Find $i_x$, using Thevenin's Theorem for nodes a-b.

Specifying the use of Thevenin's Theorem for terminals or nodes a-b means that whatever is connected between nodes a-b (if anything) must be removed first.

Find $R_{Th}$

Set sources = 0.

Traveling from node a to b we find two 10Ω resistors in parallel, and then a series 5Ω resistor, so

$$R_{Th} = \frac{10}{10} + 5 = 5 + 5 = 10Ω$$

Find $V_{Th}$

With the 6Ω resistor removed, we have 2 simpler circuits to solve.

On the left $V_a = 20V \left(\frac{10}{10+10}\right) = 10V$.

On the right $V_b = (3)(5) = 15V$.

Now using KVL in the center $-V_a + V_{Th} + V_b = 0$ so $V_{Th} = 10 - 15 = -5V$.

The Thevenin Equivalent Circuit with $R_L$.

Find $i_x$ with $R_L = 6Ω$

$$i_x = \frac{V_{ba}}{R_{eq}} = \frac{-V_{Th}}{16} = \frac{-(-5)}{16} = 0.3A$$
Thevenin Practice Problem

Find $V_o$ using Thevenin’s Theorem.

Find $R_{TH}$:
* Remove $R_L$
* Set sources $= 0$

$$R_{TH} = \frac{10 + 2 + 12}{24} = \frac{24}{24} = 10 + 2 + 8 = 20k\Omega$$

Find $V_{TH}$: This can be solved many different ways, perhaps nodal analysis, or superposition?

Using Nodal Analysis

@ $V_i$:
$$\frac{36 - V_i}{12k} = \frac{V_i - 0}{24k} + \frac{V_i - V_2}{2k}$$

@ $V_2$:
$$\frac{V_i - V_2}{2k} = 3mA + I_{10k}$$

*Note* $I_{10k} = 0$ since this is connected to an open circuit branch.

Therefore $V_2 = V_{TH}$

from 1) $2(36 - V_i) = V_i + (24k)(3m) \Rightarrow V_i = 0$

Therefore $V_i - 6 = 0 - 6 = -6V = V_{TH}$

The Thevenin Equivalent circuit w/$R_L$

Find $V_o$ with $R_L = 1k\Omega$

$$V_o = -6 \left( \frac{1}{21} \right) = -286mV$$
Op Amp Practice Problem

Find $v_o$ and $i_o$

Golden Rules

$V_+ = V_-$

$I_{in} = 0$

Find $V_+$: using voltage division

$V_+ = 8 \left( \frac{3}{4} \right) = 6V$

Therefore $V_- = 6V$

Note: We can use voltage divider here because $I_{in} = 0$

Find $V_o$ using KCL

$\frac{10 - V_-}{2} = I_{in} + \frac{V_- - V_o}{4} \Rightarrow 2(10 - 6) = 6 - V_o$ so $V_o = -2V$

Did this behave as a difference amplifier?

does $V_+ - V_- = V_o$? $8 - 10 = -2V$ yes!

Find $i_o$ using KCL

$\frac{V_- - V_o}{4k} + i_o = \frac{V_o - 0}{5k}$

$6 - (-2) \cdot \frac{-2}{5k} = -i_o$

$2m - (-0.4) = 2.4mA = -i_o$ so $i_o = -2.4mA$
2. Find $V_o$ and $i_o$:

$V_+ = 1 \left( \frac{90}{100} \right) = 0.9V$

Golden Rule $V_- = V_+ = 0.9V$

Voltage divider at the output side:

$V_- = V_0 \left( \frac{50}{150} \right)$  so  $V_0 = 3V_- = 2.7V$

Find $i_o$:

using KCL: $i_o = \frac{V_0 - 0}{(50+100)k} + \frac{V_0 - 0}{10k}$

$= 18\mu A + 270\mu A = 288\mu A$

3. Find $V_0$:

$V_+ = 7.5 \left( \frac{24}{40} \right) = 4.5V$

Golden Rule $V_- = V_+ = 4.5V$

so $V_x$ also = 4.5V

Applying the voltage divider at the output:

$V_0 = V_x \left( \frac{12}{12+8} \right) = 4.5 \left( \frac{12}{20} \right) = 2.7V$

As with the previous problem, we can use the voltage divider because Im = 0.
Find $\frac{V_0}{I_5}$

Using KCL at the input:

$\frac{I_5}{R_1} = \frac{V_0 - V_1}{R_1} + \frac{I_m}{R_1}$

$V_0 = V_1$ from Golden Rule

and $V_- = V_+ = 0$ from Golden Rule

so $V_1 = -I_5 R_1$

Using KCL at node $V_1$

$\frac{I_5}{R_2} = \frac{V_1 - 0}{R_2} + \frac{V_1 - V_0}{R_3}$

$I_5 = \frac{-I_5 R_1}{R_2} + \frac{(-I_5 R_1) - V_0}{R_3}$

$V_0 = \frac{-I_5}{R_5} \left( 1 + \frac{R_1}{R_2} + \frac{R_1}{R_3} \right) = \frac{-V_0}{R_3}$

$\frac{V_0}{I_5} = -\left( \frac{R_1}{R_2} + \frac{R_1}{R_3} \right)$

Using resistor values

$R_1 = 20 \text{k} \Omega$
$R_2 = 25 \text{k} \Omega$
$R_3 = 40 \text{k} \Omega$

we find $\frac{V_0}{I_5} = -\left( 20 + 40 + 32 \right) = -92 \text{k} \Omega$
Find $i_0$

Carefully apply the Golden Rules to simplify this analysis.

Applying $V_2 = V_1$ to the right op amp we see that $V_4 = 0V$ so $V_2 = 0V$ so $V_3 = 0V$.

This means the 5kΩ and 3kΩ resistors are in parallel from $V_1$ to ground.

$V_1$: Using the voltage divider $V_1 = 0.6 \left( \frac{3/(5)}{1+3/(5)} \right) = 0.39V$.

$V_2$: For the left op amp $V_1 = V_2$ so $V_2 = V_1 = 0.39V$ and with the feedback wire $V_2 = 0.39V$.

$V_0$: Apply KCL @ $V_3$ in order to solve for $V_0$.

$$\frac{V_0 - V_3}{2} + \frac{V_1 - V_3}{5} = \frac{V_3 - V_0}{10} + I_m \Rightarrow \frac{0.39}{2} + \frac{0.39}{5} = \frac{-V_0}{10}$$

Solving to find $V_0 = -2.7V$.

Keeping careful attention to all polarities (!)

$$i_0 = \frac{0 - V_0}{4k} = \frac{0 - (-2.7)}{4k} = 0.68mA$$