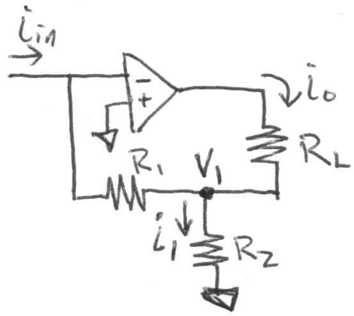
1.



Have negative fb., so $v^- = v^+ = 0$

$$i_{in} = \frac{0 - V_1}{R_1}, \quad V_1 = -i_{in} R_1$$

$$i_1 = \frac{V_1}{R_2}, \quad V_1 = i_1 R_2 \Rightarrow -\frac{i_{in} R_1}{R_2} = i_1$$

$$i_o = -i_{in} + i_1$$

$$\boxed{i_o = -i_{in}\left(1 + \frac{R_1}{R_2}\right)}$$

This is a current amplifier. The current through $R_L (i_o)$ is independent of the value of R_L.

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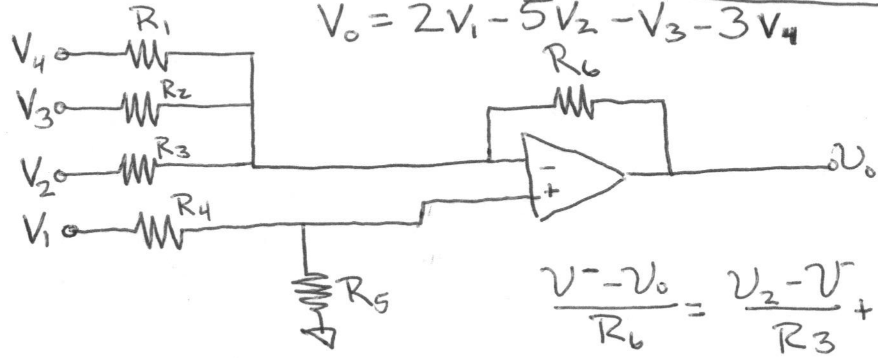
2. $V_o = 2V_1 - 5V_2 - V_3 - 3V_4$



$$v^+ = V_1\left(\frac{R_5}{R_4+R_5}\right) = v^-$$

summing pt.

$$\frac{v^- - v_o}{R_6} = \frac{v_2 - v^-}{R_3} + \frac{v_3 - v^-}{R_2} + \frac{v_4 - v^-}{R_1}$$

$$V_1\left(\frac{R_5}{R_4+R_5}\right) - V_o = R_6\left(\frac{V_2}{R_3} - V_1 \frac{R_5}{R_3}\left(\frac{1}{R_4+R_5}\right) + \frac{V_3}{R_2} - V_1 \frac{R_5}{R_2(R_4+R_5)} + \frac{V_4}{R_1} - \frac{V_1 R_5}{R_1(R_4+R_5)}\right)$$

$$V_o = V_1 \underbrace{\left(\frac{R_5}{R_4+R_5}\right)}\left(1 + \frac{1}{R_3} + \frac{1}{R_2} + \frac{1}{R_1}\right)R_6 - V_2 \frac{R_6}{R_3} - V_3 \frac{R_6}{R_2} - V_4 \frac{R_6}{R_1}$$

$\boxed{\text{Let } R_6 = 100\Omega}$

~~$R_5 = 100\Omega$~~

~~$R_4 = 100\Omega$~~

$$V_o = V_1 \left(1 + \frac{1}{R_3} + \frac{1}{R_2} + \frac{1}{R_1}\right)(100) - V_2\left(\frac{100}{R_3}\right) - V_3\left(\frac{100}{R_2}\right) - V_4\left(\frac{100}{R_1}\right)$$

so, $\frac{100}{R_3} = 5$, $\frac{100}{R_2} = 1$, $\frac{100}{R_1} = +3$

$$\boxed{R_3 = 20\Omega, \quad R_2 = 100\Omega, \quad R_1 = 33\Omega}$$

$$2 = \left(1 + \frac{1}{20} + \frac{1}{100} + \frac{1}{33}\right)(100)\left(\frac{R_5}{R_4+R_5}\right)$$

$$2 = (100 + 5 + 1 + 3)\left(\frac{R_5}{R_4+R_5}\right)$$

$$\frac{2}{109} = \frac{R_5}{R_4+R_5} \quad \text{so,} \quad \boxed{R_5 = 2\Omega, \; R_4 = 107\Omega}$$

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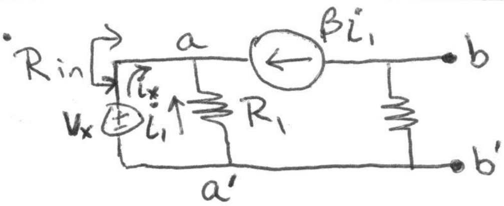
3. a.

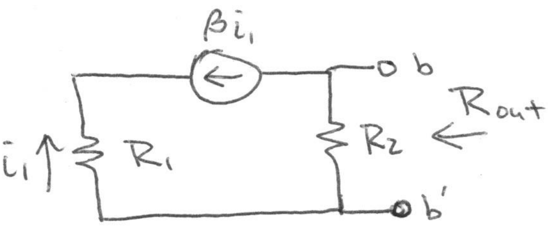


apply test voltage across a, a'

$$i_1 = -\frac{V_x}{R_1}$$

$$i_x = -\beta i_1 - i_1 = \frac{V_x}{R_1}(1+\beta) \Rightarrow \boxed{R_{in} = \frac{R_1}{1+\beta}}$$

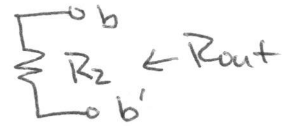
b.



apply V_x across b, b'

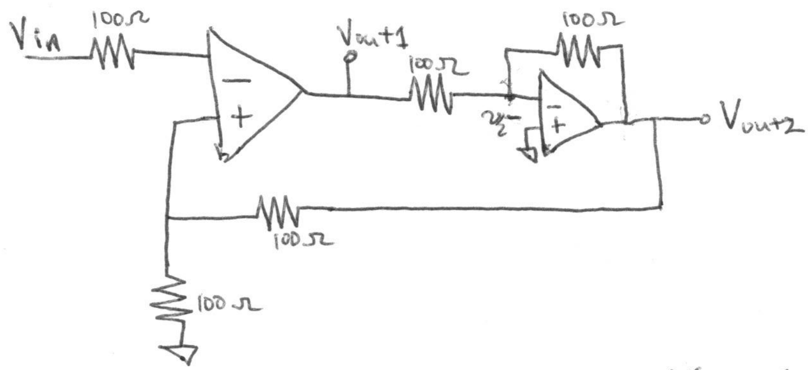
$i_1 = 0$ (no voltage across R_1)

$\Rightarrow$



$\boxed{R_{out} = R_2}$

4.



a. $V_{out2} = -A(v_2^-) \Rightarrow v_2^- = -\frac{V_{out2}}{A}$

$$\frac{V_{out1} - v_2^-}{100} = \frac{v_2^- - V_{out2}}{100}$$

$$V_{out2} = 2v_2^- - V_{out1}$$

$$V_{out2} = -2\frac{V_{out2}}{A} - V_{out1}$$

$$V_{out2} = \frac{-V_{out1}}{1 + 2/A}$$

$$v_1^+ = V_{out2}\left(\tfrac{1}{2}\right)$$

$$V_{out1} = \left(\tfrac{1}{2}V_{out2} - V_{in}\right)A$$

$$V_{out2} = -\frac{\left(\frac{1}{2}V_{out2} - V_{in}\right)A}{1 + 2/A}$$

$$V_{out2} = \frac{-\frac{1}{2}V_{out2}A^2 + V_{in}A^2}{A + 2}$$

$$V_{out2}\left(A + 2 + \tfrac{1}{2}A^2\right) = V_{in}A^2$$

$$\boxed{V_{out2} = \frac{2V_{in}A^2}{4 + 2A + A^2}}$$

b. $v_1^+ = \frac{1}{2}V_{out2}$, so $v_1^+ = \frac{V_{in}A^2}{4 + 2A + A^2}$, $\boxed{\lim_{A\to\infty} v_1^+ = V_{in}}$ (summing pt. !)

c. The amp connecting Vout1 to Vout2 is the typical inverting neg. fb. op amp.

d. i) increase $\left(A(v_1^+ - v_1^-)\right)$

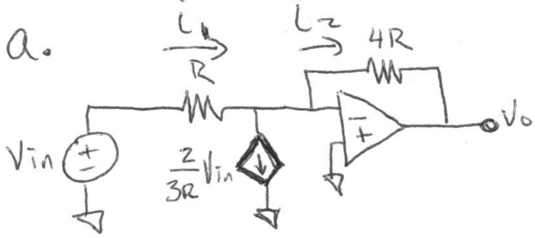
ii) decrease (now v_2^- went up)

iii) decrease (just a resistive voltage divider connection to Vout2)

~~iv)~~

e. Of course! As pointed out, b. gives the summing pt. cnst. Also, c & d are a great intuitive way of showing neg fb. exists.

5. a.



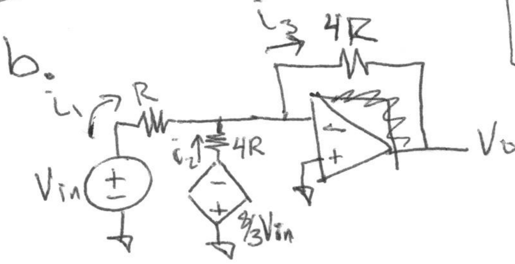
by summing pt. $v^- = 0\,V$

$$i_1 = \frac{V_{in}}{R}$$

$$i_2 = i_1 - \frac{2}{3R} V_{in} = \frac{1}{3}\frac{V_{in}}{R}$$

$$\cancel{V_o = 0} \quad \frac{0 - V_o}{4R} = i_2 \Rightarrow \boxed{V_o = -\frac{4}{3} V_{in}}$$

b.



$v^- = 0\,V$

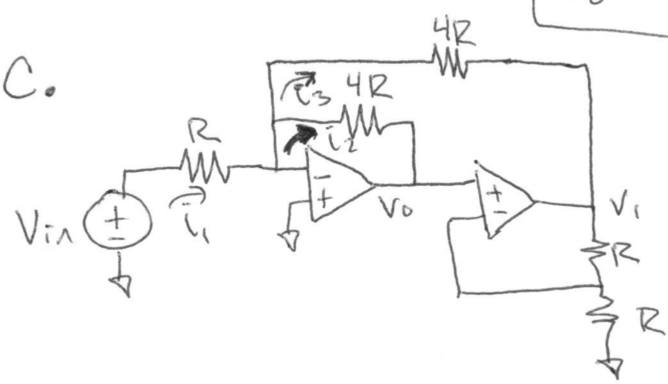
$$i_3 = i_1 + i_2$$

$$i_1 = \frac{V_{in}}{R} \qquad i_2 = -\frac{8}{3}\frac{V_{in}}{4R}$$

$$i_3 = V_{in}\left(\frac{1}{R} - \frac{2}{3R}\right) = \frac{V_{in}}{3R}$$

$$\boxed{V_o = -\frac{4}{3} V_{in}}$$

C.



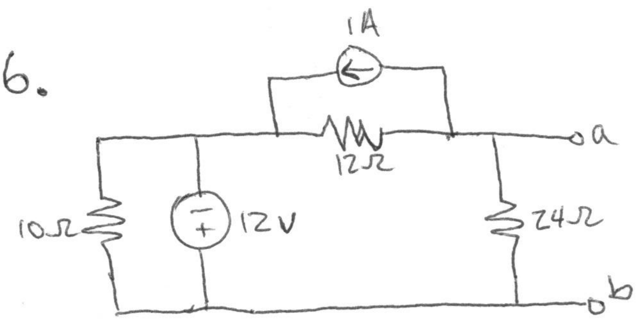
$V_1 = \frac{V_o}{2}$ (basic non-inverting topology)

$v_1^- = 0$

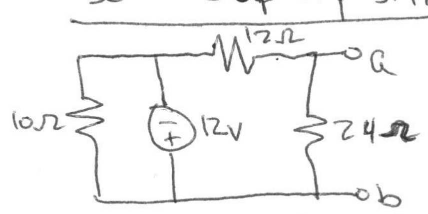
$$\frac{V_{in}}{R} = -\frac{V_o}{4R} - \frac{V_o}{8R}$$

$$\boxed{V_o = \frac{-8V_{in}}{3} \Rightarrow V_1 = -\frac{4}{3} V_{in}}$$

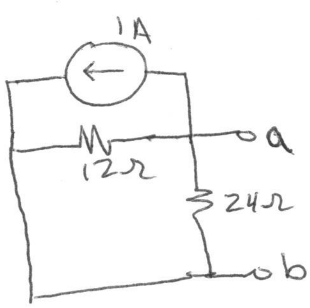
6.



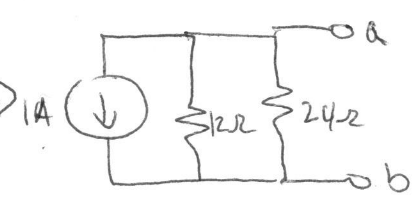
Use superposition (this is one of the most powerful techniques for solving circuits. Along with node voltage there isn't much you can't solve)



$V_{oc} = -8V \quad i_{sc} = -1A$



$\Rightarrow$

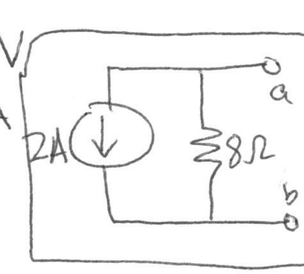


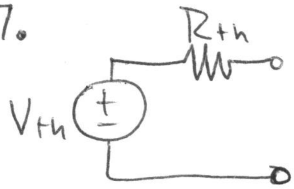
$V_{oc} = -8V \quad i_{sc} = -1A$

$V_{oc,tot} = -16V$

$i_{sc,tot} = -2A$

$\Rightarrow R_{th} = 8\Omega$



7. 

$I = \frac{V}{k_1} + k_2$ when $V = V_{th}$, $I = 0$

so, $\frac{V_{th}}{k_1} = k_2$

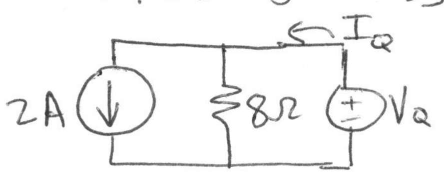
when $I = +I_N$ (or $I_{th} = I_{sc}$)

$V = 0$

$\boxed{+I_N = k_2}$

$\Rightarrow \boxed{\frac{1}{k_1} = \frac{+I_N}{V_{th}} = \frac{+1}{R_{th}}}$

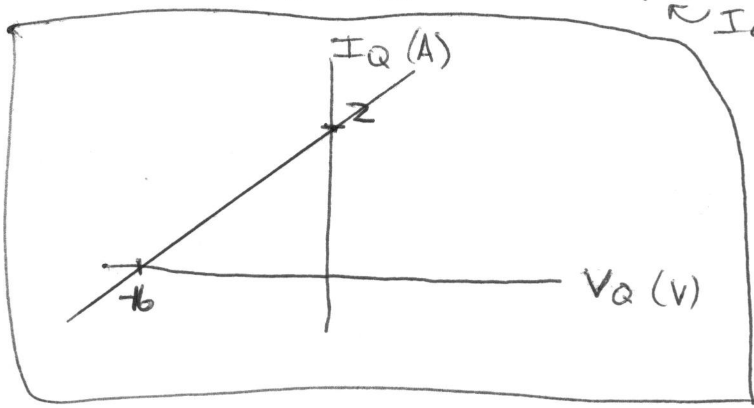
8. a. Use Norton equivalent from 6. (If you don't do this, maybe you don't trust Norton/Thevenin. If that's the case you need to convince yourself fast. These will continue to be extremely important in this class and future circuits classes.) Without them you'll waste a lot of time!



$I_Q(0) = 2A = +I_N$

$V_Q(0) = -2(8) = -16V = V_{th}$

from 7, $\boxed{I_Q = +\frac{V_Q}{8} + 2}$



b. Yes, we can see this quickly by finding ~~Rth between a & c which is~~ I_{sc} between a & c using superposition

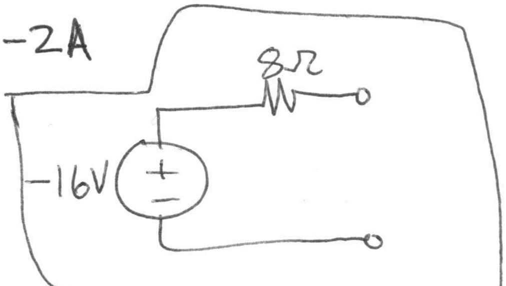
$I_{source} \Rightarrow I_{sc} = -1A$

$V_{source} \Rightarrow I_{sc} = \frac{12}{24} = \frac{1}{2}A \Rightarrow \boxed{I_{sc} = -\frac{1}{2}A \neq -2A}$

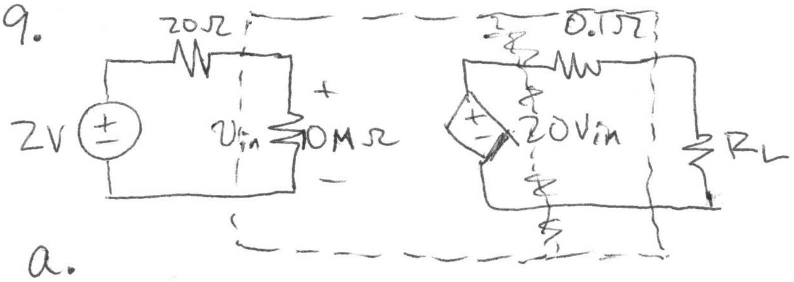
c. $I_N = -I_Q(0) = \frac{V_{th}}{R_{th}} = -2A$

$R_{th} = 8\Omega$

$\Rightarrow V_{th} = -16V$ $\Rightarrow$



9.



a.

↑ amp is boxed

$P = \frac{V^2}{R}$, $V \approx 2V$ $\left(\frac{10M}{20+10M} \approx 1\right)$

$P = \frac{4}{10^7} = \boxed{400nW}$

b.

$v_{out} = \left(\frac{R_L}{0.1+R_L}\right)40$

$\frac{20}{40} = \frac{R_L}{0.1+R_L} \Rightarrow \boxed{R_L = 0.1\Omega}$

c.

$P_L = \frac{V_L^2}{R_L} = \frac{V_s^2\left(\frac{R_L^2}{(R_s+R_L)^2}\right)}{R_L} = \frac{V_s^2 R_L}{R_s^2+2R_sR_L+R_L^2}$

want to minimize denom.

$R_s^2+2R_sR_L+R_L^2$ with $R_s>0$, $R_L>0$

fixed

so want to minimize

$R_s^2+2R_sR_L = R_s(R_s+2R_L)$, set $\boxed{R_s = 0}$