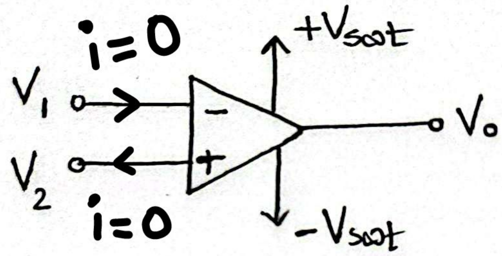
2.1 Op-Amp OL Practice Problem Solution



V_o = output terminal

V_1 = inverting terminal

V_2 = non-inverting terminal

gain equation $\Rightarrow V_o = A V_d$

$= A(V_2 - V_1)$

$\downarrow$

A = open-loop gain

Problem 1

1. $V_2 = -40\ \mu V$

$A = 150{,}000$

$V_o = +15\ V$

$V_1 = ?$

Use,

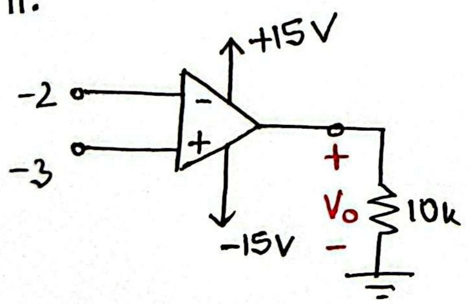
$$V_o = A(V_2 - V_1)$$

$$\Rightarrow 15 = 150{,}000(-40\times10^{-6} - V_1)$$

$$\therefore V_1 = -1.4\times10^{-4}\ V$$

$$= -140\ \mu V$$

II.



$$V_o = A(V_2 - V_1)$$

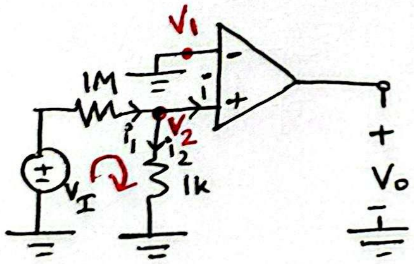
$$= 10^4(-3-(-2))$$

$= -10{,}000\ V \longrightarrow$ not possible.

Output will go to negative saturation.

$$\therefore V_o = -15\ V$$

Problem 2



A common mistake in problems like these – many of you will consider that V_I is being applied to the non-inverting terminal directly, but $V_I \neq V_2$, as there is a $1k\Omega$ resistor.

KCL at V_2,

$$i_1 = i + i_2 \quad (\text{but } i = 0)$$

$\therefore\ i_1 = i_2$, so V_I, $1M\Omega$, $1k\Omega$ are all in series with each other.

KVL at highlighted loop,

$$-V_I + (1M \times i_1) + (1k \times i_1) = 0$$

$$i_1 = \frac{V_I}{1M + 1k}$$

$$= \frac{2.0}{10^{+6} + 10^{+3}} = 1.998\ \mu A$$

$$\therefore V_2 = i_2 \times 1k$$

$$= 1.998\ \mu A \times 1k$$

$$= 1.998\ mV$$

Alternative to this KVL,

$$V_2 = \frac{1k}{1k + 1M} \times V_I$$

$$= 1.998\ mV$$

(voltage divider rule)

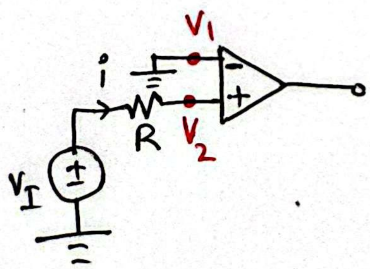
We know,

$$V_o = A(V_2 - V_1)$$

$$\Rightarrow 4 = A(1.998 mV - 0)$$

$$\therefore A = 2002$$

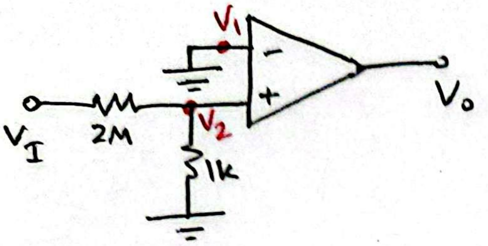
*** If the problem looked like –



We know that $i = 0$ here (as $R_i = \infty$), but we can define i as –

$$i = \frac{V_I - V_2}{R} = 0 \quad \Rightarrow V_I = V_2$$

Problem 3 → A variation of problem 2.



Using voltage divider rule,

$$V_2 = \frac{1k}{1k + 2M} \times V_I$$

$$V_I = \frac{(1k + 2M) \times V_2}{1k}$$

$$= \frac{(10^3 + 2\times10^6)\times(-2\times10^{-4})}{10^3}$$

$$= -0.4002 \text{ V}$$

Given, $A = 10^4$,

$V_o = -2.0\text{V}$,

$V_1 = 0$ (grounded)

$\Rightarrow V_o = A(V_2 - V_1)$

$\Rightarrow -2 = 10^4(V_2 - 0)$

$\therefore V_2 = -2\times10^{-4}$ V

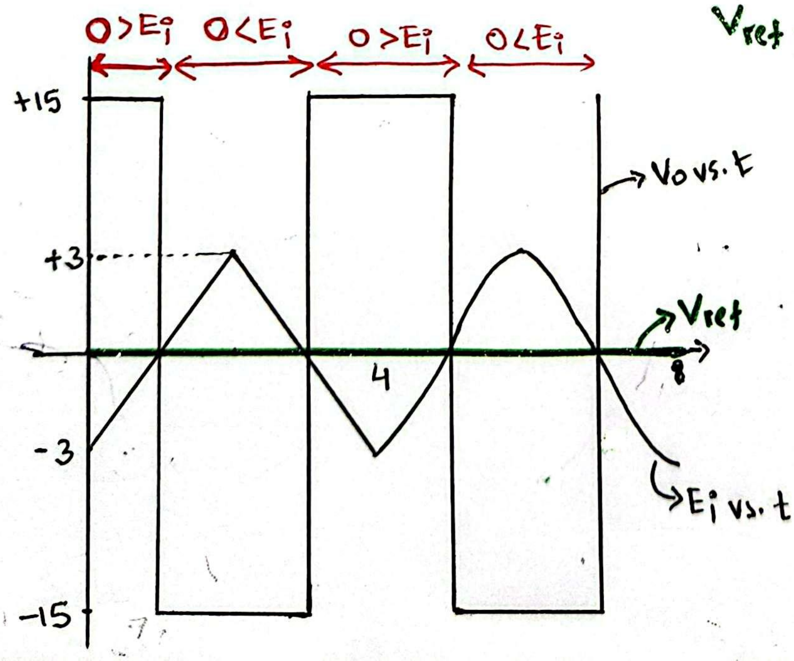
Problem 4

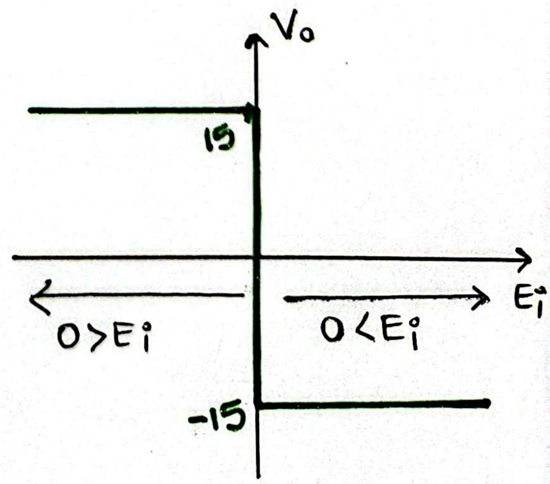
For problems like these, write these conditions first: $\cancel{V_2}^{\to 0} > \cancel{V_1}^{\to E_i}$, $V_o = +V_{sat}$

$\cancel{V_2}^{\to 0} < \cancel{V_1}^{\to E_i}$, $V_o = -V_{sat}$

V_o vs. t,

$V_{ref} = 0 \leftarrow \begin{cases} \therefore 0 > E_i, V_o = +15\text{V} \\ 0 < E_i, V_o = -15 \text{ V} \end{cases}$



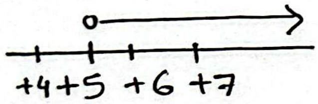


Problem 5

1. Given that $\underbrace{V_i > +5\,V}$, $V_o = \overset{+V_{sat}}{+15V} \longrightarrow V_2 > V_1,\ V_o = +V_{sat}$

or, $V_2 < V_1,\ V_o = -V_{sat}$

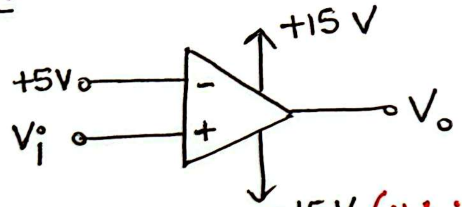
input signal crosses +5V in the positive direction.



$V_o = +V_{sat}$

for $V_2 > V_1$

Circuit:



$\therefore V_2 = V_i\ ,\ V_1 = +5$

(this is an arbitrary value. You can consider anything less than 0, as question states 'output voltage will go positive to...')

II. Given that $\underbrace{V_i < -4}$, $V_o = +15\,V$ (and $V_i > -4$, $V_o = -15\,V$)

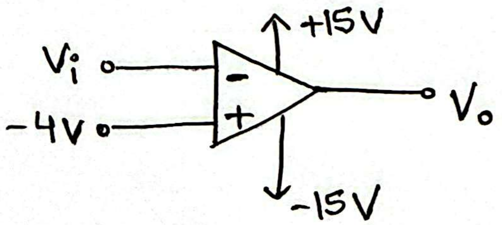
input signal is below −4V.

$\longrightarrow V_2 > V_1\ ,\ V_o = +V_{sat}$

$V_2 < V_1\ ,\ V_o = -V_{sat}$

$-4 > V_i\ ,\ V_o = +15\,V$

Circuit:



$\therefore V_2 = -4\ ,\ V_1 = V_i$

* this time, both $\pm V_{sat}$ were specified in the question.

Problem 6

$V_2 > V_1$, $V_o = +V_{sat}$

$V_2 < V_1$, $V_o = -V_{sat}$

given, $V_2 = V_{temp} = 4$

$V_1 = E_c$

$+V_{sat} = +15\text{ V}$

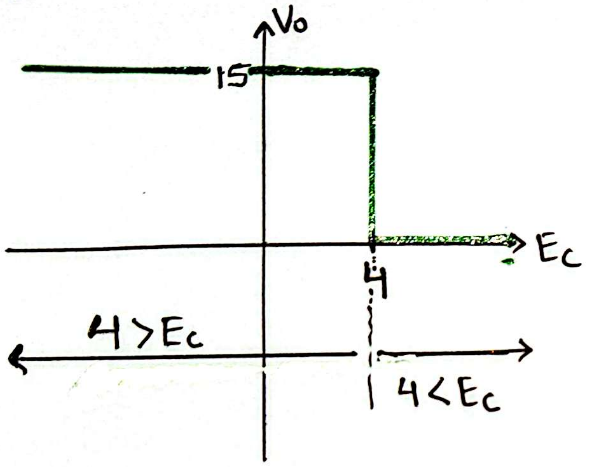
$-V_{sat} = 0\text{ V}$

$\longrightarrow$

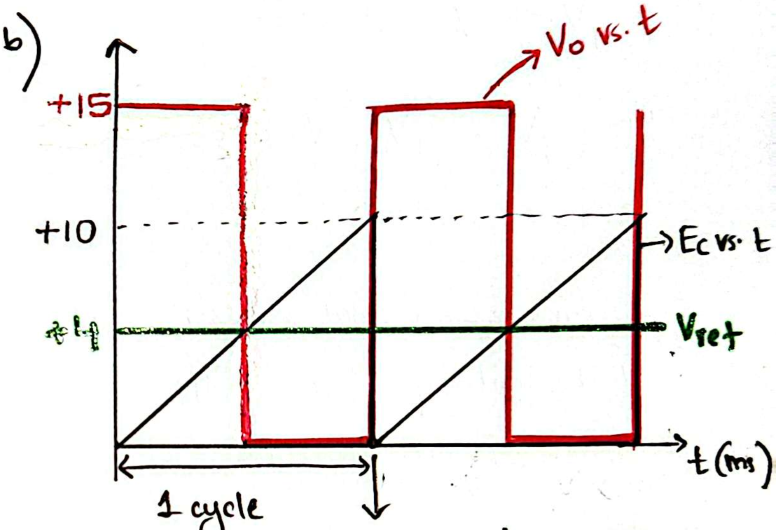
$4 > E_c$, $V_o = +15\text{ V}$

$4 < E_c$, $V_o = 0\text{ V}$

a) V_o vs. E_c



b)



$$T = \frac{1}{f} = \frac{1}{50} = 20\text{ ms}$$

c) [optional]

Find the straight line equation for E_c.

Two data points $(t, V) = (0, 0)$ and $(20\text{ ms}, 10\text{ V})$

$$\Rightarrow \cancel{E}\ V - 0 = \frac{10 - 0}{20 - 0}(t - 0)$$

$$\therefore V = \frac{1}{2} t \quad (t \text{ is in ms})$$

The first intersection occurs when $V = 4$,

$$\Rightarrow 4 = \frac{1}{2} t$$

$t = 8\text{ ms} \longrightarrow$ HIGH TIME, as from 0 to 8 ms, $V_o = +15\text{ V}$.

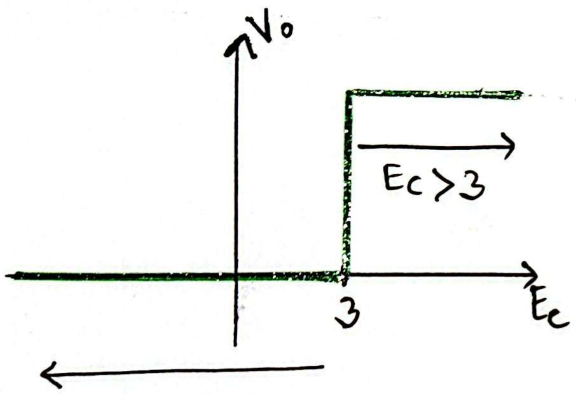
Problem 7 ⟶ variation of problem 6

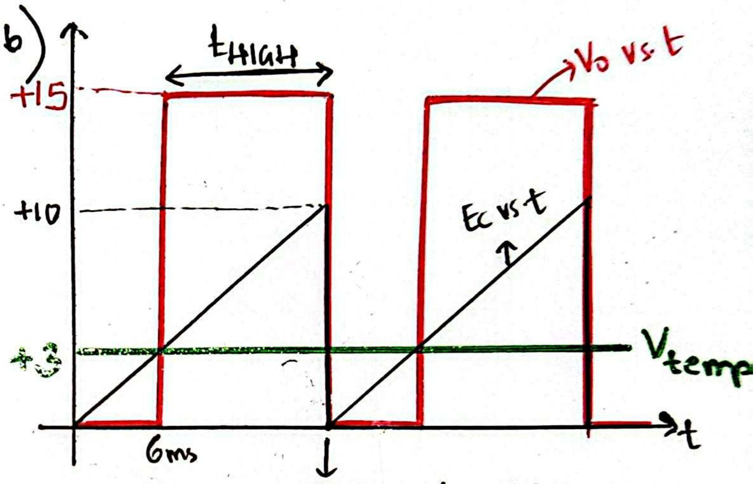
$V_2 > V_1$, $V_o = +V_{sat}$
$V_2 < V_1$, $V_o = -V_{sat}$

given $V_2 = E_c$

$V_1 = V_{temp} = +3V \longrightarrow E_c > 3, V_o = +15V$
$+V_{sat} = 15V$ $\quad E_c < 3, V_o = -15V$
$-V_{sat} = 0V$

a) V_o vs. E_c





$T = \frac{1}{f} = \frac{1}{50} = 20ms$

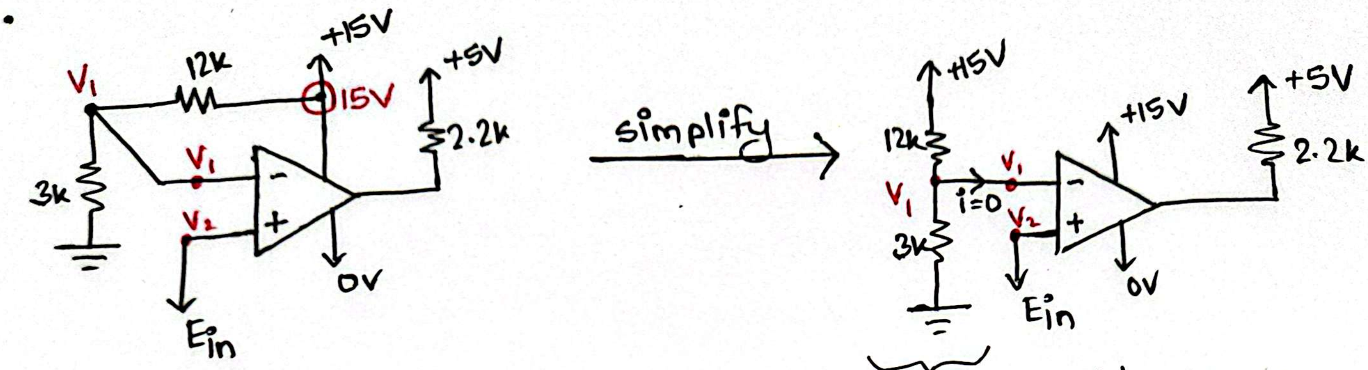
c) [optional] $\quad V = \frac{1}{2}t$ [see problem 6]

at $V = 3$, $\quad 3 = \frac{1}{2}t$

$t = 6$ ms
↳ LOW TIME

$\therefore t_{HIGH} = 20 - 6 = 14ms$

Problem 8



$\underbrace{\qquad}_{\text{simple voltage divider network}}$

$$V_1 = \frac{3}{12+3} \times 15 = 3\,V$$

a) Write the conditions:

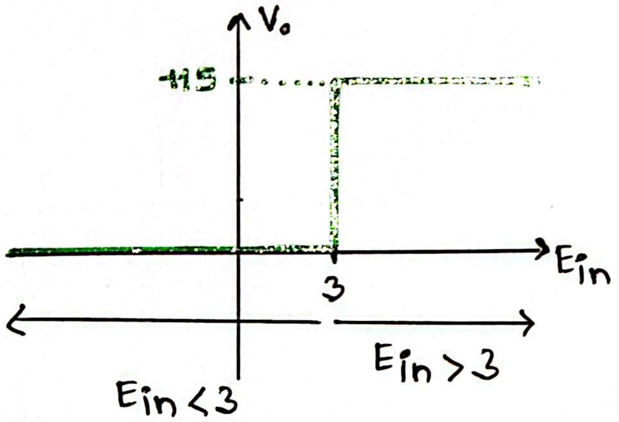
$\cancel{V_2}^{E_{in}} > \cancel{V_1}^{3}$, $V_o = +V_{sat}$

$\cancel{V_2}^{E_{in}} < \cancel{V_1}^{3}$, $V_o = -V_{sat}$

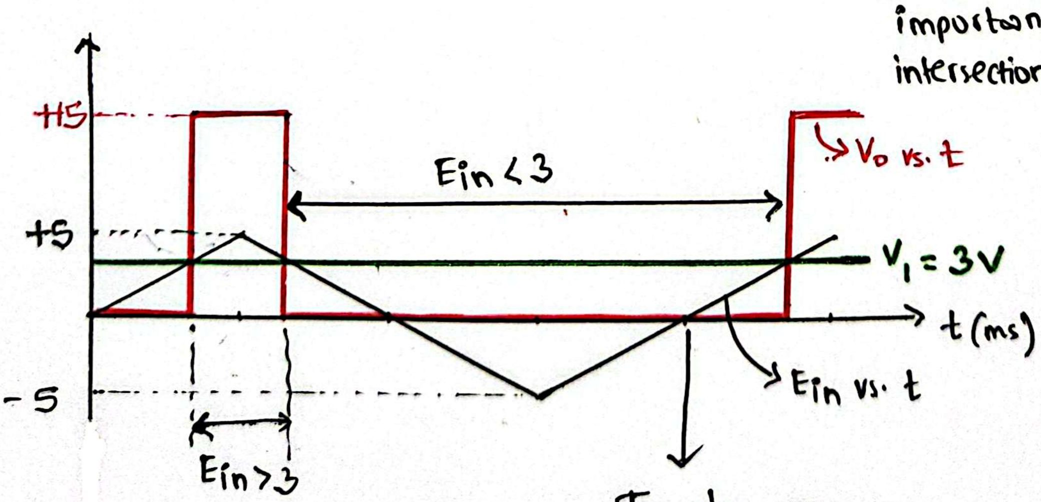
$\longrightarrow$

$E_{in} > 3$, $V_o = +V_{sat} = +15\,V$

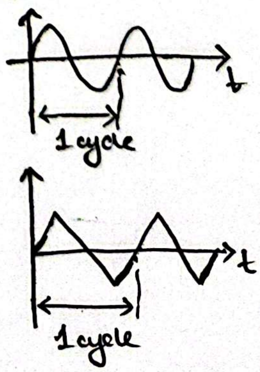
$E_{in} < 3$, $V_o = -V_{sat} = 0\,V$



b) E_{in} = triangular wave with 5V amplitude and $\underbrace{\text{100Hz frequency}}_{\text{important for axis intersection points}}$

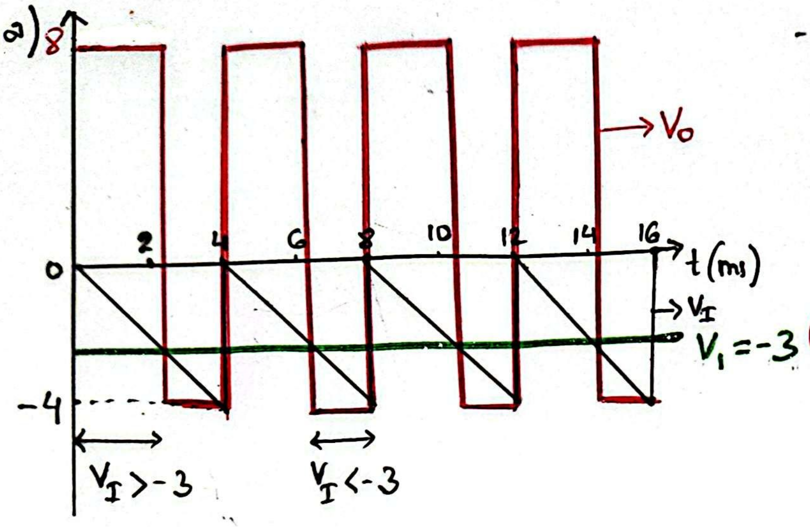


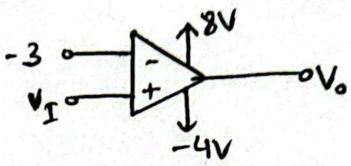
$$T = \frac{1}{100} = 10\,ms$$



Problem 9

a)





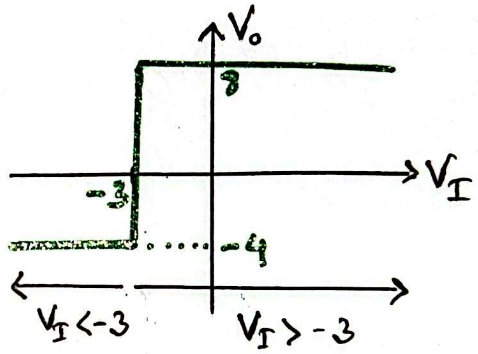
$V_2 > V_1$, $V_o = +V_{sat}$

$V_2 < V_1$, $V_o = -V_{sat}$

$V_I > -3$, $V_o = +8\ V$

$V_I < -3$, $V_o = -4\ V$

b)



Problem 10

From circuit, $V_2 = -3V$

$V_1 = V_I$

$+V_{sat} = +15V$

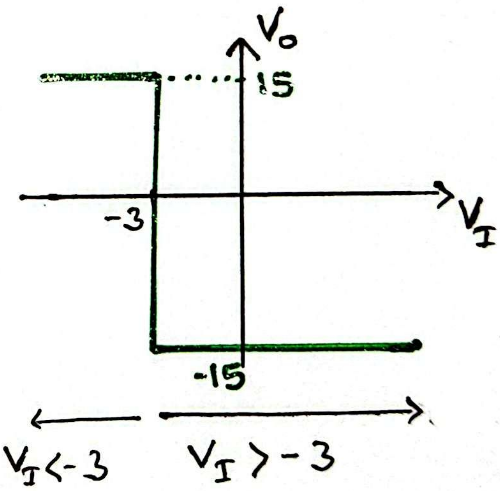
$-V_{sat} = -15V$

$V_2 > V_1$, $V_o = +V_{sat}$

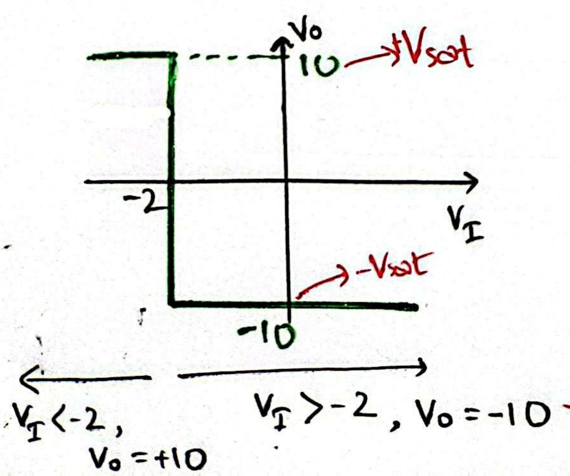
$(-3 > V_I, V_o = +15V)$

$V_2 < V_1$, $V_o = -V_{sat}$

$(-3 < V_I, V_o = -15V)$



Problem 11



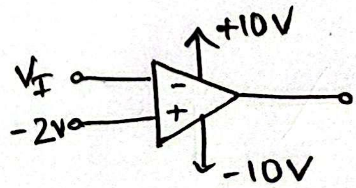
Write the conditions:

$V_2 > V_1$, $V_o = +V_{sat}$

$V_2 < V_1$, $V_o = -V_{sat}$

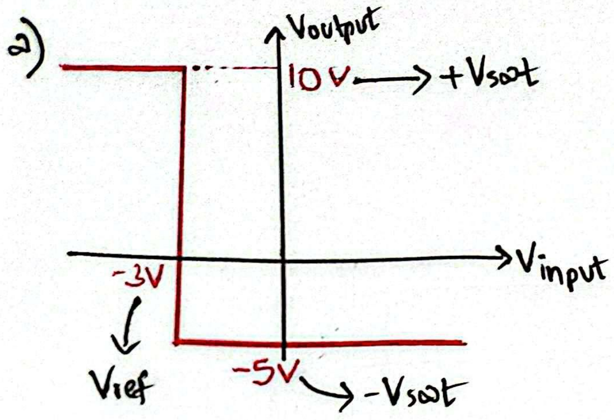
matches.

$\therefore V_2 = -2, V_1 = V_I$



Problem 12

a)



$V_i < -3$, $V_o = +V_{sat}$

$V_i > -3$, $V_o = -V_{sat}$

matches

Write the conditions,

$V_2 > V_1$, $V_o = +V_{sat}$

$V_2 \to -3$, $V_1 \to V_i$

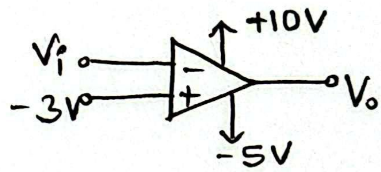
$-3 > V_i$, $V_o = +10V$

$V_2 < V_1$, $V_o = -V_{sat}$

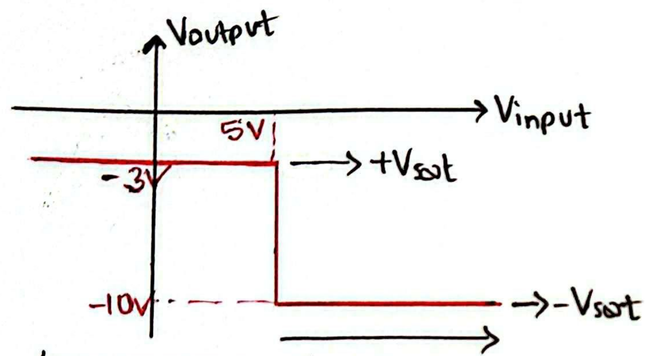
$V_2 \to -3$, $V_1 \to V_i$

$V_i > -3$, $V_o = -5V$

$\therefore$ circuit:



b)



$V_i < 5$, $V_o = +V_{sat}$

$V_i > 5$, $V_o = -V_{sat}$

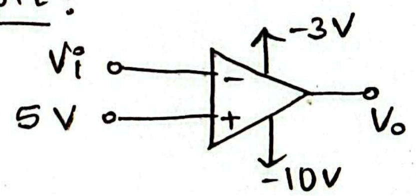
matches

$V_2 > V_1$, $V_o = +V_{sat}$

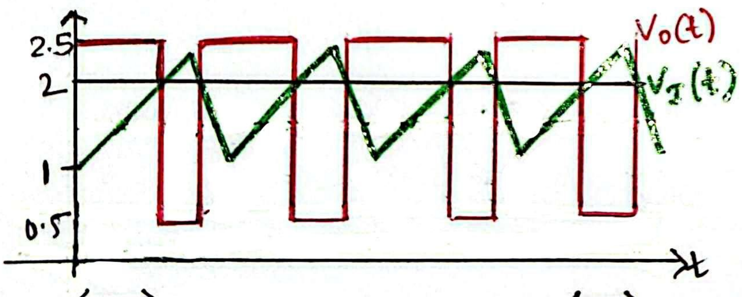
$V_2 < V_1$, $V_o = -V_{sat}$

$\therefore V_2 = 5$, $V_1 = V_i$

$\therefore$ circuit:



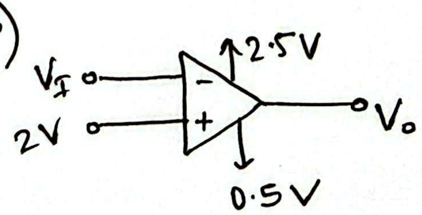
Problem 13



$V_o = +V_{sat} = 2.5V$ when $V_{ref} = 2V > V_I(t)$

$V_o = -V_{sat} = 0.5V$ when $2V < V_I(t)$

b)



a) $V_2 > V_1$, $V_o = V_{sat}$

$V_o = 2.5$ for $2V > V_I(t)$

$\therefore V_2 = 2$, $V_1 = V_I$