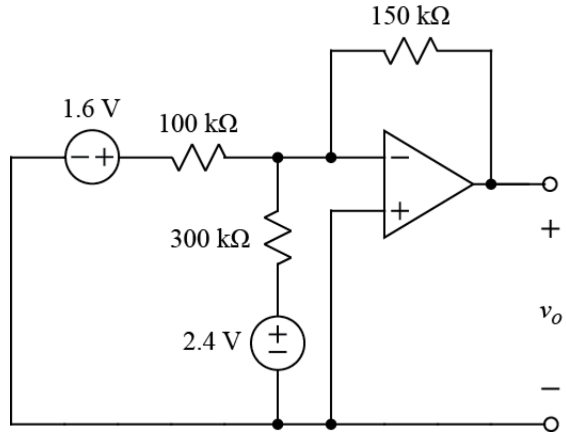
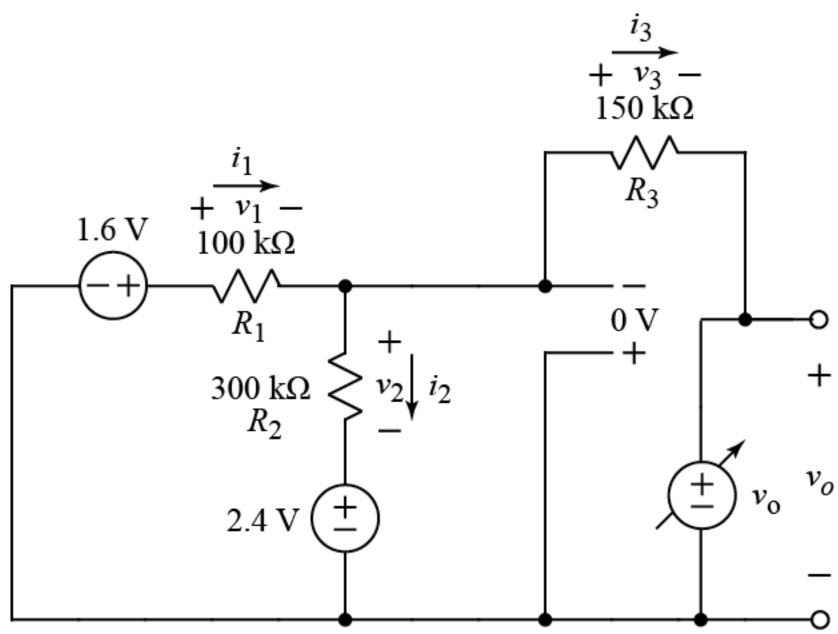
Ex:



The op-amp operates in the linear mode. Using an appropriate model of the op-amp, find the value of v_o.

SOL'N: The figure below shows the circuit with one possible way of labeling voltages and currents for resistors.



There are three inner voltage loops:

left-side: $1.6\,\text{V} - v_1 - v_2 - 2.4\,\text{V} = 0\,\text{V}$

middle: $2.4\,\text{V} + v_2 + 0\,\text{V} = 0\,\text{V}$

right-side: $-0\,\text{V} - v_3 - v_o = 0\,\text{V}$

We write a current summation for the node at the – input of the op-amp. Note that there is only one node where R_1, R_2, and R_3 meet since these R's are connected by wires. The nodes above and below v_o are not candidates for current summations because they are connected to each other by only a voltage source.

i-sum: $i_1 = i_2 + i_3$

Ohm's law for the three resistors:

$$v_1 = i_1 R_1$$

$$v_2 = i_2 R_2$$

$$v_3 = i_3 R_3$$

We substitute for the voltages using the Ohm's law equations, and we eliminate i_1 using the *i*-sum equation.

left-side: $1.6\,\text{V} - (i_2 + i_3)R_1 - i_2 R_2 - 2.4\,\text{V} = 0\,\text{V}$

middle: $2.4\,\text{V} + i_2 R_2 + 0\,\text{V} = 0\,\text{V}$

right-side: $-0\,\text{V} - i_3 R_3 - v_o = 0\,\text{V}$

The middle-loop equation gives the value of i_2.

$$i_2 = -\frac{2.4\,\text{V}}{R_2}$$

The middle-loop equation also says that the last two terms on the left side of the left-side equation sum to zero and may be dropped.

left-side: $1.6\,\text{V} - (i_2 + i_3)R_1 = 0\,\text{V}$

Substituting for i_2, we have the following left-side equation:

left-side: $1.6\,\text{V} - \left(-\frac{2.4\,\text{V}}{R_2} + i_3\right)R_1 = 0\,\text{V}$

Solving for i_3:

left-side: $1.6\,\text{V} + \frac{2.4\,\text{V}}{R_2}R_1 - i_3 R_1 = 0\,\text{V}$

or

left-side: $i_3 = \dfrac{1.6\,\text{V} + \frac{2.4\,\text{V}}{R_2}R_1}{R_1}$

Substituting this into the right-side equation gives the desired expression for v_o:

$$v_o = -i_3 R_3 = -\left(1.6\,\text{V} + 2.4\,\text{V}\frac{R_1}{R_2}\right)\frac{R_3}{R_1}$$

or

$$v_o = -\left(1.6\,\text{V} + 2.4\,\text{V}\frac{100\,\text{k}\Omega}{300\,\text{k}\Omega}\right)\frac{150\,\text{k}\Omega}{100\,\text{k}\Omega} = -3.6\,\text{V}$$