1. * Operational Amplifier *

* Op amp is ~~a~~ multistage amplifier in which number of amplifier stage interconnected to each othe in complicated manner.
- Internal circuits consists many transistors, FETs & resistors. All these are packed in small packages(in) Integrated circuits (IC) form.
- It performs, amplification, substra, differentiation, addition, integration etc.

e.g IC 741.
- It has two input & one output.

−ve is inverting terminal &
+ve in non — " —

If input signal to −ve then output 180° out phase
— " — +ve — " — in phase.

* **Working :**

If ~~a~~ we apply two signals one at inverting & non-inverting terminal, ideal op-amp will amplify difference btn to input signals, this differce is differential input signal.

$$V_o = A_d (V_A - V_B) \quad \text{In fig.}$$

A_d = open load / differential gain

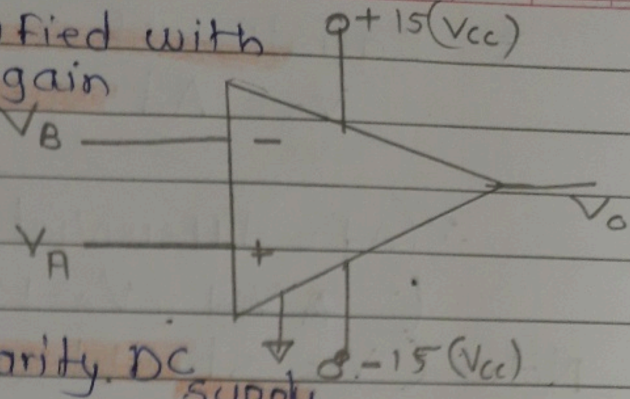
It has two input power supply terminals $+V_{cc}$ & $-V_{cc}$

V_A & V_B are equal when $V_A - V_B = 0$ (diffe. ~~gain~~ input voltage)

* Operational Amplifiers.

DC coupled voltage amplified with
* Opam : very high voltage gain

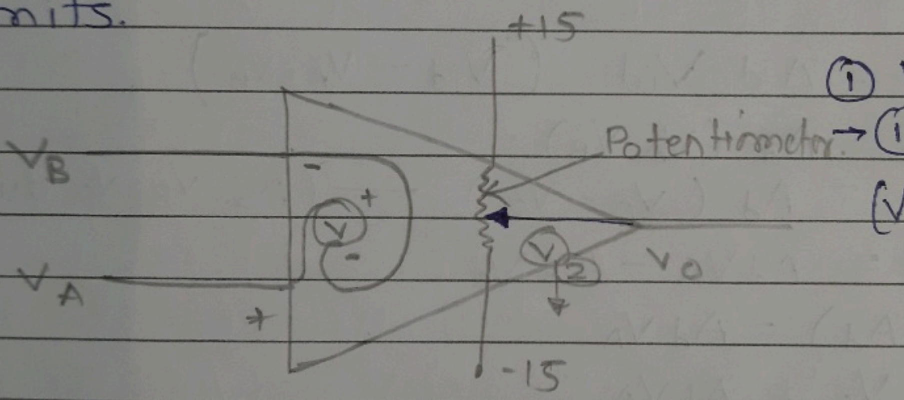
V_B, V_A are inverting & non-inverting ~~op amp~~ inputs
$V_o \rightarrow$ output.



For opam (operational) dual polarity. DC supply

* Working :

→ It has three terminals V_B & V_A are inverting & non-inverting inputs & V_o outputs in which opam ensure that $V_o = 100000 V_{id}$.
$V_{id} = V_A - V_B$ subject to condition that V_o is restricted between +15v (upper) & −15v (lower) limits.



① Watch voltmeter ① ∴ $V_{id} = V_A - V_B$ (V_{id} = input differential)

② Watch Voltmeter ② (V_o) and ensure that or consider $V_o = 100000 V_{id}$.

③ Given opam ~~op~~ amplifier runs between +15v to −15v inputs.

e.g. ~~For~~ ~~~~

e.g. Consider $V_{id} = V_A - V_B = 10\mu V$. &
if $V_o = 0.5V$ then $V_o \neq 100000 V_{id}$.
∴ current output is less than expected, then change voltmeter nob to left.

Hence,
What you want is less than expected then move left and vice versa, (move right)
~~Here~~ $(V_A - V_B)$ is differential input voltage

* Equation of opamp

Subject

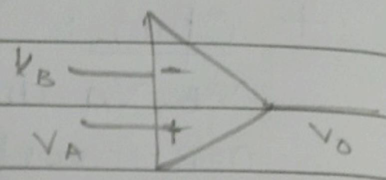
$V_o = A_d V_{id}$

$V_o = 10^5 V_{id}$.

$\because (A_d = \text{differential gain})$

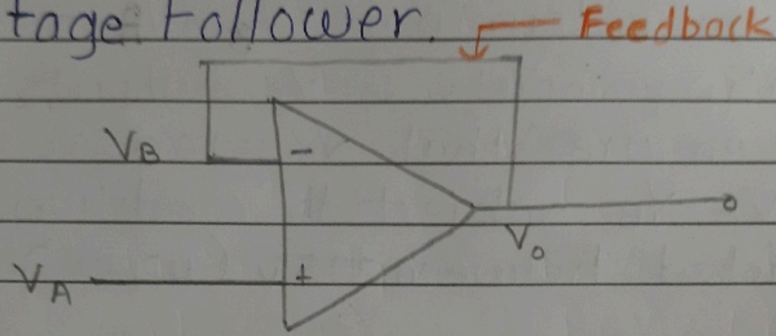
$(\because V_{id} = V_A - V_B)$

$-\left[\begin{array}{l} +15 \text{ (i.e } V_{CC}) \\ -15 \text{ (i.e } V_{EE}) \end{array}\right.$



Note (Vcc should any value betn ~~+15~~ $+V_{cc}$ to $-V_{cc}$)

* Voltage Follower.



V_o depends on $V_A V_B$

V_B ⟵ V_o.

$\boxed{V_B \text{ is } V_o}$ — (1)

$\therefore V_o = A_d V_{id} \quad (V_{id} = V_A - V_B)$,

$\therefore V_o = A_d (V_A - V_B)$.

$\therefore \quad = A_d (V_A - V_o)$ ⟵ (As $V_B = V_o$ due to feedback)

$\therefore \quad = A_d V_A - A_d V_o$

$V_o (1 + A_d) = A_d V_A$

$\therefore V_o = \dfrac{A_d V_A}{(1 + A_d)}$ Divide by A_d.

$\therefore V_o = \left(\dfrac{1}{1 + 1/A_d}\right) V_A$

if $A_d = 100000$ $\therefore \boxed{V_o \approx V_A}$

$\therefore$ Output follows the input.

if $V_A = 15$ $V_o = 14.99$.

if $V_A = 20$ then $V_o = 15$ because Op pam can't deliever beyond $+15$v.

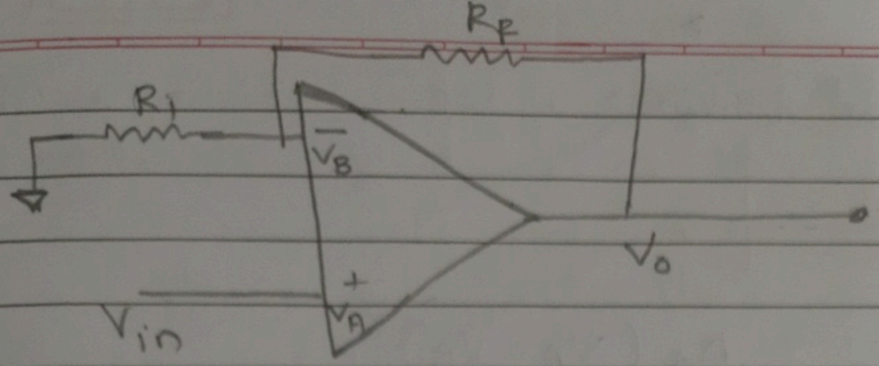
* Non - Inverting Amplifier.

- It has positive gain. (R_1 & R_f in kΩ)

Input is +ve & output is +ve.

V_A & V_B are internal.

Opamp donot draw current



As $V_o = A_d (V_A - V_B)$

$= A_d (V_{in} -$

$\because V_B$ is potential divider ~~elemement~~ element of R_f, R_1 & ground V_o.

$$\therefore V_B = \left(\frac{R_1}{R_f + R_1}\right) V_o$$

$$\therefore V_o = A_d \left(V_{in} - \frac{R_1}{R_f + R_1} V_o\right)$$

$$\therefore \quad = A_d V_{in} - \frac{A_d R_1}{R_f + R_1} V_o$$

$$(R_f + R_1) V_o = A_d V_{in} (R_f + R_1) - A_d R_1 V_o$$

$$\therefore V_o (R_f + R_1 + A_d R_1) = A_d V_{in} (R_f + R_1)$$

$$\therefore V_o = \frac{A_d (R_f + R_1) V_{in}}{R_f + R_1 + A_d R_1}$$

Divide by A_d.

$$V_o = \frac{R_f + R_1}{R_1 + \left(\frac{R_f + R_1}{A_d}\right)} V_{in}$$

$\because A_d$ is quite large then

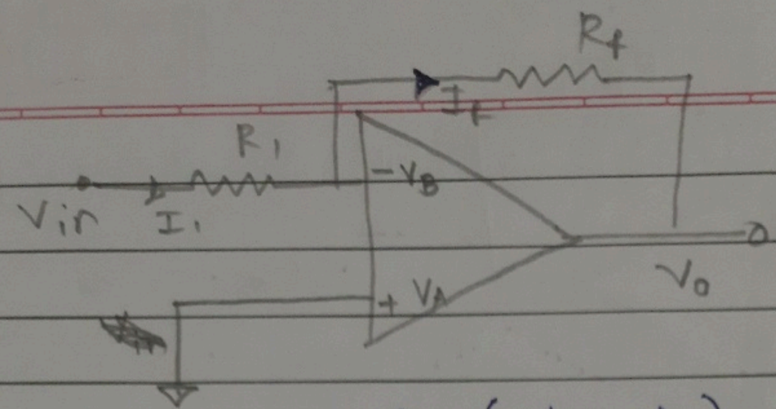
As compare to R_1 $\frac{R_f + R_1}{A_d}$ is negligible.

$$\therefore V_o = \frac{R_f + R_1}{R_1} V_{in}$$

$$\therefore \boxed{V_o \approx 1 + \frac{R_f}{R_1}} V_{in}$$

V_o is $-Ve$ or $+Ve$ but it can't beyond its limit.

* Inverting Amplifier.



$$\because \quad V_o = A_d (V_A - V_B)$$
$$= A_d (0 - V_B)$$
$$\therefore \quad V_o = -A_d V_B \quad \text{———} (1)$$

$\therefore$ V_B is calculated by kirchof law, R_1 R_f, V_o

If I_1 through R_1 & I_2 is R_f they by KVL

$$\therefore \quad \frac{V_{in} - V_B}{R_f} = \frac{V_B - V_o}{R_f}$$

$$\therefore R_f V_{in} - R_f V_B = R_1 V_B - V_o R_1$$
$$\therefore \quad V_B (R_1 + R_f) = R_f V_{in} + R_1 V_o$$
$$\therefore \quad V_B = \frac{R_f V_{in} + R_1 V_o}{R_1 + R_f}$$

from (1)

$$V_o = -A_d \left(\frac{R_f V_{in} + R_1 V_o}{R_1 + R_f} \right)$$
$$(R_1 + R_f) V_o = -A_d R_f V_{in} - A_d R_1 V_o$$
$$V_o (R_1 + R_f + A_d R_1) = -A_d R_f V_{in}$$
$$= \frac{-A_d R_f V_{in}}{(R_1 + R_f) + A_d R_1}$$

Dividing by A_d.

$$= \frac{-R_f V_{in}}{\left(\frac{R_1 + R_f}{A_d}\right) + R_1}$$

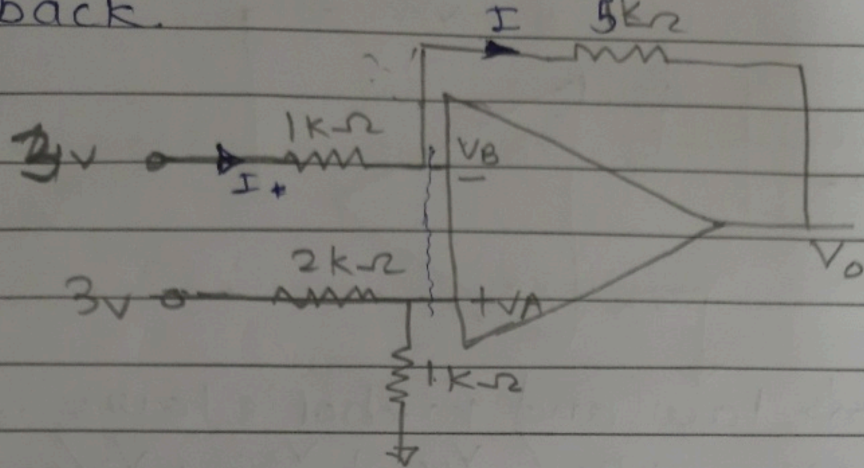
Here by negleting $\frac{R_1 + R_f}{A_d}$ Ad large to compare R_1 & R_f

$$\therefore \boxed{V_o = \left(\frac{-R_f}{R_1}\right) V_{in}}$$ as -ve inverting gain is -ve.

$\because$ There is Feedback from output to V_B terminal

* Thum Rule to deal with Op Amp. with -Ve feedback.

e.g



Supply +15 v

-15v

Rule.

1) Disconnect oppam input terminals logically
(Opam terminals don't draw any current)

2) Calculate voltage → non-inverting (V_A)

3) Transfer —— " —————— " ——— to inverting terminal
i.e. have $V_B = V_A$

4) Calculate V_o by ohm's & kirchoff's laws around inverting terminal node.

e.g Here $\frac{3-1}{10^3} = \frac{1-V_o}{10^3}$

$\therefore \boxed{V_o = -9}$

If the V_o value = 15 greater than -15 then

5) If $-15v \le V_o \le +15v$. answer is correct but if not, then

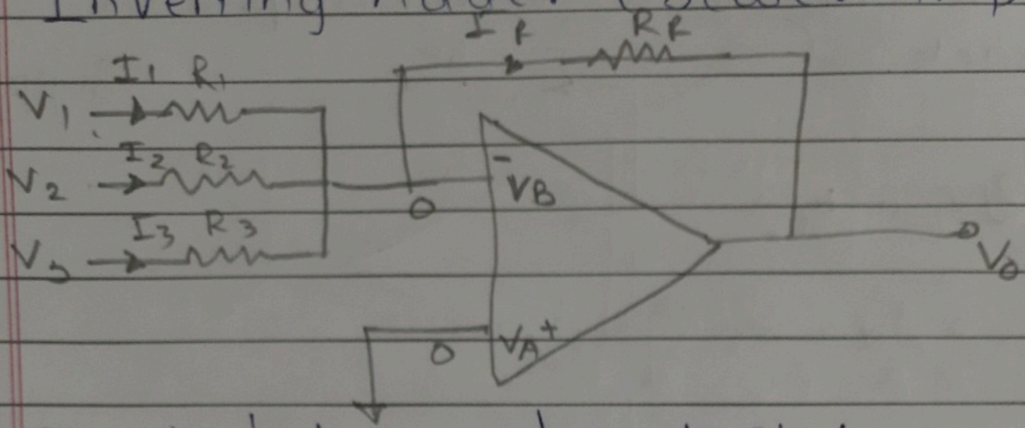
6) If (a) $V_o < -15 \Rightarrow$ make $V_o = -15V$

(b) $V_o > +15 \Rightarrow$ —"— $V_o = +15$

Here, $V_A = B$ called virtual shot it is valid. iff ouput computed is betn window +15 to -15v then, $V_A \neq V_B$.

7) Recalculate V_B. based on ohm's & kirchoff's OR based on given voltages & V_o (± 15 or) at inverting terminal.
if V_o = +15 OR -15

* Inverting Adder (Scaler Amplifier)



By ohm's law and kirchof's laws.

$$V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

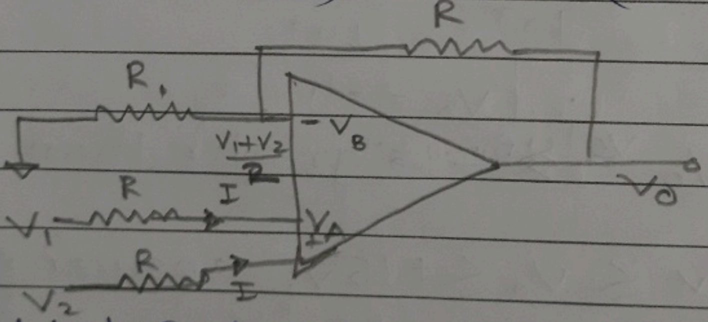
$(\because$ If $R_1 + R_2 + R_3 = R)$

$$V_o = \frac{-R_f}{R}\left(V_1 + V_2 + V_3\right)$$

If further $R_f = R$.

$$\boxed{\therefore V_o = -\left(V_1 + V_2 + V_3\right)}$$ -ve inverting.

* Non-inverting Adder (scalar amp)



By kirchofs law.

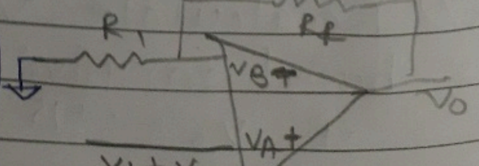
$$\therefore V_A = \frac{V_1 + V_2}{2} \quad \text{—— (1)}$$

By KVL $\quad \dfrac{\frac{V_1+V_2}{2}}{R} = \dfrac{V_o - \frac{V_1+V_2}{2}}{R}$

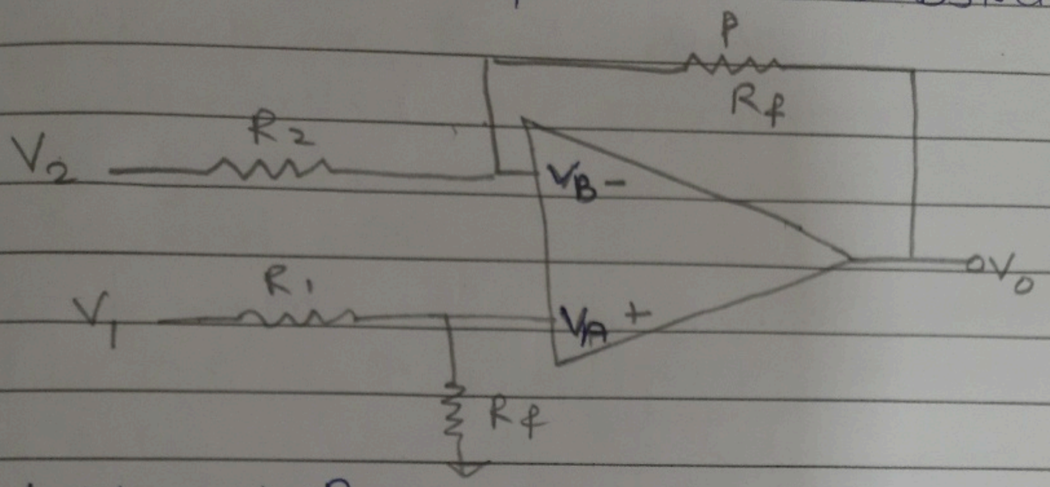
$$\therefore \boxed{V_o = V_1 + V_2}$$ - direct addition

If

$$\therefore \boxed{V_o = \left(\frac{1 + R_f/R_1}{2}\right)(V_1 + V_2)}$$



Difference Amplifier ⇒ Substractor.



$$\therefore V_A = \frac{R_f}{R_f + R_1} V_1 \quad \text{——— (1)}$$

By KVL,

$$\frac{V_2 - V_B}{R_1} = \frac{V_B - V_0}{R_f}$$

$$\therefore R_f V_2 - R_f V_B = R_1 V_B - R_1 V_0$$

$$R_1 V_0 = (R_f + R_1) V_B - R_f V_2$$

As $V_A = V_B$ $\therefore V_B =$ ——— from (1)

$$\therefore R_1 V_0 = R_f V_1 - R_f V_2$$

$$\therefore \boxed{V_0 = \frac{R_f}{R_1}(V_1 - V_2)}$$

If $R_f = R_1$ then

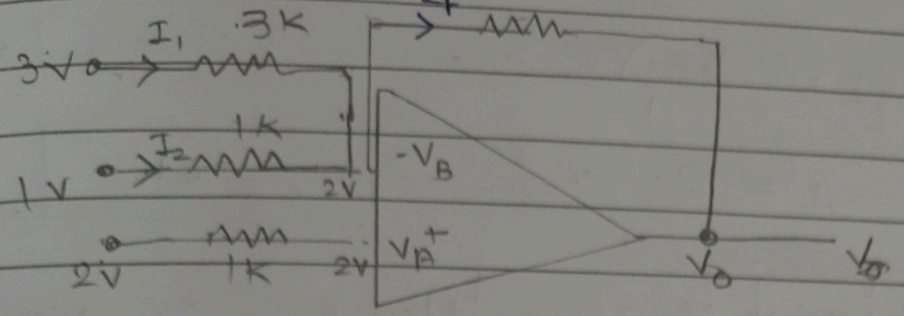
$$\boxed{V_0 = V_1 - V_2}$$

All these circuits uses negative feedback provided that input is betn +15v & −15v

Numericals of opam

For output +15 to -15V

Q1. Calculate V_o & V_B in given opam.



→ Here: $\boxed{V_A = 2V}$ — (opamp draws no current in 2V to V_A) As

∴ $I_f = I_1 + I_2$ —— (KCL)

$$\frac{2-V_0}{2} = \frac{3-2}{3} + \frac{1-2}{1}$$

$$\frac{2-V_0}{2} = \frac{1}{3} - 1$$

$$6-3V_0 = 2-6$$

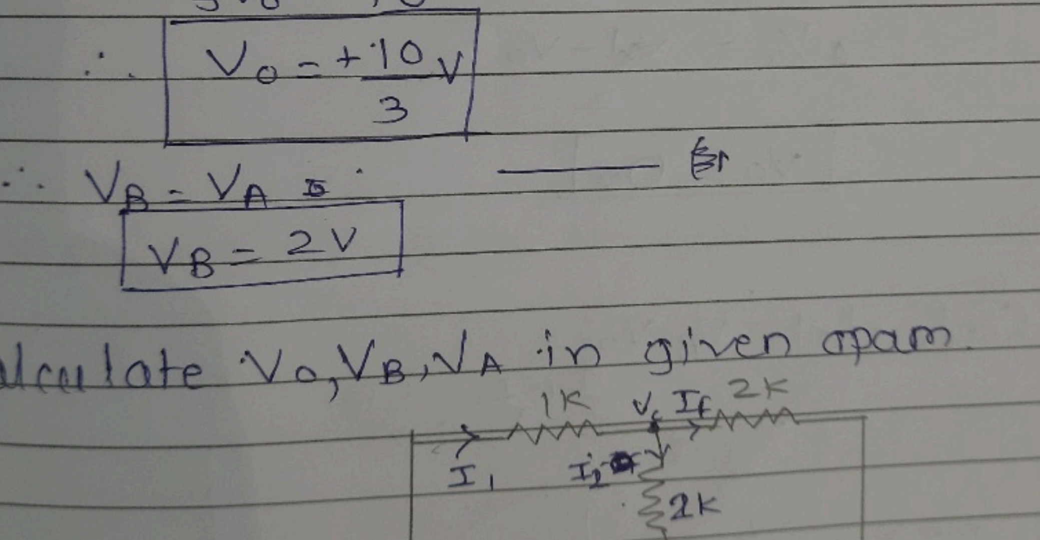
$$-3V_0 = -10$$

$$\therefore \boxed{V_0 = +\frac{10}{3}V}$$

As ∴ $V_B = V_A$

$\boxed{V_B = 2V}$

Q2) Calculate V_o, V_B, V_A in given opam.



① Calculating V_A.

$$V_A = \frac{4}{2(1K+1K)} = 2$$

$\boxed{V_A = 2V}$

Now, $\boxed{I_1} = \frac{3-2}{1} = \boxed{1\,mA}$ $\boxed{V_A = V_B = 2V}$

Now, $I_1 = \frac{V_B - V_C}{1}$ —— (ohm's law)

$\therefore 1 = \frac{2 - V_C}{1}$ $\therefore \boxed{V_C = +1V}$

$\therefore \boxed{I_2} = \frac{V_C - 0}{2} = \boxed{+\frac{1}{2} mA}$ — by KCL

Now ~~$I_F = V_C - V_0$~~ KCL at V_C

$I_1 = I_2 + I_F$

$1 = 1/2 + I_F$

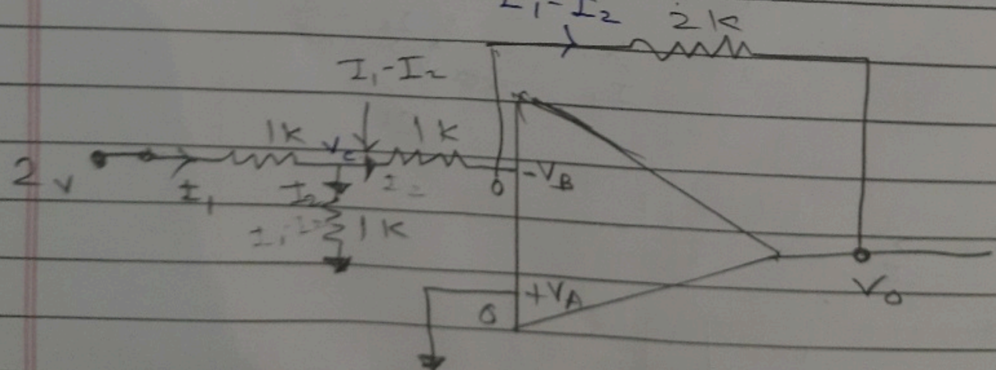
$\therefore \boxed{I_F = +\frac{1}{2} mA}$

Now, $I_F = \frac{V_C - V_0}{2}$ —— (by ohm's law)

$1/2 = \frac{1 - V_0}{2}$

$\therefore \boxed{V_0 = 0V}$

Q3) Calculate V_B, V_0



→ In given, $V_A = 0 = V_B$

$I_1 = \frac{2 - V_C}{1}$ $\therefore \boxed{I_1 = 2 - V_C}$ —— (By ohm's law)

$I_2 = \frac{V_C - 0}{1}$ $\boxed{I_2 = V_C}$

$$\boxed{I_1 - I_2 = 2 - 2V_C} \quad \text{——— ① – (from fig)}$$

$$I_1 - I_2 = \frac{V_C - 0}{1} = V_C \quad \text{——— ②}$$

from ① & ②

$$\cancel{V_C = 2 - 2V_C}$$

$$\cancel{V_C = 2/3\ V}$$

$$(I_1 - I_2) = 2 - 2(I_1 - I_2)$$

$$3(I_1 - I_2) = 2$$

$$\boxed{I_1 - I_2 = 2/3}$$

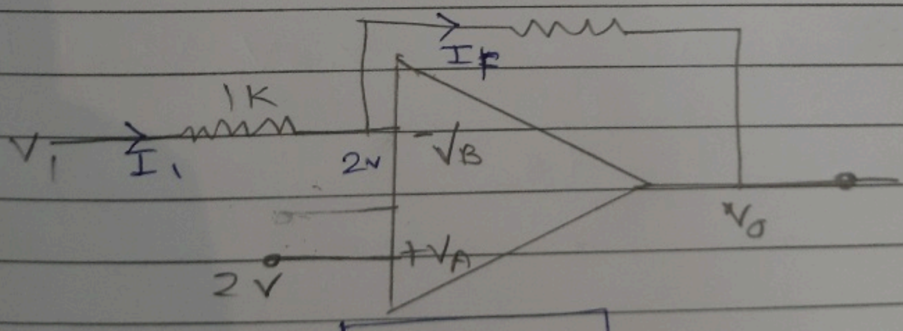
Now,

$$\frac{0 - V_0}{2} = I_1 - I_2 \quad \text{——— (Ohm's law)}$$

$$\therefore -V_0 = 4/3$$

$$\therefore \boxed{V_0 = -\frac{4}{3}\ V}$$

Q4) Calculate V_B & V_0 in case ① If $\boxed{V_1 = 3}$ ② If $\boxed{V_1 = 8}$



→ ① $V_A = 2V$ then $\boxed{V_B = 2V}$

$\boxed{V_1 = 3V}$

$$\therefore I_F = I_1 \qquad \left(\because I_1 = \frac{V_1 - 2}{1} \quad I_F = \frac{2 - V_0}{5}\right)$$

$$I_1 = \frac{2 - V_0}{5} = \frac{3 - 2}{1}$$

$$2 - V_0 = 10$$

$$\boxed{V_0 = -8V}$$

→ (2) for $\boxed{V_1 = 8V}$ assume $V_B = 2V$.

$\therefore I_f = I_1$

$\therefore \frac{2 - V_o}{5} = \frac{8 - 2}{1}$

$\therefore \boxed{V_o = -28V}$ but $\boxed{V_o = -15V}$ — should

assumption $V_B = 2V$ is wrong.

so, for V_B

$$\frac{V_1 - V_B}{1} = \frac{V_B - (-15)}{5} \quad \text{— (ohm's law)}$$

$$\therefore \frac{8 - V_B}{1} = \frac{V_B + 15}{5}$$

$$\therefore 6V_B = 25$$

$$\therefore \boxed{V_B = \frac{25}{6} V}$$