1. Define percent error as $100 \left( e^x - (1 + x) \right) / e^x$.

<table>
<thead>
<tr>
<th>$x$</th>
<th>$1 + x$</th>
<th>$e^x$</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>1.001</td>
<td>1.001</td>
<td>5×10⁻⁵</td>
</tr>
<tr>
<td>0.005</td>
<td>1.005</td>
<td>1.005</td>
<td>1×10⁻³</td>
</tr>
<tr>
<td>0.01</td>
<td>1.01</td>
<td>1.010</td>
<td>5×10⁻⁴</td>
</tr>
<tr>
<td>0.05</td>
<td>1.05</td>
<td>1.051</td>
<td>0.1</td>
</tr>
<tr>
<td>0.10</td>
<td>1.10</td>
<td>1.105</td>
<td>0.5</td>
</tr>
<tr>
<td>0.50</td>
<td>1.50</td>
<td>1.649</td>
<td>9</td>
</tr>
<tr>
<td>1.00</td>
<td>2.00</td>
<td>2.718</td>
<td>26</td>
</tr>
<tr>
<td>5.00</td>
<td>6.00</td>
<td>148.4</td>
<td>96</td>
</tr>
</tbody>
</table>

Of course, “reasonable” is a very subjective term. However, if we choose $x < 0.1$, we ensure that the error is less than 1%.
2. \( i_A, v_B \) “on”, \( v_C = 0 \): \( i_x = 20 \) A  
\( i_A, v_C \) “on”, \( v_B = 0 \): \( i_x = -5 \) A  
\( i_A, v_B, v_C \) “on” : \( i_x = 12 \) A  

so, we can write  

\[
\begin{align*}
    i_x' + i_x'' + i_x''' &= 12 \\
    i_x' + i_x'' &= 20 \\
    i_x' + i_x''' &= -5 \\
\end{align*}
\]

In matrix form,  

\[
\begin{bmatrix}
    1 & 1 & 1 \\
    1 & 1 & 0 \\
    1 & 0 & 1 \\
\end{bmatrix}
\begin{bmatrix}
    i_x' \\
    i_x'' \\
    i_x''' \\
\end{bmatrix}
= 
\begin{bmatrix}
    12 \\
    20 \\
    -5 \\
\end{bmatrix}
\]

(a) with \( i_A \) on only, the response \( i_x = i_x' = 3 \) A.  
(b) with \( v_B \) on only, the response \( i_x = i_x'' = 17 \) A.  
(c) with \( v_C \) on only, the response \( i_x = i_x''' = -8 \) A.  
(d) \( i_A \) and \( v_C \) doubled, \( v_B \) reversed: \( 2(3) + 2(-8) + (-1)(17) = -27 \) A.
CHAPTER FIVE SOLUTIONS

3. One source at a time:
The contribution from the 24-V source may be found by shorting the 45-V source and open-circuiting the 2-A source. Applying voltage division,

\[ v_x' = 24 \frac{20}{10 + 20 + 45 \parallel 30} = 24 \frac{20}{10 + 20 + 18} = 10 \text{ V} \]

We find the contribution of the 2-A source by shorting both voltage sources and applying current division:

\[ v_x'' = 20 \left[ 2 \frac{10}{10 + 20 + 18} \right] = 8.333 \text{ V} \]

Finally, the contribution from the 45-V source is found by open-circuiting the 2-A source and shorting the 24-V source. Defining \( v_{30} \) across the 30-Ω resistor with the “+” reference on top:

\[ 0 = v_{30}/20 + v_{30}/(10 + 20) + (v_{30} - 45)/45 \]

solving, \( v_{30} = 11.25 \text{ V} \) and hence \( v_x''' = -11.25(20)/(10 + 20) = -7.5 \text{ V} \)

Adding the individual contributions, we find that \( v_x = v_x' + v_x'' + v_x''' = 10.83 \text{ V} \).
4. The contribution of the 8-A source is found by shorting out the two voltage sources and employing simple current division:

\[ i_3' = -8 \frac{50}{50 + 30} = -5 \text{ A} \]

The contribution of the voltage sources may be found collectively or individually. The contribution of the 100-V source is found by open-circuiting the 8-A source and shorting the 60-V source. Then,

\[ i_3'' = \frac{100}{(50 + 30) || 60 || 30} = 6.25 \text{ A} \]

The contribution of the 60-V source is found in a similar way as \( i_3''' = -60/30 = -2 \text{ A} \).

The total response is \( i_3 = i_3' + i_3'' + i_3''' = -750 \text{ mA} \).
5. (a) By current division, the contribution of the 1-A source $i_2'$ is
$i_2' = 1 \times \frac{200}{250} = 800 \text{ mA}$.

The contribution of the 100-V source is $i_2'' = \frac{100}{250} = 400 \text{ mA}$.

The contribution of the 0.5-A source is found by current division once the 1-A source
is open-circuited and the voltage source is shorted. Thus,

$$i_2''' = 0.5 \times \frac{50}{250} = 100 \text{ mA}$$

Thus,

$$i_2 = i_2' + i_2'' + i_2''' = 1.3 \text{ A}$$

(b) Power calculations:

$$P_{1A} = (1) \times [(200)(1 - 1.3)] = 60 \text{ W}$$
$$P_{200} = (1 - 1.3)^2 \times (200) = 18 \text{ W}$$
$$P_{100V} = -(1.3)(100) = -130 \text{ W}$$
$$P_{50} = (1.3 - 0.5)^2 \times (50) = 32 \text{ W}$$
$$P_{0.5A} = (0.5) \times [(50)(1.3 - 0.5)] = 20 \text{ W}$$

Check: $60 + 18 + 32 + 20 = +130$. 
6. We find the contribution of the 4-A source by shorting out the 100-V source and analysing the resulting circuit:

\[
4 = \frac{V_1'}{20} + \frac{(V_1' - V')}{10} \quad [1]
\]

\[
0.4 i_1' = \frac{V_1'}{30} + \frac{(V' - V_1')}{10} \quad [2]
\]

where \( i_1' = \frac{V_1'}{20} \)

Simplifying & collecting terms, we obtain

\[
30 V_1' - 20 V' = 800 \quad [1]
\]

\[
-7.2 V_1' + 8 V' = 0 \quad [2]
\]

Solving, we find that \( V' = 60 \text{ V} \). Proceeding to the contribution of the 60-V source, we analyse the following circuit after defining a clockwise mesh current \( i_a \) flowing in the left mesh and a clockwise mesh current \( i_b \) flowing in the right mesh.

\[
30 i_a - 60 + 30 i_a - 30 i_b = 0 \quad [1]
\]

\[
i_b = -0.4 i_1'' = +0.4 i_a \quad [2]
\]

Solving, we find that \( i_a = 1.25 \text{ A} \) and so \( V'' = 30(i_a - i_b) = 22.5 \text{ V} \).

Thus, \( V = V' + V'' = 82.5 \text{ V} \).
7. (a) Linearity allows us to consider this by viewing each source as being scaled by \(25/10\). This means that the response \(v_3\) will be scaled by the same factor:

\[25 i_A'/10 + 25 i_B'/10 = 25 v_3'/10\]

\[\therefore v_3 = 25v_3'/10 = 25(80)/10 = 200 \text{ V}\]

(b) \(i_A' = 10 \text{ A}, i_B' = 25 \text{ A}\) \(\rightarrow v_4' = 100 \text{ V}\)

\(i_A'' = 10 \text{ A}, i_B'' = 25 \text{ A}\) \(\rightarrow v_4'' = -50 \text{ V}\)

\(i_A = 20 \text{ A}, i_B = -10 \text{ A}\) \(\rightarrow v_4 = ?\)

We can view this in a somewhat abstract form: the currents \(i_A\) and \(i_B\) multiply the same circuit parameters regardless of their value; the result is \(v_4\).

Writing in matrix form,

\[
\begin{bmatrix}
10 & 25 \\
25 & 10
\end{bmatrix}
\begin{bmatrix}
a \\
b
\end{bmatrix} =
\begin{bmatrix}
100 \\
-50
\end{bmatrix},
\]

we can solve to find

\(a = -4.286\) and \(b = 5.714\), so that \(20a - 10b\) leads to \(v_4 = -142.9 \text{ V}\)
8. With the current source open-circuited and the 7-V source shorted, we are left with 100k || (22k + 4.7k) = 21.07 kΩ.

Thus, \( V_{3V} = 3 \frac{21.07}{21.07 + 47} = 0.9286 \) V.

In a similar fashion, we find that the contribution of the 7-V source is:

\[ V_{7V} = 7 \frac{31.97}{31.97 + 26.7} = 3.814 \text{ V} \]

Finally, the contribution of the current source to the voltage \( V \) across it is:

\[ V_{5mA} = (5 \times 10^{-3}) (47k || 100k || 26.7k) = 72.75 \text{ V} \]

Adding, we find that \( V = 0.9286 + 3.814 + 72.75 = 77.49 \text{ V} \).
9. We must find the current through the 500-kΩ resistor using superposition, and then calculate the dissipated power.

The contribution from the current source may be calculated by first noting that

\[ 1 \text{M} \parallel 2.7 \text{M} \parallel 5 \text{M} = 636.8 \text{ kΩ} \]. Then,

\[
i_{60\mu A} = 60 \times 10^{-6} \left( \frac{3}{0.5 + 3 + 0.6368} \right) = 43.51 \mu A
\]

The contribution from the voltage source is found by first noting that

\[ 2.7 \text{M} \parallel 5 \text{M} = 1.753 \text{ MΩ} \]. The total current flowing from the voltage source (with the current source open-circuited) is 

\[ -1.5/ (3.5 \parallel 1.753 + 1) \] µA = -0.6919 µA. The current flowing through the 500-kΩ resistor due to the voltage source acting alone is then

\[
i_{1.5V} = 0.6919 (1.753)/(1.753 + 3.5) \text{ mA} = 230.9 \text{ nA}.
\]

The total current through the 500-kΩ resistor is then \( i_{60\mu A} + i_{1.5V} = 43.74 \mu A \) and the dissipated power is \((43.74 \times 10^{-9})^2 (500 \times 10^3) = 956.6 \mu W\).

956.6 \mu W.
10. We first determine the contribution of the voltage source:

Via mesh analysis, we write:

\[ 5 = 18000 I_1' - 17000 I_x' - 6 I_y' = -17000 I_x' + 39000 I_x' \]

Solving, we find \( I_1' = 472.1 \text{ mA} \) and \( I_x' = 205.8 \text{ mA} \), so \( V' = 17 \times 10^3 (I_1' - I_x') = 4.527 \text{ V} \). We proceed to find the contribution of the current source:

Via supernode:

\[ -20 \times 10^{-3} = V_{x''}/22 \times 10^3 + V''/0.9444 \times 10^3 \quad [1] \]

and

\[ V'' - V_{x''} = 6I_{x''} \quad \text{or} \quad V'' - V_{x''} = 6 V_{x''}/22 \times 10^3 \quad [2] \]

Solving, we find that \( V'' = -18.11 \text{ V} \). Thus, \( V = V' + V'' = -13.58 \text{ V} \).

The maximum power is \( V^2/17 \times 10^3 = V^2/17 \text{ mW} = 250 \text{ mW} \), so

\[ V = \sqrt{(17)(250)} = 65.19 \text{ V} = V' + 13.58 \text{ V}. \]

Solving, we find \( V_{\text{max}} = 78.77 \text{ V} \). The 5-V source may then be increased by a factor of \( 78.77/4.527 \), so that its maximum positive value is \( 87 \text{ V} \); past this value, and the resistor will overheat.
11. It is impossible to identify the individual contribution of each source to the power dissipated in the resistor; superposition cannot be used for such a purpose.

Simplifying the circuit, we may at least determine the total power dissipated in the resistor:

![Circuit Diagram]

Via superposition in one step, we may write

\[
i = \frac{5}{2 + 2.1} - 2 \cdot \frac{2.1}{2 + 2.1} = 195.1 \text{ mA}
\]

Thus,

\[
P_{2}\Omega = i^{2} \cdot 2 = 76.15 \text{ mW}
\]
12. We will analyse this circuit by first considering the combined effect of both dc sources (left), and then finding the effect of the single ac source acting alone (right).

\[
\begin{align*}
1, 3 \text{ supernode: } & \quad V_1/100 + V_1/17 \times 10^3 + (V_1 - 15)/33 \times 10^3 + V_3/10^3 = 20 I_B \quad [1] \\
\text{and: } & \quad V_1 - V_3 = 0.7 \quad [2] \\
\text{Node 2: } & \quad -20 I_B = (V_2 - 15)/1000 \quad [3] \\
\text{We require one additional equation if we wish to have } I_B \text{ as an unknown: } & \quad 20 I_B + I_B = V_3/1000 \quad [4] \\
\text{Simplifying and collecting terms, } & \quad 10.08912 V_1 + V_3 - 20 \times 10^3 I_B = 0.4545 \quad [1] \\
& \quad V_1 - V_3 = 0.7 \quad [2] \\
& \quad V_2 + 20 \times 10^3 I_B = 15 \quad [3] \\
& \quad -V_3 + 21 \times 10^3 I_B = 0 \quad [4] \\
\text{Solving, we find that } I_B = -31.04 \mu A. \\
\end{align*}
\]

To analyse the right-hand circuit, we first find the Thévenin equivalent to the left of the wire marked \( i_B' \), noting that the 33-kΩ and 17-kΩ resistors are now in parallel. We find that \( V_{TH} = 16.85 \cos 6t \) V by voltage division, and \( R_{TH} = 100 \parallel 17k \parallel 33k = 99.12 \) Ω. We may now proceed:

\[
\begin{align*}
20 i_B' = v_x'/1000 + (v_x' - 16.85 \cos 6t)/99.12 \quad [1] \\
20 i_B' + i_B'' = v_x'/1000 \quad [2] \\
\end{align*}
\]

Solving, we find that \( i_B' = 798.6 \cos 6t \) mA. Thus, adding our two results, we find the complete current is

\[ i_B = i_B' + I_B = -31.04 + 798.6 \cos 6t \mu A. \]
We first consider the effect of the 2-A source separately, using the left circuit:

\[ V_x' = 5 \left( \frac{2 - \frac{3}{3 + 14}}{3 + 14} \right) = 1.765 \text{ V} \]

Next we consider the effect of the 6-A source on its own using the right circuit:

\[ V_x'' = 5 \left( \frac{6 - \frac{9}{9 + 8}}{9 + 8} \right) = 15.88 \text{ V} \]

Thus, \( V_x = V_x' + V_x'' = 17.65 \text{ V} \).

(b) PSpice verification (DC Sweep)

The DC sweep results below confirm that \( V_x = 1.765 \text{ V} \).
14.

(a) Beginning with the circuit on the left, we find the contribution of the 2-V source to $V_x$:

$$-4V'_x = \frac{V'_x}{100} + \frac{V'_x - 2}{50}$$

which leads to $V'_x = 9.926 \text{ mV}$.

The circuit on the right yields the contribution of the 6-A source to $V_x$:

$$-4V''_x = \frac{V''_x}{100} + \frac{V''_x}{50}$$

which leads to $V''_x = 0$.

Thus, $V_x = V'_x + V''_x = 9.926 \text{ mV}$.

(b) PSpice verification.

As can be seen from the two separate PSpice simulations, our hand calculations are correct; the pV-scale voltage in the second simulation is a result of numerical inaccuracy.
Adding, we find that \( V_x' + V_x'' = 2.455 \text{ V} = V_x \) as promised.
16. (a) \[ \frac{120 \cos 400t}{60} = 2 \cos 400t \text{ A}. \quad 60 \| 120 = 40 \Omega. \]

\[ [2 \cos 400t](40) = 80 \cos 400t \text{ V}. \quad 40 + 10 = 50 \Omega. \]

\[ [80 \cos 400t]/50 = 1.6 \cos 400t \text{ A}. \quad 50 \| 50 = 25 \Omega. \]

(b) \( 2k \| 3k + 6k = 7.2 \text{ k}\Omega. \quad 7.2k \| 12k = 4.5 \text{ k}\Omega \)

\[ (20)(4.5) = 90 \text{ V}. \]
17. We can ignore the 1-kΩ resistor, at least when performing a source transformation on this circuit, as the 1-mA source will pump 1 mA through whatever value resistor we place there. So, we need only combine the 1 and 2 mA sources (which are in parallel once we replace the 1-kΩ resistor with a 0-Ω resistor). The current through the 5.8-kΩ resistor is then simply given by voltage division:

\[ i = \frac{3 \times 10^{-3} \cdot \frac{4.7}{4.7 + 5.8}}{4.7 + 5.8} = 1.343 \text{ mA} \]

The power dissipated by the 5.8-kΩ resistor is then \( i^2 \cdot 5.8 \times 10^3 = 10.46 \text{ mW} \).
18. We may ignore the 10-k\(\Omega\) and 9.7-k\(\Omega\) resistors, as 3-V will appear across them regardless of their value. Performing a quick source transformation on the 10-k\(\Omega\) resistor/4-mA current source combination, we replace them with a 40-V source in series with a 10-k\(\Omega\) resistor:

\[
I = \frac{43}{15.8} \text{mA} = 2.722 \text{mA}. \quad \text{Therefore, } P_{5.8\Omega} = I^2 \times 5.8 \times 10^3 = 42.97 \text{ mW}.
\]
19. \((100 \text{ k}\Omega)(6 \text{ mA}) = 0.6 \text{ V}\)

\[
\frac{470 \text{ k} \parallel 300 \text{ k}}{\Omega} = 183.1 \text{ k}\Omega
\]

\[
\frac{-3 - 0.6}{300 \times 10^3} = -12 \text{ \mu A}
\]

\[
(183.1 \text{ k}\Omega)(-12 \text{ \mu A}) = -2.197 \text{ V}
\]

Solving, \(9 + 1183.1 \times 10^3 I - 2.197 = 0\), so \(I = -5.750 \text{ \mu A}\). Thus,

\[
\mathcal{P}_{1\Omega} = I^2 \cdot 10^6 = 33.06 \text{ \mu W.}
\]
20. (1)(47) = 47 V. (20)(10) = 200 V. Each voltage source “+” corresponds to its corresponding current source’s arrow head.

Using KVL on the simplified circuit above,

\[ 47 + 47 \times 10^3 I_1 - 4 I_1 + 13.3 \times 10^3 I_1 + 200 = 0 \]

Solving, we find that \( I_1 = \frac{-247}{(60.3 \times 10^3 - 4)} = \boxed{-4.096 \text{ mA}} \).
21. \( (2 V_1)(17) = 34 V_1 \)

Analysing the simplified circuit above,

\[
34 V_1 - 0.6 + 7 I + 2 I + 17 I = 0 \quad [1] \quad \text{and} \quad V_1 = 2 I \quad [2]
\]

Substituting, we find that \( I = 0.6 / (68 + 7 + 2 + 17) = 6.383 \text{ mA} \). Thus,

\[
V_1 = 2 I = 12.77 \text{ mV}
\]
22. \( \frac{12}{9000} = 1.333 \text{ mA}. \) \( 9k \parallel 7k = 3.938 \text{ k}\Omega. \) \( \rightarrow (1.333 \text{ mA})(3.938 \text{ k}\Omega) = 5.249 \text{ V}. \)

\[ \frac{5.249}{473.938 \times 10^3} = 11.08 \mu\text{A} \]

473.9 \text{ k} \parallel 10 \text{ k} = 9.793 \text{ k}\Omega. \( (11.08 \mu\text{A})(9.793 \text{ k}\Omega) = 0.1085 \text{ V} \)

\[ I_x = \frac{0.1085}{28.793 \times 10^3} = 3.768 \mu\text{A}. \]
23. First, \((-7 \mu A)(2 \, \text{M}\Omega) = -14 \, \text{V}\), “+” reference down. \(2 \, \text{M}\Omega + 4 \, \text{M}\Omega = 6 \, \text{M}\Omega\).

\[ +14 \, \text{V/6 M}\Omega = 2.333 \, \mu A, \text{arrow pointing up}; \]

\[ 6 \, \text{M} \parallel 10 \, \text{M} = 3.75 \, \text{M}\Omega. \]

\[ (2.333)(3.75) = 8.749 \, \text{V}. \quad R_{\text{eq}} = 6.75 \, \text{M}\Omega \]

\[ \therefore I_x = \frac{8.749}{(6.75 + 4.7)} \mu A = 764.1 \, \text{nA}. \]
24. To begin, note that $(1 \text{ mA})(9 \ \Omega) = 9 \text{ mV}$, and $5 \parallel 4 = 2.222 \ \Omega$.

The above circuit may not be further simplified using only source transformation techniques.
25. Label the “-” terminal of the 9-V source node x and the other terminal node x'. The 9-V source will force the voltage across these two terminals to be –9 V regardless of the value of the current source and resistor to its left. These two components may therefore be neglected from the perspective of terminals a & b. Thus, we may draw:
26. Beware of the temptation to employ superposition to compute the dissipated power— it won’t work!

Instead, define a current $I$ flowing into the bottom terminal of the 1-M$\Omega$ resistor. Using superposition to compute this current,

$$I = \frac{1.8}{1.840} + 0 + 0 \ \mu\text{A} = 978.3 \ \text{nA}.$$ 

Thus,

$$P_{1\Omega} = (978.3 \times 10^{-9})^2 (10^6) = 957.1 \ \text{nW}.$$
27. Let’s begin by plotting the experimental results, along with a least-squares fit to part of the data:

![Experimental Data](image)

**Least-squares fit results:**

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.567</td>
<td>1.6681</td>
</tr>
<tr>
<td>1.563</td>
<td>6.599</td>
</tr>
<tr>
<td>1.558</td>
<td>12.763</td>
</tr>
</tbody>
</table>

We see from the figure that we cannot draw a very good line through all data points representing currents from 1 mA to 20 mA. We have therefore chosen to perform a linear fit for the three lower voltages only, as shown. Our model will not be as accurate at 1 mA; there is no way to know if our model will be accurate at 20 mA, since that is beyond the range of the experimental data.

Modeling this system as an ideal voltage source in series with a resistance (representing the internal resistance of the battery) and a varying load resistance, we may write the following two equations based on the linear fit to the data:

\[
1.567 = V_{\text{src}} - R_s (1.6681 \times 10^{-3}) \\
1.558 = V_{\text{src}} - R_s (12.763 \times 10^{-3})
\]

Solving, \( V_{\text{src}} = 1.568 \) V and \( R_s = 811.2 \) mΩ. It should be noted that depending on the line fit to the experimental data, these values can change somewhat, particularly the series resistance value.
28. Let’s begin by plotting the experimental results, along with a least-squares fit to part of the data:

We see from the figure that we cannot draw a very good line through all data points representing currents from 1 mA to 20 mA. We have therefore chosen to perform a linear fit for the three lower voltages only, as shown. Our model will not be as accurate at 1 mA; there is no way to know if our model will be accurate at 20 mA, since that is beyond the range of the experimental data.

Modeling this system as an ideal current source in parallel with a resistance \( R_p \) (representing the internal resistance of the battery) and a varying load resistance, we may write the following two equations based on the linear fit to the data:

\[
1.6681 \times 10^{-3} = I_{\text{src}} - \frac{1.567}{R_p}
\]

\[
12.763 \times 10^{-3} = I_{\text{src}} - \frac{1.558}{R_p}
\]

Solving, \( I_{\text{src}} = 1.933 \text{ A} \) and \( R_s = 811.2 \text{ m\Omega} \). It should be noted that depending on the line fit to the experimental data, these values can change somewhat, particularly the series resistance value.
29. Reference terminals are required to avoid ambiguity: depending on the sources with which we begin the transformation process, we will obtain entirely different answers. Working from left to right in this case,

\[ 2 \mu A - 1.8 \mu A = 200 \text{ nA}, \text{ arrow up.} \]
\[ 1.4 \text{ M}\Omega + 2.7 \text{ M}\Omega = 4.1 \text{ M}\Omega \]

An additional transformation back to a voltage source yields \((200 \text{ nA})(4.1 \text{ M}\Omega) = 0.82 \text{ V}\) in series with \(4.1 \text{ M}\Omega + 2 \text{ M}\Omega = 6.1 \text{ M}\Omega\), as shown below:

Then, \(0.82 \text{ V}/6.1 \text{ M}\Omega = 134.4 \text{ nA, arrow up.} \)
\(6.1 \text{ M}\Omega || 3 \text{ M}\Omega = 2.011 \text{ M}\Omega \)
\(4.1 \mu A + 134.4 \text{ nA} = 4.234 \text{ mA, arrow up.} \)
\((4.234 \mu A)(2.011 \text{ M}\Omega) = 8.515 \text{ V.}\)
To begin, we note that the 5-V and 2-V sources are in series:

Next, noting that $3 \, \text{V} / 1 \, \Omega = 3 \, \text{A}$, and $4 \, \text{A} - 3 \, \text{A} = +1 \, \text{A}$ (arrow down), we obtain:

By voltage division, the voltage across the $5\,-\Omega$ resistor in the circuit to the right is:

$$(-1) \, \frac{2 \| 5}{2 \| 5 + 2} = -0.4167 \, \text{V}.$$  

Thus, the power dissipated by the $5\,-\Omega$ resistor is $(0.4167)^2 / 5 = 34.73 \, \text{mW}$.  

The left-hand resistor and the current source are easily transformed into a 1-V source in series with a 1-\Omega resistor:
31. (a) $R_{TH} = 25 \parallel (10 + 15) = 25 \parallel 25 = 12.5 \, \Omega$.

$V_{TH} = V_{ab} = 50 \left( \frac{25}{10 + 15 + 25} \right) + 100 \left( \frac{15 + 10}{15 + 10 + 25} \right) = 75 \, \text{V}$. 

(b) If $R_{ab} = 50 \, \Omega$,

$P_{50\Omega} = \left[ 75 \left( \frac{50}{50 + 12.5} \right) \right]^2 \left( \frac{1}{50} \right) = 72 \, \text{W}$

(c) If $R_{ab} = 12.5 \, \Omega$,

$P_{12.5\Omega} = \left[ 75 \left( \frac{12.5}{12.5 + 12.5} \right) \right]^2 \left( \frac{1}{12.5} \right) = 112.5 \, \text{W}$
32. (a) Removing terminal \( c \), we need write only one nodal equation:

\[
0.1 = \frac{V_b - 2}{12} + \frac{V_b - 5}{15},
\]

which may be solved to yield \( V_b = 4 \) V. Therefore, \( V_{ab} = V_{TH} = 2 - 4 = -2 \) V.

\[
R_{TH} = \frac{12}{15} = 6.667 \ \Omega.
\]

We may then calculate \( I_N \) as

\[
I_N = \frac{V_{TH}}{R_{TH}} = -300 \text{ mA (arrow pointing upwards)}.
\]

(b) Removing terminal \( a \), we again find \( R_{TH} = 6.667 \ \Omega \), and only need write a single nodal equation; in fact, it is identical to that written for the circuit above, and we once again find that \( V_b = 4 \) V. In this case, \( V_{TH} = V_{bc} = 4 - 5 = -1 \) V, so

\[
I_N = \frac{-1}{6.667} = -150 \text{ mA (arrow pointing upwards)}.
\]
33. (a) Shorting out the 88-V source and open-circuiting the 1-A source, we see looking into the terminals x and x’ a 50-Ω resistor in parallel with 10 Ω in parallel with (20 Ω + 40 Ω), so

\[ R_{TH} = 50 \parallel 10 \parallel (20 + 40) = \boxed{7.317} \Omega \]

Using superposition to determine the voltage \( V_{xx'} \) across the 50-Ω resistor, we find

\[
V_{xx'} = V_{TH} = \left[ \frac{50 (20 + 40)}{10 + [50 \parallel (20 + 40)]} \right] + (1)(50 \parallel 10) \left[ \frac{40}{40 + 20 + (50 \parallel 10)} \right]
\]

\[
= \left[ \frac{88 \times 27.27}{37.27} \right] + (1)(8.333) \left[ \frac{40}{40 + 20 + 8.333} \right] = \boxed{69.27} \text{ V}
\]

(b) Shorting out the 88-V source and open-circuiting the 1-A source, we see looking into the terminals y and y’ a 40-Ω resistor in parallel with [20 Ω + (10 Ω \parallel 50 Ω)]:

\[ R_{TH} = 40 \parallel [20 + (10 \parallel 50)] = \boxed{16.59} \Omega \]

Using superposition to determine the voltage \( V_{yy} \) across the 1-A source, we find

\[
V_{yy} = V_{TH} = (1)(R_{TH}) + \left[ \frac{88 \times 27.27}{10 + 27.27} \right] \left( \frac{40}{20 + 40} \right)
\]

\[ = \boxed{59.52} \text{ V} \]
34. (a) Select terminal \( b \) as the reference terminal, and define a nodal voltage \( V_1 \) at the top of the 200-\( \Omega \) resistor. Then,

\[
0 = \frac{V_1 - 20}{40} + \frac{V_1 - V_{TH}}{100} + \frac{V_1}{200} \tag{1}
\]

\[
1.5 i_1 = \frac{(V_{TH} - V_1)}{100} \tag{2}
\]

where \( i_1 = V_i/200 \), so Eq. [2] becomes

\[
150 \frac{V_i}{200} + V_1 - V_{TH} = 0 \tag{2}
\]

Simplifying and collecting terms, these equations may be re-written as:

\[
(0.25 + 0.1 + 0.05) V_1 - 0.1 V_{TH} = 5 \tag{1}
\]

\[
(1 + 15/20) V_1 - V_{TH} = 0 \tag{2}
\]

Solving, we find that \( V_{TH} = 38.89 \text{ V} \). To find \( R_{TH} \), we short the voltage source and inject 1 A into the port:

\[
0 = \frac{V_1 - V_m}{100} + \frac{V_i}{40} + \frac{V_1}{200} \tag{1}
\]

\[
1.5 i_1 + 1 = \frac{V_m - V_1}{100} \tag{2}
\]

\[
i_1 = \frac{V_i}{200} \tag{3}
\]


\[
1.75 V_1 - V_m = -100 \tag{4}
\]

Solving Eqs. [1] & [4] then results in \( V_m = 177.8 \text{ V} \), so that \( R_{TH} = V_m/1 \text{ A} = 177.8 \Omega \).

(b) Adding a 100-\( \Omega \) load to the original circuit or our Thévenin equivalent, the voltage across the load is

\[
V_{100\Omega} = V_{TH} \left( \frac{100}{100 + 177.8} \right) = 14.00 \text{ V}, \text{ and so } P_{100\Omega} = \frac{(V_{100\Omega})^2}{100} = 1.96 \text{ W}. \]
35. We inject a current of 1 A into the port (arrow pointing up), select the bottom terminal as our reference terminal, and define the nodal voltage $V_x$ across the 200-$\Omega$ resistor.

Then, 

\[ 1 = \frac{V_1}{100} + \frac{(V_1 - V_x)}{50} \quad [1] \]
\[ -0.1 V_1 = \frac{V_x}{200} + \frac{(V_x - V_1)}{50} \quad [2] \]

which may be simplified to

\[ 3 V_1 - 2 V_x = 100 \quad [1] \]
\[ 16 V_1 + 5 V_x = 0 \quad [2] \]

Solving, we find that $V_1 = 10.64$ V, so $R_{TH} = \frac{V_1}{1 \text{ A}} = 10.64 \Omega$.

Since there are no independent sources present in the original network, $I_N = 0$. 
36. With no independent sources present, \( V_{TH} = 0 \).

We decide to inject a 1-A current into the port:

\[
0.01 v_{ab} = \frac{v_x}{200} + \frac{(v_x - v_f)}{50} \quad [1]
\]

\[
1 = \frac{v_{ab}}{100} + \frac{(v_f - v_x)}{} \quad [2]
\]

and:

\[
v_{ab} - v_f = 0.2 v_{ab} \quad [3]
\]

Rearranging and collecting terms,

\[
\begin{align*}
-2 v_{ab} + 5 v_x - 4 v_f &= 0 \quad [1] \\
v_{ab} - 2 v_x + 2 v_f &= 100 \quad [2] \\
0.8 v_{ab} - v_f &= 0 \quad [3]
\end{align*}
\]

Solving, we find that \( v_{ab} = 192.3 \text{ V} \), so \( R_{TH} = \frac{v_{ab}}{(1 \text{ A})} = 192.3 \text{ \Omega} \).
37. We first find $R_{TH}$ by shorting out the voltage source and open-circuiting the current source. Looking into the terminals a & b, we see

$$R_{TH} = 10 \parallel (47 + (100 \parallel 12))$$

$$= 8.523 \Omega.$$ 

Returning to the original circuit, we decide to perform nodal analysis to obtain $V_{TH}$:

\[-12 \times 10^3 = (V_1 - 12)/100 \times 10^3 + V_1/12 \times 10^3 + (V_1 - V_{TH})/47 \times 10^3 \quad [1]\]
\[12 \times 10^3 = V_{TH}/10 \times 10^3 + (V_{TH} - V_1)/47 \times 10^3 \quad [2]\]

Rearranging and collecting terms,

\[0.1146 V_1 - 0.02128 V_{TH} = -11.88 \quad [1]\]
\[-0.02128 V_1 + 0.02128 V_{TH} = 12 \quad [2]\]

Solving, we find that $V_{TH} = 83.48 V$. 

38. (a) $R_{TH} = 4 + 2 \parallel 2 + 10 = 15 \Omega$.
(b) same as above: 15 $\Omega$. 
39. For Fig. 5.78a, $I_N = \frac{12}{\infty} \rightarrow \infty \text{ A in parallel with } \sim 0 \Omega.$

For Fig. 5.78b, $V_{TH} = (2)(\infty) \rightarrow \infty V \text{ in series with } \sim \infty \Omega.$
40. With no independent sources present, $V_{TH} = 0$.

Connecting a 1-V source to the port and measuring the current that flows as a result,

$I = 0.5 V_x + 0.25 V_x = 0.5 + 0.25 = 0.75$ A.

$R_{TH} = 1/I = 1.333 \, \Omega$.

The Norton equivalent is 0 A in parallel with 1.333 $\Omega$. 
41. Performing nodal analysis to determine \( V_{TH} \),

\[
100 \times 10^{-3} = \frac{V_x}{250} + \frac{V_{oc}}{7.5 \times 10^3} \quad [1]
\]

and \( V_x - V_{oc} = 5 \, i_x \)

where \( i_x = \frac{V_x}{250} \). Thus, we may write the second equation as

\[
0.98 \, V_x - V_{oc} = 0 \quad [2]
\]

Solving, we find that \( V_{oc} = V_{TH} = 23.72 \, \text{V} \).

In order to determine \( R_{TH} \), we inject 1 A into the port:

\[
\frac{V_{ab}}{7.5 \times 10^3} + \frac{V_x}{250} = 1 \quad [1]
\]

and \( V_x - V_{ab} = 5 \, i_x = 5 \frac{V_x}{250} \) or

\[-V_{ab} + (1 - 5/250) \, V_x = 0 \quad [2]
\]

Solving, we find that \( V_{ab} = 237.2 \, \text{V} \). Since \( R_{TH} = \frac{V_{ab}}{1 \, \text{A}} \), \( R_{TH} = 237.2 \, \Omega \).

Finally, \( I_N = \frac{V_{TH}}{R_{TH}} = 100 \, \text{mA} \).
42. We first note that $V_{TH} = V_x$, so performing nodal analysis,

$$-5 V_x = V_x/19$$

which has the solution $V_x = 0$ V.

Thus, $V_{TH}$ (and hence $I_N$) = 0. (Assuming $R_{TH} \neq 0$)

To find $R_{TH}$, we inject 1 A into the port, noting that $R_{TH} = V_x/1$ A:

$$-5 V_x + 1 = V_x/19$$

Solving, we find that $V_x = 197.9$ mV, so that $R_{TH} = R_N = 197.9$ mV.
43.  Shorting out the voltage source, we redraw the circuit with a 1-A source in place of
the 2-kΩ resistor:

Noting that $300 \, \Omega \parallel 2 \, M\Omega = 300 \, \Omega$,

\begin{align*}
0 &= \frac{(v_{gs} - V)}{300} \quad [1] \\
1 - 0.02 \, v_{gs} &= \frac{V}{1000} + \frac{(V - v_{gs})}{300} \quad [2]
\end{align*}

Simplifying & collecting terms,

\begin{align*}
v_{gs} \quad - V &= 0 \quad [1] \\
0.01667 \, v_{gs} + 0.00433 \, V &= 1 \quad [2]
\end{align*}

Solving, we find that $v_{gs} = V = 47.62 \, V$. Hence, $R_{TH} = \frac{V}{1 \, A} = 47.62 \, \Omega$. 
44. We replace the source $v_s$ and the 300-Ω resistor with a 1-A source and seek its voltage:

By nodal analysis, $1 = V_1/2 \times 10^6$ so $V_1 = 2 \times 10^6 \text{ V}$.

Since $V = V_1$, we have $R_{\text{in}} = V/1 \text{ A} = 2 \text{ MΩ}$. 

![Circuit Diagram](image-url)
45. Removing the voltage source and the 300-Ω resistor, we replace them with a 1-A source and seek the voltage that develops across its terminals:

We select the bottom node as our reference terminal, and define nodal voltages $V_1$ and $V_2$. Then,

$$1 = \frac{V_1}{2 \times 10^6} + \frac{V_1 - V_2}{r_\pi} \quad [1]$$

$$0.02 v_\pi = \frac{V_2 - V_1}{r_\pi} + \frac{V_1}{1000} + \frac{V_2}{2000} \quad [2]$$

where $v_\pi = V_1 - V_2$

Simplifying & collecting terms,

$$(2 \times 10^6 + r_\pi) V_1 - 2 \times 10^6 V_2 = 2 \times 10^6 r_\pi \quad [1]$$

$$-(2000 + 40 r_\pi) V_1 + (2000 + 43 r_\pi) V_2 = 0 \quad [2]$$

Solving, we find that $V_1 = V = 2 \times 10^6 \left( \frac{666.7 + 14.33 r_\pi}{2 \times 10^6 + 666.7 + 14.33 r_\pi} \right)$.

Thus, $R_{\text{TH}} = 2 \times 10^6 \| (666.7 + 14.33 r_\pi) \Omega$. 
Such a scheme probably would lead to maximum or at least near-maximum power transfer to our home. Since we pay the utility company based on the power we use, however, this might not be such a hot idea…
We need to find the Thévenin equivalent resistance of the circuit connected to $R_L$, so we short the 20-V source and open-circuit the 2-A source; by inspection, then

$$R_{TH} = 12 \parallel 8 + 5 + 6 = 15.8 \Omega$$

Analyzing the original circuit to obtain $V_1$ and $V_2$ with $R_L$ removed:

$$V_1 = 20 \frac{8}{20} = 8 \text{ V}; \quad V_2 = -2 (6) = -12 \text{ V}.$$  

We define $V_{TH} = V_1 - V_2 = 8 + 12 = 20 \text{ V}$. Then,

$$P_{RL_{max}} = \frac{V_{TH}^2}{4R_L} = \frac{400}{4(15.8)} = 6.329 \text{ W}$$
48. (a) $R_{TH} = 25 \parallel (10 + 15) = 12.5 \Omega$

Using superposition, $V_{ab} = V_{TH} = \frac{50 \cdot 25}{15 + 10 + 25} + \frac{100 \cdot 15 + 10}{50} = 75$ V.

(b) Connecting a 50-Ω resistor,

$$P_{load} = \frac{V_{TH}^2}{R_{TH} + R_{load}} = \frac{75^2}{12.5 + 50} = 90 \text{ W}$$

(c) Connecting a 12.5-Ω resistor,

$$P_{load} = \frac{V_{TH}^2}{4R_{TH}} = \frac{75^2}{4 \cdot 12.5} = 112.5 \text{ W}$$
49. (a) By inspection, we see that $i_{10} = 5$ A, so

$$V_{TH} = V_{ab} = 2(0) + 3i_{10} + 10i_{10} = 13i_{10} = 13(5) = 65 \text{ V}.$$ 

To find $R_{TH}$, we connect a 1-A source between terminals $a$ & $b$:

$$5 = V_1/10 + (V_2 - V)/2 \quad [1] \quad \Rightarrow \quad V_1 + 5V_2 - 5V = 50 \quad [1]$$

$$1 = (V - V_2)/2 \quad [2] \quad \Rightarrow \quad -V_2 + V = 2 \quad [2]$$

and $V_2 - V_1 = 3i_{10} \quad [3]$

where $i_{10} = V_1/10 \quad \Rightarrow \quad -13V_1 + 10V_2 = 0 \quad [3]$

Solving, we find that $V = 80$ V, so that $R_{TH} = V / 1 \text{ A} = 80 \Omega$.

(b) $P_{\text{max}} = \frac{V_{TH}^2}{4R_{TH}} = \frac{65^2}{4(80)} = 13.20 \text{ W}$
50. (a) Replacing the resistor $R_L$ with a 1-A source, we seek the voltage that develops across its terminals with the independent voltage source shorted:

\[-10i_1 + 20i_2 + 40i_i = 0\] \[\Rightarrow 30i_1 + 20i_i = 0 \quad [1]\]

and $i_i - i_s = 1$ \[\Rightarrow i_i - i_s = 1 \quad [2]\]

Solving, $i_i = 400 \text{ mA}$

So $V = 40i_i = 16 \text{ V}$ and $R_{TH} = \frac{V}{1 \text{ A}} = 16\Omega$

(b) Removing the resistor $R_L$ from the original circuit, we seek the resulting open-circuit voltage:

\[0 = \frac{V_{TH} - 10i_i}{20} + \frac{V_{TH} - 50}{40} \quad [1]\]

where $i_i = \frac{V_{TH} - 50}{40}$

so $[1]$ becomes

\[0 = \frac{V_{TH}}{20} - \frac{1}{2} \left( \frac{V_{TH} - 50}{40} \right) + \left( \frac{V_{TH} - 50}{40} \right)\]

\[0 = \frac{V_{TH}}{20} + \frac{V_{TH} - 50}{80}\]

\[0 = 4V_{TH} + V_{TH} - 50\]

\[5V_{TH} = 50\]

or $V_{TH} = 10 \text{ V}$

Thus, if $R_L = R_{TH} = 16\Omega$,

\[V_{R_L} = V_{TH} \frac{R_L}{R_L + R_{TH}} = \frac{V_{TH}}{2} = 5 \text{ V}\]
51.

(a) \( I_N = 2.5 \, \text{A} \)

By current division,

\[
2 = 2.5 \frac{R_N}{R_N + 20}
\]

Solving, \( R_N = R_{TH} = 80 \, \Omega \)

Thus, \( V_{TH} = V_{OC} = 2.5 \times 80 = 200 \, \text{V} \)

(b) \[ P_{\text{max}} = \frac{V_{TH}^2}{4R_{TH}} = \frac{200^2}{4 \times 80} = 125 \, \text{W} \]

(c) \( R_L = R_{TH} = 80 \, \Omega \)
52. 

By Voltage $\div$, 

$$ I_R = I_N \frac{R_N}{R + R_N} $$

So 

$$ 0.2 = I_N \frac{R_N}{250 + R_N} \quad [1] $$

$$ 0.5 = I_N \frac{R_N}{80 + R_N} \quad [2] $$

Solving, $I_N = 1.7 \text{ A}$ and $R_N = 33.33 \Omega$

(a) If $v_i i_L$ is a maximum,

$$ R_L = R_N = 33.33 \Omega $$

$$ i_L = 1.7 \times \frac{33.33}{33.33 + 33.33} = 850 \text{ mA} $$

$$ v_L = 33.33 i_L = 28.33 \text{ V} $$

(b) If $v_L$ is a maximum

$$ v_L = I_N (R_N \parallel R_L) $$

So $v_L$ is a maximum when $R_N \parallel R_L$ is a maximum, which occurs at $R_L = \infty$.

Then $i_L = 0$ and $v_L = 1.7 \times R_N = 56.66 \text{ V}$

(c) If $i_L$ is a maximum

$$ i_L = I_N \frac{R_N}{R_N + R_L} ; \text{ max when } R_L = 0 \Omega $$

So $i_L = 1.7 \text{ A}$

$$ v_L = 0 \text{ V} $$
53. There is no conflict with our derivation concerning maximum power. While a dead short across the battery terminals will indeed result in maximum current draw from the battery, and power is indeed proportional to $i^2$, the power delivered to the load is $i^2 R_{LOAD} = i^2(0) = 0$ watts. This is the minimum, not the maximum, power that the battery can deliver to a load.
54. Remove $R_E$: $R_{TH} = R_E \parallel R_m$

bottom node: $1 - 3 \times 10^{-3} v_x = \frac{V - v_x}{300} + \frac{V - v_x}{70 \times 10^3}$ \hspace{1cm} [1]

at other node: $0 = \frac{v_x}{10 \times 10^3} + \frac{v_x - V}{300} + \frac{v_x - V}{70 \times 10^3}$ \hspace{1cm} [2]

Simplifying and collecting terms,

$210 \times 10^5 = 70 \times 10^3 V + 300 V + 63000 v_x - 70 \times 10^3 v_x - 300 v_x$

or $70.3 \times 10^3 V - 7300 v_x = 210 \times 10^5$ \hspace{1cm} [1]

$0 = 2100 v_x + 70 \times 10^3 v_x - 70 \times 10^3 V + 300 v_x - 300 V$

or $-69.7 \times 10^3 V + 72.4 \times 10^3 v_x = 0$ \hspace{1cm} [2]

solving, $V = 331.9 V$ So $R_{TH} = R_E \parallel 331.9 \Omega$

Next, we determine $v_{TH}$ using mesh analysis:

$-v_i + 70.3 \times 10^3 i_1 - 70 \times 10^3 i_2 = 0$ \hspace{1cm} [1]

$80 \times 10^3 i_2 - 70 \times 10^3 i_1 + R_E i_3 = 0$ \hspace{1cm} [2]

and: $i_3 - i_2 = 3 \times 10^{-3} v_x$ \hspace{1cm} [3]

or $i_3 - i_2 = 3 \times 10^{-3} \times 10^3 i_2$

or $i_3 - i_2 = 30 i_2$

or $-31 i_2 + i_3 = 0$ \hspace{1cm} [3]

Solving:

$\begin{bmatrix} 70.3 \times 10^3 & -70 \times 10^3 & 0 \\ -70 \times 10^3 & 80 \times 10^3 & R_E \\ 0 & -31 & 1 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} v_x \\ 0 \\ 0 \end{bmatrix}$

We seek $i_3$:

$i_3 = \frac{-21.7 \times 10^3 v_x}{7.24 \times 10^6 + 21.79 \times 10^3 R_E}$

So $V_{OC} = V_{TH} = R_E i_1 = \frac{-21.7 \times 10^3 R_E}{7.24 \times 10^6 + 21.79 \times 10^3 R_E} v_x$

$P_{\text{OM}} = 8 \left[ \frac{V_{TH}}{R_{TH} + 8} \right]^2 = \left[ \frac{-21.7 \times 10^3 R_E}{7.24 \times 10^6 + 21.79 \times 10^3 R_E} \right]^2 \frac{8 v_s^2}{\left[ \frac{331.9 R_E}{331.9 + R_E} \right]^2}$

$= \frac{11.35 \times 10^6 (331.9 + R_E)^2}{(7.24 \times 10^6 + 21.79 \times 10^3 R_E)^2} v_s^2$

This is maximized by setting $R_E = \infty$. 

---

55. Thévenize the left-hand network, assigning the nodal voltage $V_x$ at the free end of right-most 1-kΩ resistor.

A single nodal equation: 

$$40 \times 10^{-3} = \frac{V_x}{7 \times 10^3}$$

So $V_{TH} = V_x \bigg|_{oc} = 280$ V

$R_{TH} = 1 \text{k} + 7 \text{k} = 8 \text{kΩ}$

Select $R_1 = R_{TH} = 8 \text{kΩ}$. 
\[ D = R_A + R_B + R_C = 1 + 850 + 0.1 = 851.1 \times 10^6 \]

\[ R_1 = \frac{R_A R_B}{D} = \frac{10^6 \times 10^5}{D} = 117.5 \Omega \]

\[ R_2 = \frac{R_B R_C}{D} = \frac{10^5 \times 850 \times 10^6}{851.1 \times 10^6} = 99.87 \, k\Omega \]

\[ R_3 = \frac{R_C R_A}{D} = \frac{850 \times 10^6 \times 10^5}{851.1 \times 10^6} = 998.7 \, k\Omega \]
57. 

\[ N = R_1 R_2 + R_2 R_3 + R_3 R_4 \]
\[ = 0.1 \times 0.4 + 0.4 \times 0.9 + 0.9 \times 0.1 \]
\[ = 0.49 \Omega \]

\[ R_A = \frac{N}{R_2} = 1.225 \Omega \]

\[ R_B = \frac{N}{R_3} = 544.4 \, \text{m}\Omega \]

\[ R_C = \frac{N}{R_4} = 4.9 \Omega \]
58.

\[ \Delta_1 : 1 + 6 + 3 = 10 \Omega \]
\[ \frac{6 \times 1}{10} = 0.6, \quad \frac{6 \times 3}{10} = 1.8, \quad \frac{3 \times 1}{10} = 0.3 \]

\[ \Delta_2 : 5 + 1 + 4 = 10 \Omega \]
\[ \frac{5 \times 1}{10} = 0.5, \quad \frac{1 \times 4}{10} = 0.4, \quad \frac{5 \times 4}{10} = 2 \]

1.8 + 2 + 0.5 = 4.3 \Omega

0.3 + 0.6 + 0.4 = 1.3 \Omega

1.3 \parallel 4.3 = 0.9982 \Omega

0.9982 + 0.6 + 2 = 3.598 \Omega

3.598 \parallel 6 = 2.249 \Omega
59.

\[ 6 \times 2 + 2 \times 3 + 3 \times 6 = 36 \Omega^2 \]
\[ \frac{36}{6} = 6 \Omega, \quad \frac{36}{2} = 18 \Omega, \quad \frac{36}{3} = 12 \Omega \]
\[ 12 \parallel 4 = 3 \Omega, \quad 6 \parallel 12 \Omega = 4 \Omega \]
\[ 4 + 3 + 18 = 25 \Omega \]
\[ 3 \times \frac{18}{25} = 2.16 \Omega \]
\[ 4 \times \frac{18}{25} = 2.88 \Omega \]
\[ 4 \times \frac{3}{25} = 0.48 \Omega \]
\[ 9.48 \times 2.16 + 9.48 \times 2.88 + 2.88 \times 2.16 = 54 \Omega^2 \]
\[ \frac{54}{2.88} = 18.75 \Omega \quad \frac{54}{9.48} = 5.696 \Omega \]
\[ \frac{54}{2.16} = 25 \Omega \]
\[ 75 \parallel 18.75 = 15 \Omega \]
\[ 100 \parallel 25 = 20 \Omega \]
\[ (15 + 20) \parallel 5.696 = 4.899 \Omega \]
\[ \therefore R_{in} = 5 + 4.899 = 9.899 \Omega \]
60. We begin by converting the \( \Delta \)-connected network consisting of the 4-, 6-, and 3-\( \Omega \) resistors to an equivalent Y-connected network:

\[
D = 6 + 4 + 3 = 13 \Omega \\
R_1 = \frac{R_A R_B}{D} = \frac{6 \times 4}{13} = 1.846 \Omega \\
R_2 = \frac{R_B R_C}{D} = \frac{4 \times 3}{13} = 0.9231 \Omega \\
R_3 = \frac{R_C R_A}{D} = \frac{3 \times 6}{13} = 1.385 \Omega 
\]

Then network becomes:

Then we may write

\[
R_{in} = 12 \parallel \left[ 13.846 + (19.385 \parallel 6.9231) \right] = 7.347 \Omega 
\]
61.

Next, we convert the Y-connected network on the left to a $\Delta$-connected network:

$$1 + 0.5 + 2 = 4 \Omega$$

$$R_1 = \frac{1 \times 2}{4} = \frac{1}{2} \Omega$$

$$R_2 = \frac{2 \times 1}{4} = \frac{1}{2} \Omega$$

$$R_3 = \frac{1 \times 1}{4} = 0.25 \Omega$$

After this procedure, we have a 3.5-$\Omega$ resistor in parallel with the 2.5-$\Omega$ resistor. Replacing them with a 1.458-$\Omega$ resistor, we may redraw the circuit:

$$1 \times 1.458 + 2 \times 1.458 = 3.5 \Omega$$

$$R_A = \frac{3.5}{0.5} = 7 \Omega$$

$$R_B = \frac{3.5}{2} = 1.75 \Omega$$

$$R_C = \frac{3.5}{1} = 3.5 \Omega$$

This circuit may be easily analysed to find:

$$V_{oc} = \frac{12 \times 1.458}{1.75 + 1.458} = 5.454 \text{ V}$$

$$R_{eq} = \frac{0.25 + 1.458}{1.75} = 1.045 \Omega$$
62. We begin by converting the Y-network to a Δ-connected network:

\[ N = 1.1 + 1.1 + 1.1 = 3 \Omega \]

\[ R_A = \frac{3}{1} = 3 \Omega \]

\[ R_B = \frac{3}{1} = 3 \Omega \]

\[ R_C = \frac{3}{1} = 3 \Omega \]

Next, we note that \( \|3 = 0.75 \Omega \), and hence have a simple Δ-network. This is easily converted to a Y-connected network:

\[ 0.75 + 3 + 3 = 6.75 \Omega \]

\[ R_1 = \frac{0.75 \times 3}{6.75} = 0.3333 \Omega \]

\[ R_2 = \frac{3 \times 3}{6.75} = 1.333 \Omega \]

\[ R_3 = \frac{3 \times 0.75}{6.75} = 0.3333 \Omega \]

Analysing this final circuit,

\[ R_N = 1.333 + 0.3333 = 1.667 \Omega \]

\[ I_N = I_{SC} = 1 \times \frac{1/3}{1/3 + 1 + 1/3} \]

\[ = \frac{1}{1 + 3 + 1} = \frac{1}{5} \]

\[ = 0.2 \text{ A} \]

\[ = 200 \text{ mA} \]
63. Since 1 V appears across the resistor associated with $I_1$, we know that $I_1 = \frac{1 \text{ V}}{10 \Omega} = 100 \text{ mA}$. From the perspective of the open terminals, the 10-Ω resistor in parallel with the voltage source has no influence if we replace the “dependent” source with a fixed 0.5-A source:

![Image of circuit diagram]

Then, we may write:

$$-1 + (10 + 10 + 10) i_a - 10 (0.5) = 0$$

so that $i_a = 200 \text{ mA}$.

We next find that $V_{TH} = V_{ab} = 10(-0.5) + 10(i_a - 0.5) + 10(-0.5) = -13 \text{ V}$. To determine $R_{TH}$, we first recognise that with the 1-V source shorted, $I_1 = 0$ and hence the dependent current source is dead. Thus, we may write $R_{TH}$ from inspection:

$$R_{TH} = 10 + 10 + 10 \parallel 20 = 26.67 \Omega.$$
64. (a) We begin by splitting the 1-kΩ resistor into two 500-Ω resistors in series. We then have two related Y-connected networks, each with a 500-Ω resistor as a leg. Converting those networks into Δ-connected networks,

\[
\Sigma = (17)(10) + (1)(4) + (4)(17) = 89 \times 10^6 \Omega^2
\]

\[
\frac{89}{0.5} = 178 \text{ k}\Omega; \quad \frac{89}{17} = 5.236 \text{ k}\Omega; \quad \frac{89}{4} = 22.25 \text{ k}\Omega
\]

Following this conversion, we find that we have two 5.235 kΩ resistors in parallel, and a 178-kΩ resistor in parallel with the 4-kΩ resistor. Noting that 5.235 k || 5.235 k = 2.618 kΩ and 178 k || 4 k = 3.912 kΩ, we may draw the circuit as:

We next attack the Y-connected network in the center:

\[
\Sigma = (22.25)(22.25) + (22.25)(2.618) + (2.618)(22.25) = 611.6 \times 10^6 \Omega^2
\]

\[
\frac{611.6}{22.25} = 27.49 \text{ k}\Omega; \quad \frac{611.6}{2.618} = 233.6 \text{ k}\Omega
\]

Noting that 178 k || 27.49 k = 23.81 kΩ and 27.49 || 3.912 = 3.425 kΩ, we are left with a simple Δ-connected network. To convert this to the requested Y-network,

\[
\Sigma = 23.81 + 233.6 + 3.425 = 260.8 \text{ k}\Omega
\]

\[
\frac{(23.81)(233.6)}{260.8} = 21.33 \text{ k}\Omega
\]

\[
\frac{(233.6)(3.425)}{260.8} = 3.068 \text{ k}\Omega
\]

\[
\frac{(3.425)(23.81)}{260.8} = 312.6 \Omega
\]
65.  
(a) Although this network may be simplified, it is not possible to replace it with a 
three-resistor equivalent.

(b) See (a).
66. First, replace network to left of the 0.7-V source with its Thévenin equivalent:

\[ V_{TH} = 20 \times \frac{15}{100 + 15} = 2.609 \text{ V} \]

\[ R_{TH} = 100k \parallel 15k = 13.04k \Omega \]

Redraw:

Analyzing the new circuit to find \( I_B \), we note that \( I_C = 250 \times I_B \):

\[
-2.609 + 13.04 \times 10^3 I_B + 0.7 + 5000(I_B + 250I_B) = 0
\]

\[
I_B = \frac{2.609 - 0.7}{13.04 \times 10^3 + 251 \times 5000} = 1.505 \mu\text{A}
\]

\[
I_C = 250I_B = 3.764 \times 10^{-4} \text{ A} = 376.4 \mu\text{A}
\]
67. (a) Define a nodal voltage $V_1$ at the top of the current source $I_S$, and a nodal voltage $V_2$ at the top of the load resistor $R_L$. Since the load resistor can safely dissipate 1 W, and we know that

$$P_{RL} = \frac{V_2^2}{1000}$$

then $V_2|_{max} = 31.62 \text{ V}$. This corresponds to a load resistor (and hence lamp) current of 32.62 mA, so we may treat the lamp as a 10.6-Ω resistor.

Proceeding with nodal analysis, we may write:

$$I_S = \frac{V_1}{200} + \frac{(V_1 - 5 V_x)}{200} \quad [1]$$
$$0 = \frac{V_2}{1000} + \frac{(V_2 - 5 V_x)}{10.6} \quad [2]$$
$$V_x = V_1 - 5 V_x \quad \text{or} \quad V_x = \frac{V_1}{6} \quad [3]$$

Substituting Eq. [3] into Eqs. [1] and [2], we find that

$$7 V_1 = 1200 I_S \quad [1]$$
$$-5000 V_1 + 6063.6 V_2 = 0 \quad [2]$$

Substituting $V_2|_{max} = 31.62 \text{ V}$ into Eq. [2] then yields $V_1 = 38.35 \text{ V}$, so that

$$I_S|_{max} = \frac{(7)(38.35)}{1200} = 223.7 \text{ mA}.$$  

(b) PSpice verification.

The lamp current does not exceed 36 mA in the range of operation allowed (i.e., a load power of $< 1 \text{ W}$.) The simulation result shows that the load will dissipate slightly more than 1 W for a source current magnitude of 224 mA, as predicted by hand analysis.
68. Short out all but the source operating at $10^4$ rad/s, and define three clockwise mesh currents $i_1$, $i_2$, and $i_3$ starting with the left-most mesh. Then

$$
608 i_1 - 300 i_2 = 3.5 \cos 10^4 t \quad [1] \\
-300 i_1 + 316 i_2 - 8 i_3 = 0 \quad [2] \\
-8 i_2 + 322 i_3 = 0 \quad [3]
$$

Solving, we find that

$$
i_1(t) = 10.84 \cos 10^4 t \text{ mA} \\
i_2(t) = 10.29 \cos 10^4 t \text{ mA} \\
i_3(t) = 255.7 \cos 10^4 t \text{ } \mu\text{A}
$$

Next, short out all but the $7 \sin 200t$ V source, and and define three clockwise mesh currents $i_a$, $i_b$, and $i_c$ starting with the left-most mesh. Then

$$
608 i_a - 300 i_b = -7 \sin 200t \quad [1] \\
-300 i_a + 316 i_b - 8 i_c = 7 \sin 200t \quad [2] \\
-8 i_b + 322 i_c = 0 \quad [3]
$$

Solving, we find that

$$
i_a(t) = -1.084 \sin 200t \text{ mA} \\
i_b(t) = 21.14 \sin 200t \text{ mA} \\
i_c(t) = 525.1 \sin 200t \text{ } \mu\text{A}
$$

Next, short out all but the source operating at $10^3$ rad/s, and define three clockwise mesh currents $i_A$, $i_B$, and $i_C$ starting with the left-most mesh. Then

$$
608 i_A - 300 i_B = 0 \quad [1] \\
-300 i_A + 316 i_B - 8 i_C = 0 \quad [2] \\
-8 i_B + 322 i_C = -8 \cos 10^4 t \quad [3]
$$

Solving, we find that

$$
i_A(t) = -584.5 \cos 10^3 t \text{ } \mu\text{A} \\
i_B(t) = -1.185 \cos 10^3 t \text{ mA} \\
i_C(t) = -24.87 \cos 10^3 t \text{ mA}
$$

We may now compute the power delivered to each of the three 8-Ω speakers:

$$
p_1 = 8[i_1 + i_a + i_A]^2 = 8[10.84\times10^{-3} \cos 10^4 t - 1.084\times10^{-3} \sin 200t - 584.5\times10^{-6} \cos 10^3 t]^2
$$

$$
p_2 = 8[i_2 + i_b + i_b]^2 = 8[10.29\times10^{-3} \cos 10^4 t + 21.14\times10^{-3} \sin 200t - 1.185\times10^{-3} \cos 10^3 t]^2
$$

$$
p_3 = 8[i_3 + i_c + i_c]^2 = 8[255.7\times10^{-6} \cos 10^4 t + 525.1\times10^{-6} \sin 200t - 24.87\times10^{-3} \cos 10^3 t]^2
$$
69. Replacing the DMM with a possible Norton equivalent (a 1-MΩ resistor in parallel with a 1-A source):

We begin by noting that $33 \Omega \parallel 1 \text{M}\Omega \approx 33 \Omega$. Then,

$$0 = (V_1 - V_{in})/33 + V_1/275 \times 10^3 \quad [1]$$

and

$$1 - 0.7 V_1 = V_{in}/10^6 + V_{in}/33 \times 10^3 + (V_{in} - V_1)/33 \quad [2]$$

Simplifying and collecting terms,

$$(275 \times 10^3 + 33) V_1 - 275 \times 10^3 V_{in} = 0 \quad [1]$$

$$22.1 V_1 + 1.001 V_{in} = 33 \quad [2]$$

Solving, we find that $V_{in} = 1.429 \text{ V}$; in other words, the DMM sees $1.429 \text{ V}$ across its terminals in response to the known current of 1 A it’s supplying. It therefore thinks that it is connected to a resistance of 1.429 $\Omega$. 
70. We know that the resistor $R$ is absorbing maximum power. We might be tempted to say that the resistance of the cylinder is therefore 10 $\Omega$, but this is wrong: The larger we make the cylinder resistance, the small the power delivery to $R$:

$$P_R = 10 \cdot i^2 = 10 \left( \frac{120}{R_{cylinder} + 10} \right)^2$$

Thus, if we are in fact delivering the maximum possible power to the resistor from the 120-V source, the resistance of the cylinder must be zero. 

This corresponds to a temperature of absolute zero using the equation given.
71. We note that the buzzer draws 15 mA at 6 V, so that it may be modeled as a 400-Ω resistor. One possible solution of many, then, is:

Note: construct the 18-V source from 12 1.5-V batteries in series, and the two 400-Ω resistors can be fabricated by soldering 400 1-Ω resistors in series, although there’s probably a much better alternative…
72. To solve this problem, we need to assume that “45 W” is a designation that applies when 120 Vac is applied directly to a particular lamp. This corresponds to a current draw of 375 mA, or a light bulb resistance of $120/0.375 = 320 \, \Omega$.

In the original wiring scheme, Lamps 1 & 2 draw $(40)^2 / 320 = 5 \, \text{W}$ of power each, and Lamp 3 draws $(80)^2 / 320 = 20 \, \text{W}$ of power. Therefore, none of the lamps is running at its maximum rating of 45 W. We require a circuit which will deliver the same intensity after the lamps are reconnected in a $\Delta$ configuration. Thus, we need a total of 30 W from the new network of lamps.

There are several ways to accomplish this, but the simplest may be to just use one 120-Vac source connected to the left port in series with a resistor whose value is chosen to obtain 30 W delivered to the three lamps.

In other words,

$$\left[120 \frac{213.3}{Rs + 213.3} \right]^2 + 2 \left[60 \frac{213.3}{Rs + 213.3} \right]^2 = 30$$

Solving, we find that we require $Rs = 106.65 \, \Omega$ as confirmed by the PSpice simulation below, which shows that both wiring configurations lead to one lamp with 80-V across it, and two lamps with 40 V across each.
73.  
- Maximum current rating for the LED is 35 mA.
- Its resistance can vary between 47 and 117 Ω.
- A 9-V battery must be used as a power source.
- Only standard resistance values may be used.

One possible current-limiting scheme is to connect a 9-V battery in series with a resistor $R_{\text{limiting}}$ and in series with the LED. From KVL,

$$I_{\text{LED}} = \frac{9}{R_{\text{limiting}} + R_{\text{LED}}}$$

The maximum value of this current will occur at the minimum LED resistance, 47 Ω. Thus, we solve

$$35 \times 10^{-3} = \frac{9}{R_{\text{limiting}} + 47}$$

to obtain $R_{\text{limiting}} \geq 210.1$ Ω to ensure an LED current of less than 35 mA. This is not a standard resistor value, however, so we select

$$R_{\text{limiting}} = 220 \text{ Ω}.$$