~~Op~~-amps

1) Goal?

$V_{out} = \sim\sim$

2) know?

a) $i^+ = i^- = 0A$

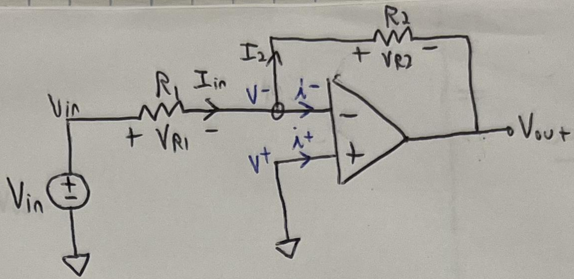
b) $V^+ = V^-$ (not always 0V!)

c) Voltage/current source values /resistor

Make observations

3) Solve

-nodal, KVL/KCL, dividers, etc.



1) $V_{out} = \sim\sim$ (V_{in}, R_1, R_2)

2) a) $i^+ = i^- = 0A$

KCL @ V^-

$I_{in} = I_2 + i^-$ ✓

$I_{in} = I_2$ ✓

b) $V^+ = V^-$

$V^+ = 0V$ (given)

$V^- = 0V$ ✓

3) nodal at V^-

$$I_{in} = I_2$$

$$\frac{V_{R1}}{R_1} = \frac{V_{R2}}{R_2}$$

$$\frac{V_{in} - V^-}{R_1} = \frac{V^- - V_{out}}{R_2}$$

$$\frac{V_{in}}{R_1} = -\frac{V_{out}}{R_2}$$

$$\boxed{V_{out} = -\frac{R_2}{R_1} V_{in}}$$

OR

3) work backwards

- equation involving V_{out}

$$I_2 = \frac{V^- - V_{out}}{R_2} = -\frac{V_{out}}{R_2}$$

$\downarrow$

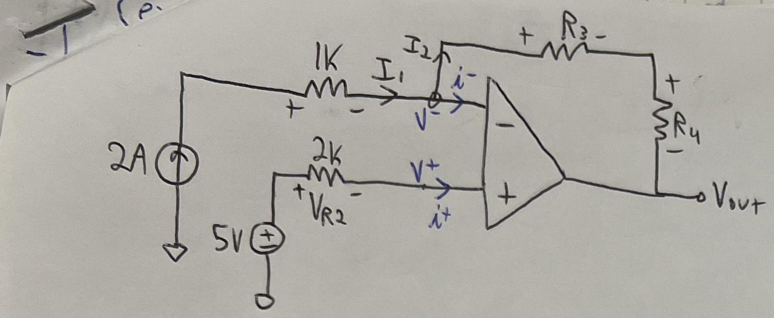
I_1

$\downarrow$

$$\frac{V_{in} - V^-}{R_1} = -\frac{V_{out}}{R_2}$$

$\vdots$

$$\boxed{V_{out} = -\frac{R_2}{R_1} V_{in}}$$



1) $V_{out} =$

(source values
R values)

2) $i^+ = 0$

→ $V_{R2} = i^+ R_2 = 0V$

→ $V^+ = 5 - V_{R2}$

$V^+ = 5V$

→ $V^- = V^+ = 5V$

$i^- = 0$

KCL @ V^-

$I_1 = I_2 + i^-$

$I_1 = I_2$

3) nodal @ V^-

$I_1 = I_2$

$$2 = \frac{V^- - V_{out}}{R_3 + R_4}$$

$$2 = \frac{5 - V_{out}}{R_3 + R_4}$$

⋮

$$\boxed{V_{out} = 5 - 2(R_3 + R_4)}$$

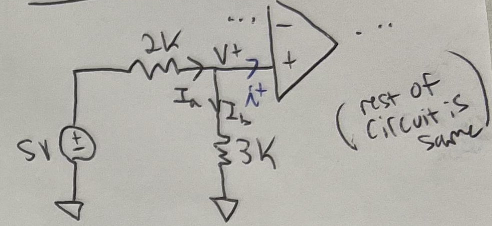
Check units!

$V = V - A(\Omega)$

$V = V - V$ ✓

$V = V$

what if?



KCL @ V^+

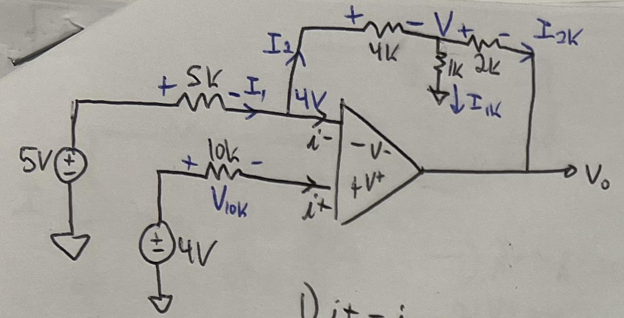
$I_a = I_b + i^+$

$I_a = I_b$ ✓

Voltage divider applies here!

$$V^+ = 5 \cdot \frac{3K}{2K+3K} = 3V$$

- Rest of analysis is unchanged.



1) $i^+ = i^- = 0$

2) $V^+ = V^-$

① $\boxed{i^+ = 0}$

$V_{10k} = 0V$

$\hookrightarrow V^+ = 4V \rightarrow \underline{V^- = 4V}$

② $\boxed{V^+ = V^-}$

③ $\boxed{i^- = 0}$

$\underline{I_1 = I_2}$

④ $I_1 = I_2 = \frac{5-4}{5K} = \underline{0.2mA}$

⑤ $4V - \overset{0.8}{\overset{0.2\cancel{K}\cdot 4\cancel{K}}{I_2 \cdot 4K}} = V$

$\underline{3.2V = V}$

goal known unknown but can find

$I_{2K} = I_2 - I_{1K}$

⑥ $I_{1K} = \frac{3.2-0}{1K} = \underline{3.2mA}$

⑦

$I_{2K} = I_2 - I_{1K}$

$= 0.2m - 3.2m = \underline{-3mA}$

⑧

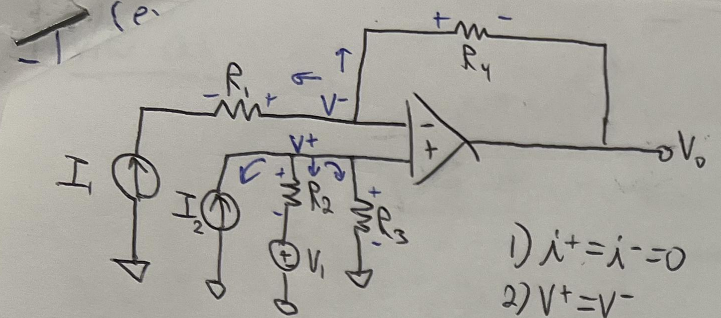
$\frac{V - V_o}{2k} = I_{2K}$

$V_o = V - 2K \cdot I_{2K}$

$= 3.2V - 2\cancel{K} \cdot (-3\cancel{m})$

$= 3.2V + 6 = \underline{9.2V}$

$\boxed{V_o = 9.2V}$



$V_0 = ?$

1) $i^+ = i^- = 0$

2) $V^+ = V^-$

$R_{eq} = \left(\frac{1}{R_2} + \frac{1}{R_3}\right)^{-1}$

$R_{eq} = \frac{R_2 R_3}{R_2 + R_3}$

V^-)

$$-I_1 + \frac{V^- - V_0}{R_4} = 0 \longrightarrow V_0 = V^- - I_1 R_4 \Rightarrow \boxed{V_0 = \frac{I_2 + V_1/R_2}{\left(\frac{1}{R_2} + \frac{1}{R_3}\right)} - I_1 R_4}$$

$$\cancel{\frac{V^-}{R_4}} - \frac{V_0}{R_4} = +I_1 - \frac{V^-}{R_4}$$

V^+)

$$-I_2 + \frac{V^+ - V_1}{R_2} + \frac{V^+ - 0}{R_3} = 0$$

$$V^+\left(\frac{1}{R_2} + \frac{1}{R_3}\right) = I_2 + \frac{V_1}{R_2}$$

$$V^+ = \frac{I_2 + V_1/R_2}{\left(\frac{1}{R_2} + \frac{1}{R_3}\right)} = V^-$$

$$= \frac{R_2 R_3 I_2 + R_3 V_1}{R_2 + R_3} - I_1 R_4$$

$$\frac{[A] + [A]}{\frac{1}{[\Omega]}} - [V] \quad ✓$$

$$\frac{\overset{V}{\cancel{\Omega} A} + \cancel{\Omega} V}{\cancel{\Omega}} - V \quad ✓$$