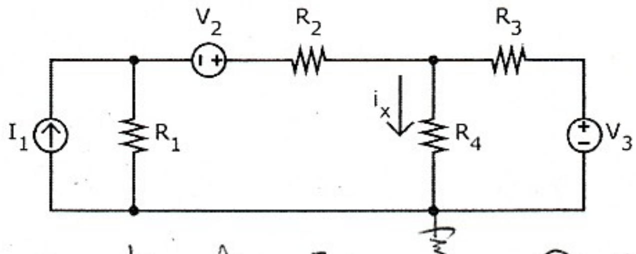
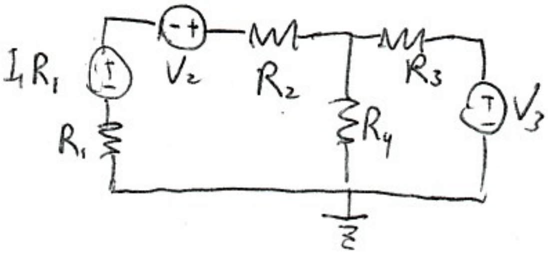
1. Calculate the value of current i_x. Parameter $I_1 = 4\,\text{mA}$, $V_2 = 3\,\text{V}$, $V_3 = 7\,\text{V}$, $R_1 = 2\,\text{k}\Omega$, $R_2 = 8\,\text{k}\Omega$, $R_3 = 8\,\text{k}\Omega$ and $R_4 = 4\,\text{k}\Omega$.

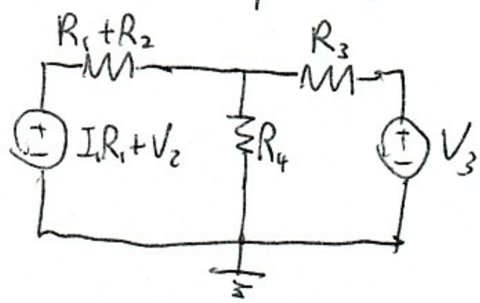
$i_x =$ [ ] 20 pts. 0



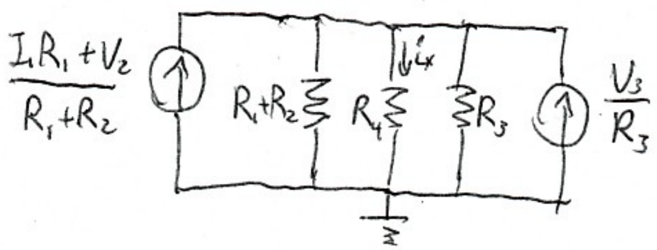
① Source transform I_1:



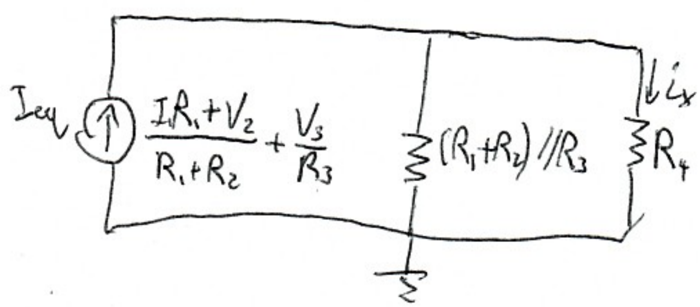
② Sum series components



③ Source transform voltages:



④ Add currents and put R_3, R_1+R_2 in parallel:



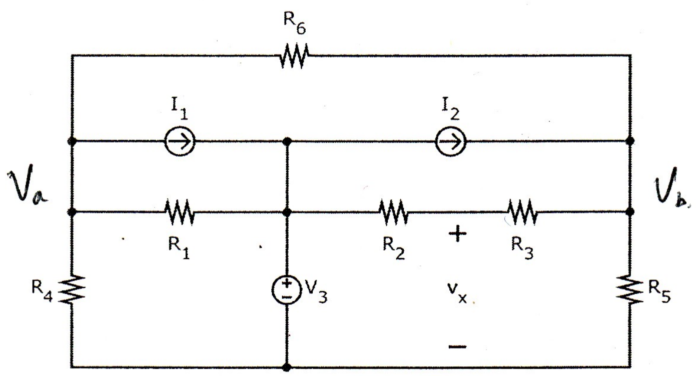
⑤ Current divider:

$$i_x = I_{eq} \cdot \frac{(R_1+R_2)//R_3}{(R_1+R_2)//R_3 + R_4}$$

Version	Answer
1	1.72 mA
2	1.37 mA
3	1.04 mA

2. Find the value of the voltage v_x. Parameter $I_1 = 6\,\text{mA}$, $I_2 = 9\,\text{mA}$, $V_3 = 4\,\text{V}$, $R_1 = 9\,\text{k}\Omega$, $R_2 = 8\,\text{k}\Omega$, $R_3 = 2\,\text{k}\Omega$, $R_4 = 5\,\text{k}\Omega$, $R_5 = 1\,\text{k}\Omega$ and $R_6 = 7\,\text{k}\Omega$.

$v_x =$ [ ] 20 pts. 1



Let $R_{23} = R_2 + R_3$

$R_{146} = R_1 // R_4 // R_6$

Write NV equations for V_a, V_b;

$$V_a: \quad \frac{V_a}{R_4} + \frac{V_a - V_3}{R_1} + I_1 + \frac{V_a - V_b}{R_6} = 0 \quad (1)$$

$$V_b: \quad \frac{V_b - V_3}{R_{23}} + \frac{V_b}{R_5} - I_2 + \frac{V_b - V_a}{R_6} = 0 \quad (3)$$

Isolate V_a:

$$(1) \quad V_a = \left(1/R_1 + 1/R_4 + 1/R_6\right)^{-1} \left(V_3/R_1 + V_b/R_6 - I_1\right) = R_{146}\left(V_3/R_6 + V_b/R_6 - I_1\right)$$

$$(2) \quad V_a = V_b - I_2 R_6 + \frac{R_6}{R_5} V_b + \frac{R_6}{R_{23}} V_b - \frac{R_1}{R_{23}} V_3$$

Equate and solve for V_b:

$$V_b = \frac{R_{146}/R_1 \cdot V_3 - I_1 R_{146} + I_2 R_6 + \frac{R_6}{R_{23}} V_3}{1 + \frac{R_6}{R_5} + \frac{R_6}{R_{23}} - \frac{R_{146}}{R_6}}$$

Once we know V_b,

$$V_x = V_3 + \frac{R_2}{R_2 + R_3}(V_b - V_3)$$

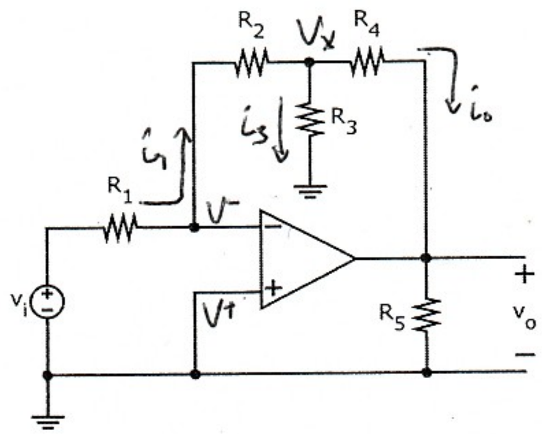
↑ many of you forgot this!

Version	Answer
1	7.21V
2	19.4V
3	5.90V

3. Opamp circuits with high closed-loop gain require large resistor ratios. On integrated circuits these take up significant area and are therefore costly. The circuit below uses a so-called T-network to reduce the required resistor ratio.

Calculate the value of resistor R_3 such that v_o/v_i = -91. Use $R_1 = 4\,\text{k}\Omega$, $R_2 = R_4 = 9\,\text{k}\Omega$ and $R_5 = 3\,\text{k}\Omega$.

$R_3 =$ [ ] 20 pts. 2



Negative feedback

$\Rightarrow V^- = V^+ = 0V$

$$i_1 = \frac{V_i}{R_1} \qquad V_x = -R_2 i_1 = -\frac{R_2}{R_1} V_i$$

$$i_2 = \frac{V_x}{R_3} = -\frac{R_2}{R_1 R_3} V_i$$

$$i_o = i_1 - i_3 = \frac{V_i}{R_1} + \frac{R_2}{R_1 R_3} V_i$$

$$V_o = V_x - i_o R_4 = -\frac{R_2}{R_1} V_i - R_4 \left(\frac{V_i}{R_1} + \frac{R_2}{R_1 R_3} V_i \right) \qquad R_2 = R_4$$

$$\Rightarrow \frac{V_o}{V_i} = -\frac{2R_2}{R_1} - \frac{R_2^2}{R_1 R_3}$$

solve for R_3:

$$R_3 = \frac{R_2^2}{R_1 \left(-\frac{V_o}{V_i} - \frac{2R_2}{R_1} \right)}$$

Version	Answer
1	340Ω
2	234Ω
3	6.45Ω

4. The output voltage of a temperature sensor element is

$$v_t(T) = -2\frac{\text{mV}}{^oC} \times T$$

where T is the temperature in degrees Celsius.

Design a thermometer circuit with output voltage

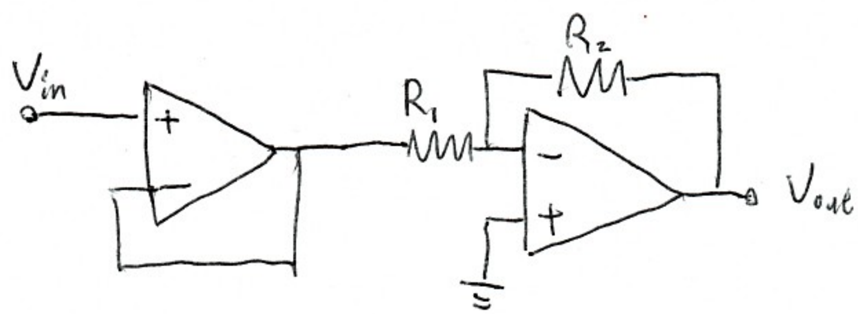
$$v_o(T) = 10\frac{\text{mV}}{^oC} \times T$$

using the sensor, resistors, and ideal opamps. Your circuit should produce the correct output independent of the output resistance R_o of the temperature sensor, which is in the range $50\,\text{k}\Omega \ldots 100\,\text{k}\Omega$. Draw the schematic diagram in the space provided below. Specify the values of all resistors (except R_o).

$$A_v = \frac{10}{-2} = -5$$

This suggests we need an inverting amplifier.

We also need a buffer for R_o independence.



20 pts.
2

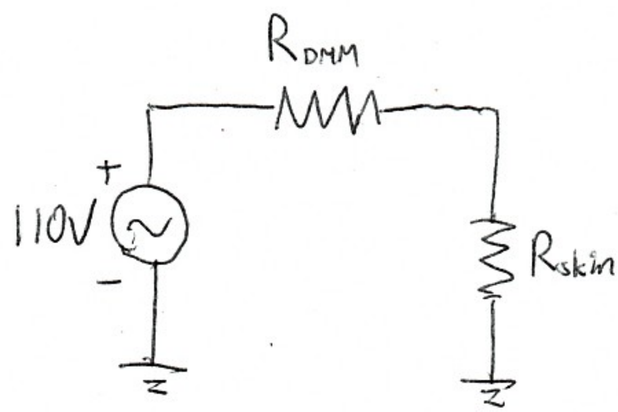
$$A = -\frac{R_2}{R_1} \Rightarrow \frac{R_2}{R_1} = 5$$

$$\Rightarrow R_2 = 5R_1$$

5. Suppose you stand barefoot on a wet floor with a hand-held digital voltmeter (DVM) in one hand. You insert one probe of the DVM into the hot output of a 110 V outlet and touch the other probe with your free hand.

Hypothetical experiment—don't try this!

a) Draw a circuit schematic of the situation. Use only circuit elements—sources and resistors—and their correct symbols. Do not draw pictures of elements. Assign reasonable values to all circuit components.



$R_{DMM} \sim 1M\Omega - 10M\Omega$

$R_{skin} \sim 10k\Omega - 100k\Omega$

We accepted values between 1k and 1MΩ for R_{skin}.

10 pts.
3

b) Would you get hurt? Explain!

No. R_{DMM} and R_{skin} form a voltage divider. So, voltage across skin is relatively small.

$$V_{skin} \sim \frac{R_{skin}}{R_{skin} + R_{DMM}} \sim \frac{10k}{10k + 1M} \approx 1.1V, \text{ which is safe.}$$

Or, since R_{DMM} and R_{skin} are in series,

$$I < \frac{V}{R_{DMM}} = \frac{110V}{1M\Omega} = 0.11mA, \text{ which won't hurt you.}$$

10 pts.
4