**Problem 2–32.** Figure P2–32 shows a subcircuit connected to the rest of the circuit at four points.

(a). Use element and connection constraints to find $v_x$ and $i_x$.

Label the 5-kΩ resistor as $R_1$ with the current flowing from left to right. Label the 2-kΩ resistor as $R_2$ with the positive sign at the bottom. Using Ohm's law, we can compute $i_1 = v_1/R_1 = 20/5000 = 4$ mA. The KCL equation at the center node is $4\,\text{mA} + i_1 - i_2 - i_x = 0$. Substituting in the known values, we can solve for $i_x$ as $i_x = 4 + i_1 - i_2 = 4 + 4 - 6 = 2$ mA. Using Ohm's law $v_x = R_x\, i_x = (8000)(0.002) = 16$ V.

(b). Show that the sum of the currents into the rest of the circuit is zero.

The sum of the currents entering the rest of the circuit is $-i_1 + i_2 - 4 + i_x = -4 + 6 - 4 + 2 = 0$ mA.

(c). Find the voltage $v_A$ with respect to the ground in the circuit.

From the ground to $v_A$ there are three voltages. First, there is an increase across the voltage source of 12 V. Next, there is an increase across $R_x$ of 16 V. Finally, there is a decrease across $R_2$ of $v_2 = R_2 i_2 = (2000)(0.006) = 12$ V. Therefore, $v_A = 12 + 16 - 12 = 16$ V.

**Problem 2–35.** Find the equivalent resistance $R_{\rm EQ}$ in Figure P2–35.

The 10-Ω resistor and the 30-Ω resistor are in parallel. That combination is in series with the 7.5-Ω resistor. We can calculate the equivalent resistance as follows:

$$R_{\rm EQ} = 7.5 + (30 \parallel 10) = 7.5 + \cfrac{1}{\cfrac{1}{30} + \cfrac{1}{10}} = 7.5 + \frac{(30)(10)}{30 + 10} = 7.5 + 7.5 = 15\,\Omega$$

**Problem 2–36.** Find the equivalent resistance $R_{\rm EQ}$ in Figure P2–36.

Combine the 33-kΩ and 47-kΩ resistors in series to get an equivalent resistance of $33+47 = 80$ kΩ. The 80-kΩ resistance is in parallel with the 100-kΩ resistor, which yields an equivalent resistance of $100 \parallel 80 = 44.4$ kΩ. That resistance is in series with the 68-kΩ resistor, which yields $R_{\rm EQ} = 68 + 44.4 = 112.4$ kΩ.

**Problem 2–37.** Find the equivalent resistance $R_{\rm EQ}$ in Figure P2–37.

Working from the right to the left, combine the 10-kΩ resistor in parallel with the 15-kΩ resistor to get an equivalent resistance of 6 kΩ. That resistance is in series with the 33-kΩ resistor, which yields an equivalent resistance of 39 kΩ. Finally, combine the 39-kΩ resistance in parallel with the 56-kΩ resistor to get $R_{\rm EQ} = 22.99$ kΩ.

**Problem 2–42.** In Figure P2–42 find the equivalent resistance between terminals A-B, A-C, A-D, B-C, B-D, and C-D.

For A-B, ignore the 20-Ω resistor and the 10-Ω resistor connected to terminal D. We then have

$$R_{\text{AB}} = [100 \parallel (60 + 40)] + 30 = [100 \parallel 100] + 30 = 50 + 30 = 80\,\Omega$$

For A-C, ignore the 30-Ω resistor and the 10-Ω resistor connected to terminal D. We then have

$$R_{\text{AC}} = [60 \parallel (100 + 40)] + 20 = [60 \parallel 140] + 20 = 42 + 20 = 62\,\Omega$$

For A-D, ignore the 30-Ω resistor and the 20-Ω resistor. We then have

$$R_{\text{AD}} == [60 \parallel (100 + 40)] + 10 = [60 \parallel 140] + 10 = 42 + 10 = 52\,\Omega$$

For B-C, ignore the A terminal and the 10-Ω resistor. We then have

$$R_{\text{BC}} = 30 + [40 \parallel (100 + 60)] + 20 = 30 + [40 \parallel 160] + 20 = 30 + 32 + 20 = 82\,\Omega$$

For B-D, ignore the A terminal and the 20-Ω resistor. We then have

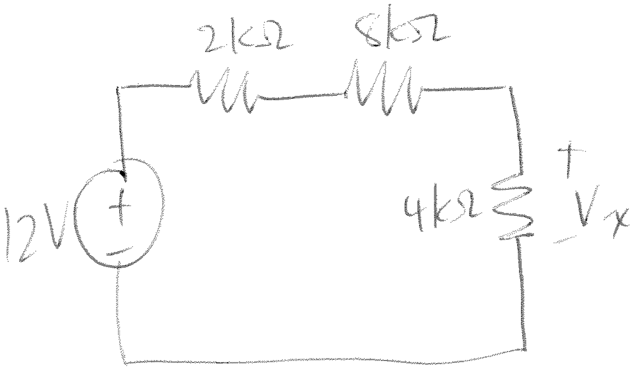
$$R_{\text{BD}} = 30 + [40 \parallel (100 + 60)] + 10 = 30 + [40 \parallel 160] + 10 = 30 + 32 + 10 = 72\,\Omega$$

For C-D, ignore the A terminal and the 30-Ω resistor. In the center of the circuit, the wire shorts out the 60, 100, and 40-Ω resistors, so we then have

$$R_{\text{CD}} = 20 + 0 + 10 = 30\,\Omega$$

**Problem 2–50.** Two 10-k$\Omega$ potentiometers (a variable resistor whose value between the two ends is 10 k$\Omega$ and between one end and the wiper—the third terminal—can range from 0 $\Omega$ to 10 k$\Omega$) are connected as shown in Figure P2–50. What is the range of $R_{\text{EQ}}$?

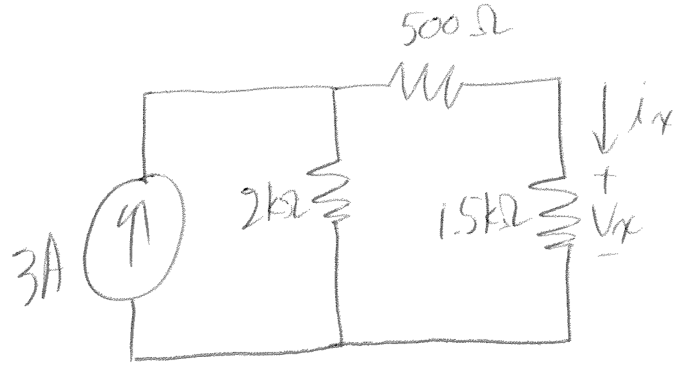
At the limits of their settings, the two poteniometers are either in series or parallel. These represent the maximum and minimum equivalent resistances that the combination can take. When the poteniometers are arranged in parallel, the equivalent resistance is $R_{\text{EQ}} = 10 \parallel 10 = 5$ k$\Omega$. When the poteniometers are arranged in series, the equivalent resistance is $R_{\text{EQ}} = 10 + 10 = 20$ k$\Omega$. The equivalent resistance ranges between 5 and 20 k$\Omega$.




**Problem 2–54.** Use voltage division in Figure P2–54 to find $v_x$.

Apply the equation for voltage division to get

$$v_x = \left(\frac{4}{2+8+4}\right)(12) = 3.4286\,\text{V}$$

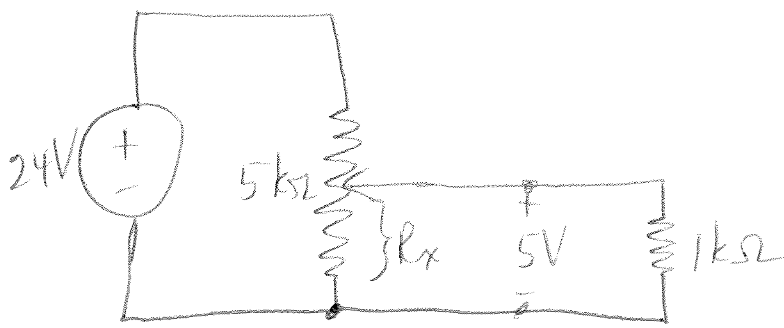



**Problem 2–56.** Use current division in Figure P2–56 to find $i_x$ and $v_x$.

Combine the 500-Ω and the 1.5-kΩ resistors in series to get an equivalent resistance of 2 kΩ. Now apply current division as follows:

$$i_{\mathrm{x}} = \left(\frac{\frac{1}{2}}{\frac{1}{2}+\frac{1}{2}}\right)(3) = \left(\frac{1}{2}\right)(3) = 1.5\,\mathrm{A}$$

$$v_{\mathrm{x}} = (1500)(1.5) = 2250\,\mathrm{V} = 2.25\,\mathrm{kV}$$




**Problem 2–60. (A)** The 1-kΩ load in Figure P2–60 needs 5 V across it to operate correctly. Where should the wiper on the potentiometer be set ($R_X$) to obtain the desired output voltage?

Figure P2–60 shows an equivalent circuit with the poteniometer split into its two equivalent components. To solve the problem, find an equivalent resistance for the parallel combination of resistors and then apply

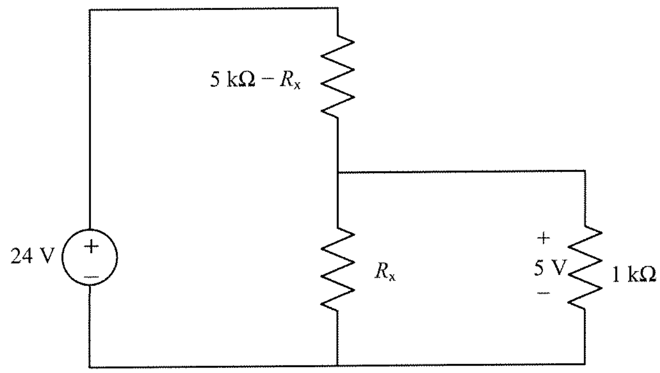


Figure P2–60

voltage division to find an expression for $R_x$. Solve for $R_x$ and select the positive result.

$$R_{EQ} = R_x \parallel 1000 = \frac{1000R_x}{1000 + R_x}$$

$$5\,\text{V} = \frac{R_{EQ}}{5000 - R_x + R_{EQ}}(24\,\text{V})$$

$$5 = \left[\frac{\dfrac{1000R_x}{1000 + R_x}}{5000 - R_x + \dfrac{1000R_x}{1000 + R_x}}\right](24) = \frac{24000R_x}{(5000 - R_x)(1000 + R_x) + 1000R_x}$$

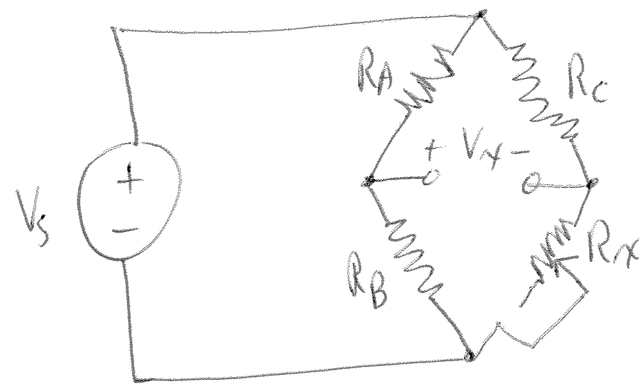
$$1 = \frac{4800R_x}{5 \times 10^6 + 4000R_x - R_x^2 + 1000R_x}$$

$$-R_x^2 + 5000R_x + 5 \times 10^6 = 4800R_x$$

$$R_x^2 - 200R_x - 5 \times 10^6 = 0$$

$$R_x = -2138 \text{ or } 2338\,\Omega$$

$$R_x = 2.338\,\text{k}\Omega$$




**Problem 2–63. (A)** Figure P2–63 shows a voltage bridge circuit, that is, two voltage dividers in parallel with a source $v_S$. One resistor $R_X$ is variable. The goal is often to "balance" the bridge by making $v_x = 0$ V. Derive an expression for $R_X$ in terms of the other resistors when the bridge is balanced.

Let the node between resistors $R_A$ and $R_B$ have a voltage $v_1$ and let the node between resistors $R_C$ and $R_X$ have a voltage $v_2$. The goal is to make $v_1$ equal $v_2$ so that $v_x$ is zero. Use voltage division to derive expressions for $v_1$ and $v_2$, set those expressions equal, and solve for $R_X$.

$$\begin{aligned}
v_1 &= \frac{R_B}{R_A + R_B}(v_S) \\
v_2 &= \frac{R_X}{R_C + R_X}(v_S) \\
\frac{R_B v_S}{R_A + R_B} &= \frac{R_X v_S}{R_C + R_X} \\
R_B(R_C + R_X) &= R_X(R_A + R_B) \\
R_B R_C + R_B R_X &= R_A R_X + R_B R_X \\
R_X &= \frac{R_B R_C}{R_A}
\end{aligned}$$