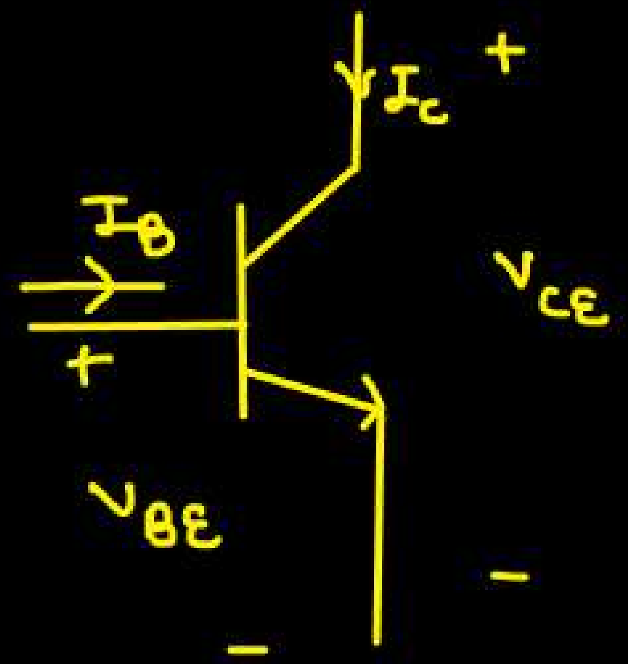


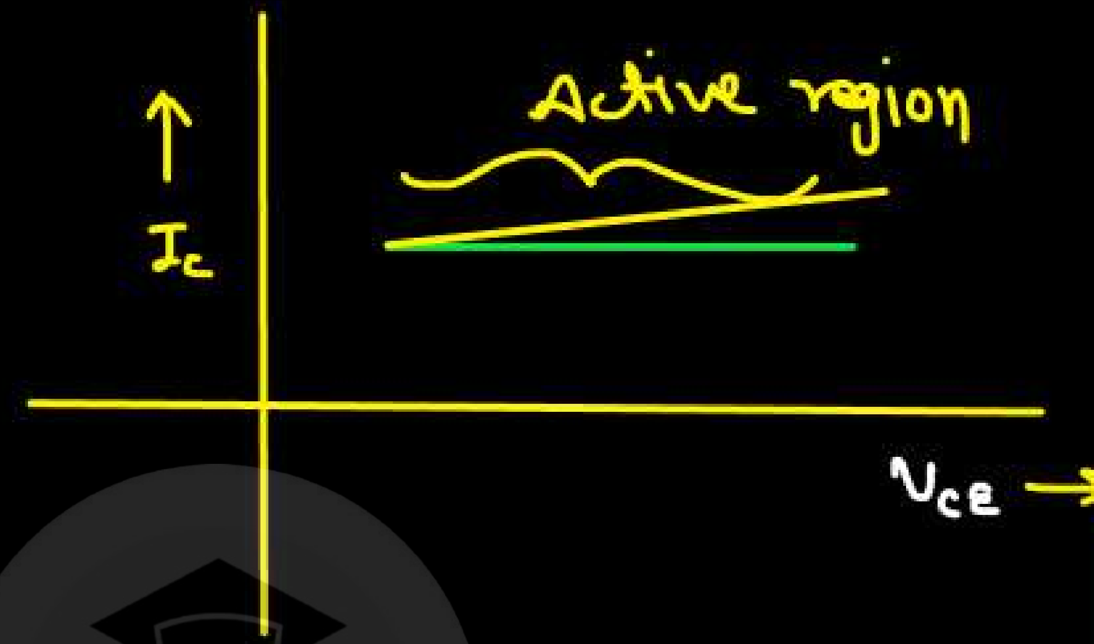
$$V_0 = 0.789 + 20K \times I$$

$$= 0.789 + 20\left(\frac{0.789 - 0.7}{5}\right)$$

$$\boxed{V_0 = 1.15\,V}$$

⇒ Small signal Model of BJT Amplifier:-

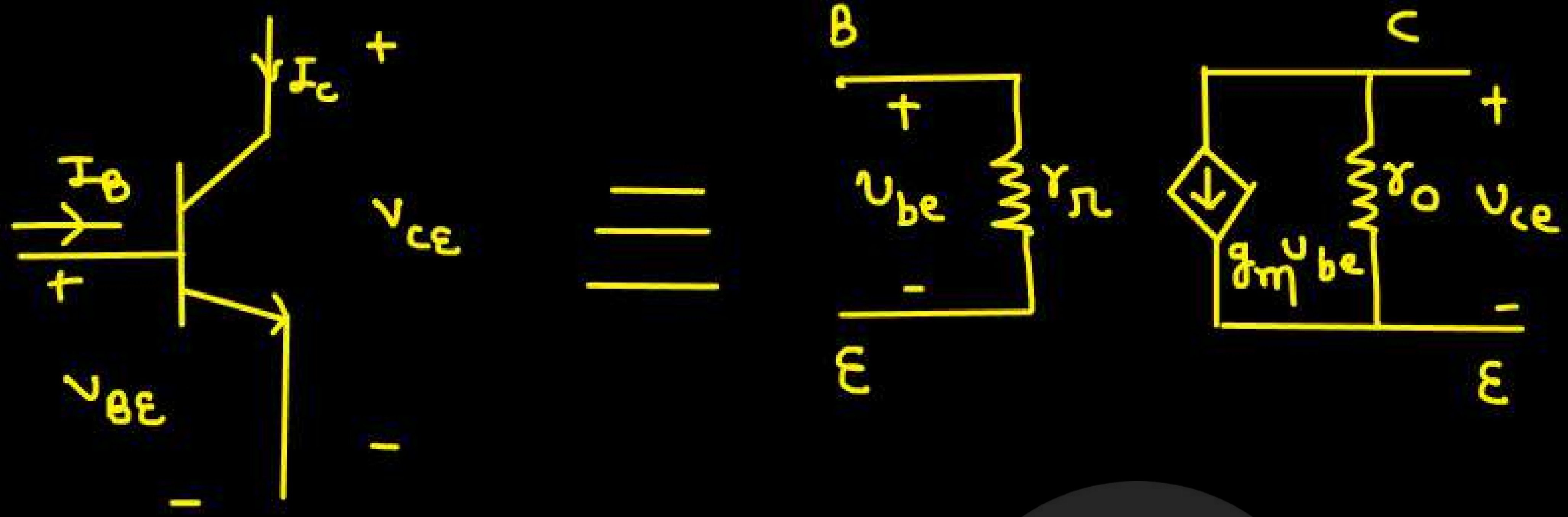




$$\boxed{I_C \neq f(V_{CE})}$$

$$I_C = I_S \exp\left(\frac{V_{BE}}{\eta V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right) \quad \text{—} \; (1)$$

$$I_B = \frac{I_C}{\beta} \quad \text{—} \; (2)$$



↳ $$\boxed{g_m = \frac{\partial I_C}{\partial V_{BE}}}$$

$$I_C = I_S \exp\left(\frac{V_{BE}}{\eta V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$\frac{\partial I_C}{\partial V_{BE}} = \frac{I_S}{\eta V_T} \exp\left(\frac{V_{BE}}{\eta V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$\boxed{g_m = \frac{I_C}{\eta V_T}}$$

if $\eta = 1$

** $$\boxed{g_m = \frac{I_C}{V_T}}$$

↳ $$r_o = \frac{\partial V_{CE}}{\partial I_C} = \frac{1}{\left(\partial I_C / \partial V_{CE}\right)}$$

$$I_C = I_S \exp\left(\frac{V_{BE}}{nV_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$\frac{\partial I_C}{\partial V_{CE}} = I_S \exp\left(\frac{V_{BE}}{nV_T}\right) \times \frac{1}{V_A}$$

$$\frac{1}{r_o} = \frac{I_C(\text{ideal})}{V_A}$$

** $$\boxed{r_o = \frac{V_A}{I_C}}$$

$$\boxed{\text{if } V_A \to \infty\ ,\ r_o \to \infty}$$

$$r_\pi = \frac{\partial V_{BE}}{\partial I_B} = \frac{1}{\partial I_B / \partial V_{BE}}$$

$$I_B = \frac{I_C}{\beta}$$

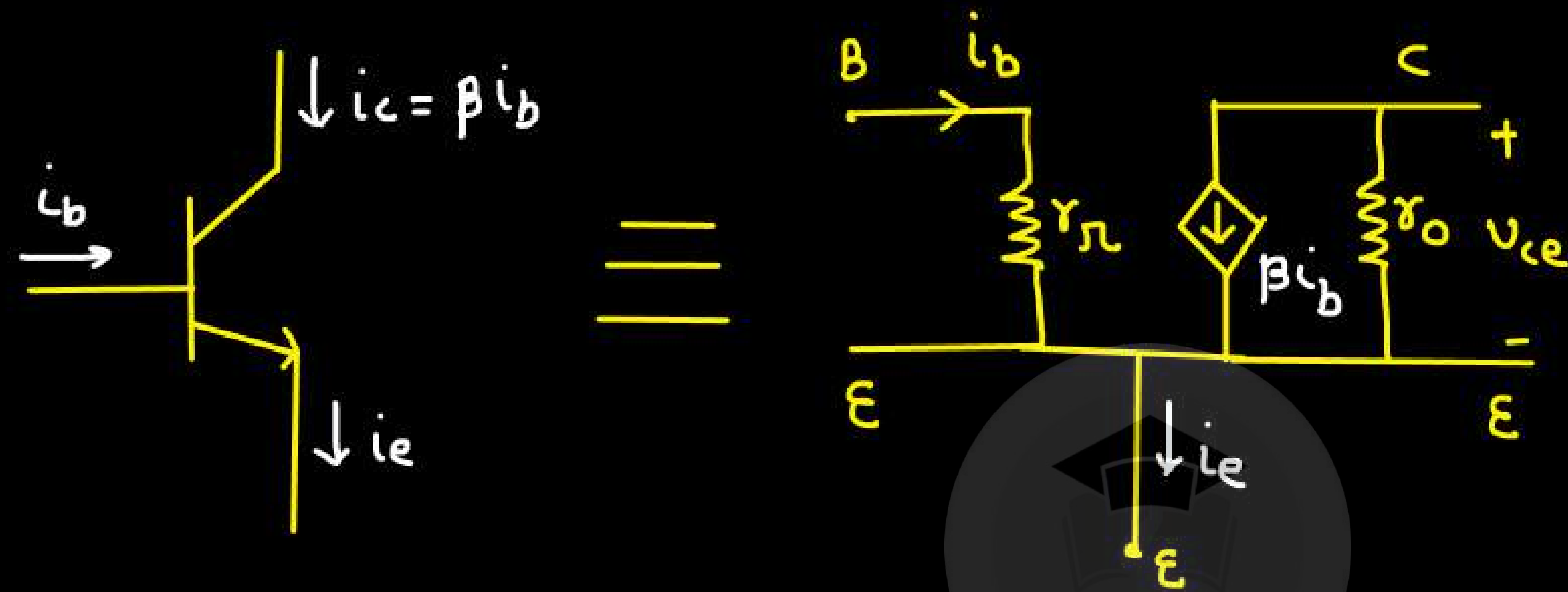
$$\frac{\partial I_B}{\partial V_{BE}} = \frac{1}{\beta} \frac{\partial I_C}{\partial V_{BE}}$$

$$\frac{1}{r_\pi} = \frac{g_m}{\beta}$$

** $$\boxed{r_\pi = \beta / g_m}$$

if $\beta \to \infty$, $r_\pi \to \infty$

N.B. -

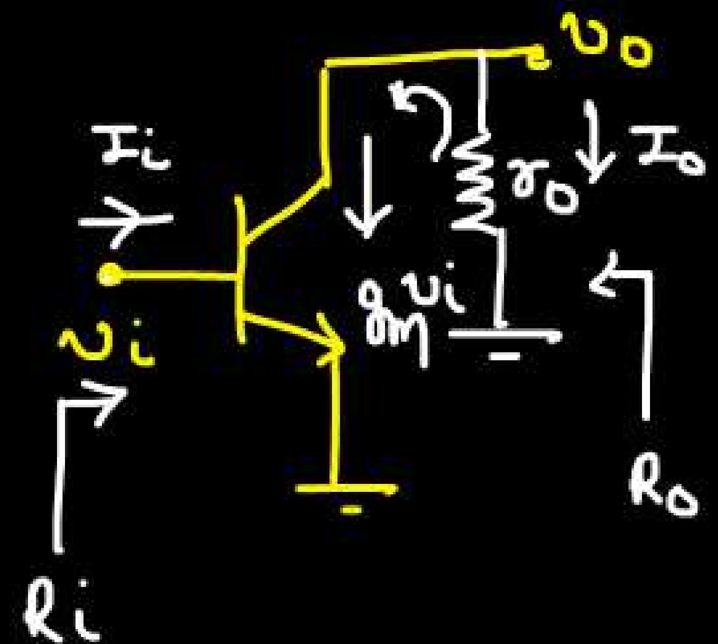


$$\boxed{r_\pi = \beta / g_m}$$

$$\boxed{r_o = \frac{V_A}{I_c}}$$

$$\boxed{g_m = \frac{I_c}{\eta V_T}}$$

Q. Find voltage gain. ($V_A \neq \infty$)

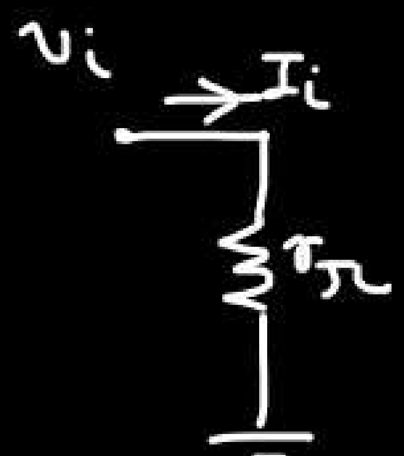


$$v_o = -g_m r_o v_i$$

$$\boxed{\frac{v_o}{v_i} = -g_m r_o}$$

$$\boxed{R_i = r_\pi}$$

$$\boxed{R_o = r_o}$$

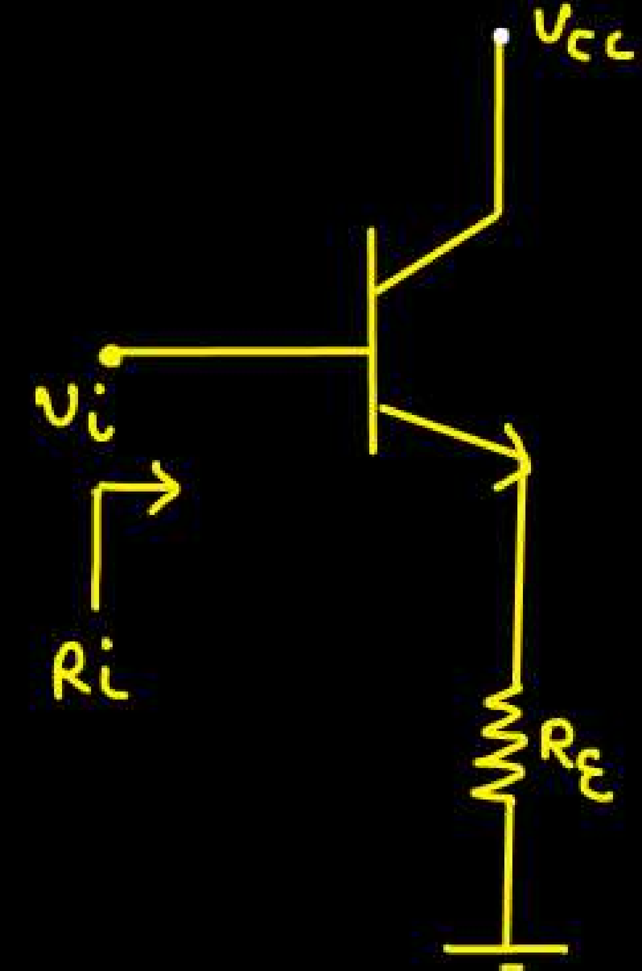


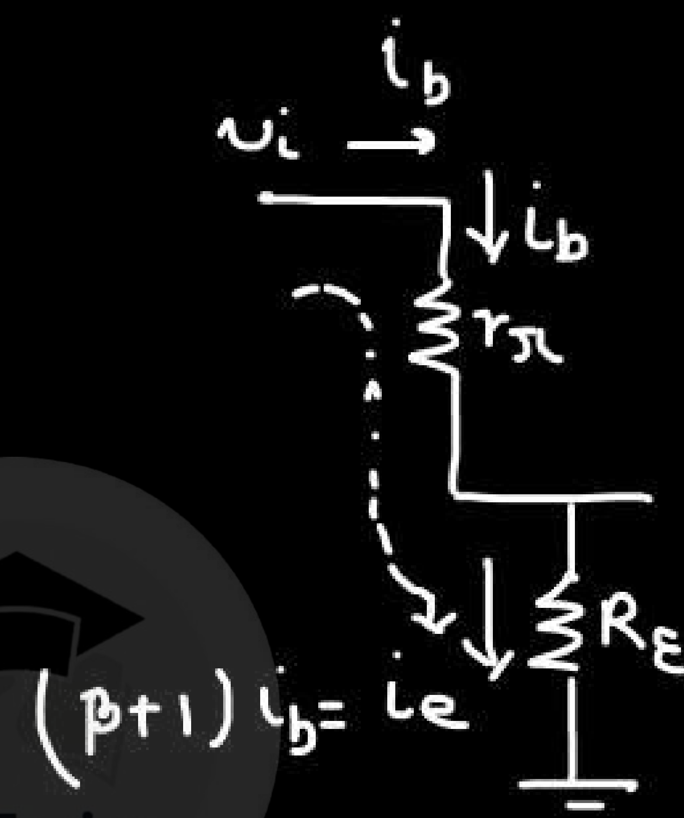
$$\Rightarrow I_i = \frac{v_i}{r_\pi}$$

$$I_o = \frac{v_o}{r_o}$$

$$\boxed{\frac{I_o}{I_i} = \frac{v_o}{r_o} \times \frac{r_\pi}{v_i} = -g_m r_o \times \frac{r_\pi}{r_o} = -g_m r_\pi = -\beta}$$

Q. Find Small Signal R_i. $(V_A = \infty)$





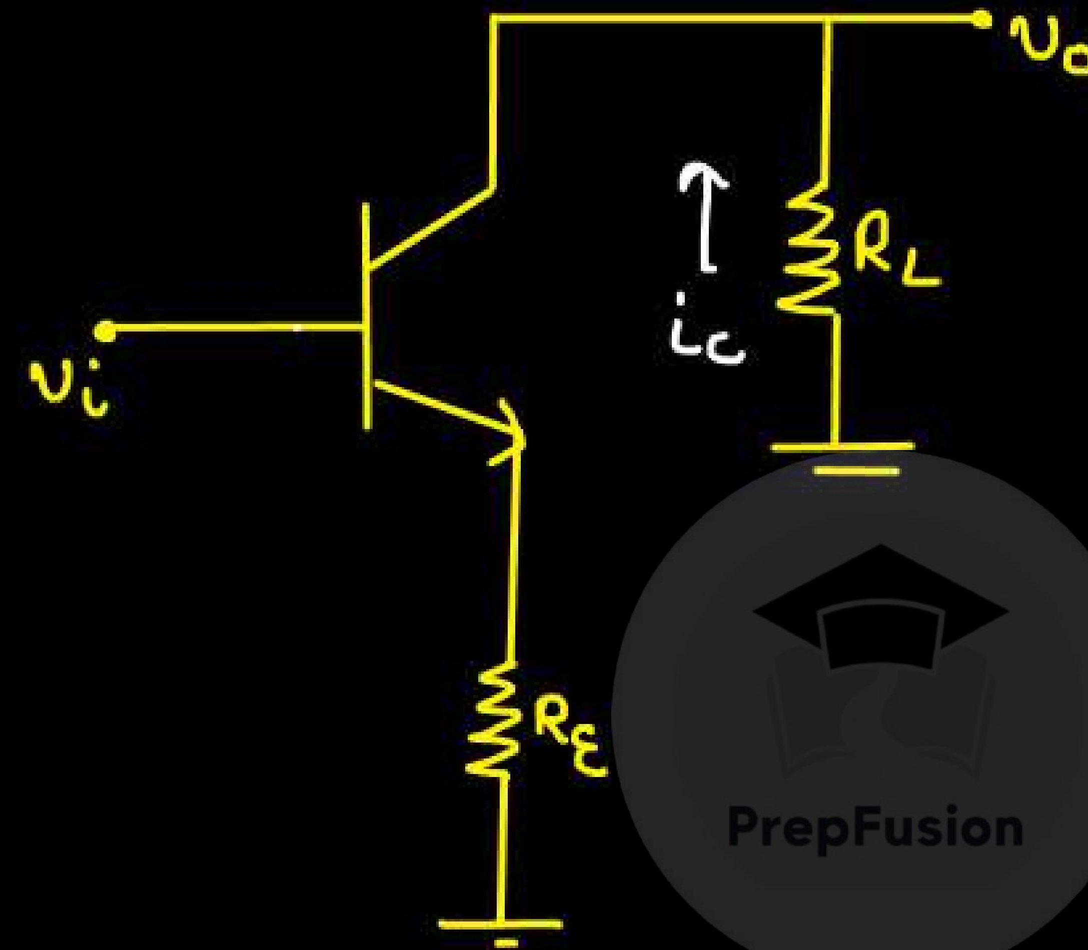
$$\boxed{R_i = \frac{v_i}{i_b}}$$

$$v_i = i_b r_\pi + (\beta+1)\, i_b R_E$$

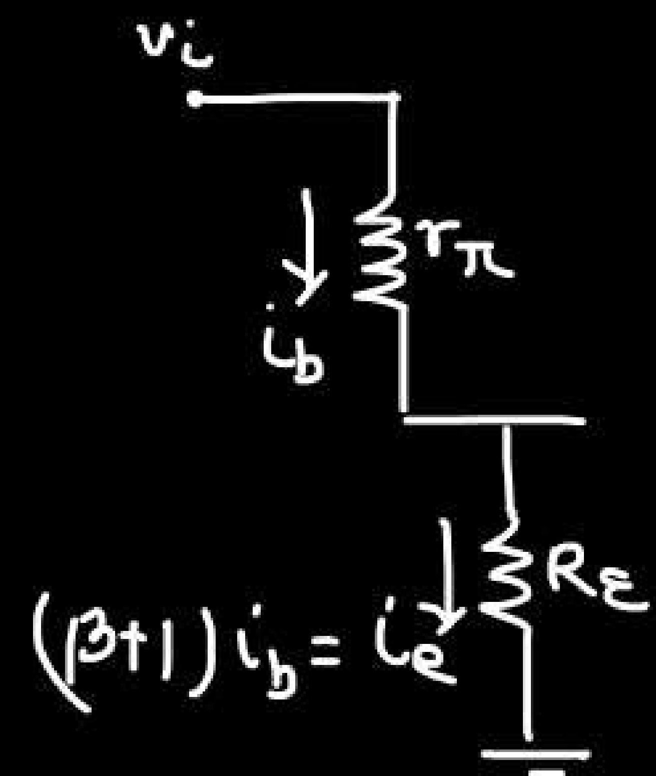
$$\boxed{\frac{v_i}{i_b} = R_i = r_\pi + (\beta+1) R_E}$$

ANS.

Q. Find small signal voltage gain. $(V_A = \infty)$



$$\boxed{v_o = -i_c R_L}$$



$$i_c = \beta i_b$$

$$i_c = \frac{\beta v_i}{r_\pi + (\beta+1) R_E}$$

$$v_o = \frac{-\beta R_L \quad v_i}{r_\pi + (\beta+1) R_E}$$

$$v_i = i_b r_\pi + (\beta+1) R_E\, i_b$$

$$i_b = \frac{v_i}{r_\pi + (\beta+1) R_E}$$

$$\boxed{\frac{v_o}{v_i} = \frac{-\beta R_L}{r_\pi + (\beta+1)R_E}}$$

$$= \frac{-\frac{\beta}{r_\pi} R_L}{1 + \frac{(\beta+1)}{r_\pi} R_E}$$

$$\left\{ \begin{array}{l} r_\pi = \beta/g_m \\ \Rightarrow \beta/r_\pi = g_m \end{array} \right\}$$

$$\boxed{\frac{v_o}{v_i} = \frac{-g_m R_L}{1 + g_m R_E}}$$

$$\{\beta + 1 \approx \beta\}$$

N.B. -

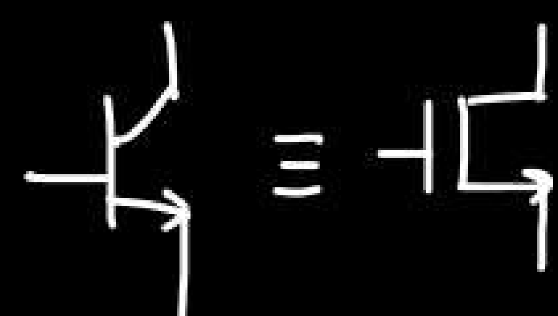
if $\beta = \infty \Rightarrow r_\pi = \dfrac{\beta}{g_m} = \infty$

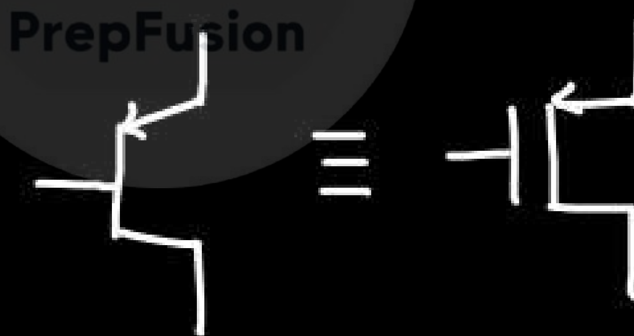
$\Downarrow$

Small signal analysis of BJT

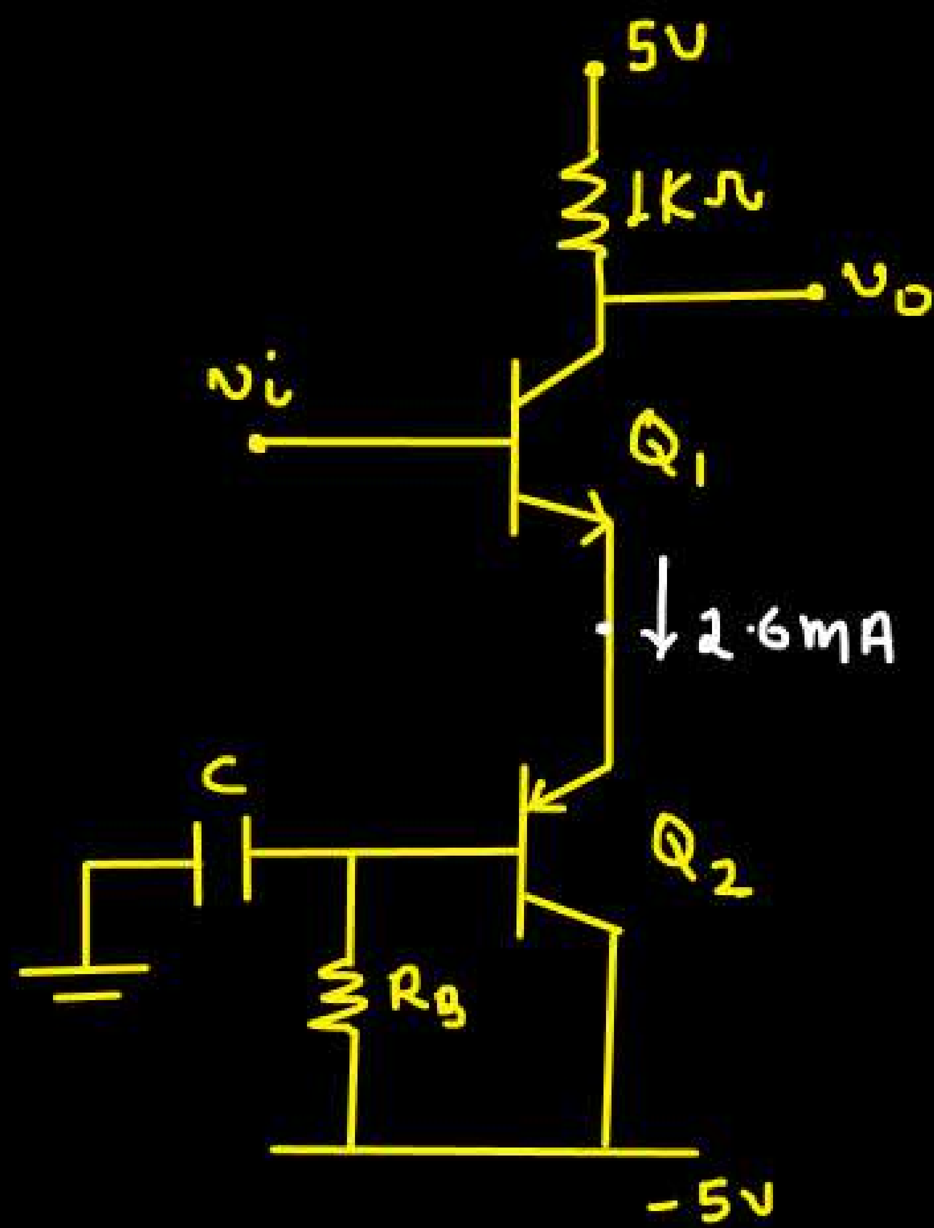
=

Small signal analysis of MOS





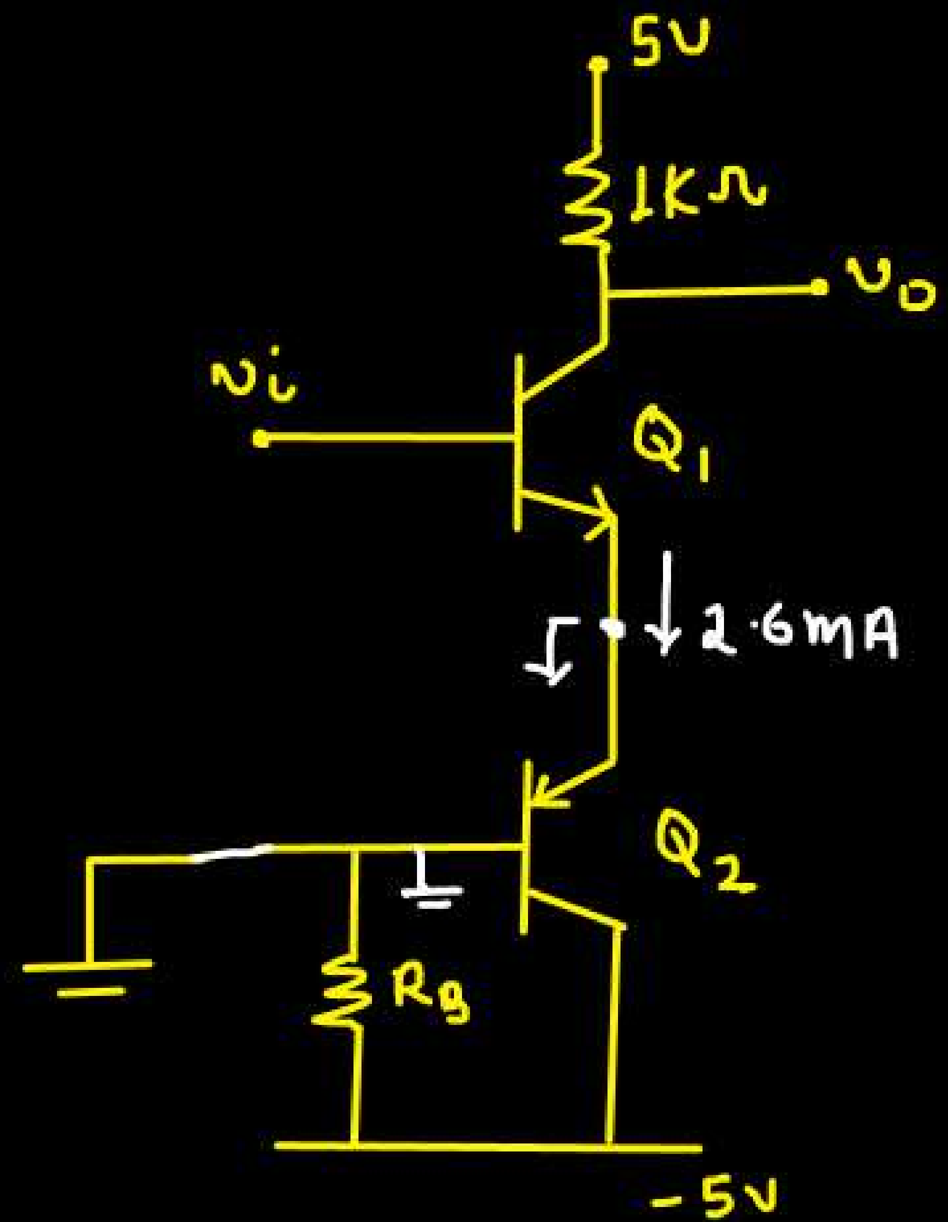
Q.



Q_1 and Q_2 are biased with collector current of 2.6mA.

$V_T = 26\,mV$, $\boxed{\beta = \infty}$, $V_A = \infty$

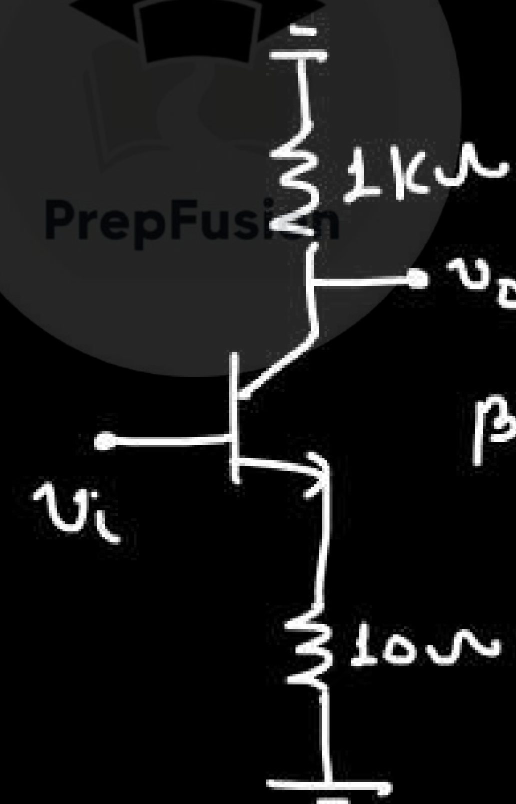
Find small signal voltage gain.



dc Analysis:-

$$g_m = \frac{I_C}{V_T} = \frac{2.6m}{26m} = \frac{1}{10}$$

$$r_o = \frac{V_A}{I_C} = \infty$$

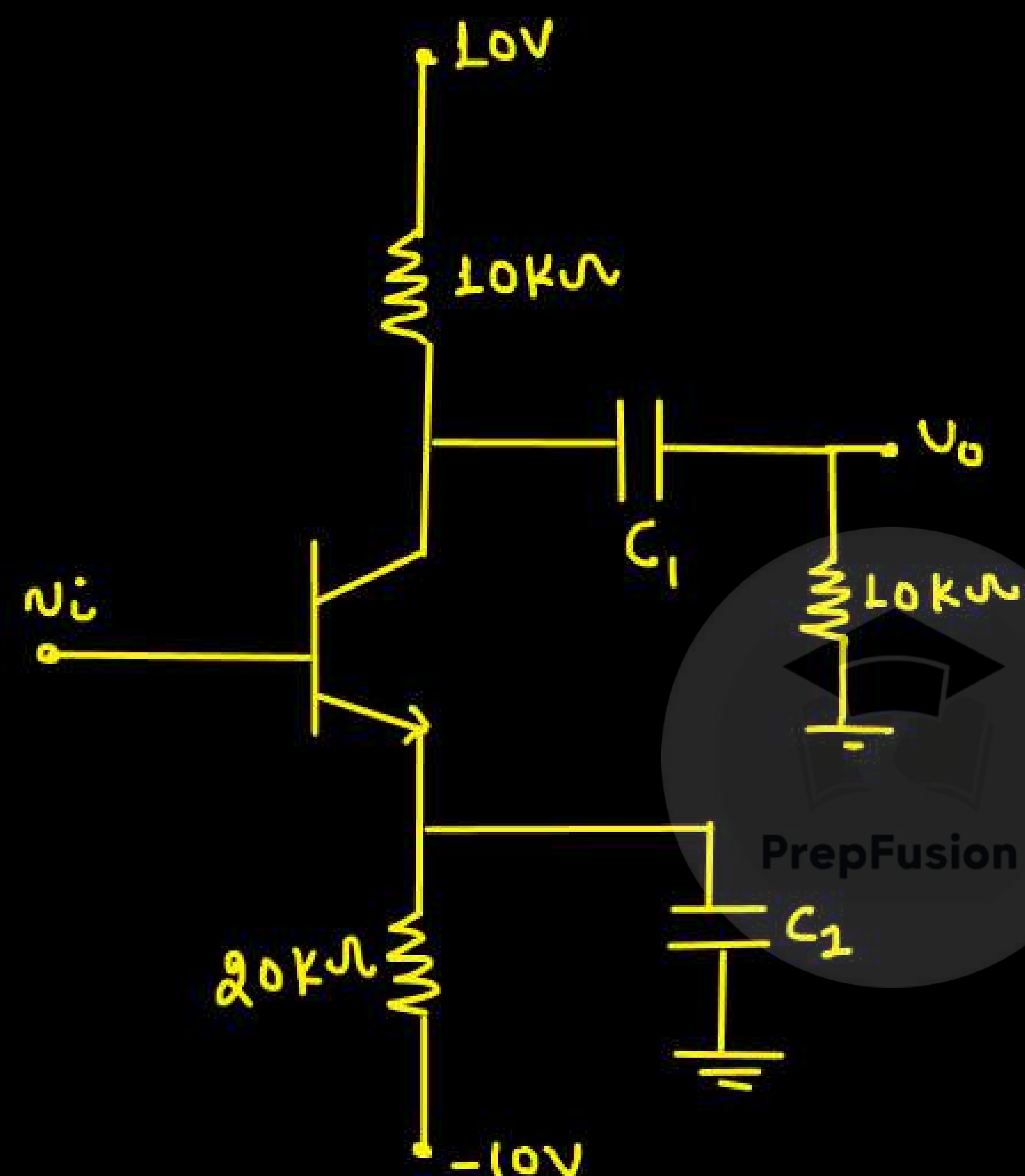


$$A_v = \frac{-g_m R_L}{1 + g_m R_S}$$

$$= \frac{-100}{1+1}$$

$$\boxed{A_v = -50}$$

Q.



$r_o = \infty$

$\beta = \infty$

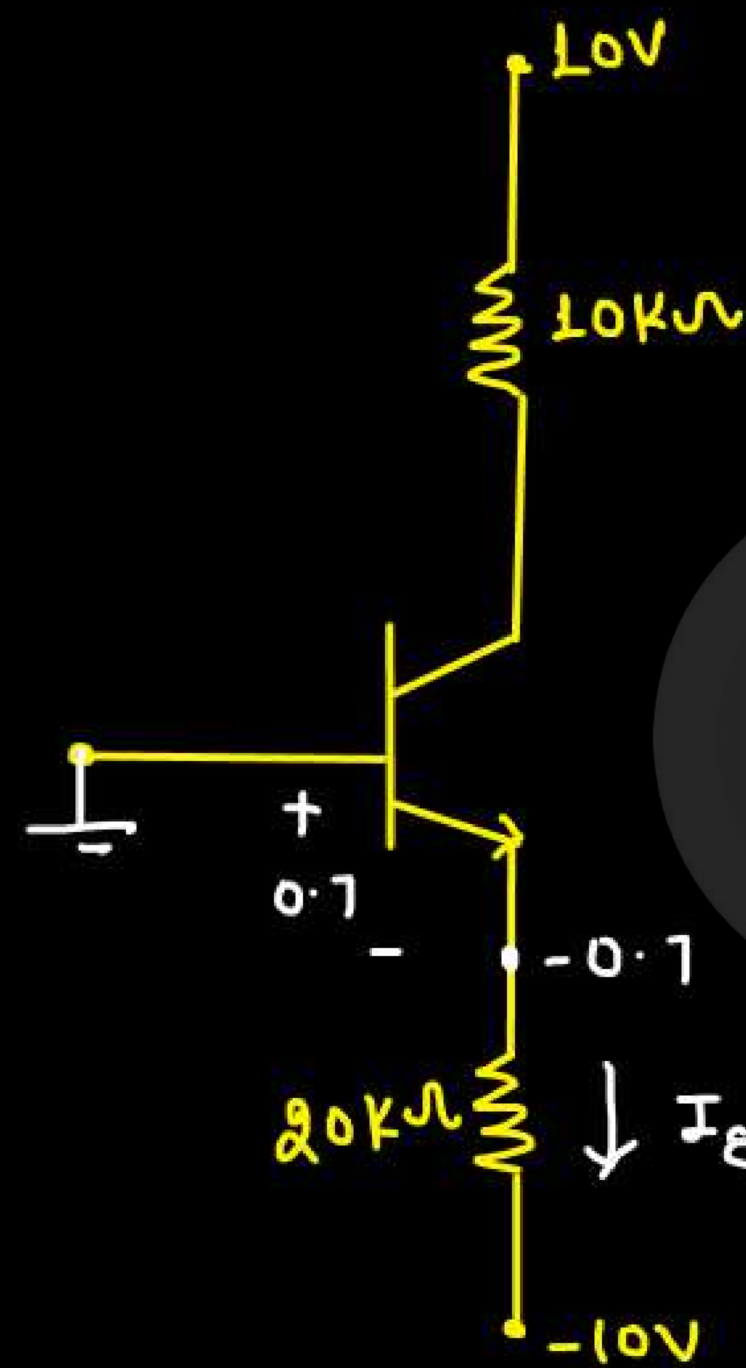
$V_{BE} = 0.7V$

$V_T = 25mV$

Capacitors are shorted at signal frequency.

Find small signal voltage gain.

dc Analysis:-

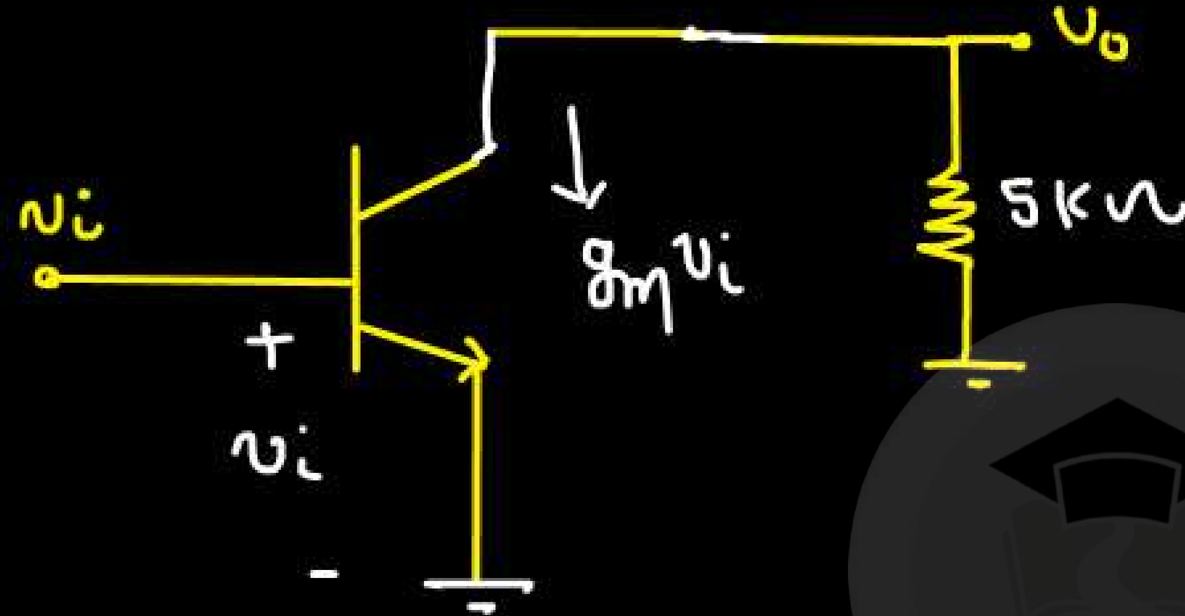


$$I_E = I_C = \frac{9.3}{20K} = 0.465\,mA$$

$$g_m = \frac{I_C}{V_T} = \frac{0.465m}{26m}$$

$$\boxed{g_m = 17.88\,m\mho}$$

Ac Analysis:-



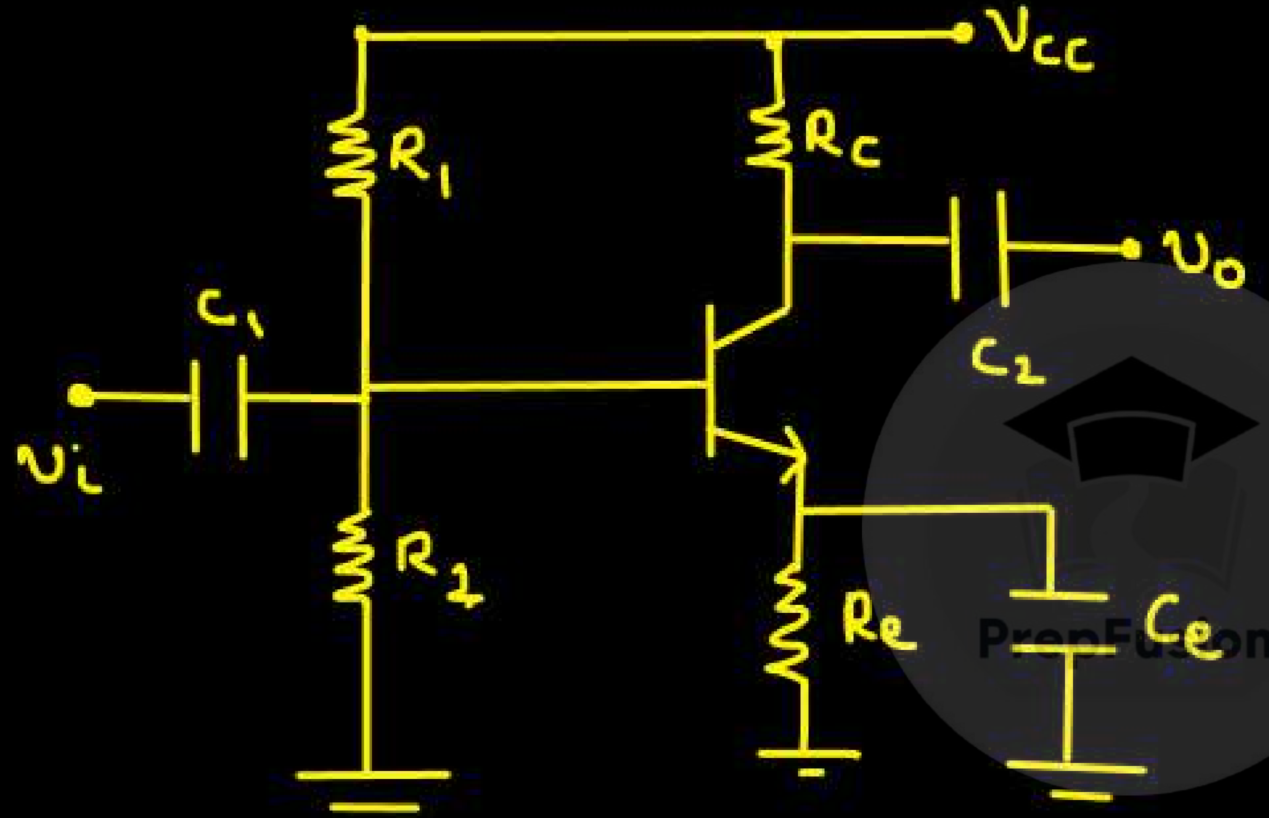
$v_o = -g_m \times 5k\, v_i$

$A_V = -17.88 \times 5$

$$\boxed{A_V = -89.4\ V/V}$$

Assignment - 20

Q.



$h_{fe} = \beta$

$h_{ie} = r_\pi$

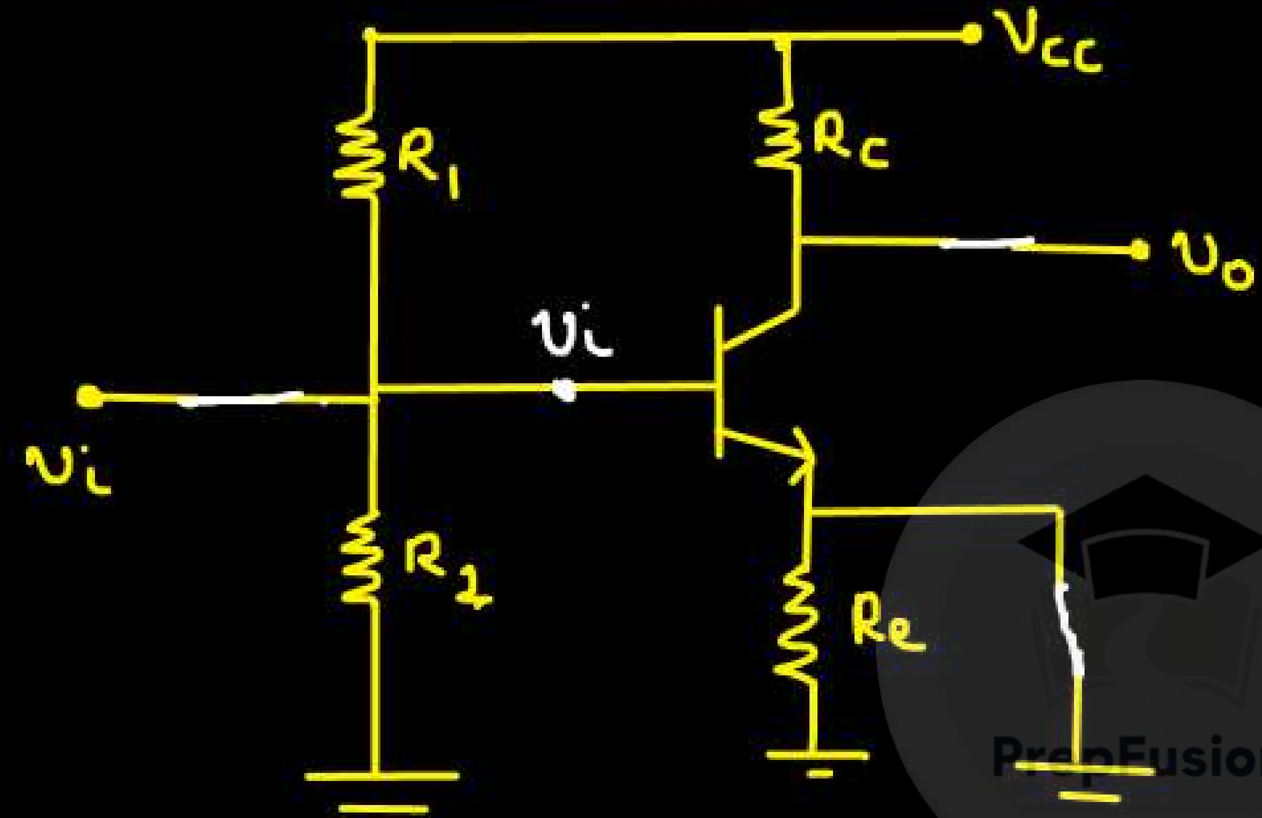
$h_{oe} = \dfrac{1}{r_o}$

Find the ratio of small signal voltage gain when emitter resistance R_e is by passed by C_e to when it's not bypassed.

(a) 1 (b) h_{fe}

(c) $\dfrac{(1+h_{fe})R_e}{h_{ie}}$ (d) $1 + \dfrac{(1+h_{fe})R_e}{h_{ie}}$

When R_e is bypassed :-



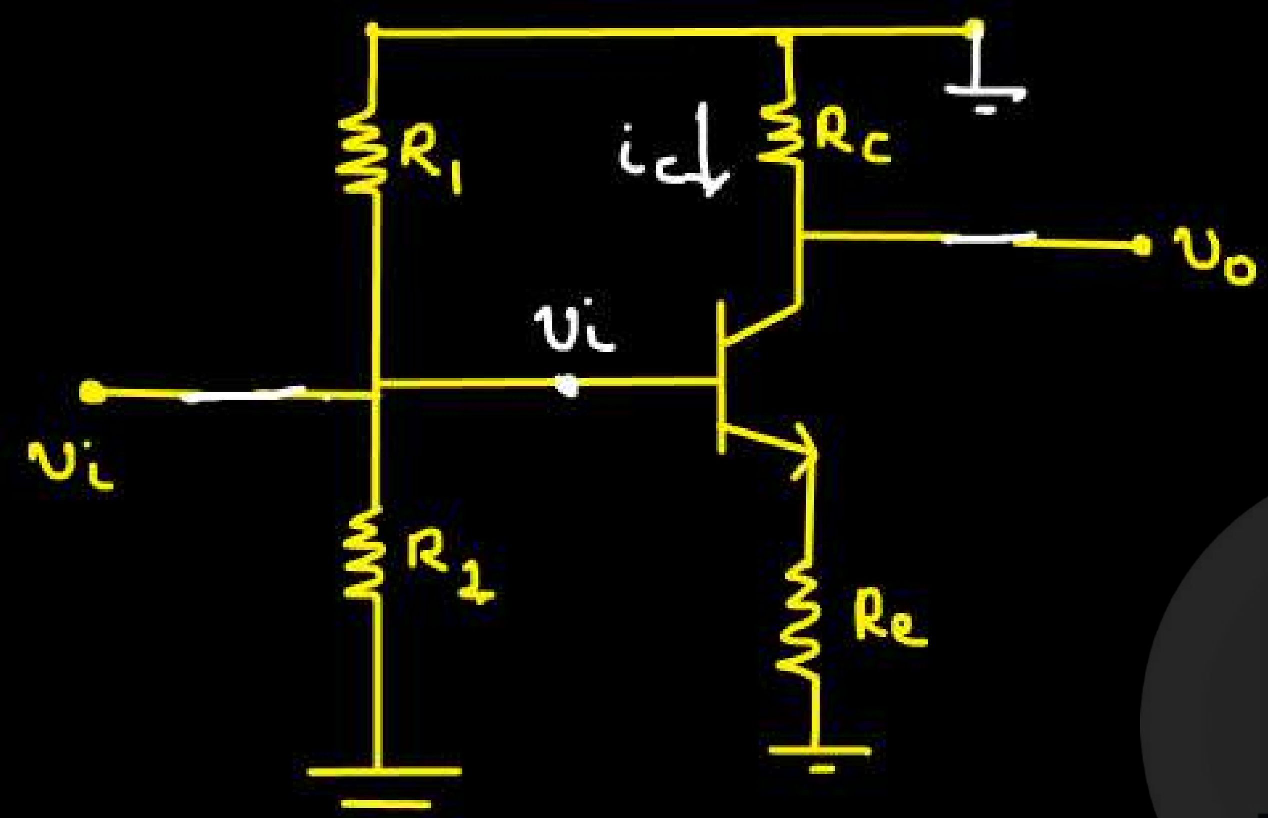
$$v_o = -g_m R_C v_i$$

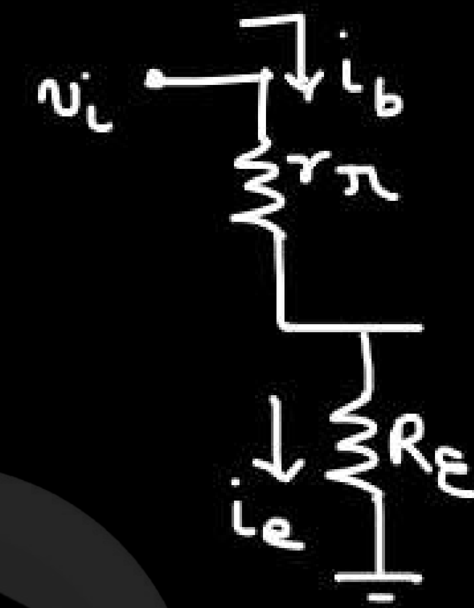
$$= -\frac{\beta}{r_\pi} R_C v_i$$

$$r_\pi = \beta / g_m$$

$$\boxed{A_{v_1} = -\frac{h_{fe}}{h_{ie}} R_C}$$

When R_e is not bypassed :-





$$v_i = [r_\pi + (\beta+1) R_E]\, i_b$$

$$i_c = \frac{\beta v_i}{r_\pi + (\beta+1) R_E}$$

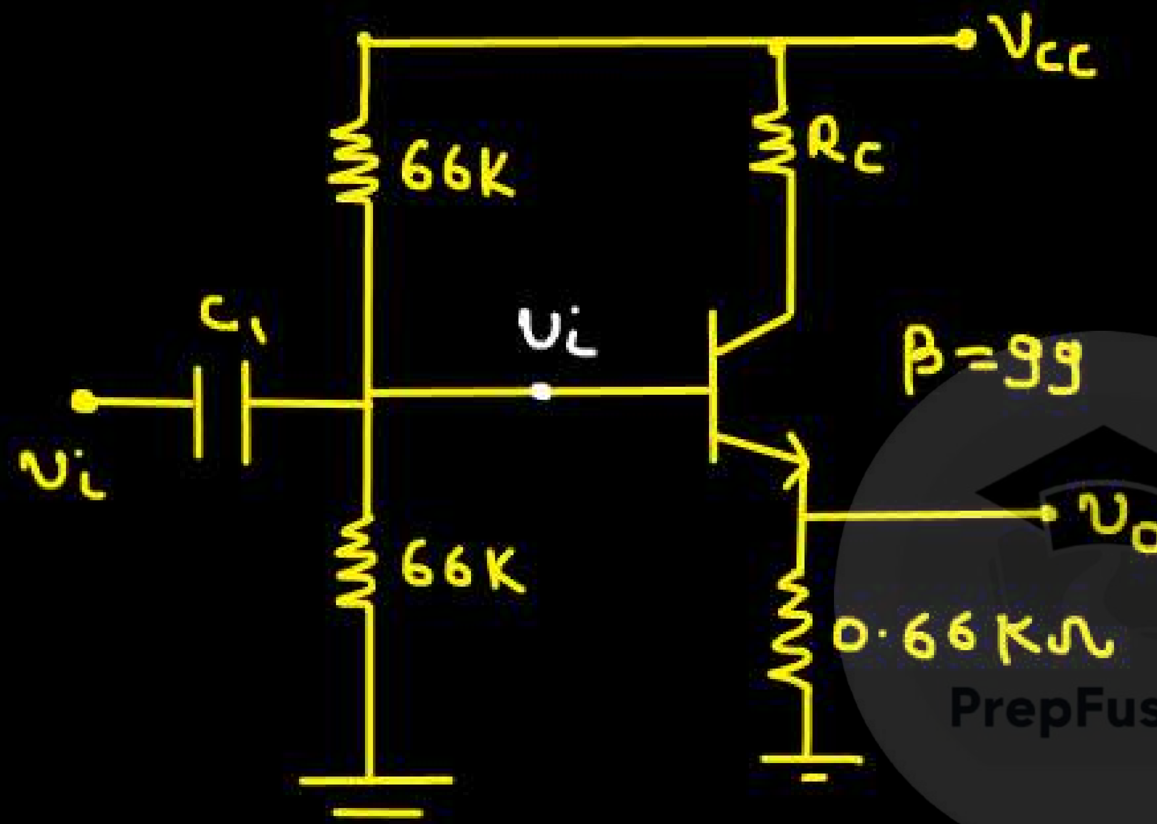
$$v_o = -i_c R_c$$

$$\boxed{A_{v_2} = \frac{-\beta R_c}{r_\pi + (\beta+1) R_E}}$$

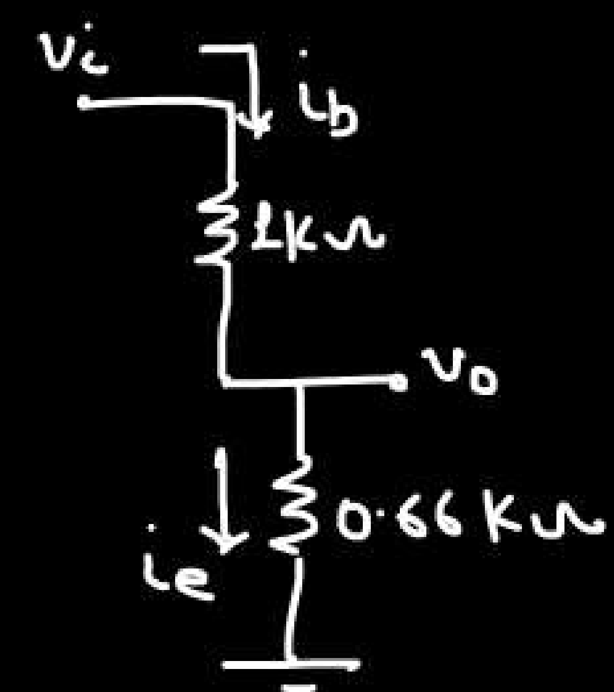
$$\frac{A_{v_1}}{A_{v_2}} = \frac{r_\pi + (\beta+1) R_c}{r_\pi}$$

$$= 1 + \frac{(\beta+1)}{r_\pi} R_c = \boxed{1 + \frac{(h_{fe}+1)}{h_{ie}} R_c}$$

Q. Find small signal voltage gain. $[V_A = \infty]$



$r_\pi = 1k\Omega$



$$v_i = 1k\, i_b + 0.66K\, i_e$$

$$v_i = 10\, i_e + 660\, i_e \qquad \left\{ i_b = \frac{i_e}{100} \right\}$$

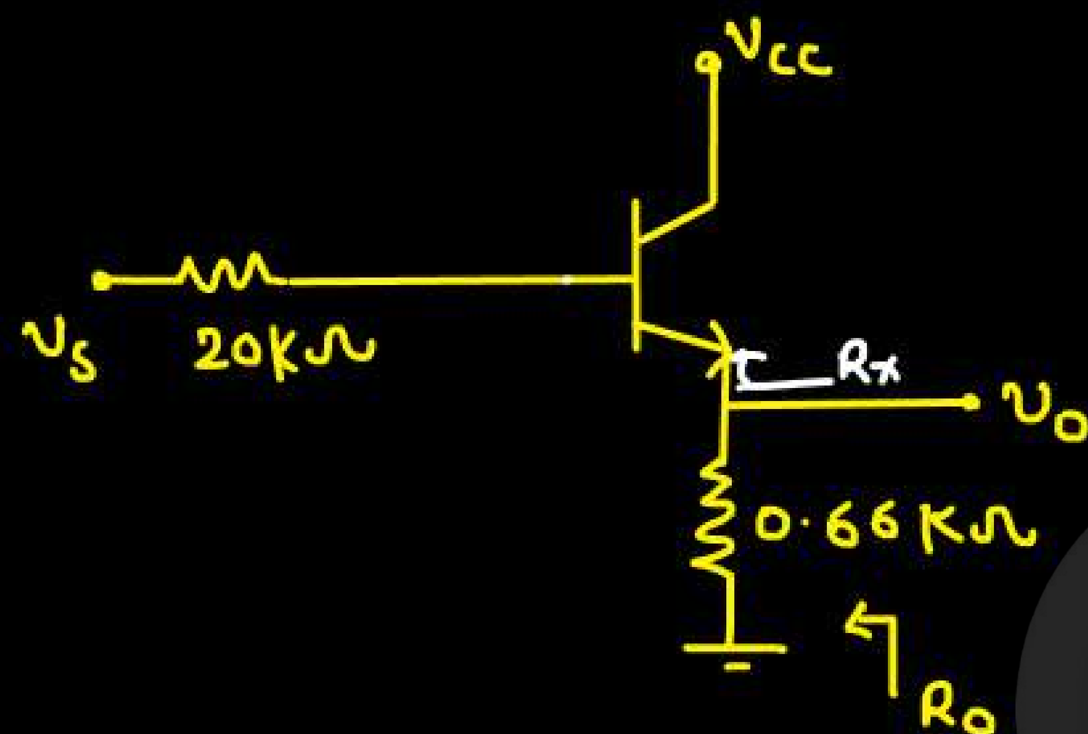
$$i_e = \frac{v_i}{670} \quad \text{—— } (2)$$

$$v_o = (0.66K)\, i_e \quad \text{—— } (1)$$

$$v_o = \frac{660 \times v_i}{670}$$

$$\boxed{A_v = 0.985}$$

Q. Find small signal output Resistance R_o.



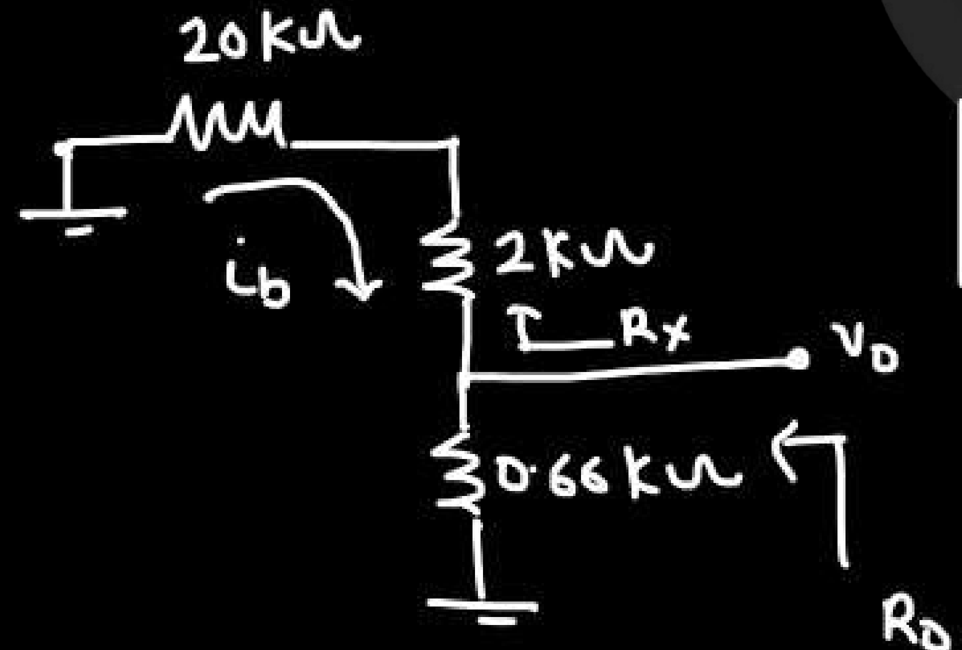
$h_{fe} = 99$, $h_{ie} = 2K\Omega$

$h_{oe} = 0$

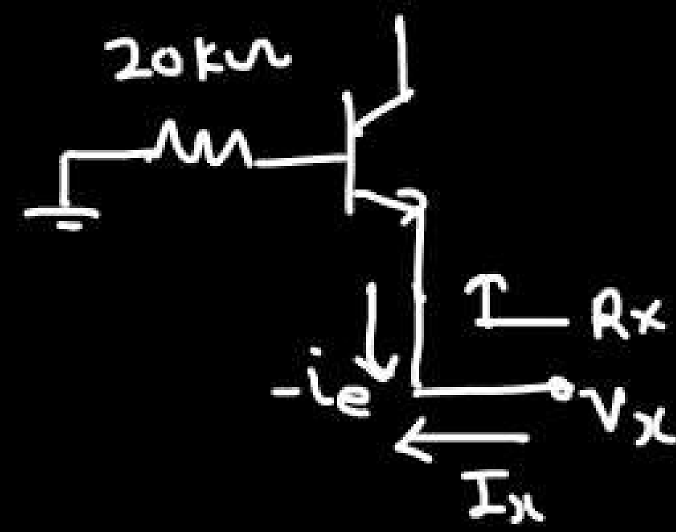
$\rightarrow$ $r_o = \infty$

$\beta = 99$

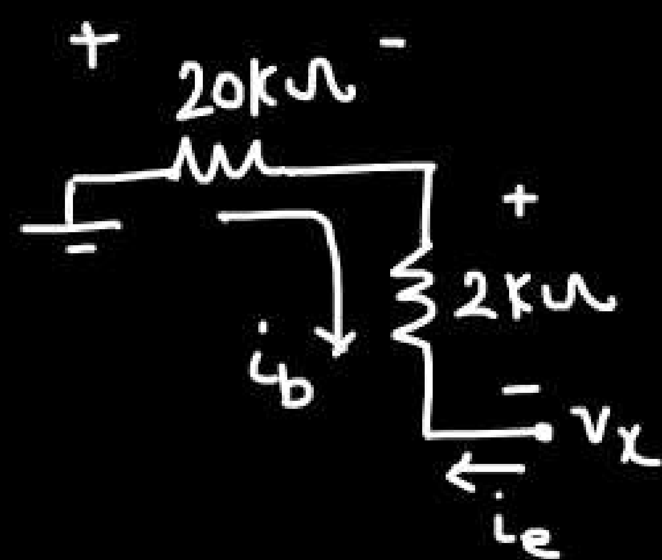
$r_\pi = 2K\Omega$



$$\boxed{R_o = 660 \| R_x}$$



$$R_x = \frac{V_x}{I_x} = \frac{-v_x}{i_e}$$



$$v_x = -22K\, i_b$$

$$= \frac{-22K \times i_e}{100}$$

$$v_x = -220 i_e$$

$$\boxed{R_x = 220\,\Omega}$$

$$R_o = 220 \| 660$$

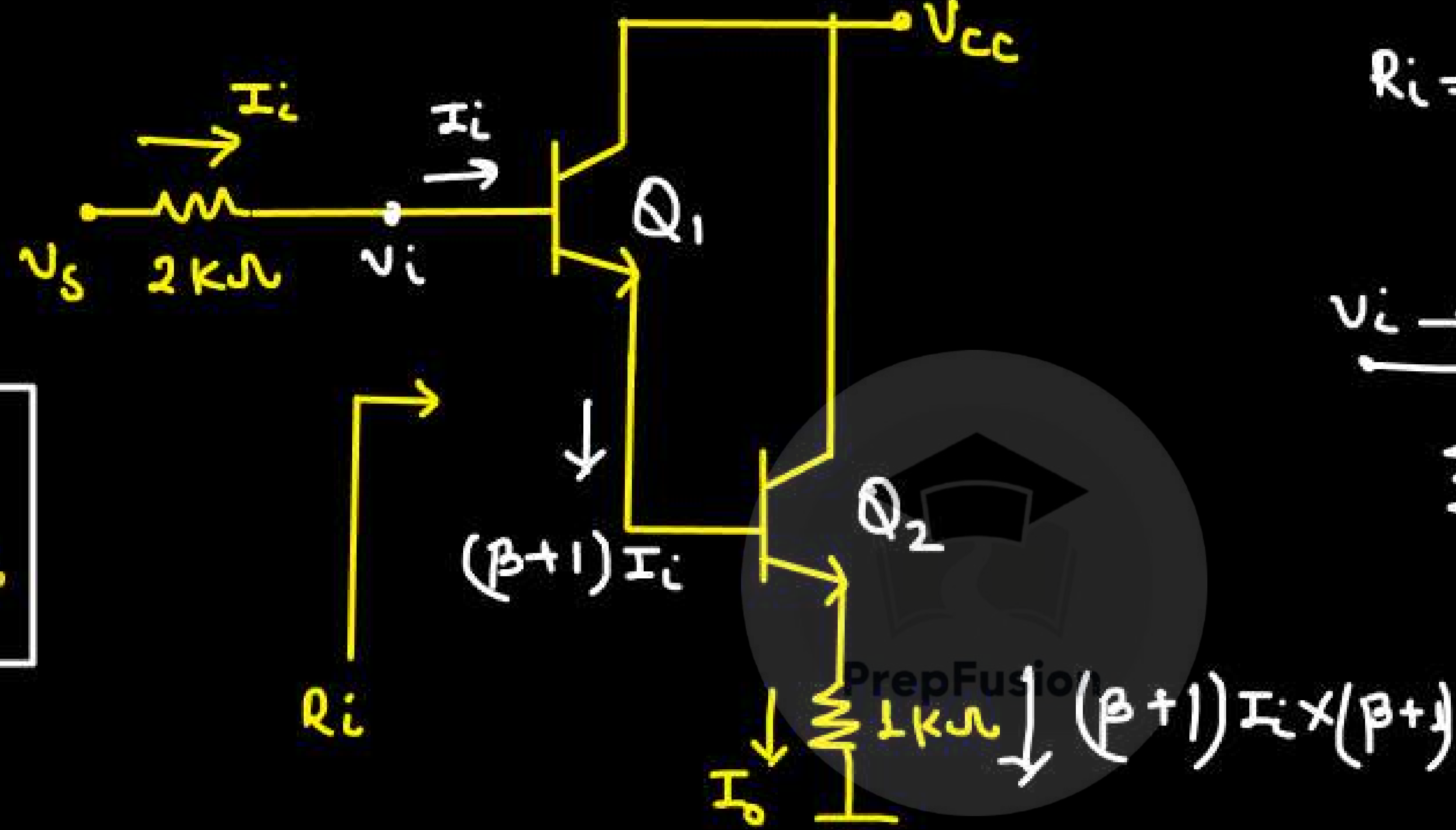
$$\boxed{R_o = 165\,\Omega}$$

Q. Find the value of input impedance. [CC-CC]

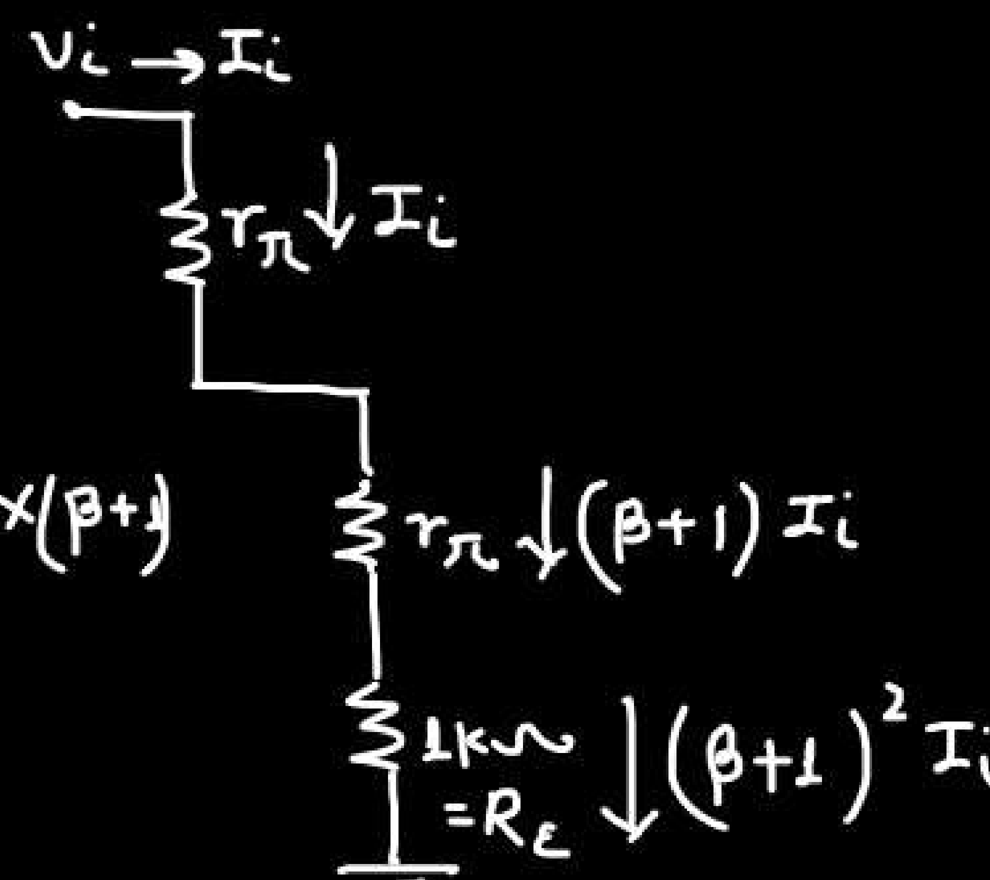
$R_i = \dfrac{v_i}{I_i}$

$\beta = 50$

$r_\pi = 1k\Omega$



$\Downarrow$ darlington pair



Q. Find current gain $\frac{I_o}{I_i}$.

$$v_i = r_\pi I_i + r_\pi(\beta+1)I_i + (\beta+1)^2 I_i \times R_E$$

$$\boxed{R_i = r_\pi + r_\pi(\beta+1) + (\beta+1)^2 R_E}$$

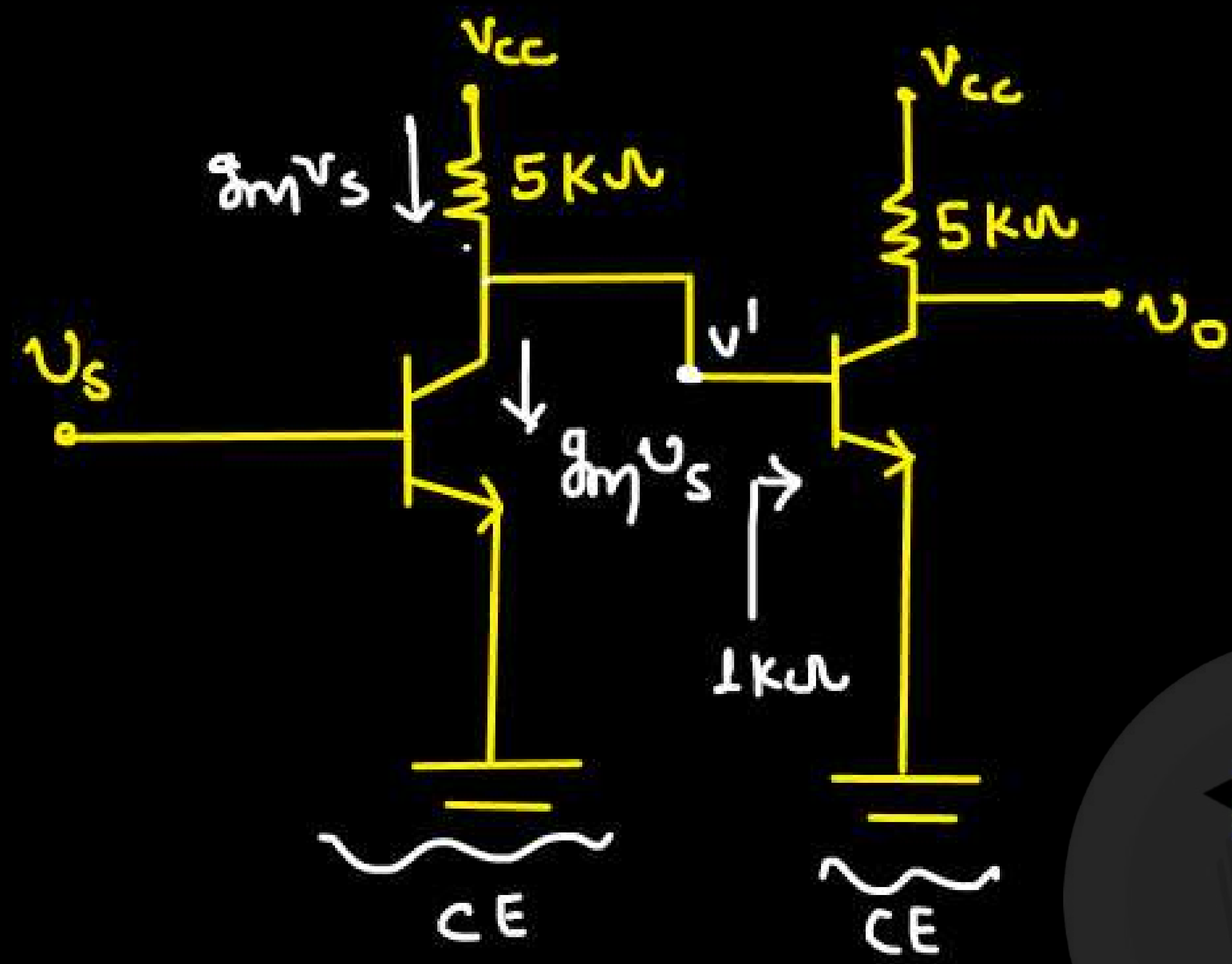
$$R_i = 1k\Omega + 51k\Omega + (51)^2 \times 1k\Omega$$

$$\boxed{R_i = 2.653\,M\Omega}$$

$$I_o = (\beta+1)^2 I_i$$

$$\boxed{\frac{I_o}{I_i} = (51)^2 = 2601}$$

Q.



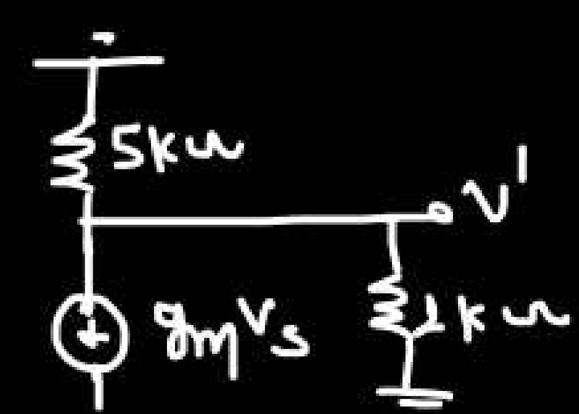
$r_\pi = 1k\Omega$

$\beta = 100$

Determine small signal voltage gain.

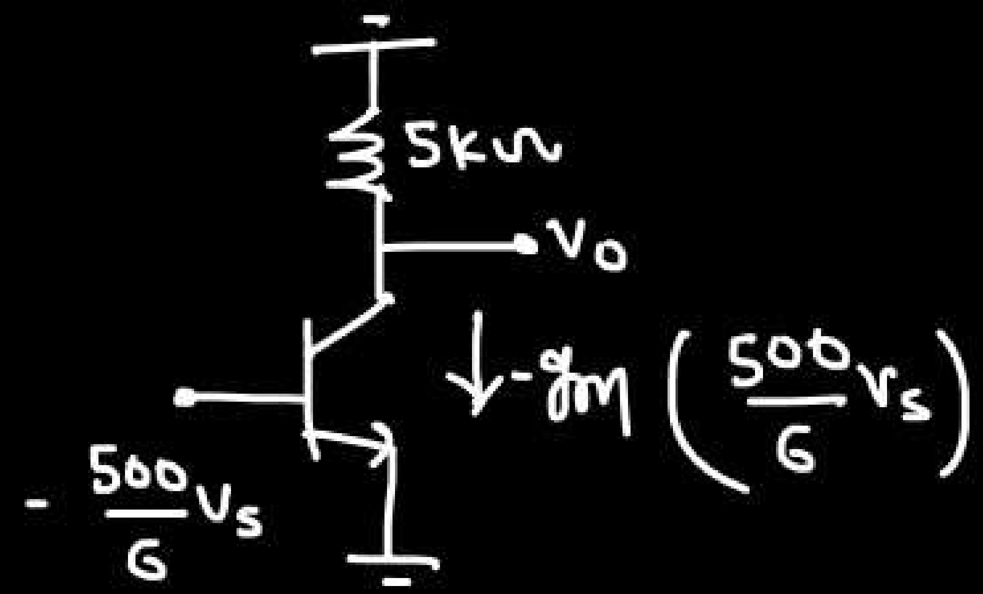
→

$$g_m = \frac{\beta}{r_\pi} = \frac{100}{1000} = 0.1 = 100\,m\mho$$



$$\Rightarrow v' = -g_m v_s \times \frac{5}{6}k = -100m \times \frac{5}{6}k \times v_s$$

$$v' = -\frac{500}{6} v_s$$



$$v_o = g_m \times 5K \times \frac{500}{6} v_s$$

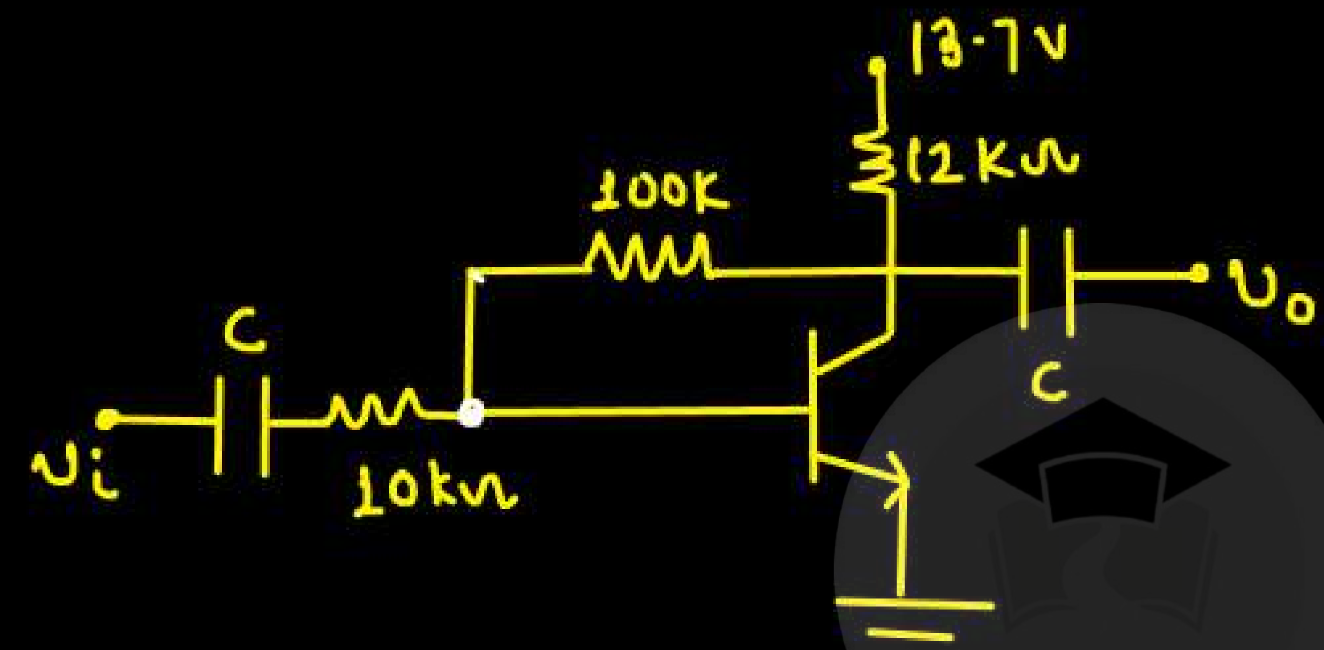
$$\frac{v_o}{v_s} = 100 \times 5 \times \frac{500}{6}$$

$$\boxed{A_v = 4166.67}$$

Q. Find small signal voltage gain $\frac{v_o}{v_s}$.

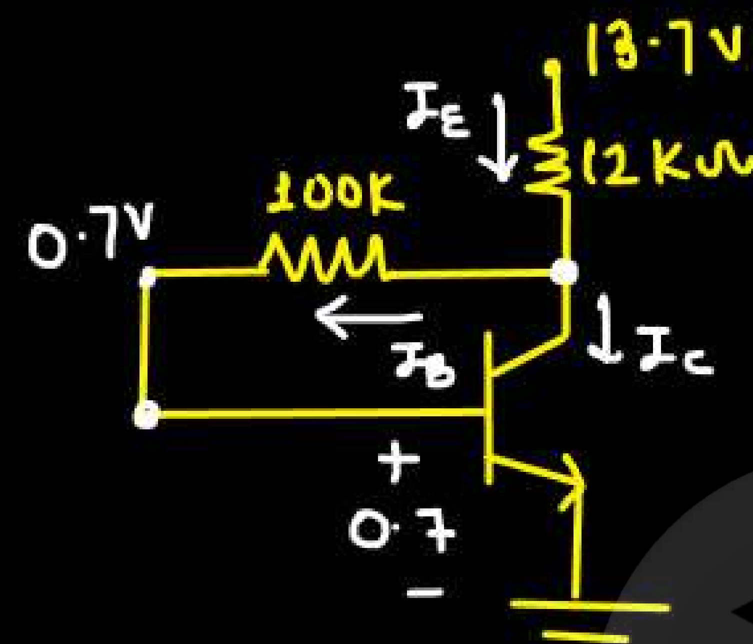
$\beta = 100$

$r_\pi = \frac{\beta}{g_m}$



(a) ≈200 (b) ≈ 100 (c) ≈ 20 (d) ≈ 10

DC Analysis:-



$$13.7 = 12K \times I_E + 100K \times I_B + 0.7$$

$$13 = 12K \times 101\, I_B + 100K \times I_B$$

$$I_B = 9.9\,\mu\text{Amp}$$

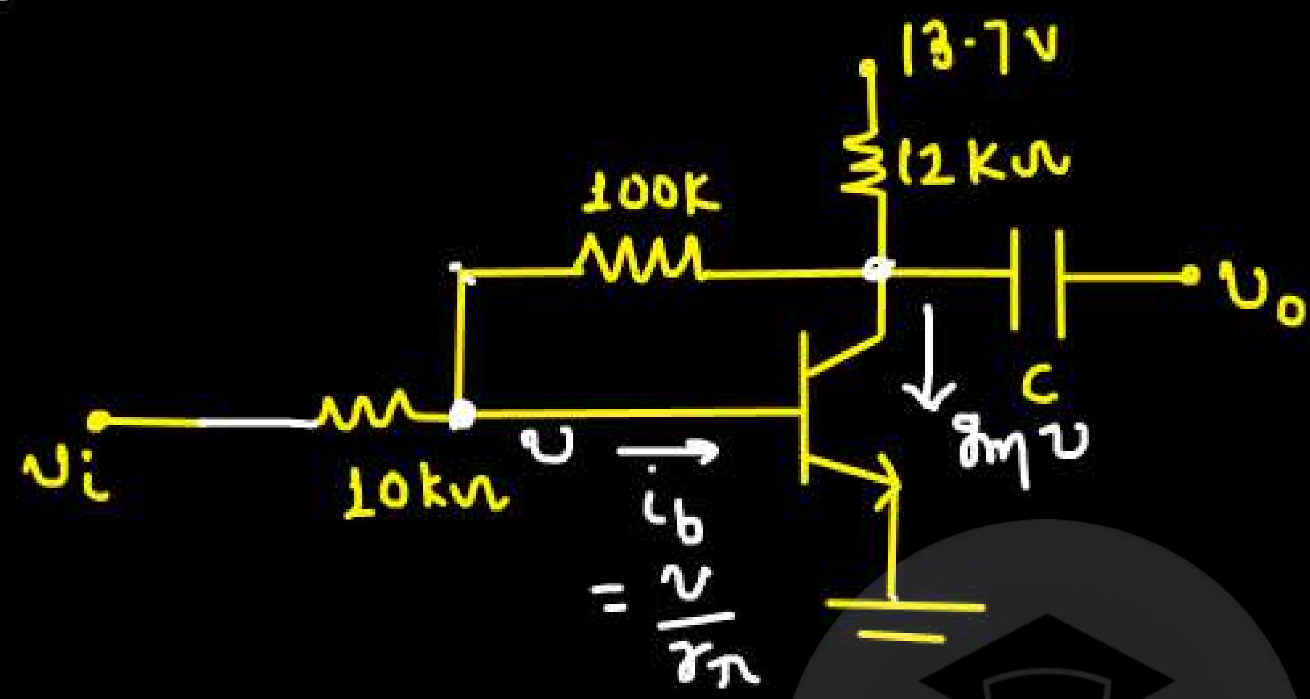
$$\boxed{I_C = 0.99\,\text{mAmp}}$$

$$\boxed{g_m = \frac{0.99m}{25m} = 39.63\,\text{m℧}}$$

$$r_\pi = \beta/g_m = \frac{100}{39.63m}$$

$$\boxed{r_\pi = 2.52\,k\Omega}$$

Ac Analysis:-



$$\frac{v - v_i}{10k} + \frac{v - v_o}{100k} + \frac{v}{r_\pi} = 0$$

$$\frac{v}{10k} + \frac{v}{100k} + \frac{v}{2.5k} = \frac{v_i}{10k} + \frac{v_o}{100k} \longrightarrow (1)$$

$$\frac{v_o - v}{100k} + \frac{v_o}{12k} + g_m v = 0$$

$$\frac{v_0}{100K} + \frac{v_0}{12K} = \frac{v}{100K} - \frac{v}{(1/g_m)} \qquad 1/g_m = 25$$

$$\frac{v_0}{100K \| 12K} = -\frac{v}{25}$$

$$v = -2.33\,m\,v_0 \quad \text{—— (2)}$$

By eq^n (1) and (2)

$$\frac{-2.33\,m\,v_0}{10K \| 100K \| 2.5K} = \frac{v_i}{10K} + \frac{v_0}{100K}$$

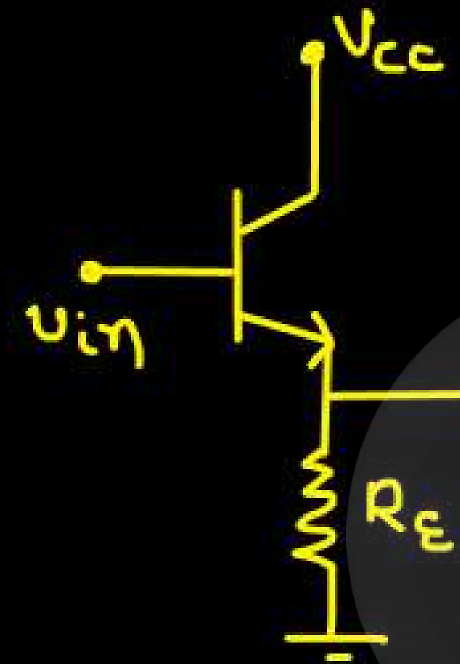
$$-0.972 \times 10^{-6} v_0 - v_0 \times 10^{-5} = \frac{v_i}{10K}$$

$$-1.0972 \times 10^{-5} v_0 = \frac{v_i}{10K}$$

$$\boxed{\frac{v_0}{v_i} \approx -9.1}$$

$$\boxed{|A_v| \approx 10}$$

Q. Which condition would ensure a nearly constant gain for large range of R_E?



(a) $g_m R_E << 1$ (b) $I_C R_E >> V_T$ (c) $g_m r_o >> 1$ (d) $V_{BE} >> V_T$

→

$$v_o = i_e R_E \quad \text{— (1)}$$

$$v_{in} = \frac{r_\pi \times i_e}{\beta+1} + R_E i_e \quad \text{— (2)}$$

$$v_o = \frac{v_{in} \, R_E}{\frac{r_\pi}{\beta+1} + R_E}$$

$$\boxed{A_v = \frac{R_E}{\frac{r_\pi}{\beta+1} + R_E}}$$

For const. gain

$$\frac{r_\pi}{\beta+1} << R_E$$

$$\frac{1}{g_m} << R_E$$

$$g_m R_E >> 1$$

$$\boxed{I_C R_E >> V_T}$$

Q.

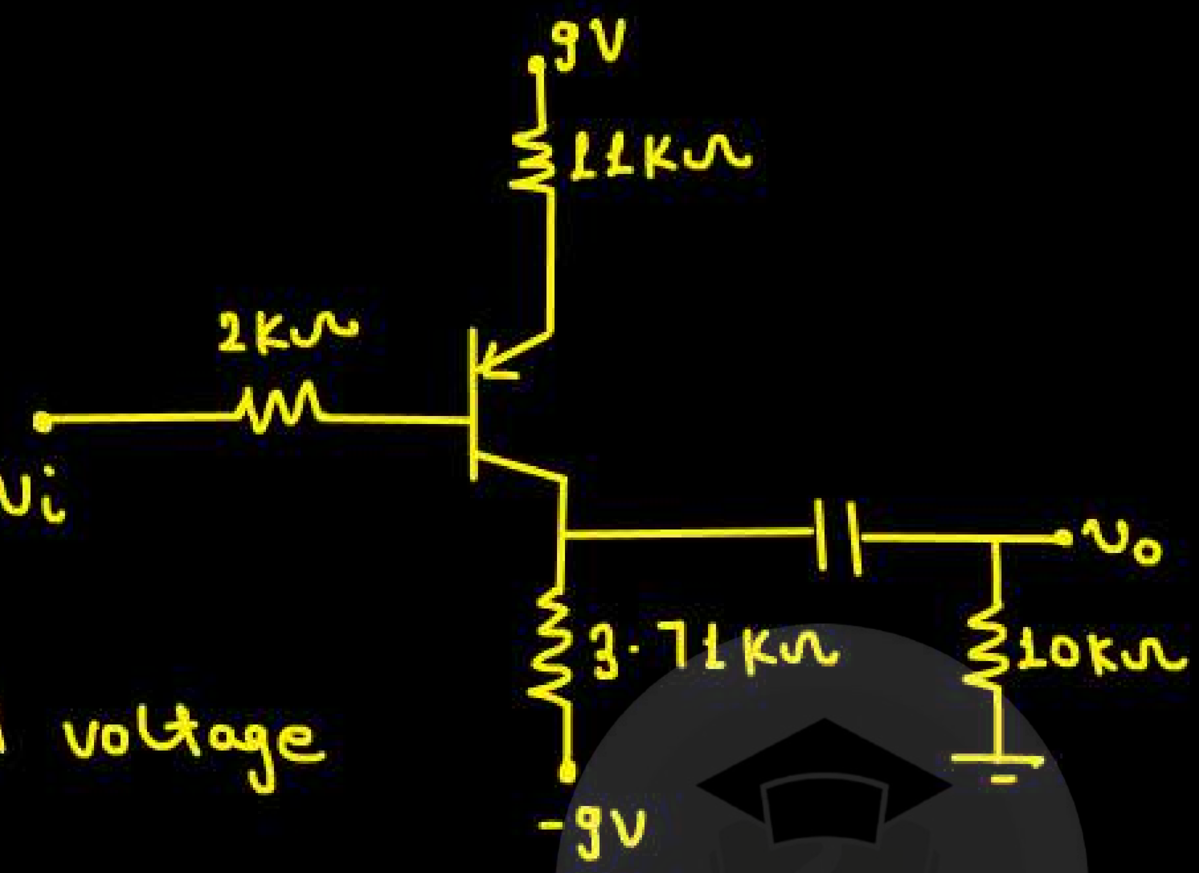
$\beta = 80$

$V_A = \infty$

$V_{EB(ON)} = 0.7$

$V_T = 25.9\,mV$

Find mid band voltage gain (A_v).



→ DC analysis

$$9V = 11K \times I_E + 0.7 + 2K \times I_B$$

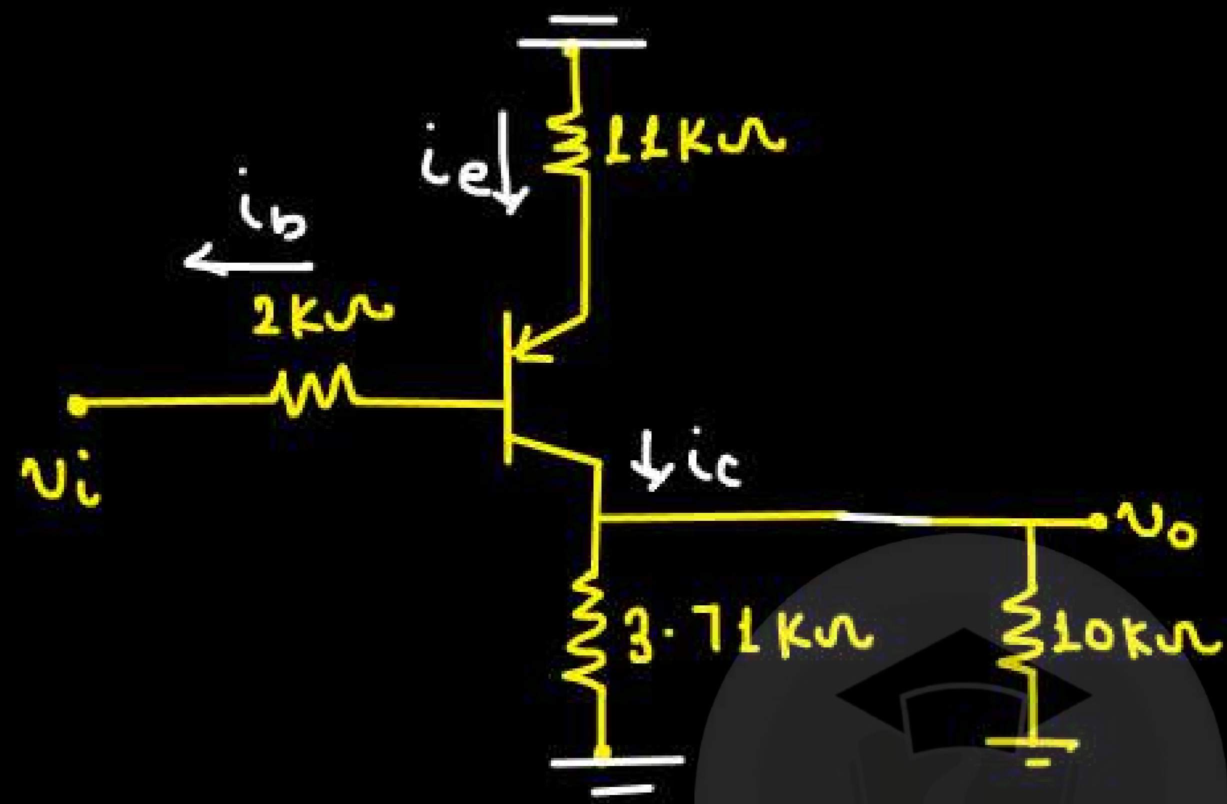
$$8.3 = 11K \times 81\, I_B + 2k\, I_B$$

$$\boxed{I_C = 0.743\,mA}$$

$$\boxed{g_m = 28.7\,m\mho}$$

$$r_\pi = \frac{80}{28.7m} = 2.78\,k\Omega$$

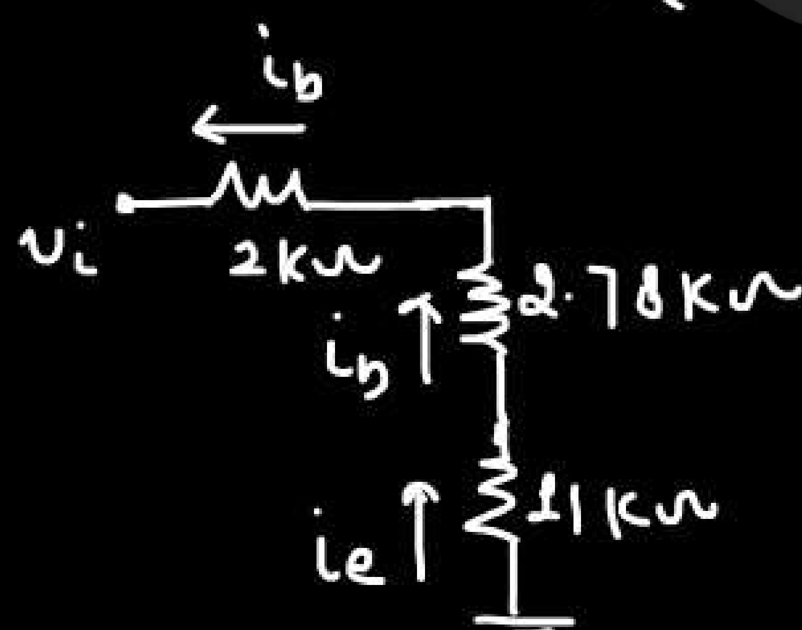
AC Analysis:-



$$\frac{v_o}{v_i} = \frac{-80\,(3.71k \,||\, 10k)}{4.78k + (11k \times 81)}$$

$$\boxed{\frac{v_o}{v_i} = -0.24 \text{ V/V}}$$

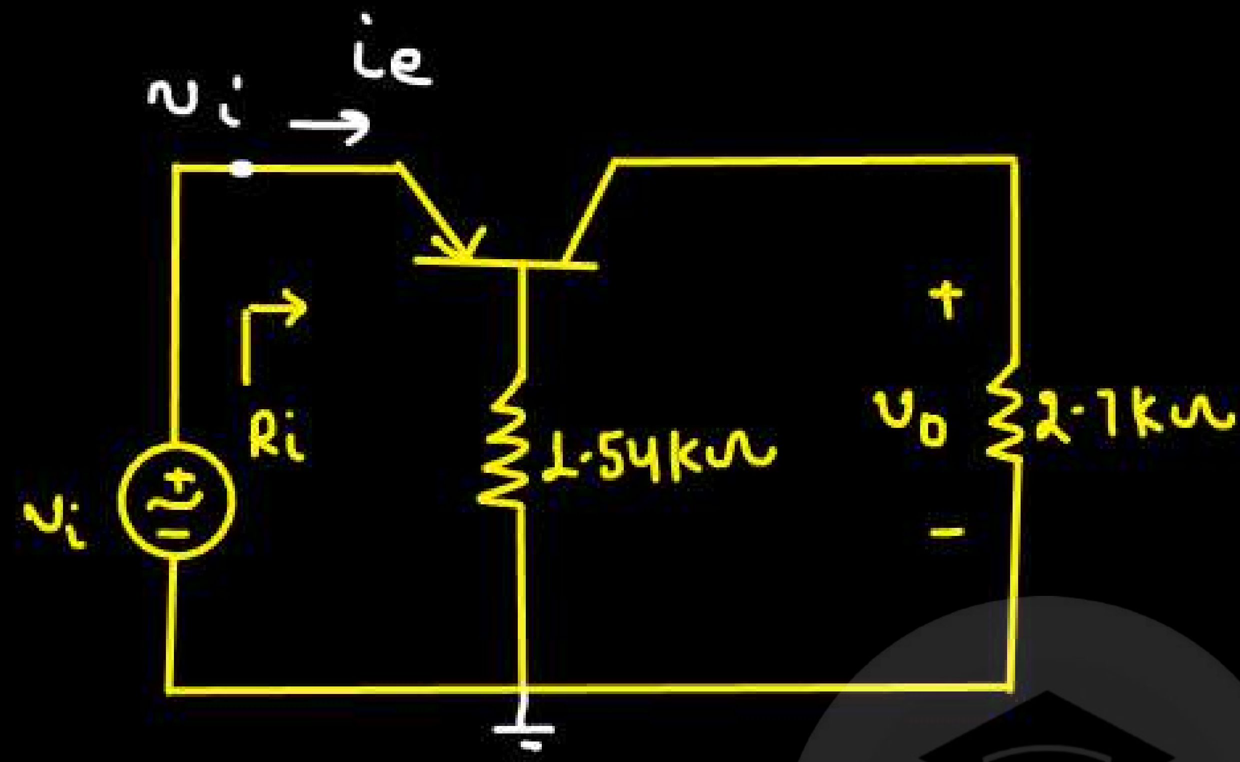
$$v_o = i_c\,(3.71k \,||\, 10k) \quad \text{— (1)}$$



$$\Rightarrow -v_i = 4.78k \times i_b + 11k \times i_e$$

$$i_c = \frac{-v_i \times 80}{4.78k + 11k \times 81}$$

Q.



$I_{CQ} = 1mA$

$\beta = 75$

$V_T = 25.9\,mV$

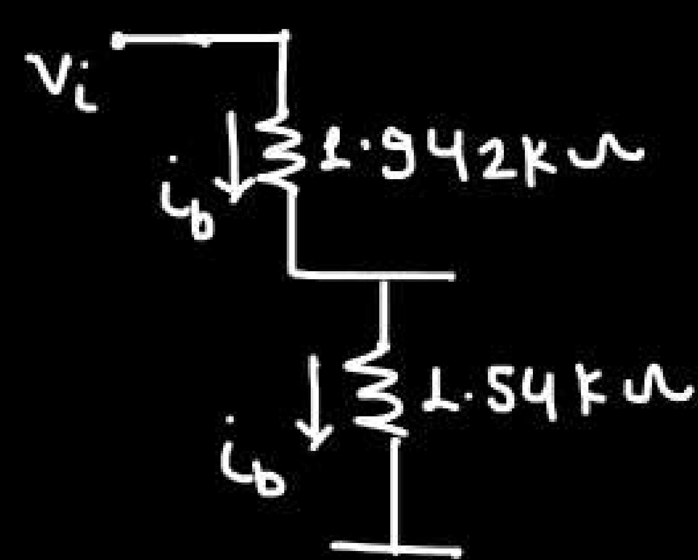
Find input Resistance ?

$R_i = v_i / i_e$

$$r_\pi = \frac{\beta}{I_c} \times V_T$$

$$= \frac{75 \times 25.9}{1}$$

$$= 1.942\,k\Omega$$

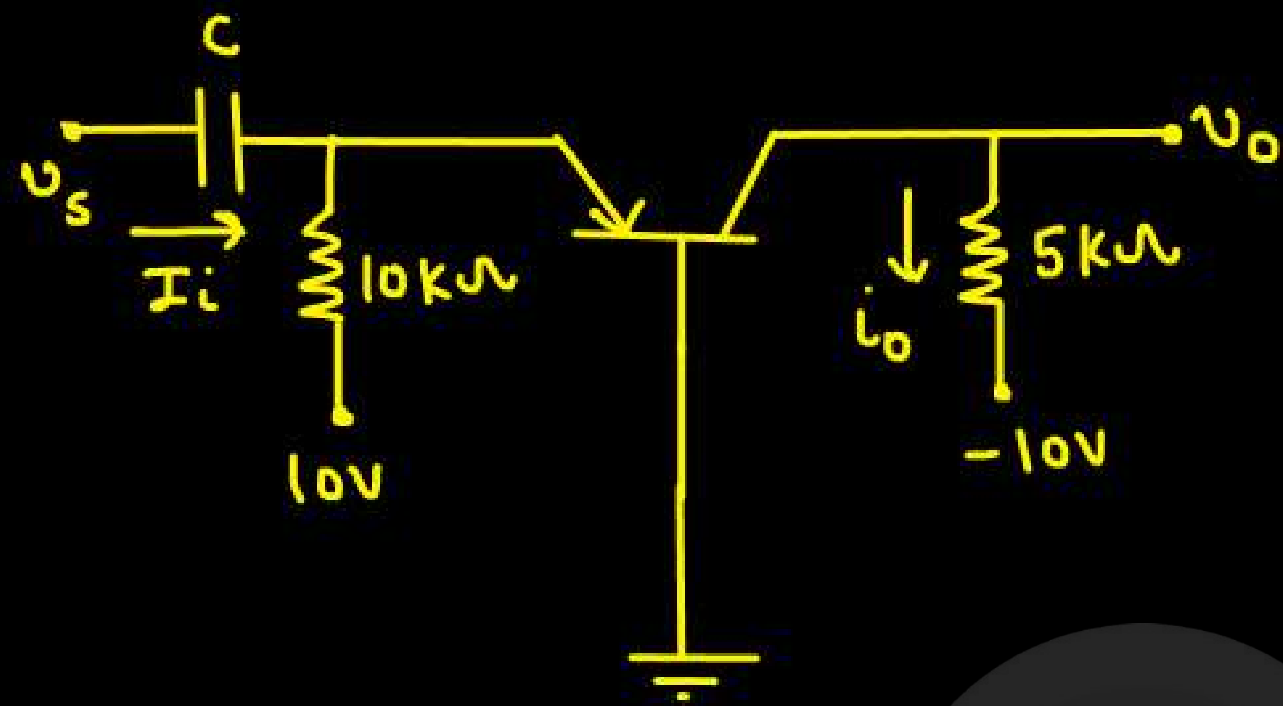


$v_i = 3.48K \times i_b$

$$= \frac{3.48K \times i_e}{76}$$

$$\boxed{R_i = 45\Omega}$$

Q.



$\beta = 100$

$V_{EB} = 0.7V$

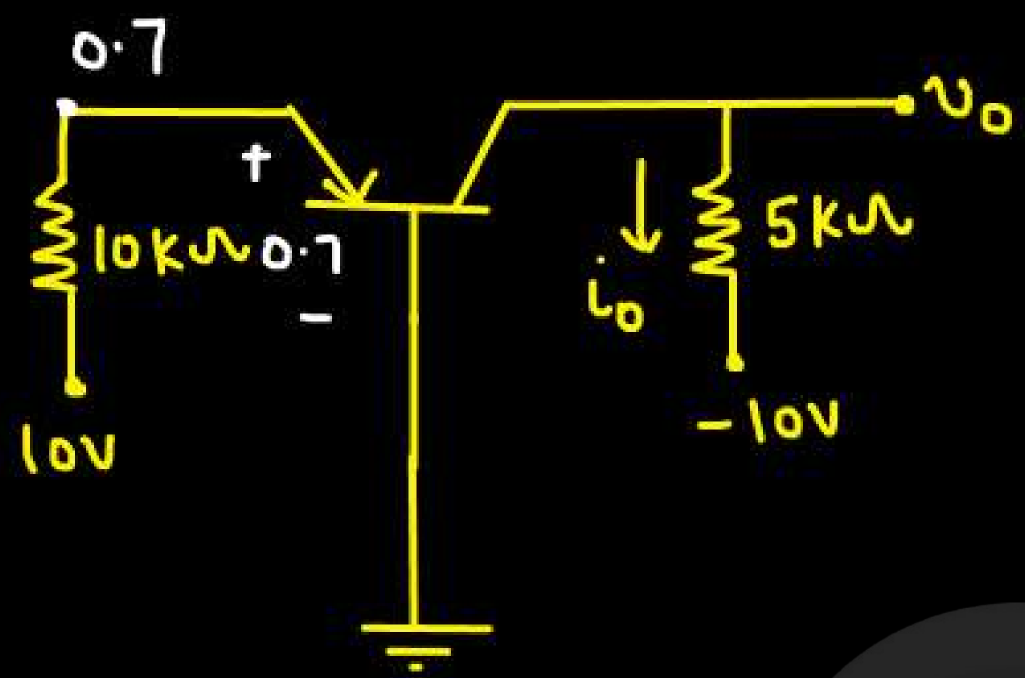
$V_T = 26mV$

$V_A = \infty$

(a) Find current gain

(b) Find voltage gain

↳

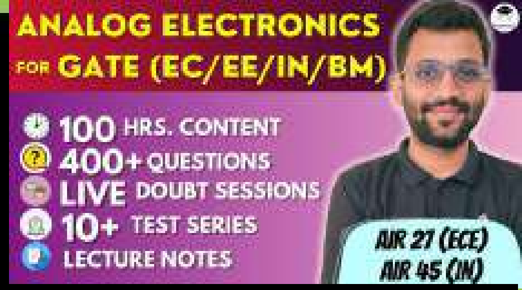


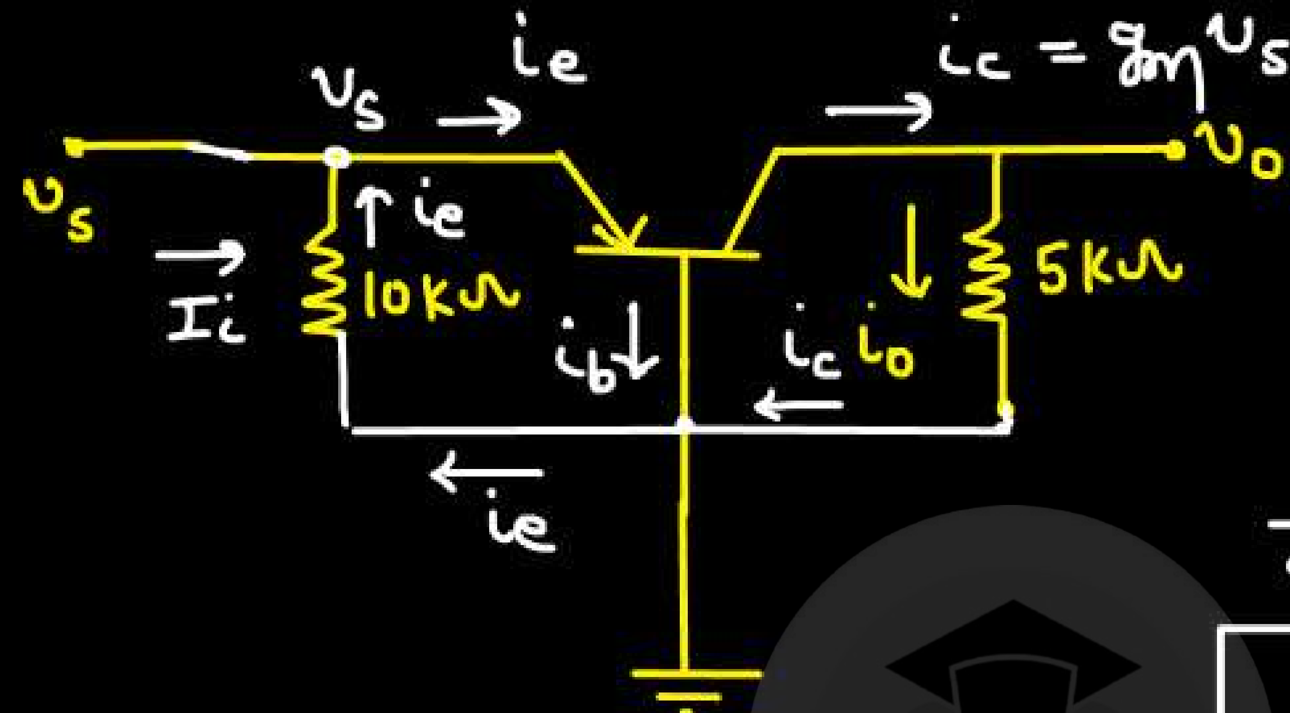
$$I_E = \frac{9.3}{10k}$$

$$I_E = 0.93\,mA$$

$$I_C = \frac{0.93 \times 100}{101}\,mA$$

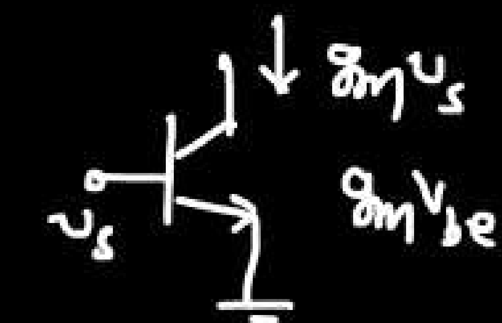
$$\boxed{g_m = \frac{I_C}{V_T} = 35.41\,m\mho}$$





$I_i = 0$ Amp

$$\boxed{\frac{I_o}{I_i} = \frac{i_c}{0} = \infty}$$

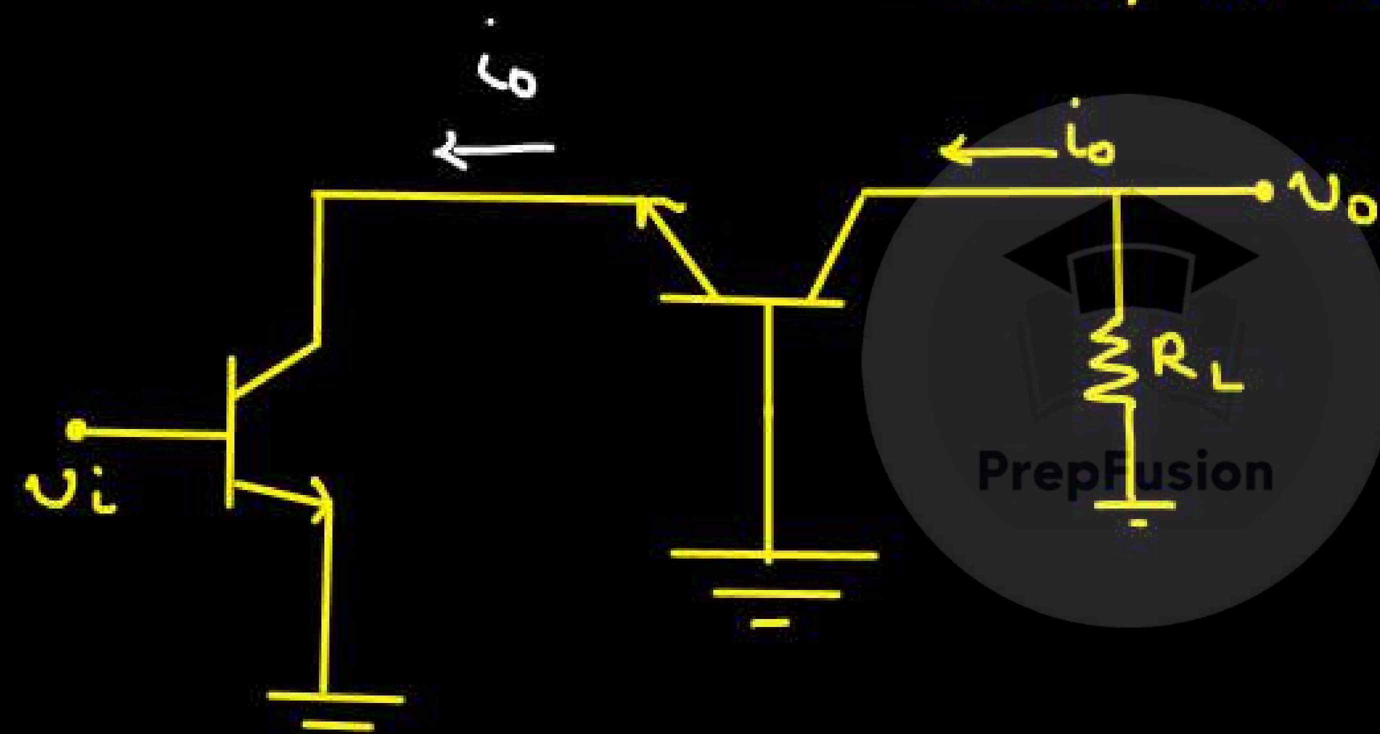


$$v_o = 5K\Omega \times g_m v_s$$

$$\frac{v_o}{v_s} = 35.41m \times 5K$$

$$\boxed{A_v = 177.1\ V/V}$$

Q. Common Emitter stage has Transconductance g_{m_1}
Common base stage has Transconductance g_{m_2}.
Overall Transconductance (g_m) of Cascaded amp. is -



$$g_m = \frac{i_o}{v_i}$$

$$g_{m_1} = \frac{i_o}{v_i}$$

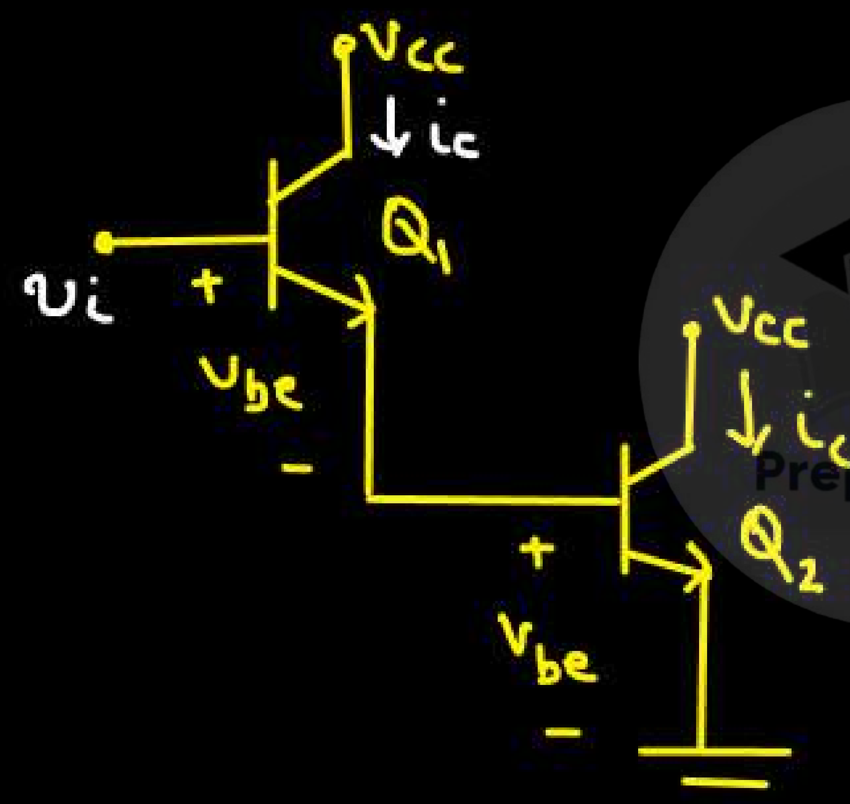
$$\boxed{g_m = g_{m_1}}$$

(a) g_{m_1} (b) g_{m_2} (c) $\frac{g_{m_1}}{2}$ (d) $\frac{g_{m_2}}{2}$

Q. Transconductance of Q_1 is g_{m_1}.

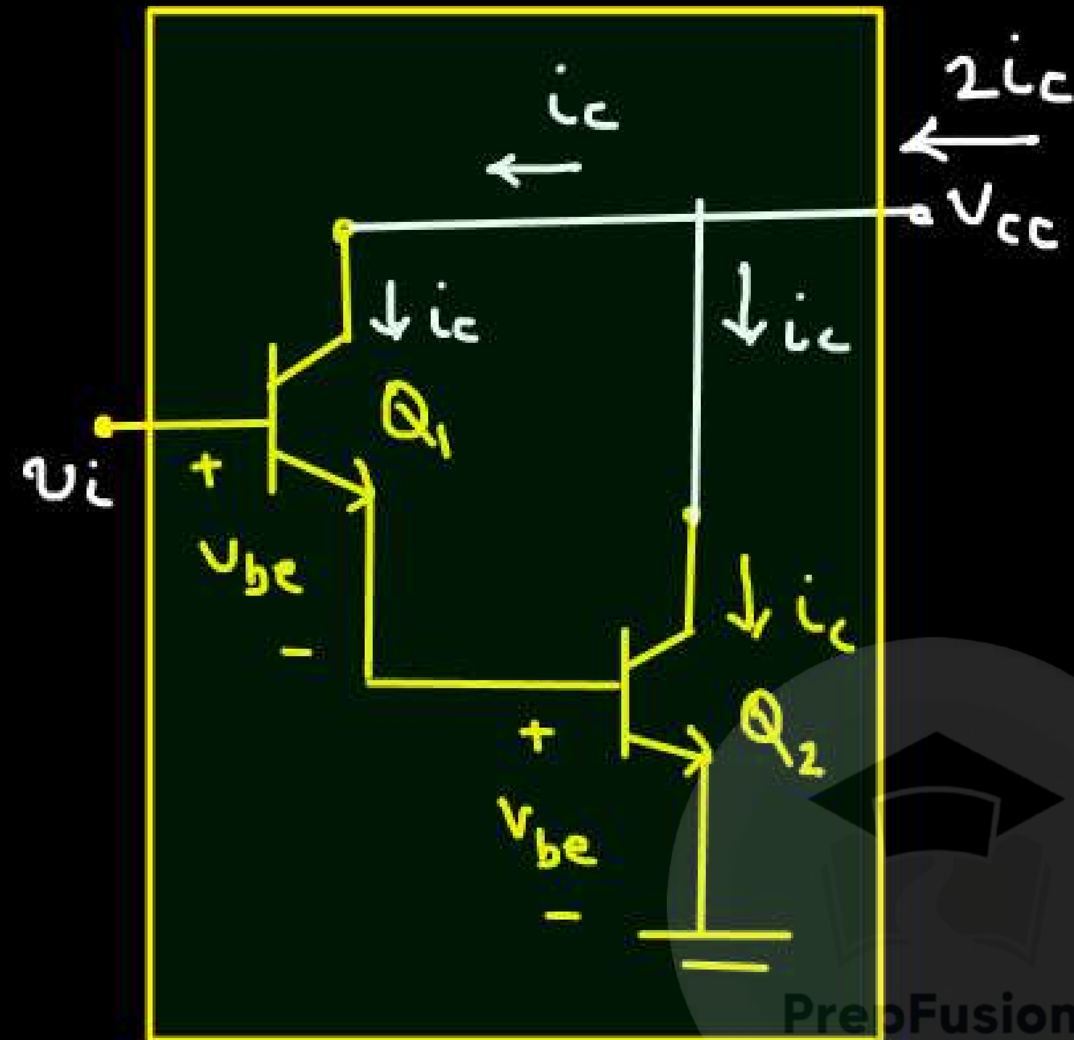
Transconductance of Q_2 is g_{m_2}.

Overall Transconductance ? $[g_m]$



$$\boxed{g_{m_2} = \frac{i_c}{v_{be}}}$$

$$\boxed{g_{m_1} = \frac{i_c}{v_{be}}}$$



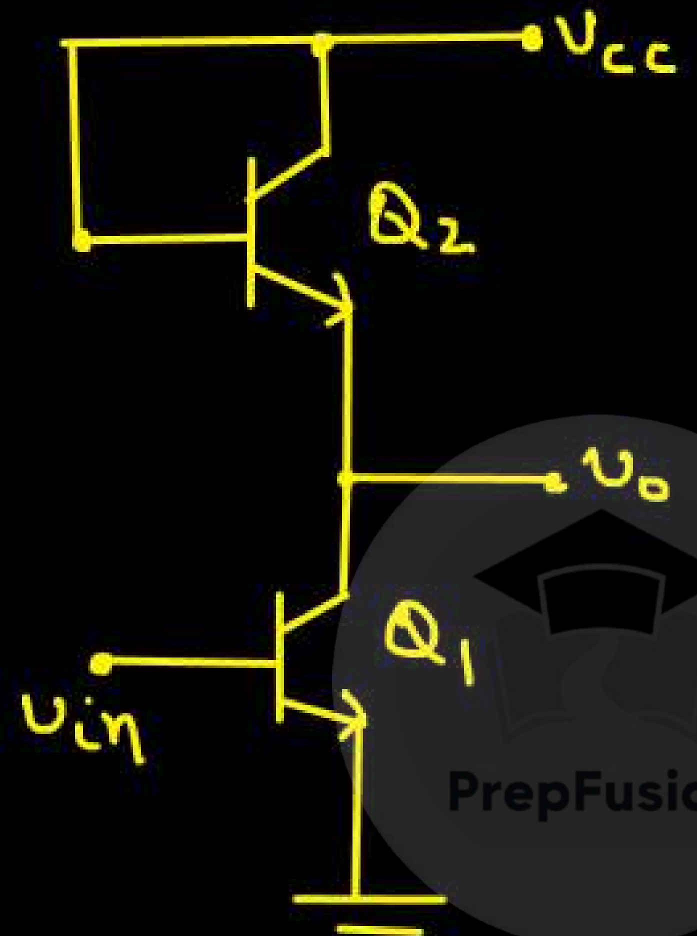
$$g_m = \frac{2i_c}{v_i}$$

$$v_i = 2v_{be}$$

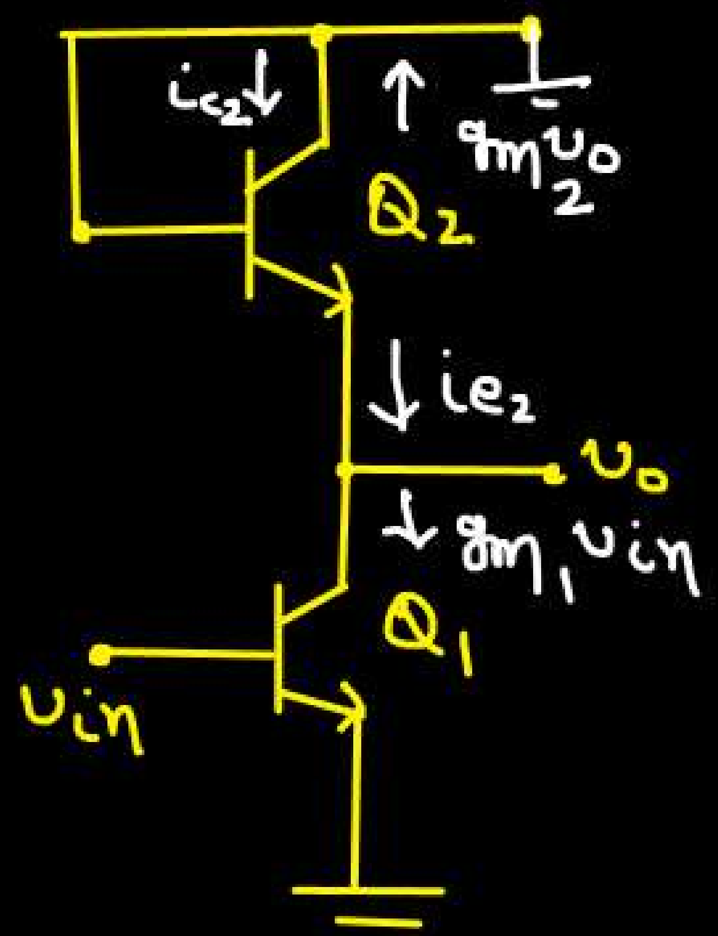
$$g_m = \frac{2i_c}{2v_{be}} = \frac{i_c}{v_{be}}$$

$$\boxed{g_m = g_{m_1} = g_{m_2}}$$

Q. Find small signal voltage gain $|A_v|$ $[V_A = \infty]$



(a) $\dfrac{g_{m_1} r_{\pi_2}}{1 + g_{m_2} r_{\pi_2}}$ (b) $\dfrac{g_{m_2} r_{\pi_2}}{1 + g_{m_2} r_{\pi_2}}$ (c) $\dfrac{g_{m_1} r_{\pi_1}}{g_{m_2} r_{\pi_2}}$ (d) $\dfrac{g_{m_1} r_{\pi_1}}{1 + g_{m_2} r_{\pi_2}}$



$$(v_{be})_2 = -v_o$$

$$i_{c_2} = -g_{m_2} v_o$$

$$i_{e_2} = -g_{m_2} v_o \times \frac{(\beta_2 + 1)}{\beta_2}$$

$$g_{m_1} v_{in} = -g_{m_2} v_o \frac{(\beta_2 + 1)}{\beta_2}$$

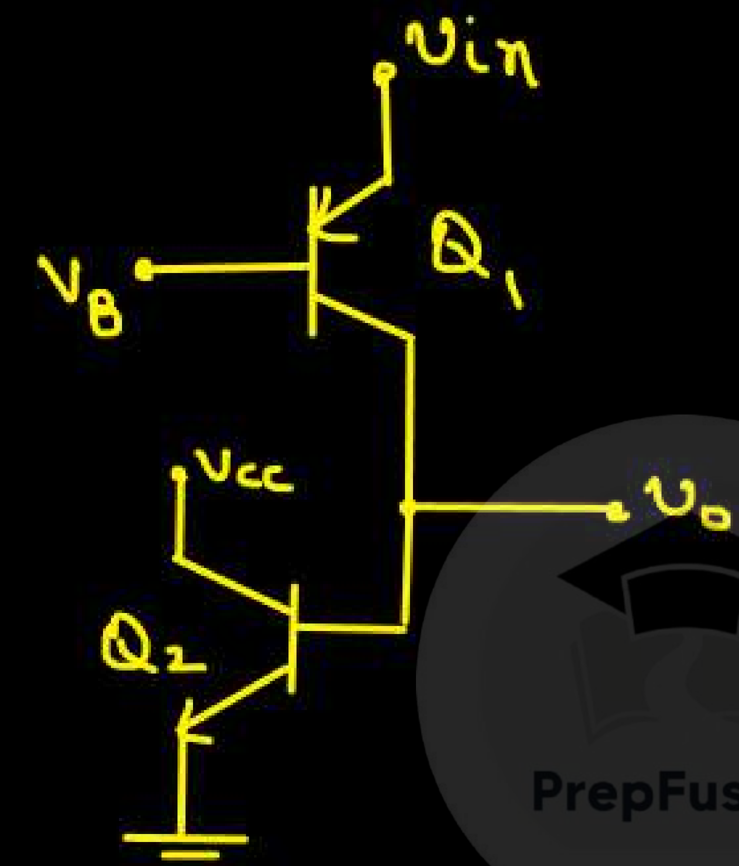
$$\frac{v_o}{v_{in}} = \frac{-g_{m_1} \beta_2}{g_{m_2}(\beta_2 + 1)}$$

$$\boxed{A_v = \frac{-g_{m_1} r_{\pi_2}}{g_{m_2} r_{\pi_2} + 1}}$$

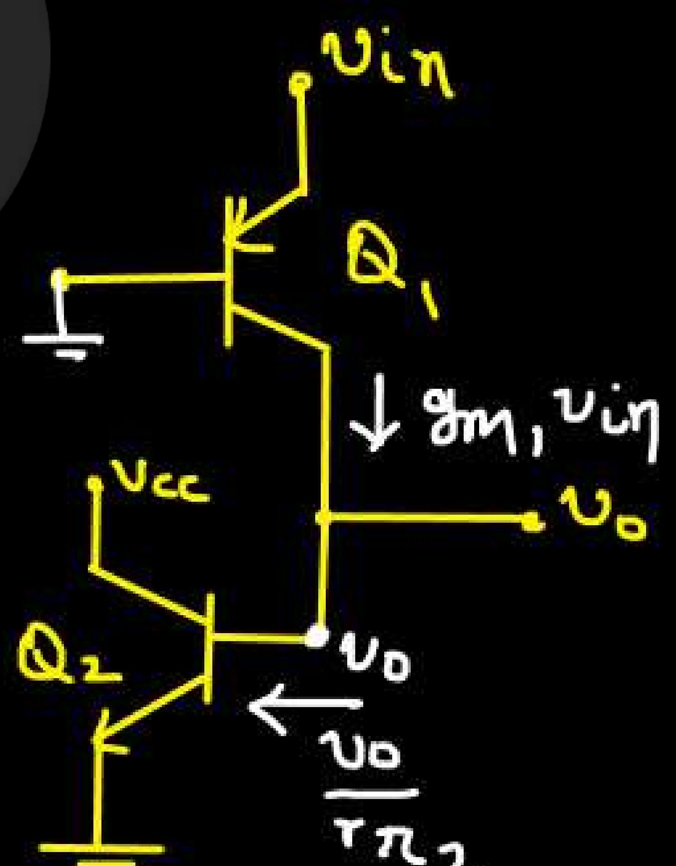
$$r_\pi = \frac{\beta}{g_m}$$

$$\beta = r_\pi g_m$$

Q. Find overall voltage gain. ($|A_v|$)



→



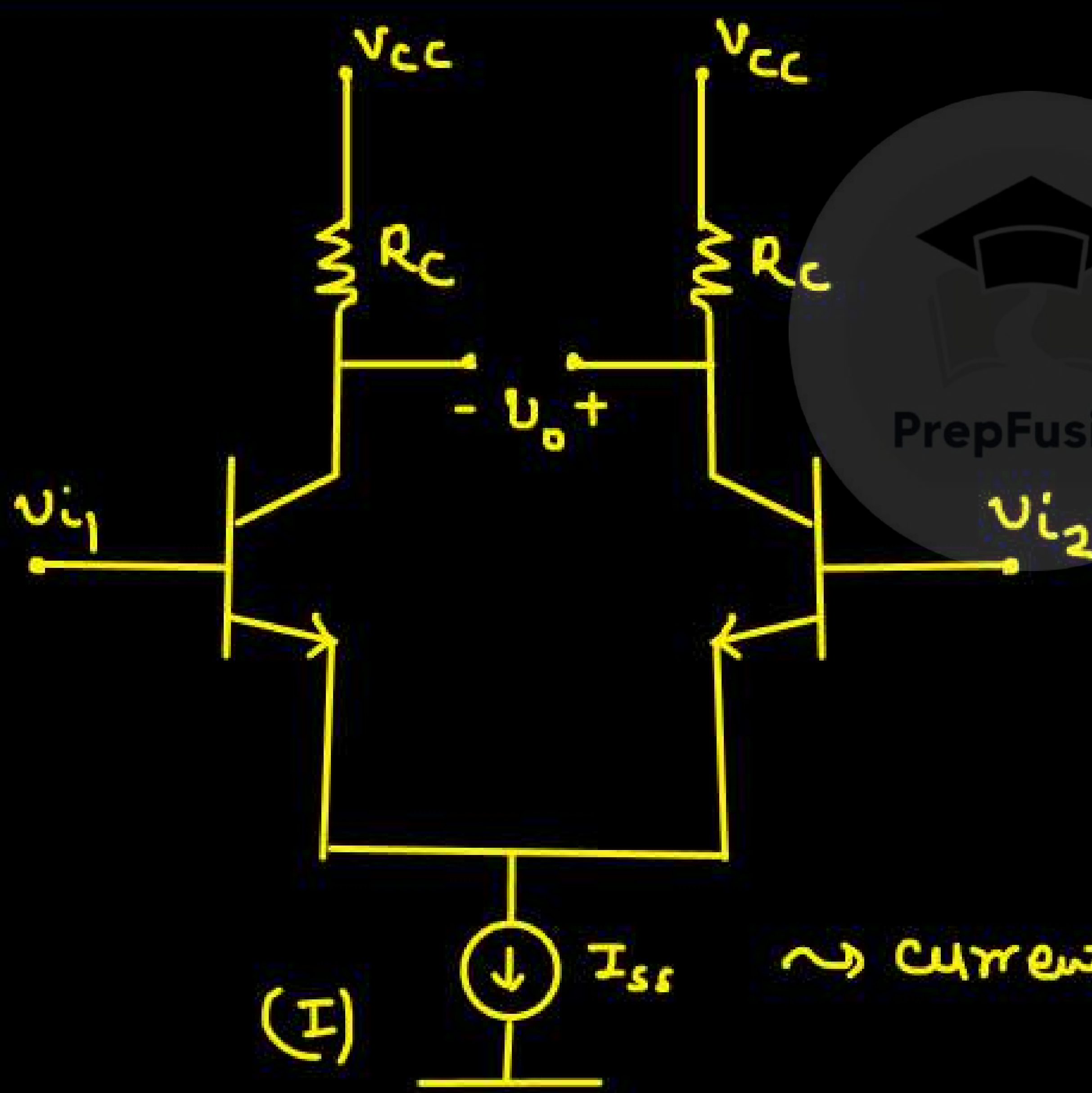
$$g_{m_1} v_{in} = \frac{v_o}{r_{\pi_2}}$$

$$\boxed{\frac{v_o}{v_{in}} = g_{m_1} r_{\pi_2}}$$

Differential Amplifier using BJT

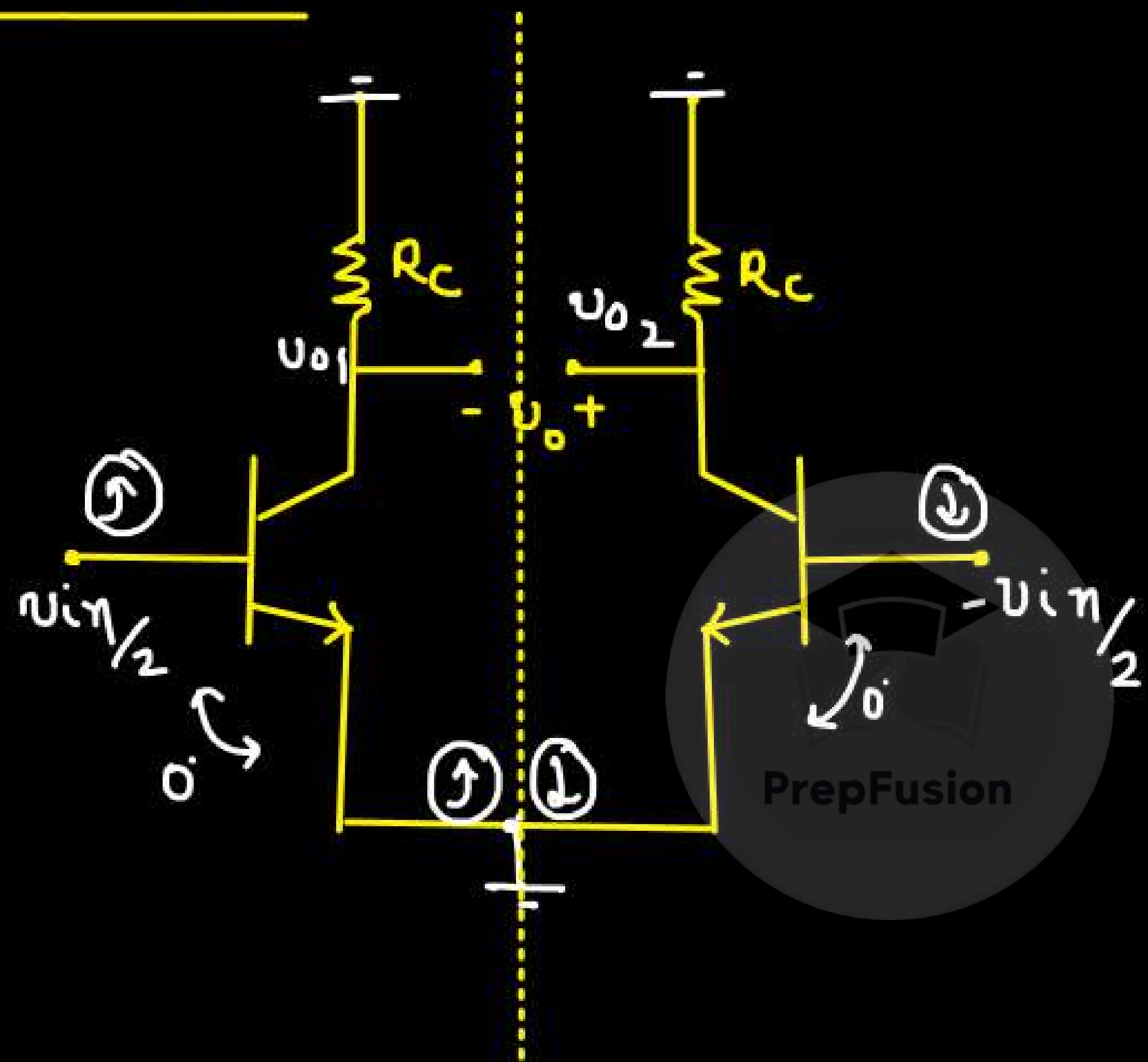
(Small Signal Analysis)

1. **Dual Input - balanced output :-**



~> current Source as a tail

(a) Differential Gain :-



$$v_{o1} = -g_m R_C \frac{v_{in}}{2}$$

$$v_{o2} = -g_m R_C\left(-\frac{v_{in}}{2}\right)$$

$$= g_m R_C \frac{v_{in}}{2}$$

$$v_o = v_{o2} - v_{o1}$$

$$v_o = g_m R_C v_{in}$$

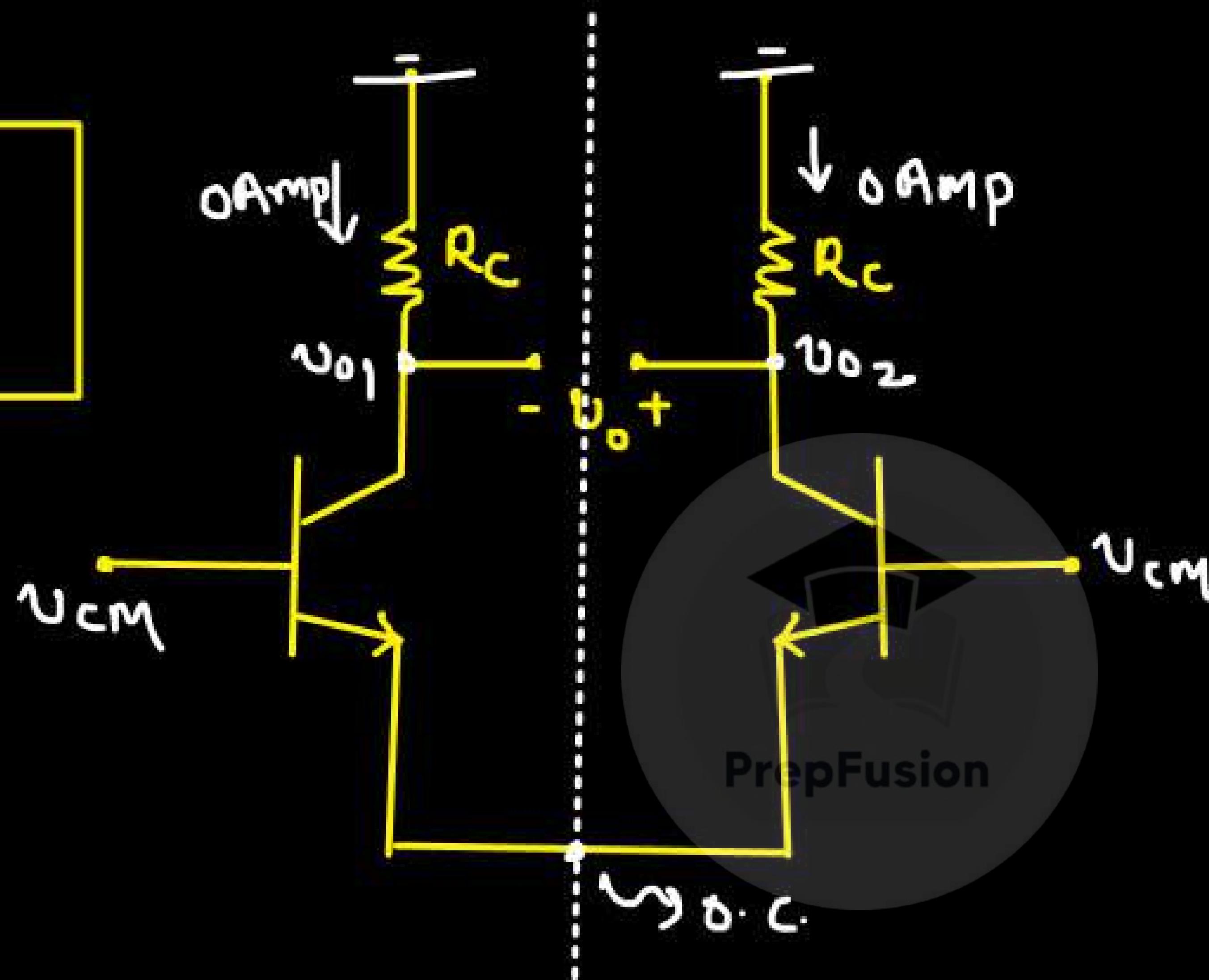
$$\boxed{A_d = \frac{v_o}{v_i} = g_m R_C}$$

(b) Common Mode Differential Gain (A_{CM-DM}):-

$$\boxed{CMRR = \frac{A_d}{A_{CM-DM}}}$$

*

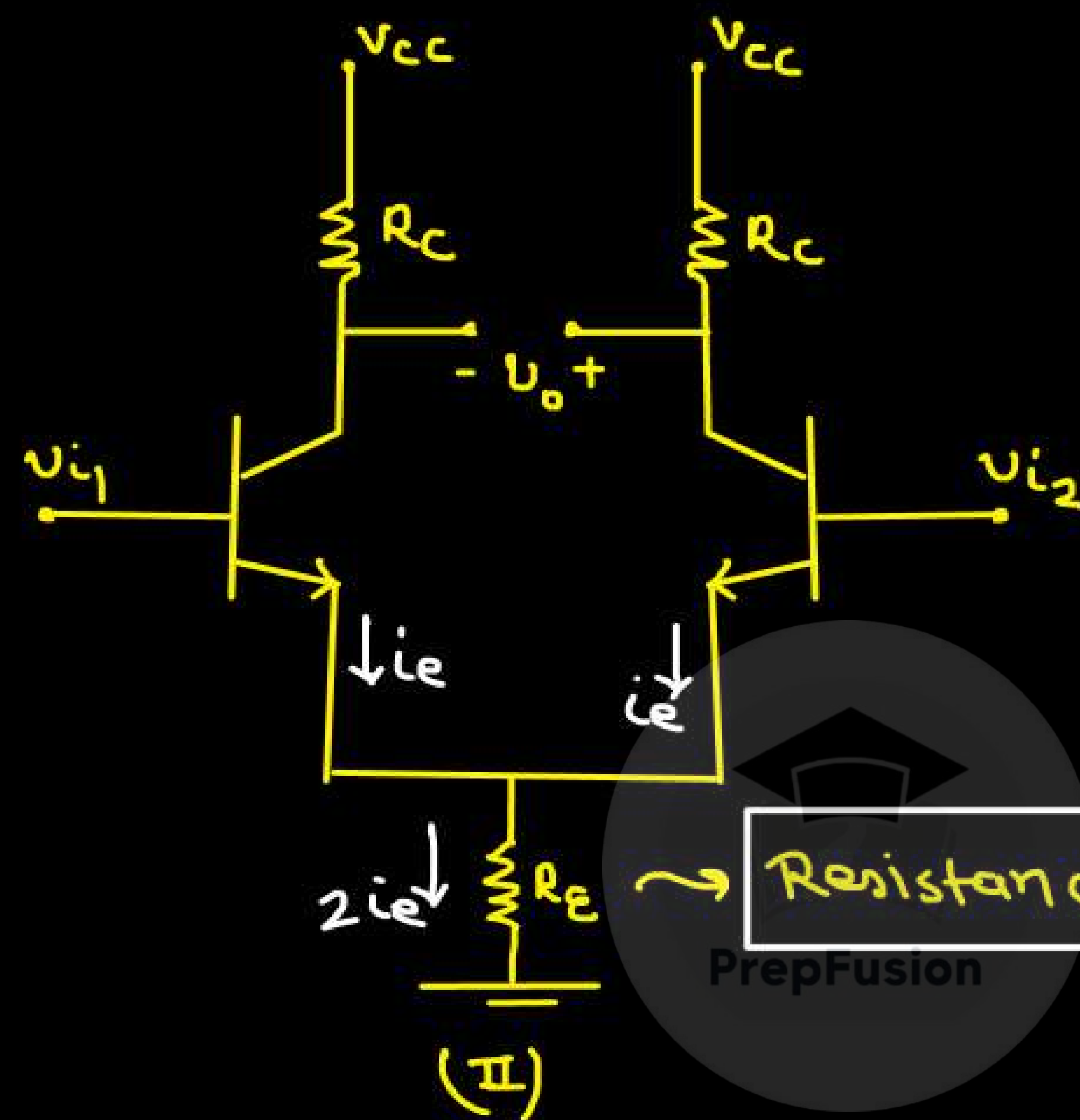
$$\boxed{CMRR = \infty}$$



$$v_{o2} = v_{o1} = 0$$

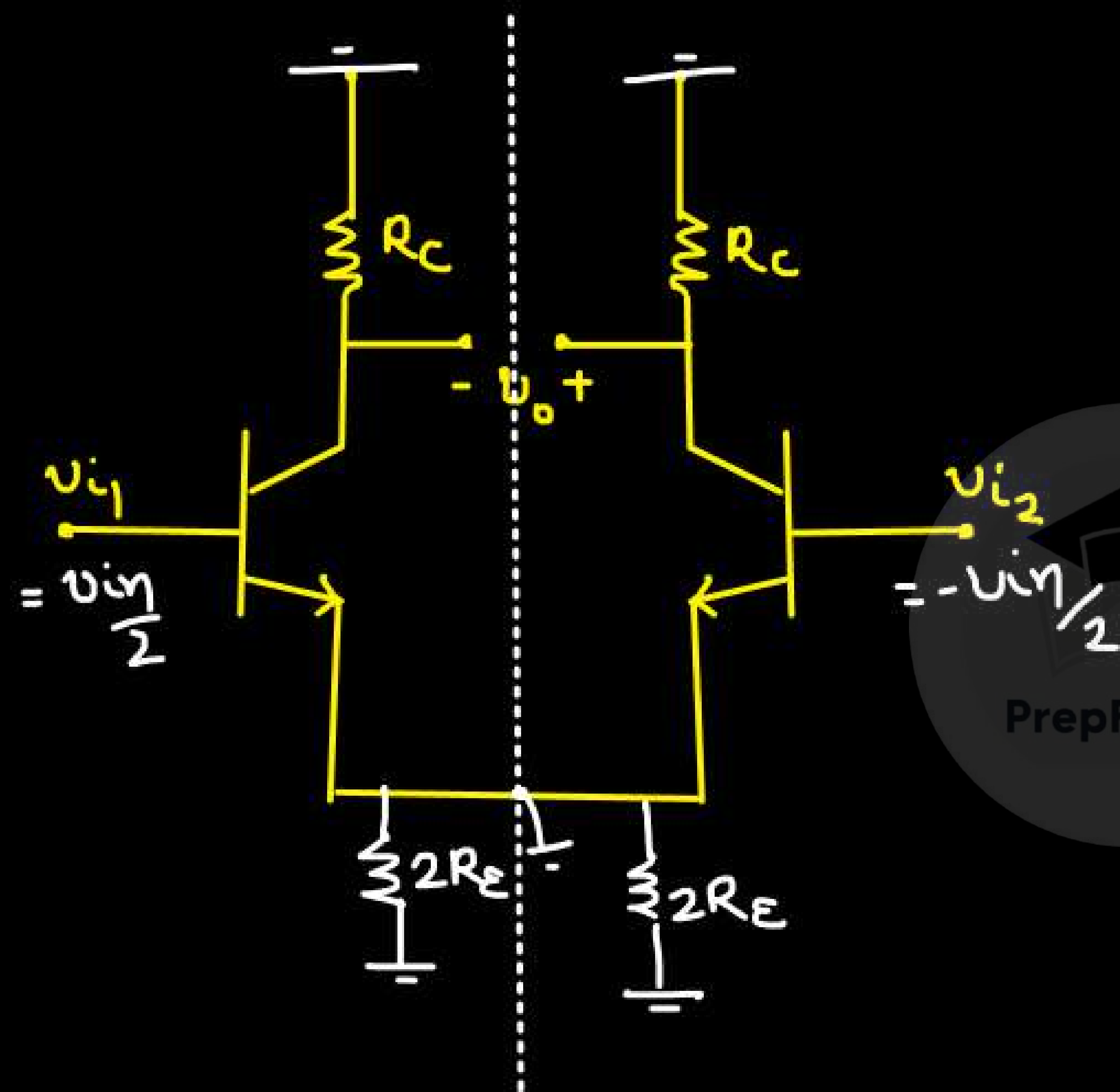
$$A_{CM-DM} = \frac{v_{o2} - v_{o1}}{v_{CM}}$$

$$\boxed{A_{CM-DM} = 0}$$



→ Resistance as tail

(a) Differential Gain (A_d):-

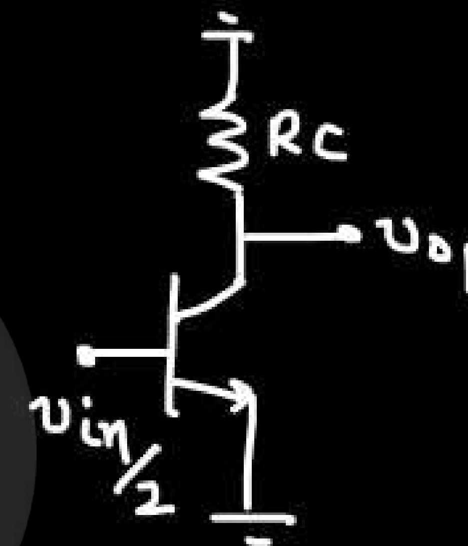


$$v_{o_1} = -g_m R_C v_{in}/2$$

$$v_{o_2} = g_m R_C v_{in}/2$$

$$v_o = g_m R_C v_{in}$$

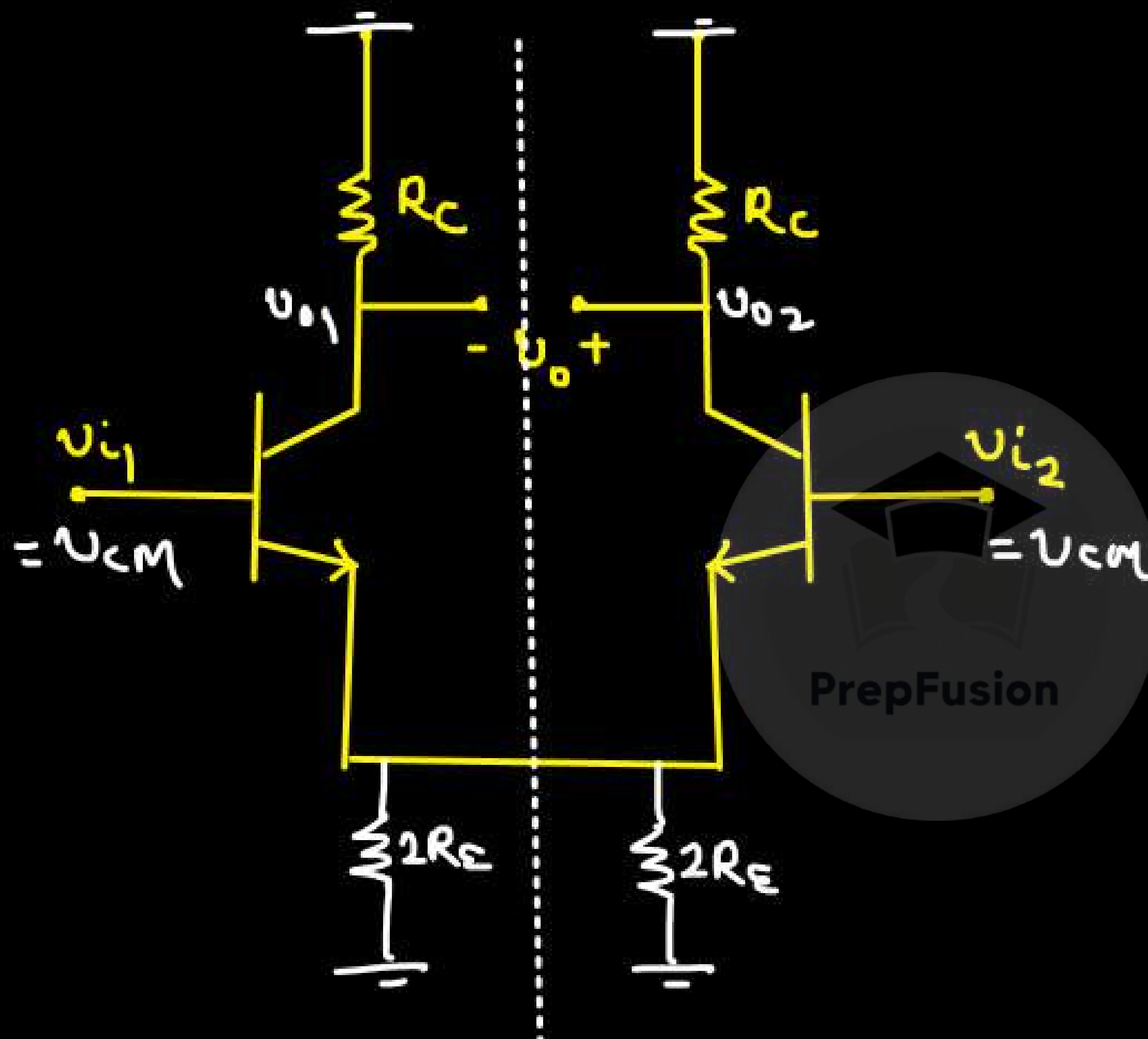
$$v_{id} = v_i$$



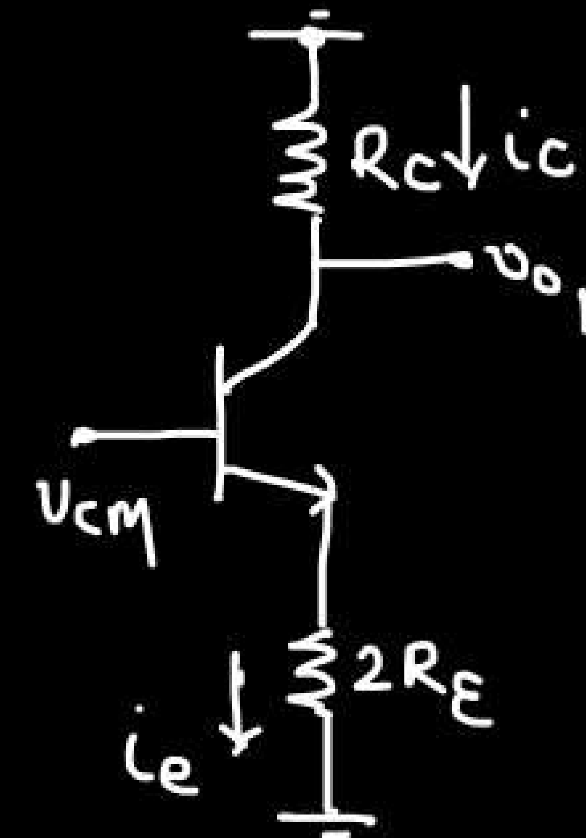
$$\boxed{A_d = g_m R_C}$$

$$\boxed{A_d = g_m R_C}$$

(b) Common Mode Differential Gain (A_{CM-DM}):-



$\Rightarrow$



$$v_{o1} = -i_c R_C$$

$$v_{CM} = r_\pi i_b + 2R_E \times (\beta+1)\, i_b$$

$$i_c = \frac{\beta v_{CM}}{r_\pi + 2R_E(\beta+1)}$$

$$\boxed{v_{o1} = \frac{-\beta R_C v_{CM}}{r_\pi + 2R_E(\beta+1)}}$$

$$v_{o_2} = \frac{-\beta R_C v_{cM}}{r_\pi + 2R_E(\beta+1)}$$

$$(v_i)_{cM} = v_{cM}$$

$$(v_o)_{cM-DM} = v_{o_2} - v_{o_1}$$

$$= 0$$

$$\boxed{A_{cM-DM} = 0}$$

$$\boxed{CMRR = \frac{A_d}{A_{cM-DM}} = \infty}$$

$$(v_i)_{cM} = v_{cM}$$

$$(v_o)_{cM} = \frac{v_{o_1} + v_{o_2}}{2}$$

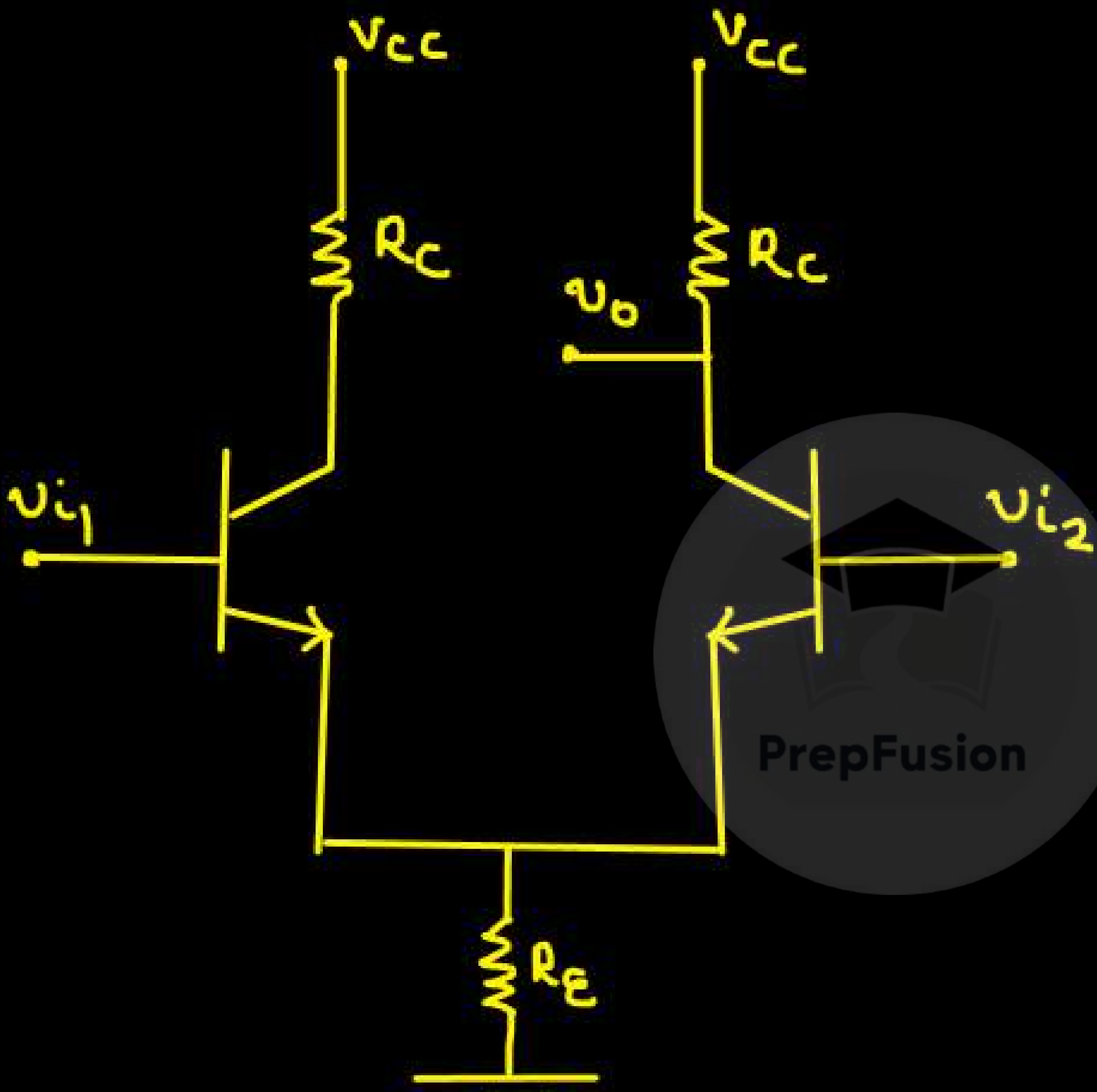
$$\boxed{A_{cM} = \frac{-\beta R_C v_{cM}}{r_\pi + 2R_E(\beta+1)}}$$

$R_E \uparrow \Rightarrow A_{cM} \downarrow$

if CMRR is defined as $\frac{A_d}{A_{cM}}$

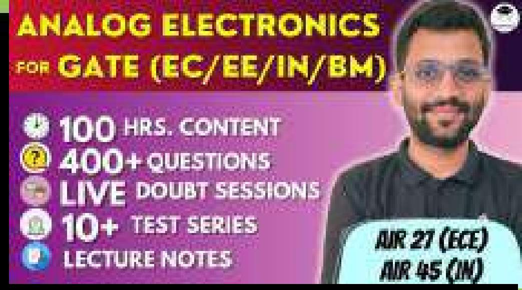
then $R_E \uparrow \Rightarrow A_{cM} \downarrow \Rightarrow CMRR \uparrow$

2. Dual Input Unbalanced Output :-

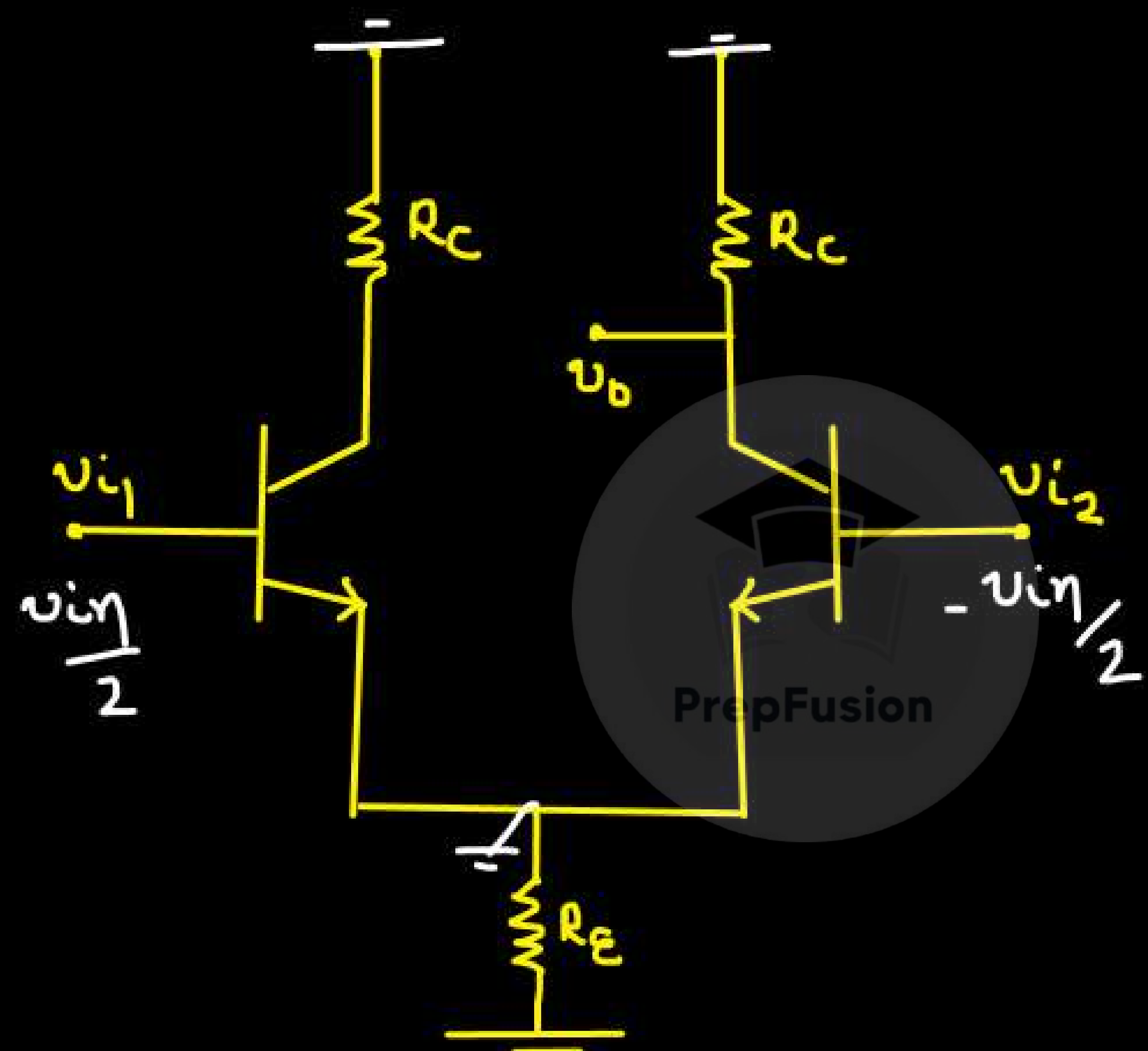


$$(v_o)_d = (v_o)_{CM}$$

$$= (v_o)_{CM-DM} = v_o$$



(a) Differential Gain (A_d):-



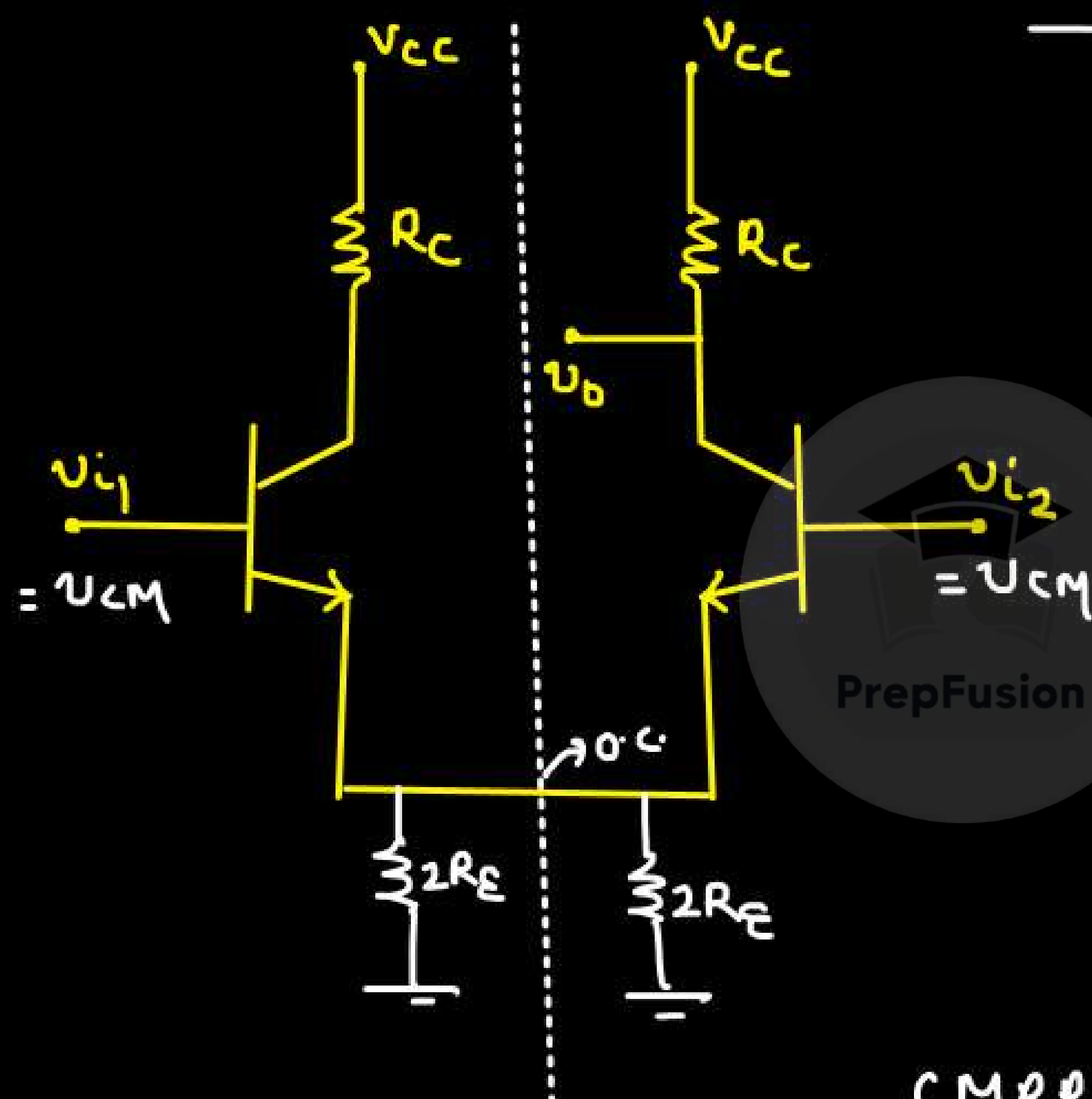
$$(v_0)_d = g_m R_c v_i/2 = v_0$$

$$(v_i)_d = v_i$$

$$\boxed{(A_v)_d = \frac{g_m R_c}{2}}$$

$$= \frac{\beta R_c}{2 r_\pi}$$

(b) Common-Mode Differential Gain :- / Common Mode Differential Gain :-



$$v_0 = \frac{\beta R_C v_{CM}}{r_\pi + 2R_E(\beta+1)}$$

$$\boxed{A_{CM} = A_{CM-DM} = \frac{\beta R_C}{r_\pi + 2R_E(\beta+1)}}$$

$$CMRR = \frac{A_d}{A_{CM-DM}} = \frac{\beta R_C}{2r_\pi} \times \frac{r_\pi + 2R_E(\beta+1)}{\beta R_C}$$

$$\boxed{CMRR = \frac{1}{2} + \frac{R_E}{r_\pi}(\beta+1)}$$

$$\left\{ \frac{\beta}{r_\pi} = g_m \right\}$$

$$\beta + 1 \approx \beta$$

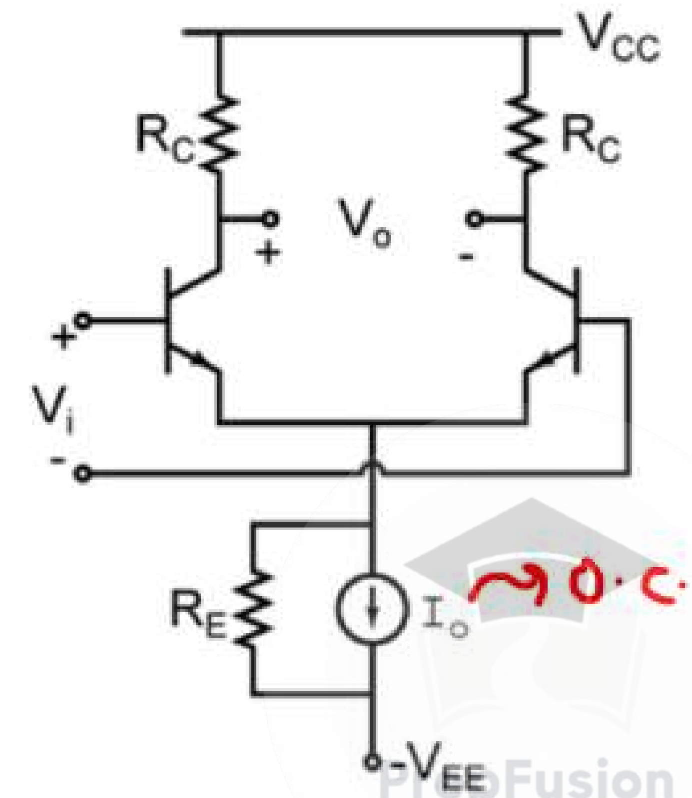
$$CMRR \approx \frac{1}{2} + g_m R_E$$

$$\boxed{CMRR \approx g_m R_E}$$

Q. 1

In the differential amplifier shown in the figure, the magnitudes of the common-mode and differential-mode gains are A_{cm} and A_d, respectively. If the resistance R_E is increased, then

$$CMRR = \frac{A_d}{A_c}$$



~~(A) A_{cm} increases~~ (B) common-mode rejection ratio increases

~~(C) A_d increases~~ (D) common-mode rejection ratio decreases

→ $A_d = g_m R_C$

$$A_c = \frac{\beta R_C}{r_\pi + 2(\beta+1) R_E}$$

$R_E \uparrow \Rightarrow A_c \downarrow$, $A_d \sim$

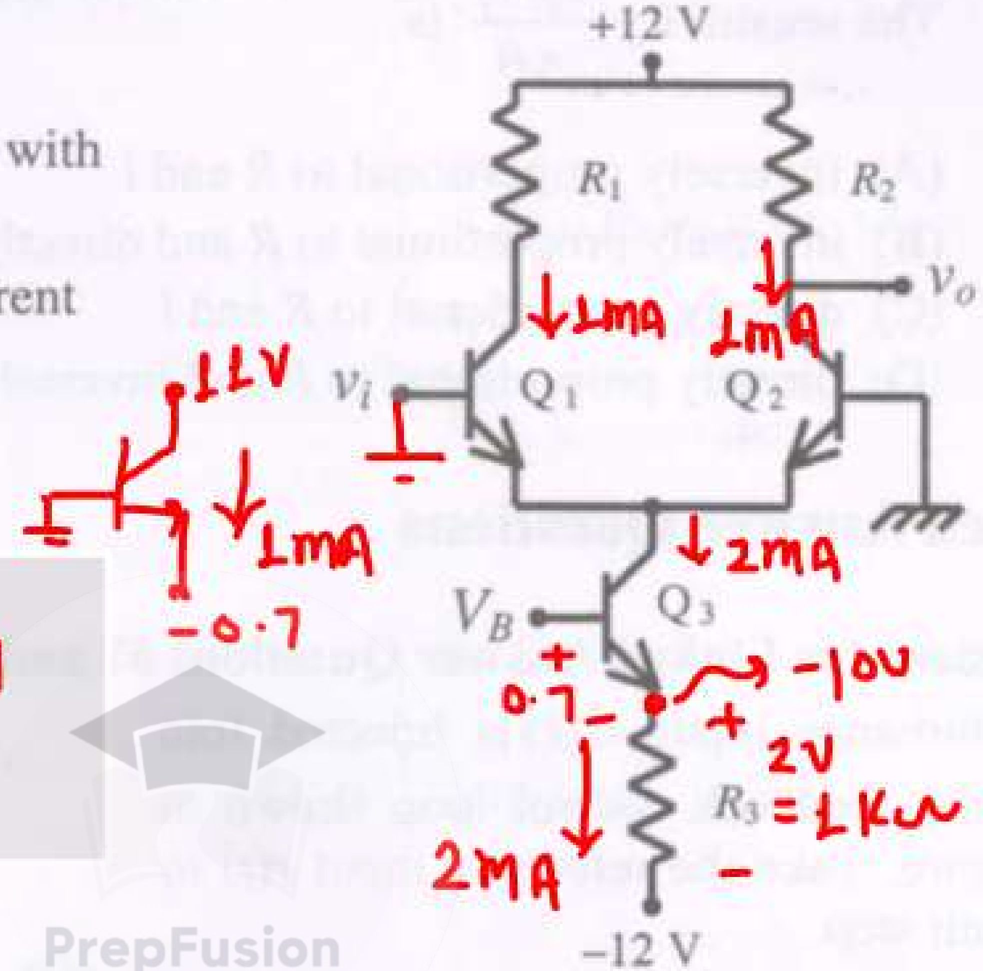
⇓

No change

CMRR ↑

Common Data for Questions 53 and 54 :

The circuit shown in the figure uses three identical transistors with $V_{BE} = 0.7$ V and $\beta = 100$.
Given $R_1 = R_2 = R_3 = 1\ \text{k}\Omega$, $kT/q_e = 25$ mV. The collector current of transistor Q_3 is 2 mA.



$g_m = \frac{1mA}{25mV}$

$V_B = -10 + 0.7$
$= -9.3V$

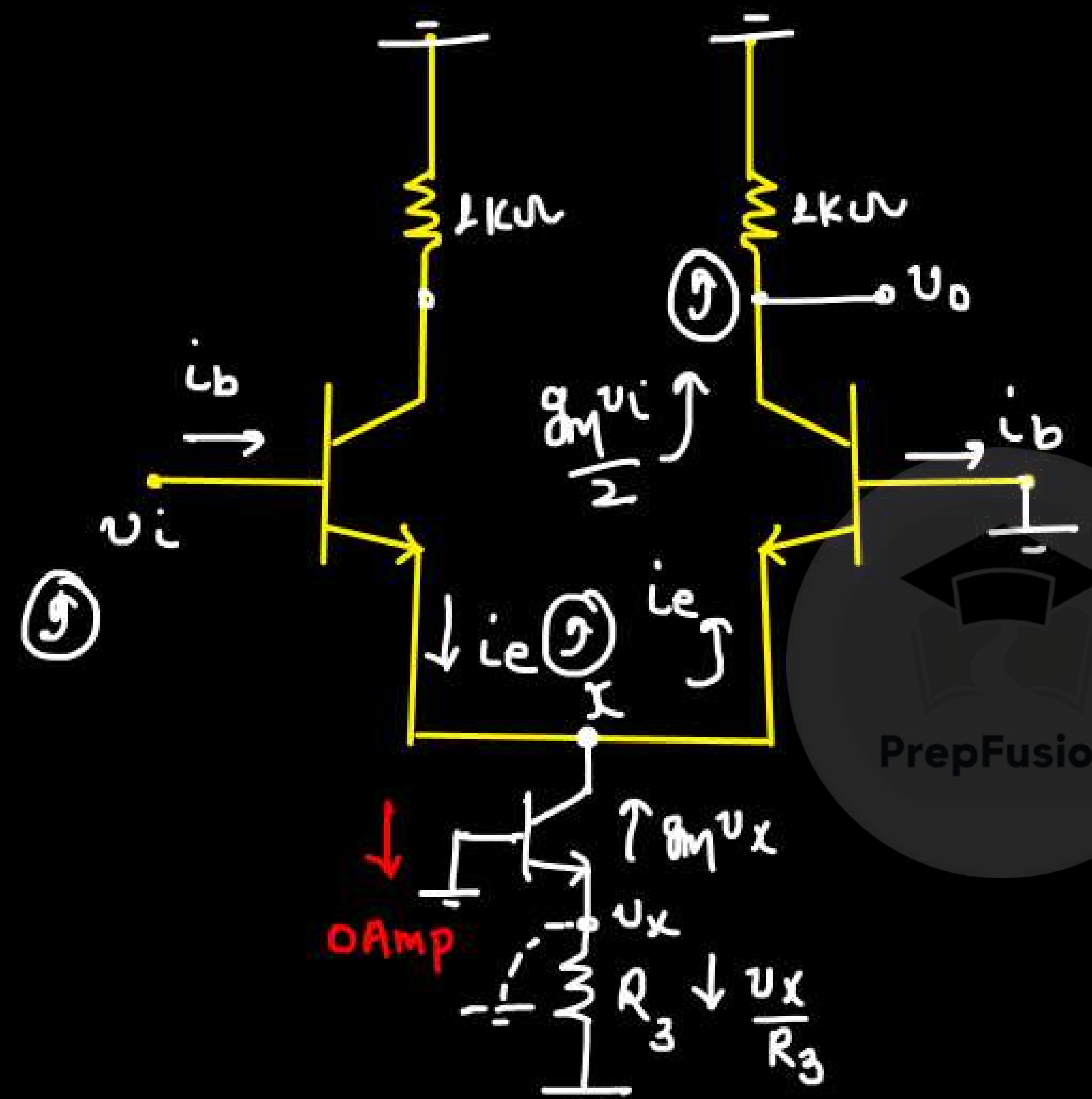
Q.53 The bias voltage V_B at the base of the transistor Q_3 is approximately

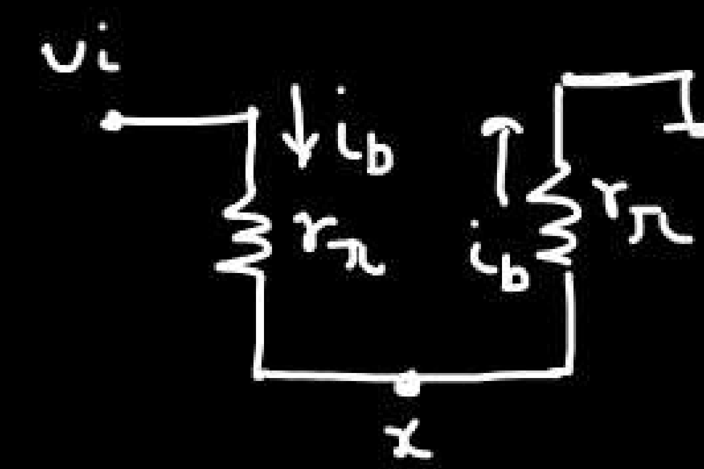
(A) – 9.3 V (B) – 10.0 V (C) – 10.3 V (D) – 11.0 V

Q.54 The small-signal voltage gain of the circuit is

(A) – 20 (B) – 40

(C) 20 (D) 40





$$\boxed{x = v_i/2}$$

$$g_m v_x = -v_x/3$$

$$\Rightarrow \boxed{v_x = 0}$$

$$\boxed{v_o = \frac{g_m v_i}{2} \times 1\,k\Omega}$$

$$\frac{v_o}{v_i} = \frac{1}{50} \times 1000$$

$$\boxed{A_v = 20\ V/V}$$

★ Feedback Topologies:-

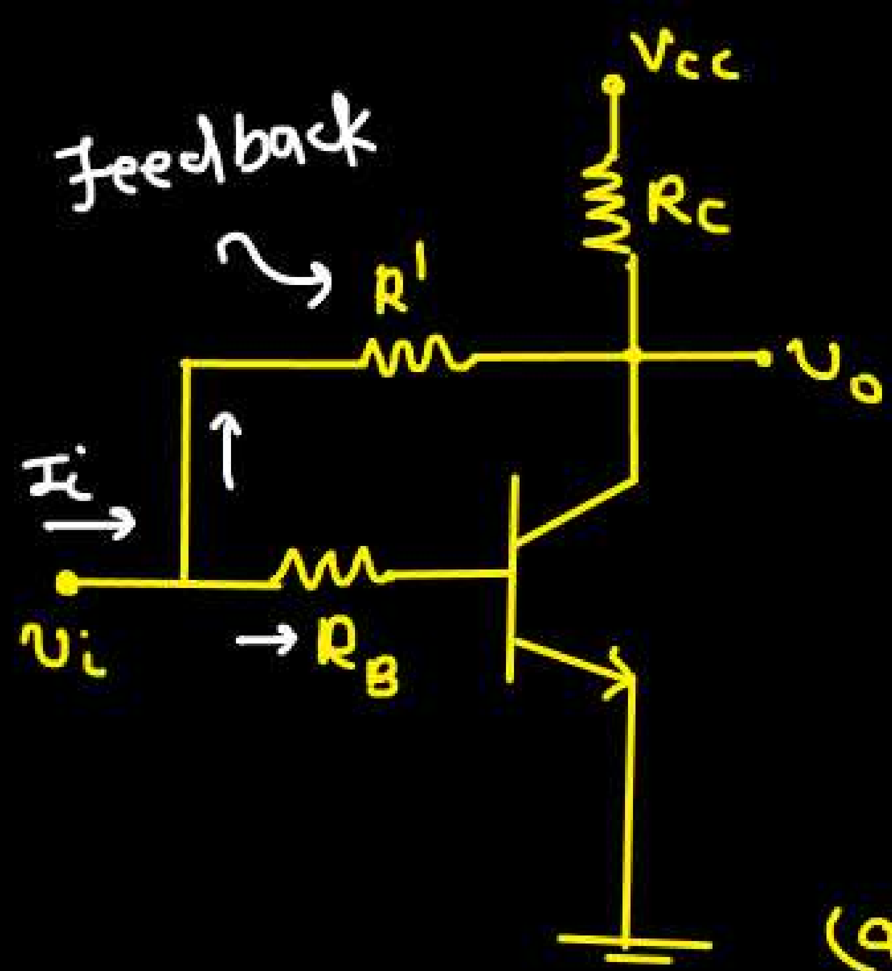
⇓

Same as MOSFETs

i/p → mixing

o/p → sampling

Q. Comment on Feedback Topology.



(a)

Feedback ⇔ output ⇒ connected

⇓

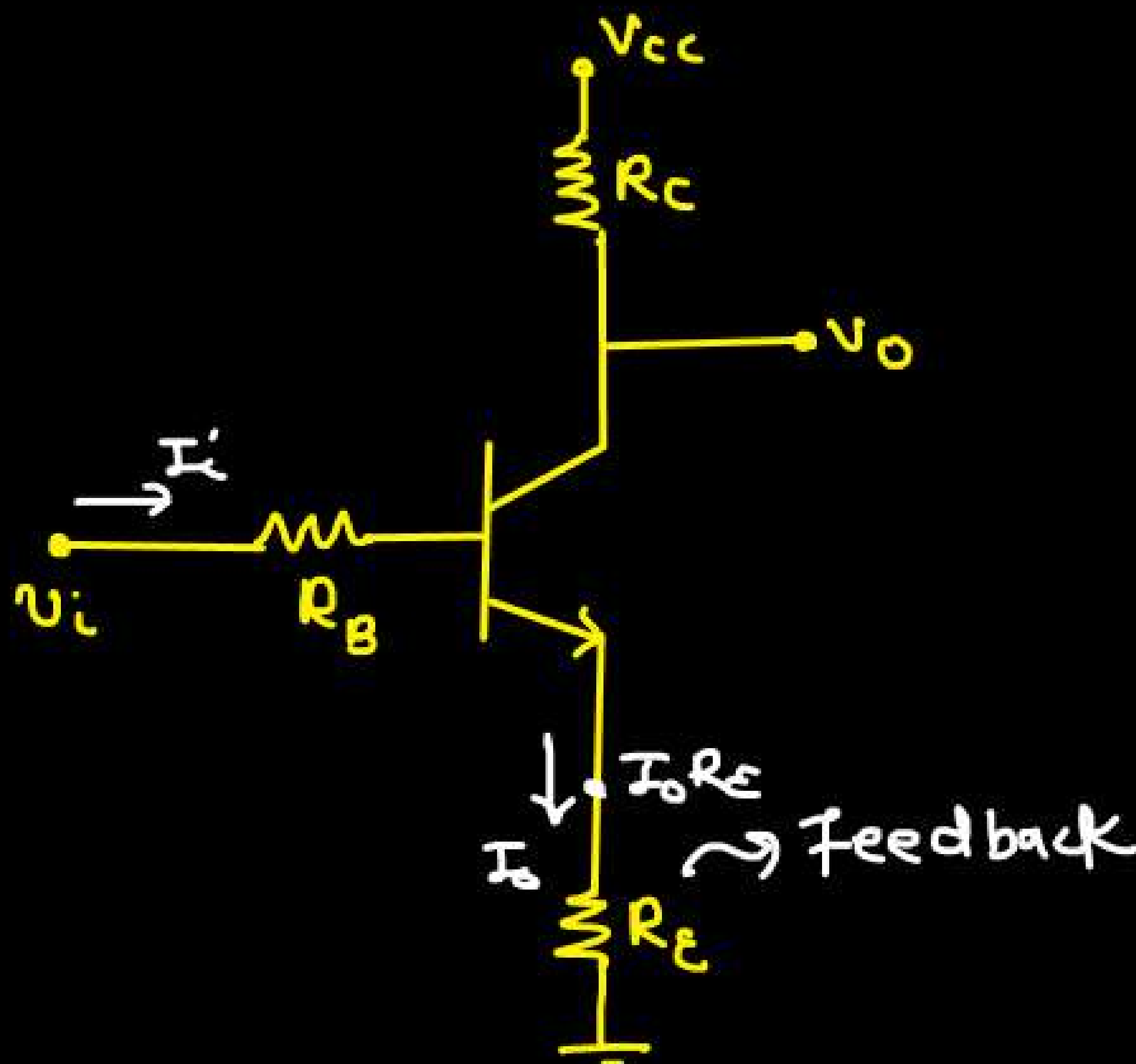
voltage sampling

current mixing

$\boxed{\text{Voltage - Current}}$

$\boxed{\text{Shunt - Shunt}}$

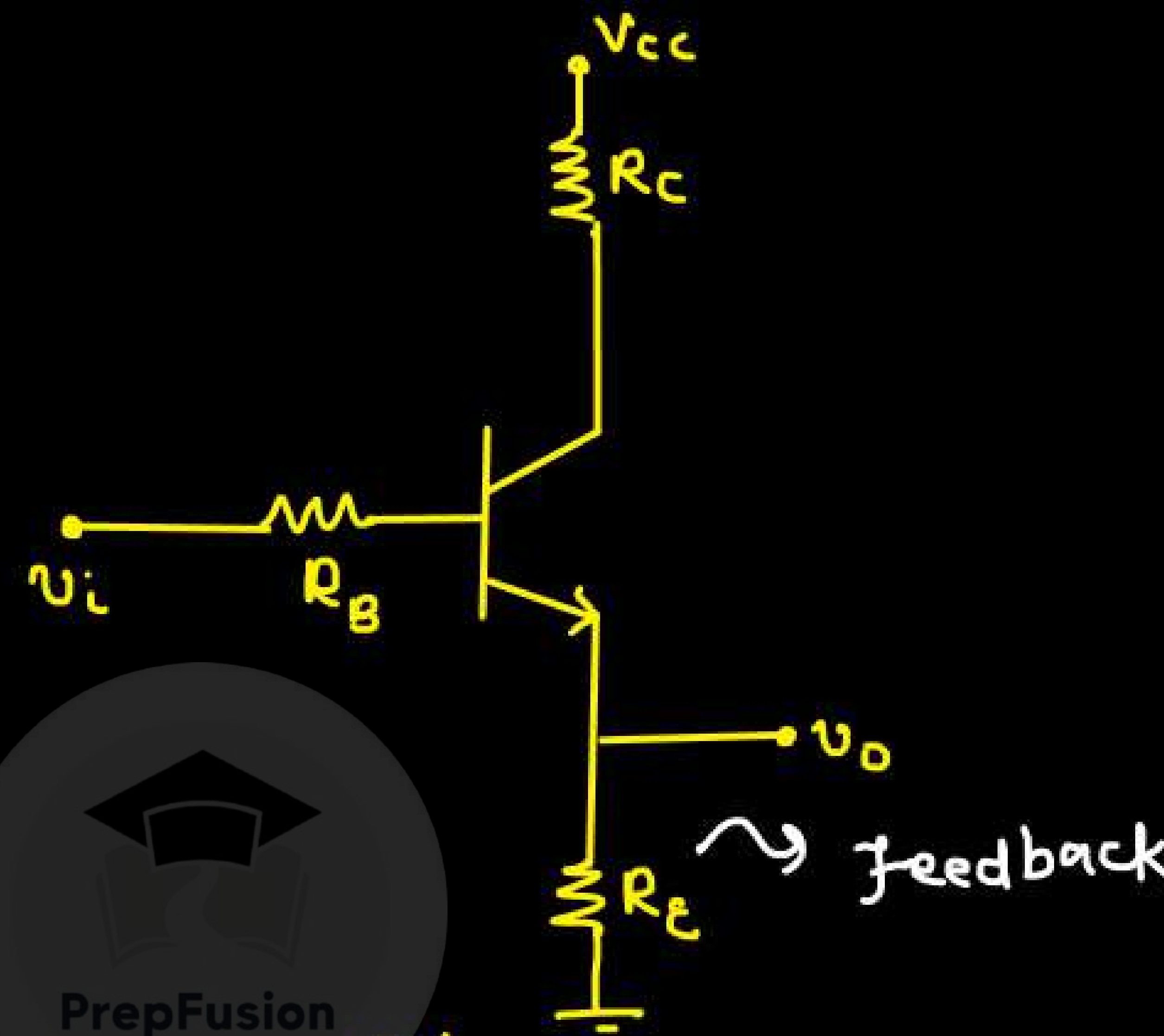
Voltage - shunt



(b)

current sampling
voltage mixing

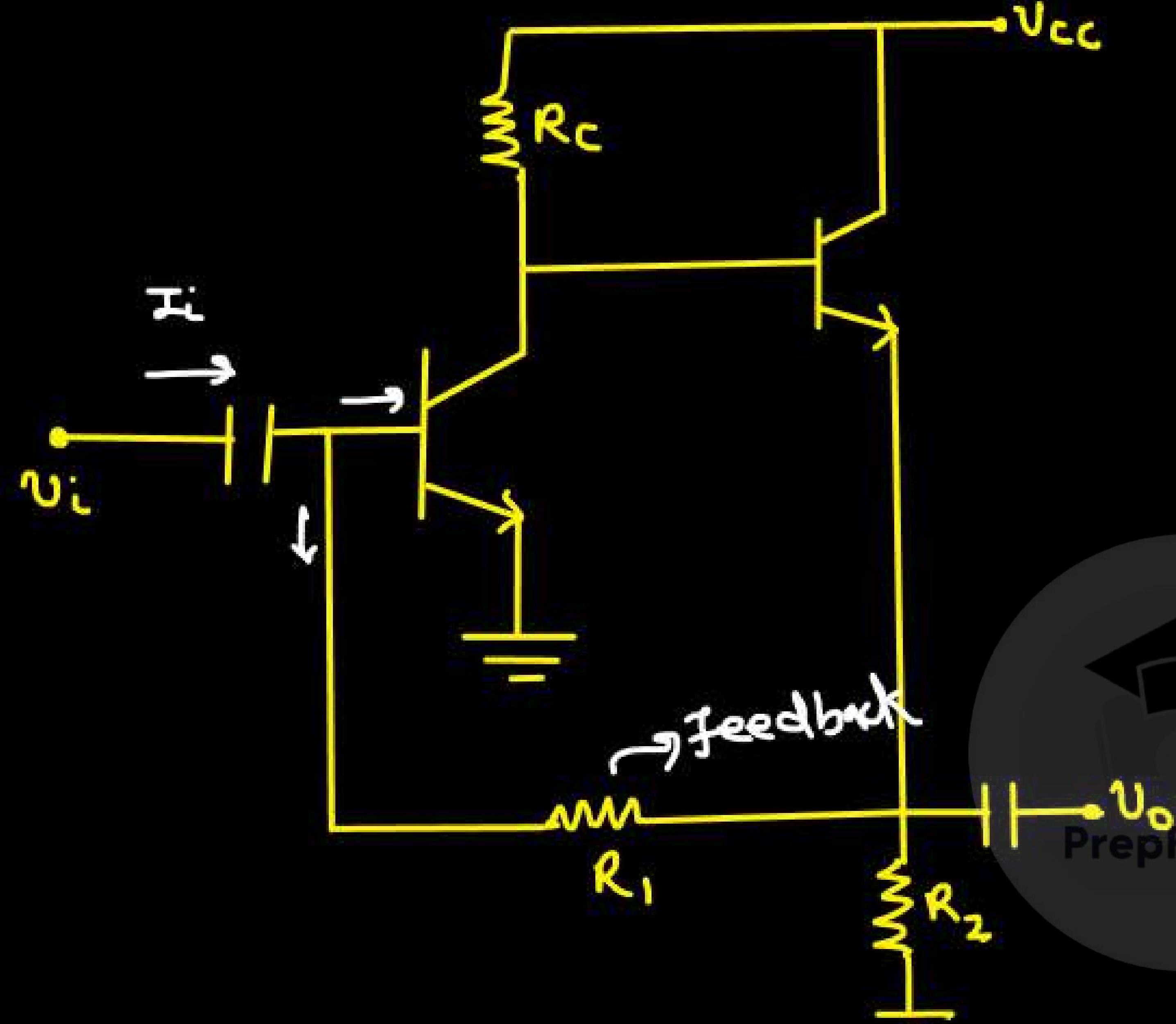
current - voltage



(c)

Voltage Sampling
voltage mixing

Voltage - Voltage



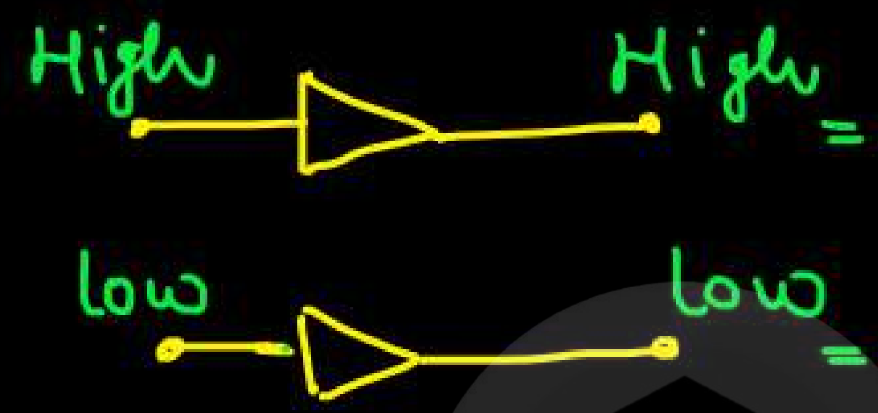
(d)

Voltage sampling
current Mixing

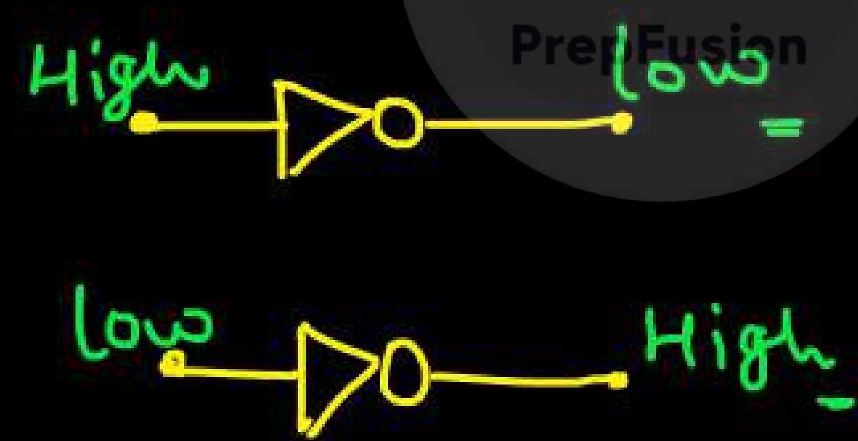
voltage - current

CMOS Inverter

* Buffer :-

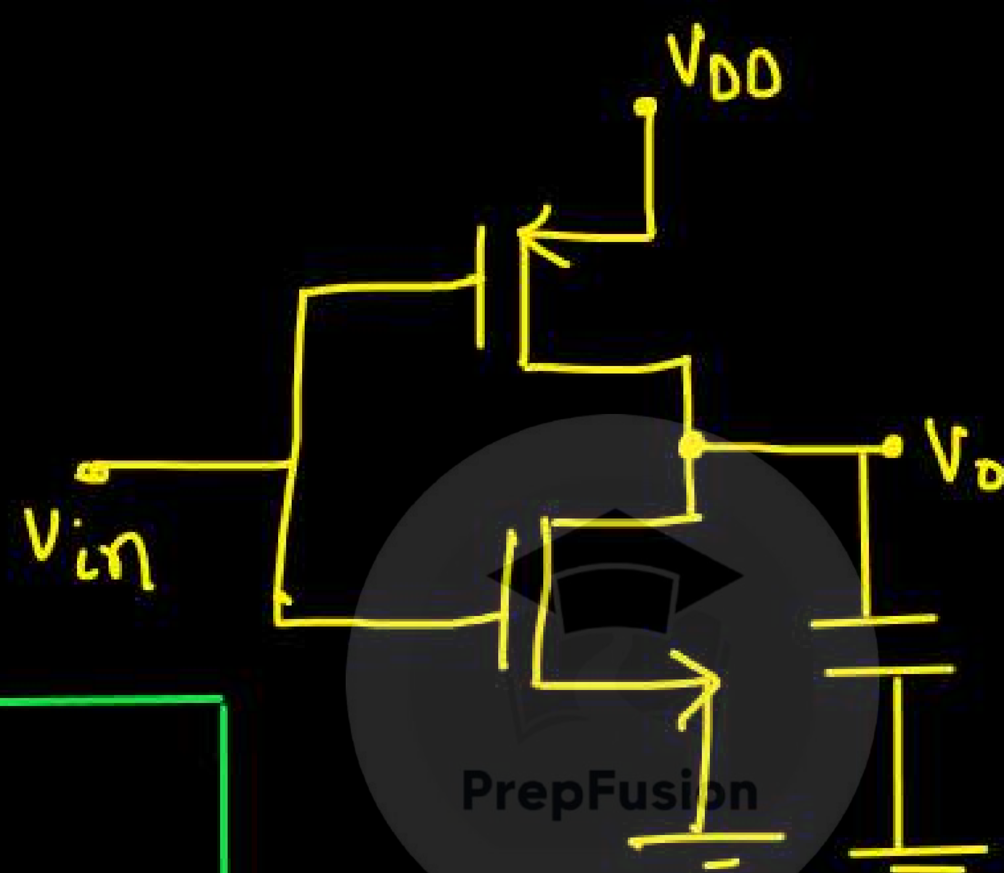


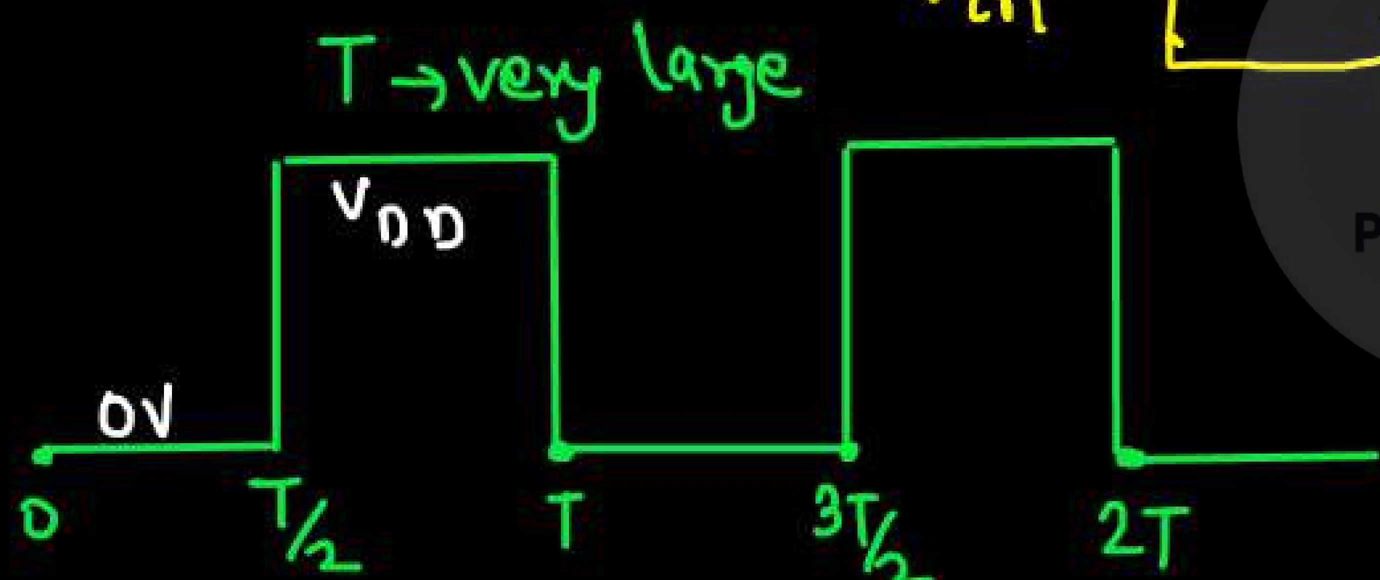
* Inverter :-



CMOS inverter to pulse input :-

→ Let $V_{DD} = 5V$, V





→ for $0 < t < T/2$

$V_{in} = 0$

PMOS →
@ $t = 0$
$V_{sg} = V_{DD} > |V_{tp}|$
$V_{SD} = V_{DD}$
ON , sat.

NMOS
@ $t = 0$
$V_{gs} = 0$
OFF

so, for $0 < t < T/2$ PMOS → ON

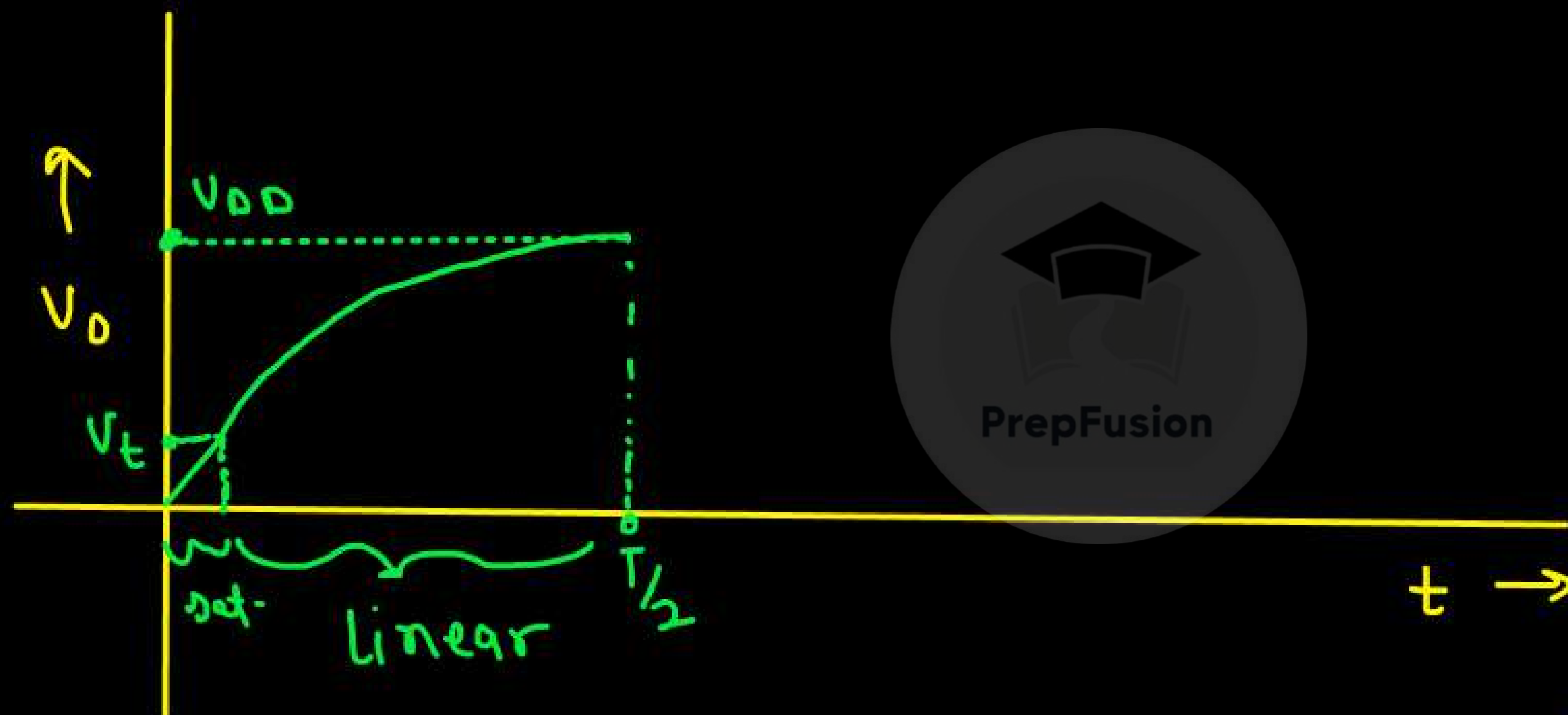
NMOS → OFF → O.C.

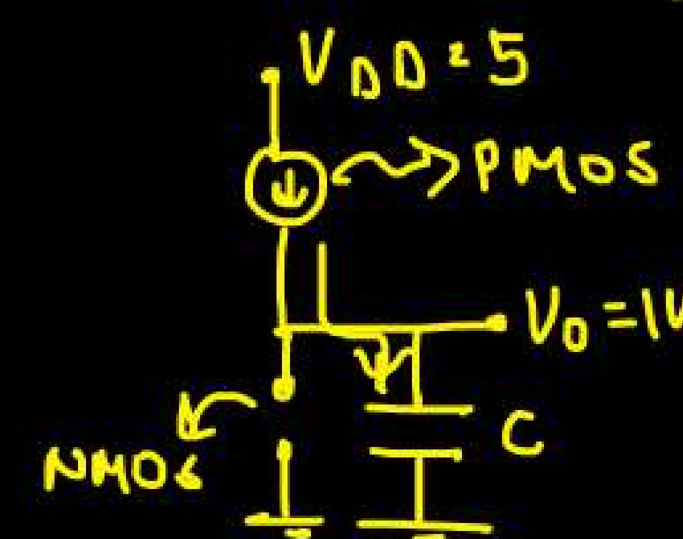
initialy, P...

in ...

⇓

PMOS can be replaced with a current source





Now, V_0 is increasing ⇒ V_{SD} ↓

But $V_{OV} = V_{SG} - |V_{TP}| = 4V$ is fixed

⇒ PMOS is moving toward linear region

so, @ $V_{SD} = V_{SG} - |V_{TP}|$

$V_{DD} - V_0 = 4$

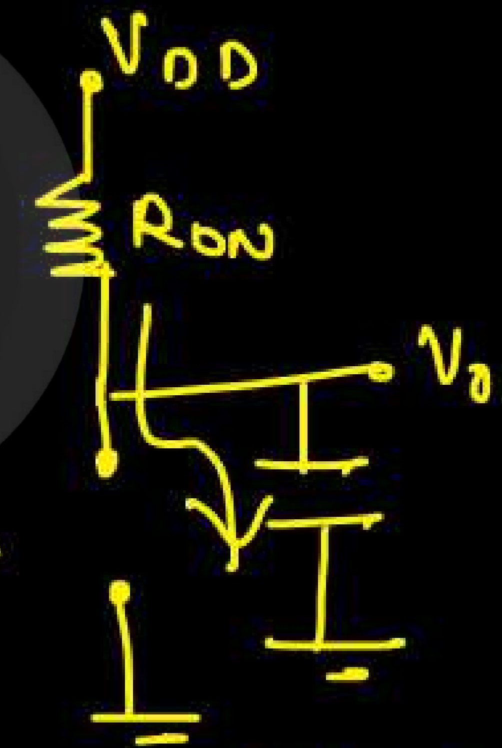
$\underbrace{V_0 = 1V}$ ⇒ when $V_0 > 1V$ ⇒ $V_{SD} < V_{SG} - |V_{TP}|$

⇓

Linear region

⇓

PMOS will be replaced with R_{ON}



NMOS is still off

exponential charging

For $T/2 < t < T$

$V_{in} = 5V$

For PMOS:-

$V_{sg} = 0V \rightarrow$ off

For NMOS

$V_{gs} = 5V$

$V_{ov} = 4V$

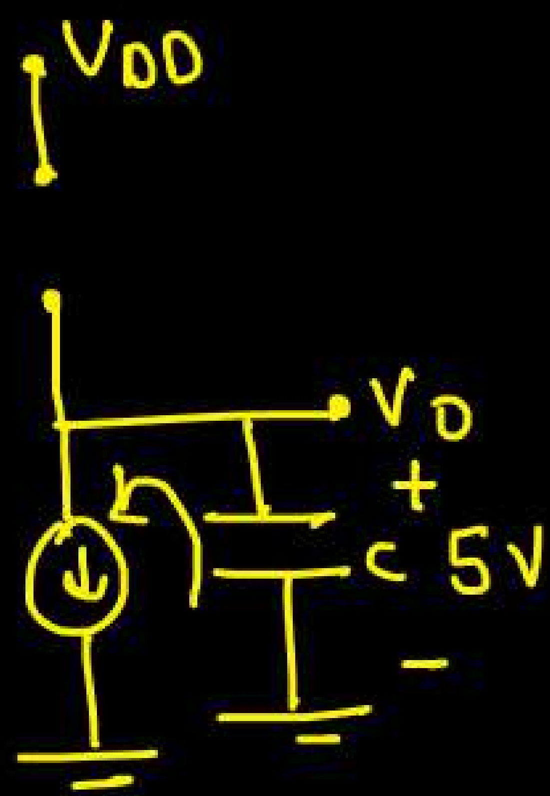
$V_{DS} = V_o$

@ $t=0$ $\quad V_{DS} = 5V$

$V_{DS} > V_{ov} \rightarrow$ sat. region

⇓

NMOS ≡ current source



⇒ This discharges the cap. linearly

⇓

V_o goes down

⇓

$(V_{DS})_n$ goes down

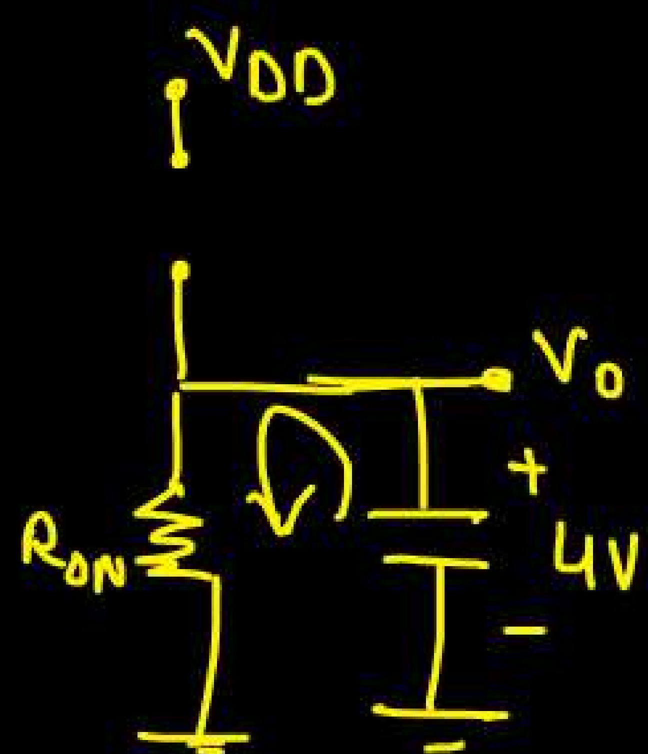
⇓

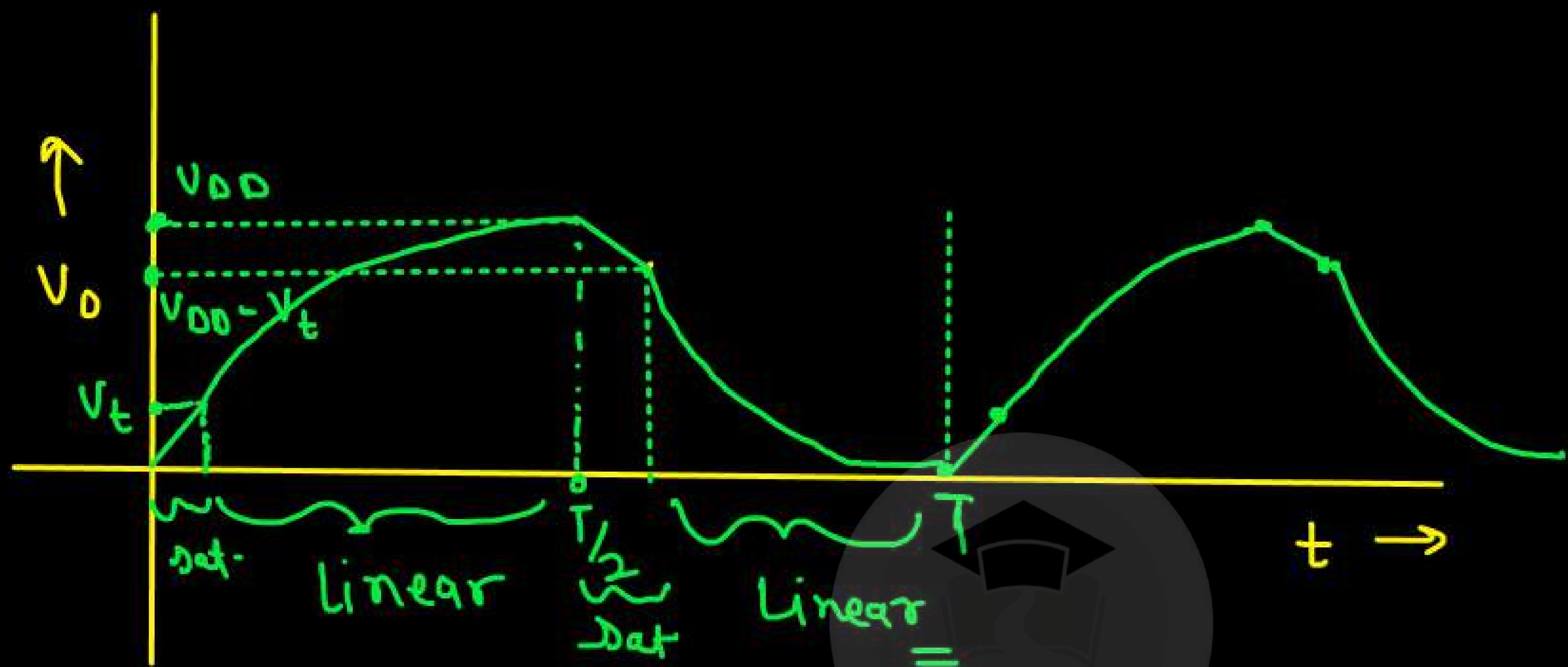
NMOS is moving towards linear region

$V_{SD} < V_{OV}$

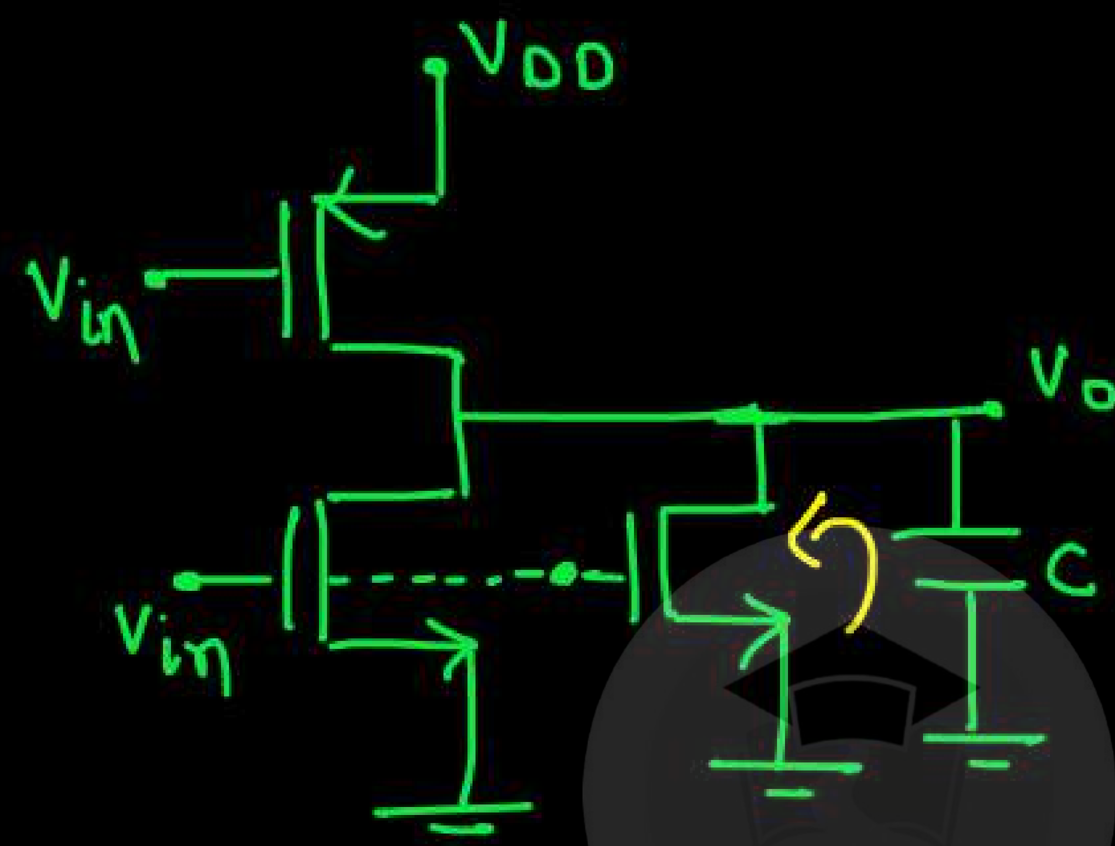
$V_o < 4V$

NMOS will be replaced with R_{ON} ⇐




V_0
V_{DD}
$V_{DD} - V_t$
V_t
sat.
linear
T/2
sat
Linear
T
t

Q.



Comment on cap. speed of charging and discharging.

→ speed of charging remains the same

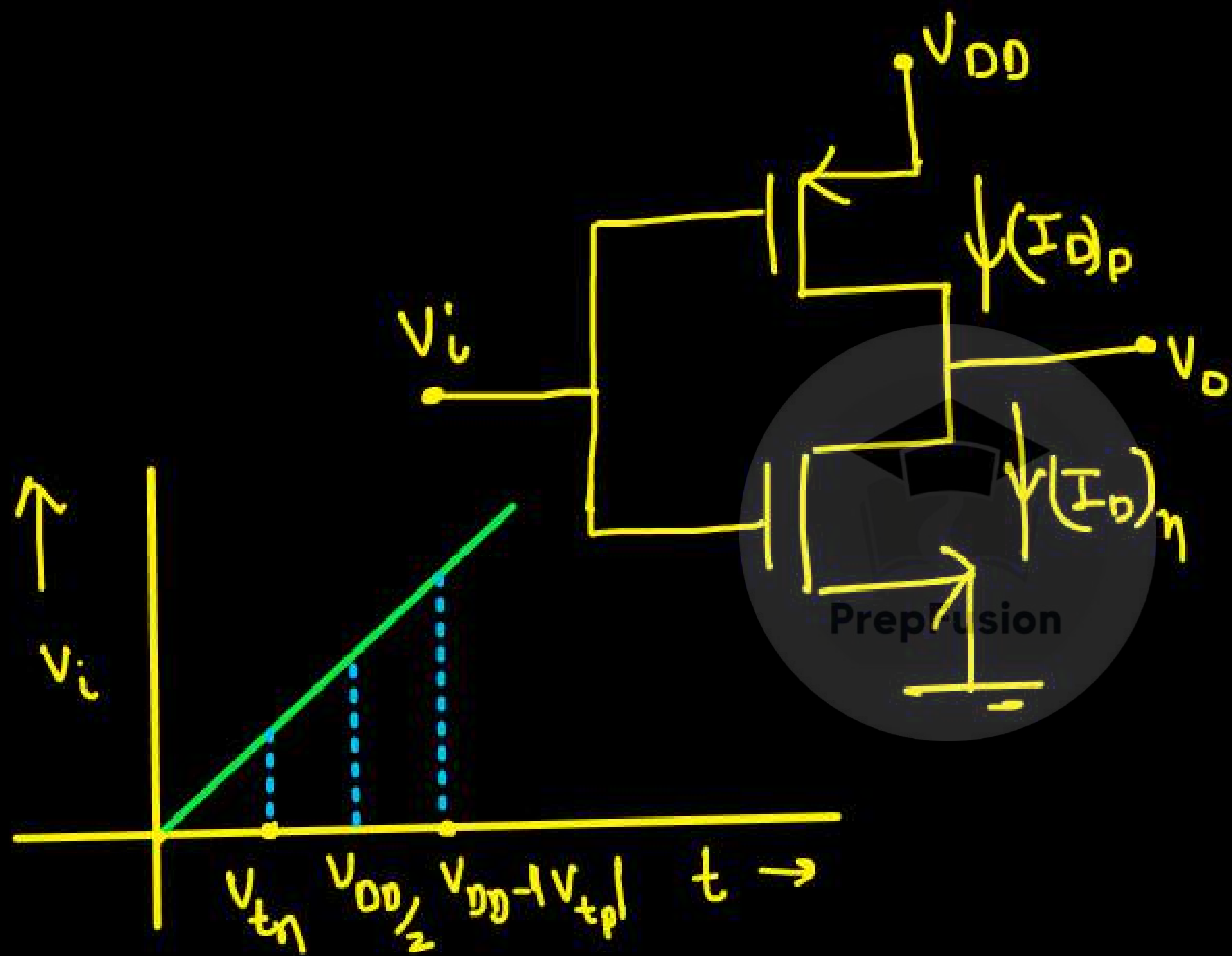
$(\tau)_{dis.} = \frac{R_{ON}}{2} C$

⇓

speed of discharging has increased.

ANALOG VLSI:COMPLETE SERIES

☆ CMOS inverter with ramp input :-



Let $V_{DD} = 5V$

$V_{tn} = |V_{tp}| = 1V$

$V_{in} \equiv 0V \rightarrow 5V$

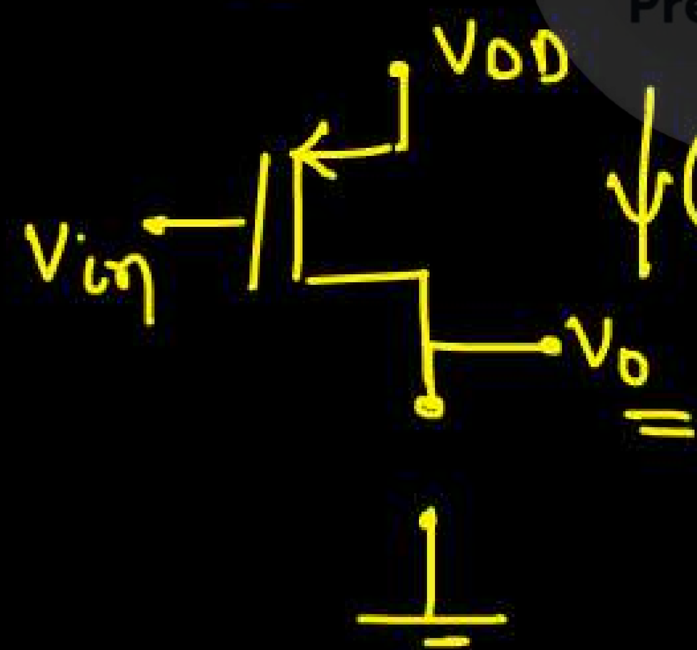
(1) when $0 < V_i < V_{tn}$

$\Rightarrow$ NMOS:-

$V_{gs} < V_{tn} \Rightarrow$ off $\Rightarrow$ cut-off

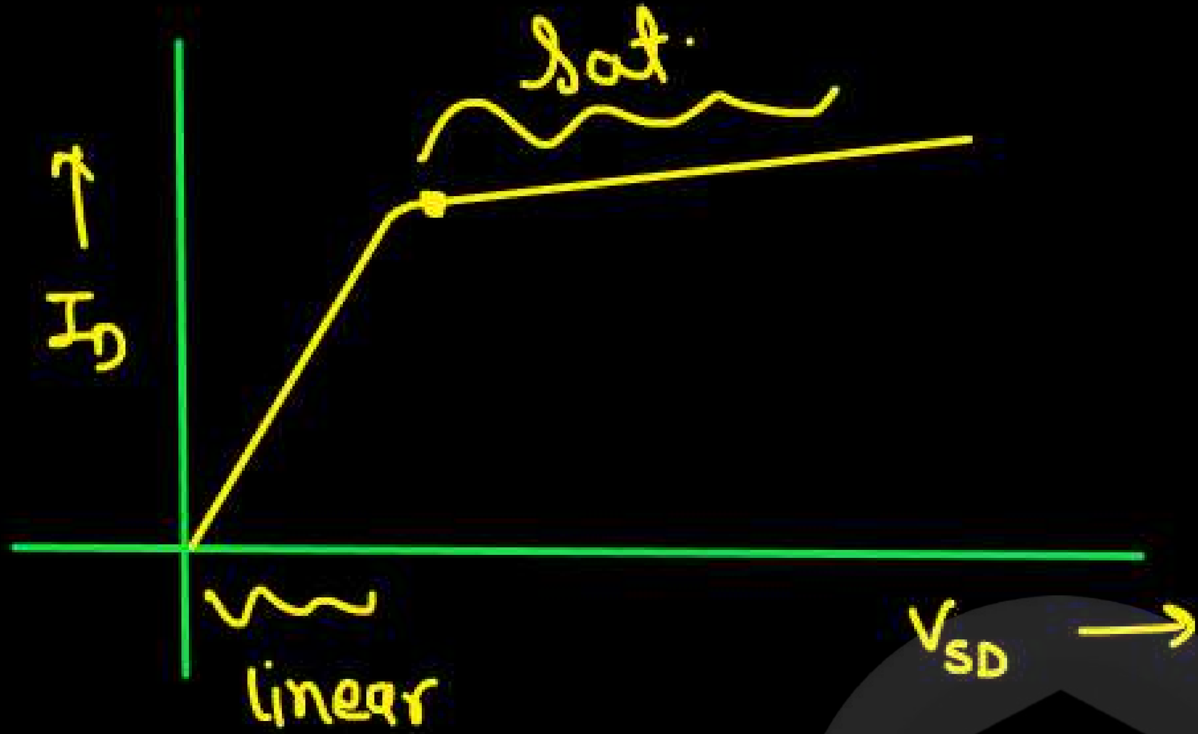
PMOS:-

$V_{sg} = \underbrace{V_{DD} - V_i} > V_{DD} - V_t \Rightarrow$ ON $\longrightarrow$ sat. or linear?



$(I_D)_p = 0$

$\Rightarrow V_o \simeq V_{DD}$



⇒ current can never go to zero in sat.

⇒ it has to be in linear region

(Because of zero current)

$0 < V_i < V_{tn}$:- $V_o = V_{DD}$

pMOS → Linear

NMOS → Cut-off

(ii) $V_t \leq V_i < V_{DD}/2$

NMOS:-

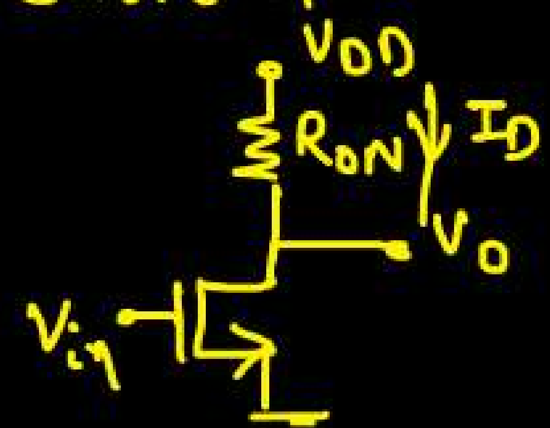
$V_{GS} = V_i > V_t \rightarrow$ ON $\rightarrow$ sat. or linear?

PMOS:-

$V_{SG} = V_{DD} - V_i > |V_{tp}| \rightarrow$ ON $\rightarrow$ sat. or linear?

$(5 - 2.5 > 1)$

$\Rightarrow$ whenever the MOS just turns on, it draws a very low amount of current.



$\Rightarrow$ I_D is very less

$\Rightarrow V_o \approx V_{DD}$ {V_i just greater than V_t}

So, for PMOS -

$V_{SD} \rightarrow$ very small $\rightarrow$ it remains in linear ...

for NMOS: -

$V_{DS} = V_0 \approx V_{DD} \rightarrow$ very large

$V_{GS} = V_{in}$

$V_{ov} = V_{in} - V_t \rightarrow$ very low (Because V_{in} is just greater than V_t)

$\Rightarrow V_{DS} >> V_{ov} \Rightarrow$ sat. region

$V_{tn} < V_{in} < V_{DD}/2 \Rightarrow V_0 \Rightarrow$ goes down

PMOS $\rightarrow$ linear

NMOS $\rightarrow$ sat.

Now, your V_{in} is increasing

$\Downarrow$

$(V_{GS})_n$ is increasing.

$\Downarrow$ NMOS in sat.

Current $(I_D)_n$ is increasing

$\Downarrow$

current in PMOS is also increasing ($(I_D)_p$ ↑)

linear eqn $(I_D)_p = 2k_p\left[(V_{SG} - V_T)V_{SD} - \frac{V_{SD}^2}{2}\right]$ $k_p = \frac{\mu_p C_{ox} W}{2L}$

→ V_{SG} ↓ $\{V_{SG} = V_{DD} - V_{in}\}$

→ But $(I_D)_p$ ↑ $\Rightarrow$ $(V_{SD})_p$ has to increase

$\Downarrow$

V_o starts going low

if $(V_{SD})_p$ is increasing $\Rightarrow$ PMOS in moving towards s

at some point, both PMOS and NMOS will be in sat region

$$(I_D)_{p_{sat}} = (I_D)_{n_{sat}}$$

$$k_p\left(V_{SG_p} - |V_{tp}|\right)^2 = k_n\left(V_{GS_n} - V_{tn}\right)^2$$

$$V_{DD} - V_i - |V_{tp}| = \sqrt{\frac{k_n}{k_p}}\left(V_i - V_{tn}\right)$$

$$V_{DD} - |V_{tp}| + \sqrt{\frac{k_n}{k_p}}\,V_{tn} = \sqrt{\frac{k_n}{k_p}}\,V_i + V_i$$

$$\boxed{V_i = \frac{V_{DD} - |V_{tp}| + \sqrt{\frac{k_n}{k_p}}\, V_{tn}}{1 + \sqrt{\frac{k_n}{k_p}}}}$$

if $|V_{tp}| = V_{tn}$ and $\underline{\underline{k_n = k_p}}$

$\Rightarrow \boxed{V_i = V_{DD}/2} \rightarrow$ both NMOS & PMOS are in sat. region.

@ $V_i = \frac{V_{DD}}{2} \Rightarrow$ Both PMOS & NMOS goes in sat.

only when $k_n = k_p$

$$\mu_n C_{ox} \left(\frac{W}{L}\right)_n = \mu_p C_{ox} \left(\frac{W}{L}\right)_p$$

$$\Rightarrow \boxed{\frac{(W/L)_p}{(W/L)_n} = \frac{\mu_n}{\mu_p}}$$

generally, $\mu_n > \mu_p \; \{\mu_n \approx 2.5 \mu_p\}$

$$\Rightarrow (W/L)_p = 2.5 (W/L)_n$$

if we want sat. region @ $V_i = V_{DD}/2$

then $\left(\frac{W}{L}\right)_p > \left(\frac{W}{L}\right)_n \quad \left\{ \left(\frac{W}{L}\right)_p \approx 2.5 \left(\frac{W}{L}\right)_n \right\}$

That's why the size of PMOS is larger than size of NMOS in CMOS inverter.

since, $V_{in} = V_{DD}/2 \rightarrow$ sat.

PMOS $\rightarrow$ sat.

$V_{SD} = V_{DD} - V_o$

$V_{ov} = V_{SG} - |V_{Tp}|$

$= V_{DD} - V_{in} - |V_{Tp}|$

@ sat. $\rightarrow$

$V_{DD} - V_o = V_{DD}/2 - |V_{Tp}|$

$V_o = V_{DD}/2 + |V_{Tp}|$

NMOS $\rightarrow$ sat.

$V_{DS} = V_o$

$V_{ov} = V_{in} - V_{TP}$

@ sat.

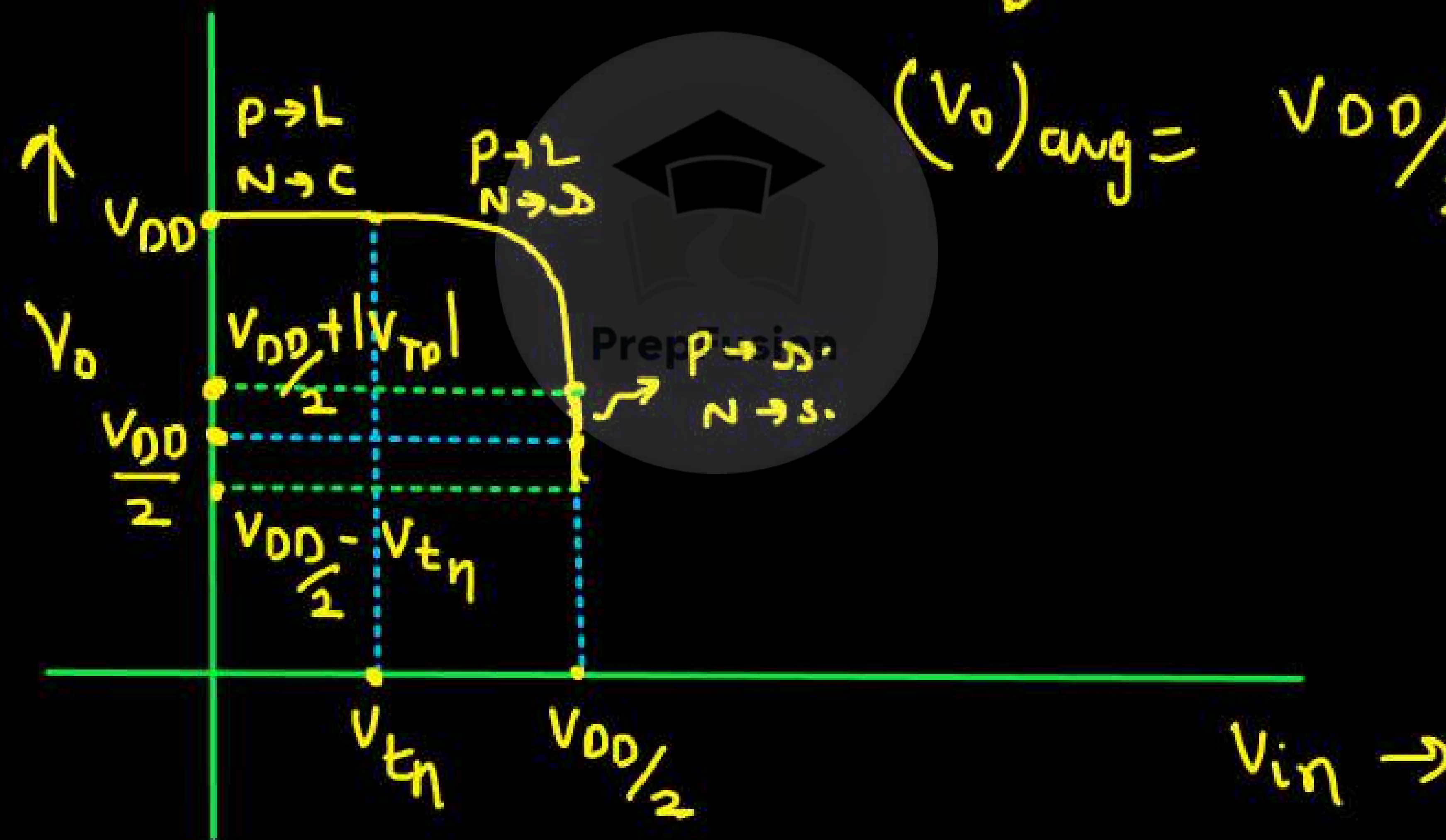
$V_o = V_{DD}/2 - V_{TP}$

So, @ $V_{in} = V_{DD}/2$, we are getting two o/p:-

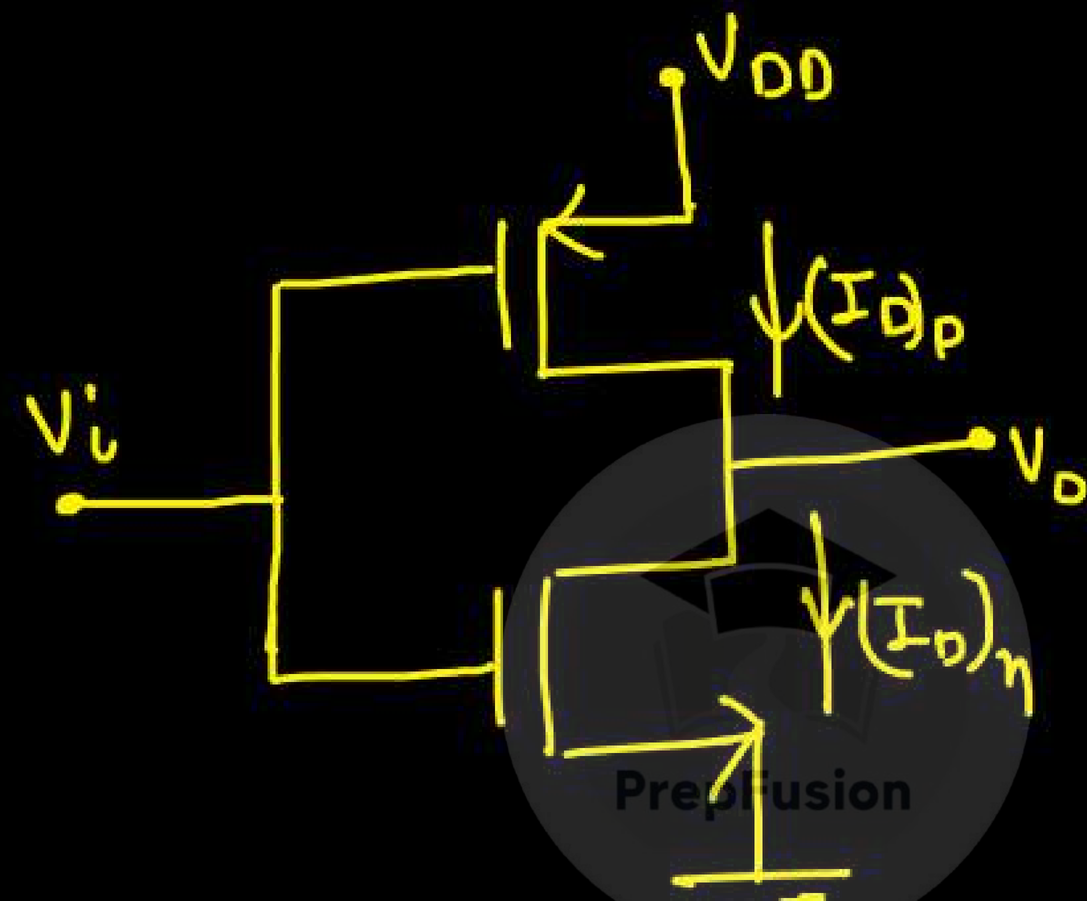
$$V_o = \frac{V_{DD}}{2} + |V_{Tp}| \quad \text{and} \quad V_o = V_{DD}/2 - V_{tn}$$

↓ Take avg.

$$(V_o)_{avg} = V_{DD}/2$$



now, $V_{DD}/2 < V_i < V_{DD} - |V_{tp}|$ $\Rightarrow$ $2.5 < V_i < 4$



→ PMOS → ON → region?

NMOS → ON → region?

PMOS →

$V_{SD} = V_{DD} - V_o$

$V_{SG} - V_T = V_{DD} - V_i/2 - V_T$

PMOS → sat.

Assume $V_{in} = 4.1 \to 3.9$

@ $V_{in} = 4.1 \Rightarrow$ PMOS off

@ $V_{in} = 3.9 \Rightarrow$ PMOS just turns ON

$\Downarrow$

$I_D \to$ less $\Rightarrow V_o$ is less $\Rightarrow (V_{SD})_p$ High

↓

sat.

NMOS →

V_o goes low ⇒ $(V_{DS})_n$ goes low ⇒ moves linear region

⇒ NMOS → linear

$\frac{V_{DD}}{2} < V_i < V_{DD} - |V_{TP}| \Rightarrow V_o$ goes low

PMOS → sat.

NMOS → linear

now, $V_{DD} - |V_{TP}| \leq V_i < V_{DD} \Rightarrow 4 \leq V_i < 5$

PMOS → off

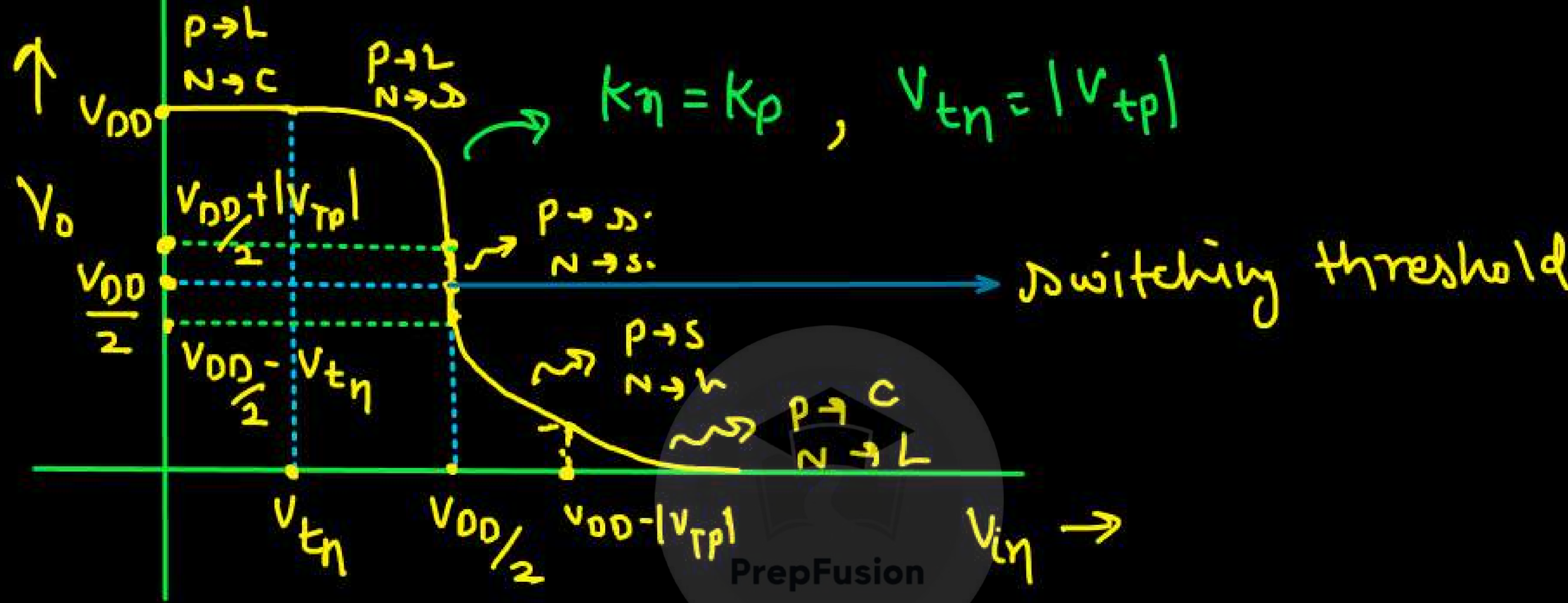
NMOS → ON ⇒ linear { $(I_D)_n = 0$ is possible only in linear region }

$V_{DD} - |V_{TP}| \leq V_i < V_{DD} \Rightarrow V_o$ nearly goes to zero

⇒ PMOS → cut off

NMOS → Linear

Voltage Transfer characteristics:-



* V_i for "sat. in both NMOS and PMOS"

$$(V_i)_{S.T.} = \frac{V_{DD} - |V_{TP}| + \sqrt{\frac{K_n}{K_p}}\, V_{tn}}{1 + \sqrt{\frac{K_n}{K_p}}}$$ → switching Threshold

when $K_n = 4K_p$ and $|V_{TP}| = V_{tn}$

$$(V_i)_{S.T.} = \frac{V_{DD} + 2}{3} = \frac{5+2}{3} = 2.33 < 2.5V$$

↓

switching Threshold decreased

when $K_n = 4K_p$ → VTC moves towards origin.

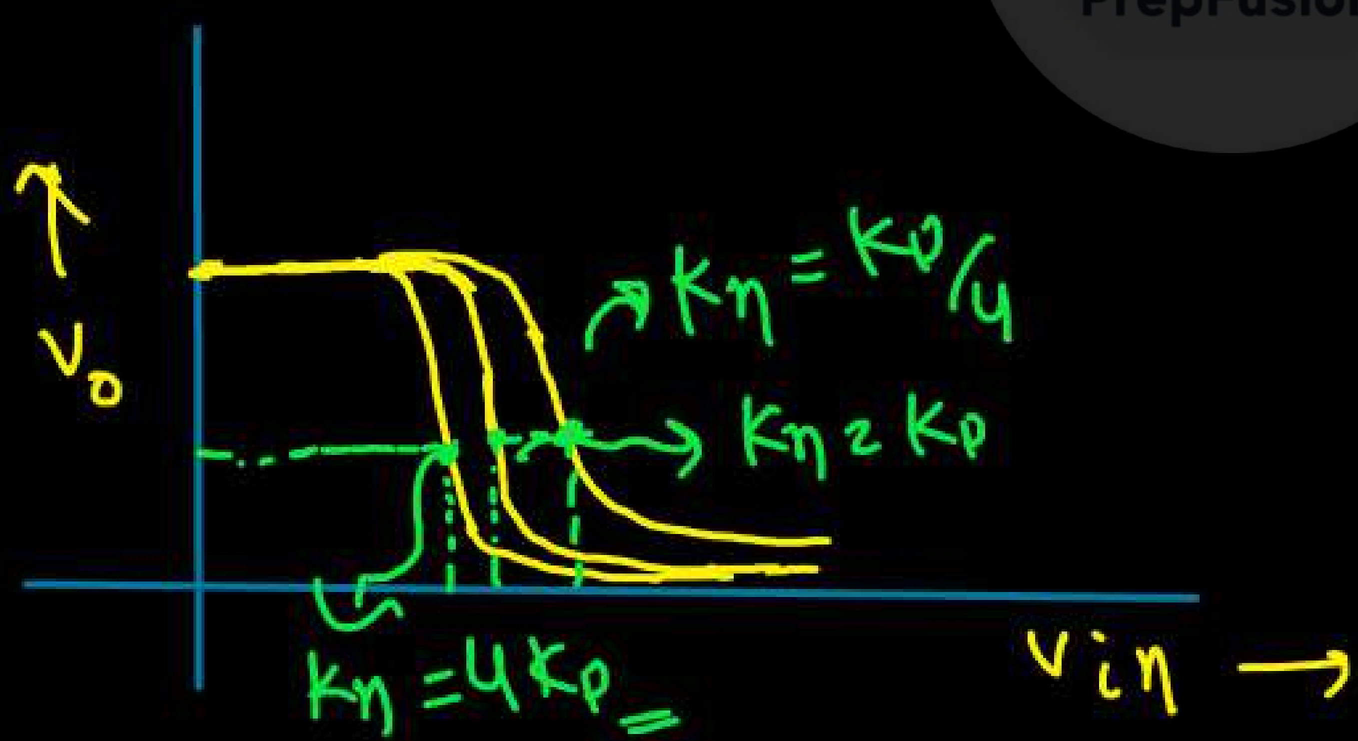
when $k_n = \frac{k_p}{4}$, $|V_{TP}| = V_{tn} = 1V$

$$(V_i)_{S.T.} = \frac{V_{DD} + 1/2}{1 + 1/2} = \frac{5.5}{1.5} = 3.66 > 2.5$$

$\downarrow$

S.T. increased

VTC move away from origin

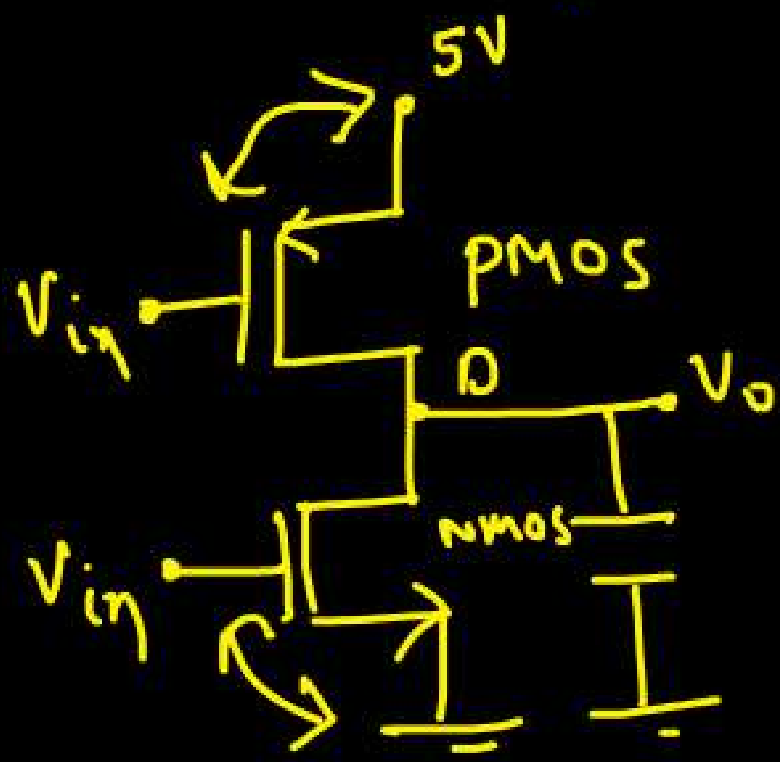


⇒ Interchanging PMOS & NMOS in CMOS inverter?

↳ Need of CMOS inverter?

→ For a High i/P, we want output to go all the way down to zero.

→ For a low i/P, we want output to go all the way up to 5V.

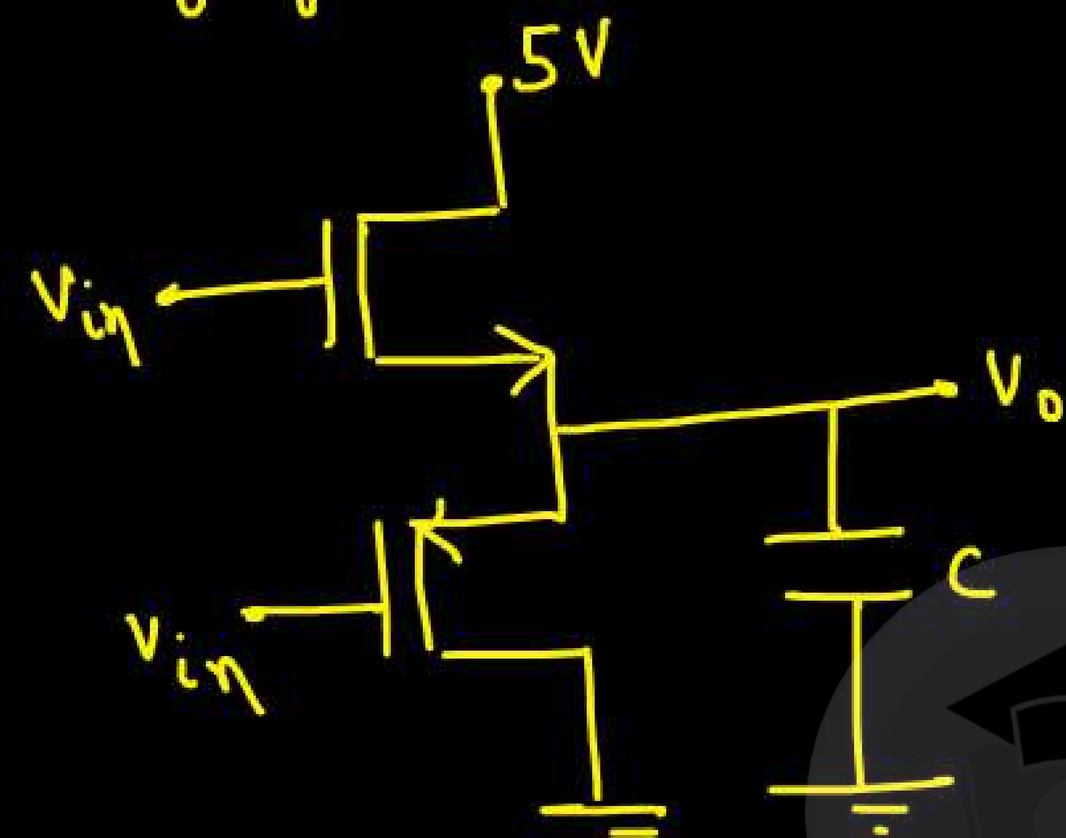


$(V_t = 1V)$

$V_{in} = 0 \Rightarrow (V_0)_{s.s.} = 5V$

$V_{in} = 5 \Rightarrow (V_0)_{s.s.} = 0V$

Interchanging:-



when $V_{in} = 5V \Rightarrow$

N → on

P → off

$(V_o)_{s.s.} = 4V$

when $V_{in} = 0V$

N → OFF

P → ON

$(V_o)_{s.s} = 1V$

→ it's acting like a buffer, not inverter.

→ your o/p doesn't go all the way up to 5V and doesn't come down all the way to 0V.