4.62 a) Use source transformations to find v_o in the circuit in Fig. P4.62.

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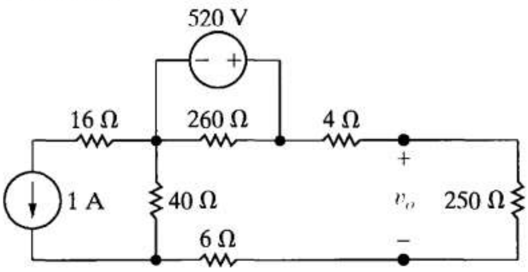
b) Find the power developed by the 520 V source.

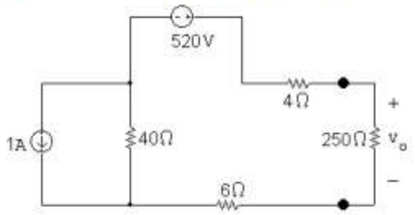
c) Find the power developed by the 1 A current source.

d) Verify that the total power developed equals the total power dissipated.

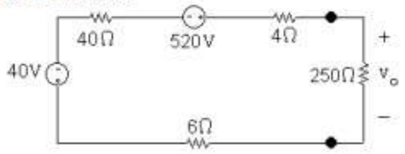
Figure P4.62



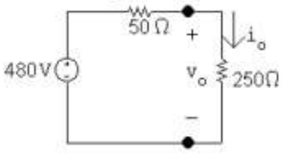
P 4.62 [**a**] First remove the 16 Ω and 260 Ω resistors:



Next use a source transformation to convert the 1 A current source and 40 Ω resistor:

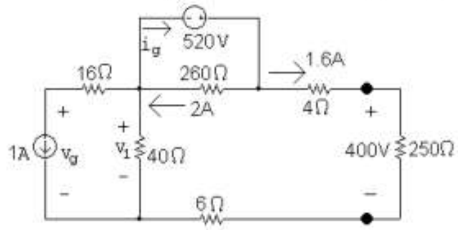


which simplifies to



$$\therefore \quad v_o = \frac{250}{300}(480) = 400 \text{ V}$$

[**b**] Return to the original circuit with $v_o = 400$ V:



$$i_g = \frac{520}{260} + 1.6 = 3.6 \text{ A}$$

$p_{520V} = -(520)(3.6) = -1872$ W

Therefore, the 520 V source is developing 1872 W.

[c] $v_1 = -520 + 1.6(4 + 250 + 6) = -104$ V

$v_g = v_1 - 1(16) = -104 - 16 = -120$ V

$p_{1A} = (1)(-120) = -120$ W

Therefore the 1 A source is developing 120 W.

[d] $\sum p_{dev} = 1872 + 120 = 1992$ W

$$\sum p_{diss} = (1)^2(16) + \frac{(104)^2}{40} + \frac{(520)^2}{260} + (1.6)^2(260) = 1992 \text{ W}$$

$\therefore \sum p_{diss} = \sum p_{dev}$

4.63 Find the Thévenin equivalent with respect to the terminals a,b for the circuit in Fig. P4.63.

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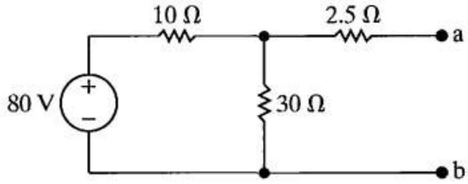
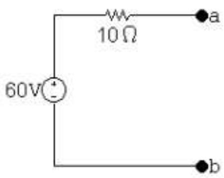
Figure P4.63



P 4.63 $v_{Th} = \frac{30}{40}(80) = 60$ V

$$R_{Th} = 2.5 + \frac{(30)(10)}{40} = 10\,\Omega$$



4.64 Find the Norton equivalent with respect to the terminals a,b in the circuit in Fig. P4.64.

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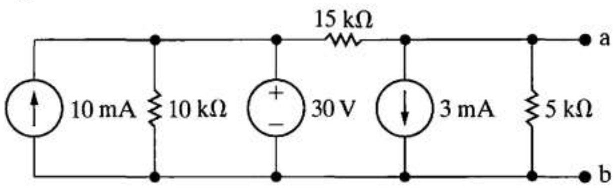
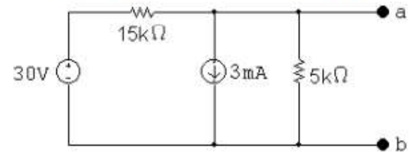
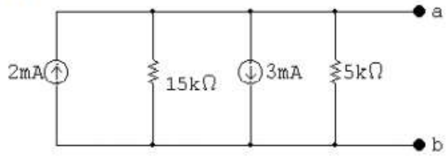
Figure P4.64



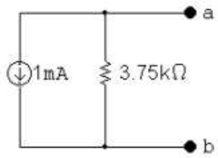
P 4.64 First we make the observation that the 10 mA current source and the 10 kΩ resistor will have no influence on the behavior of the circuit with respect to the terminals a,b. This follows because they are in parallel with an ideal voltage source. Hence our circuit can be simplified to



or



Therefore the Norton equivalent is



4.66 Find the Thévenin equivalent with respect to the terminals a,b for the circuit in Fig. P4.66.

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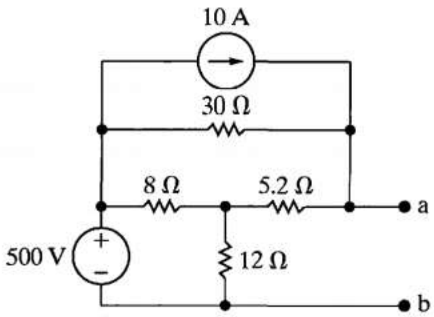
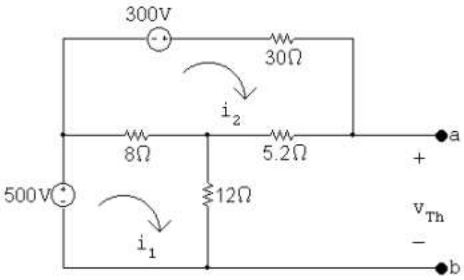
Figure P4.66



P 4.66 After making a source transformation the circuit becomes



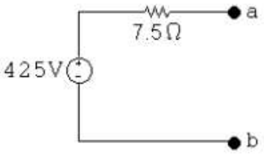
$$500 = 20i_1 - 8i_2$$

$$300 = -8i_1 + 43.2i_2$$

$$\therefore \quad i_1 = 30 \text{ A and } i_2 = 12.5 \text{ A}$$

$$v_{\text{Th}} = 12i_1 + 5.2i_2 = 425 \text{ V}$$

$$R_{\text{Th}} = (8\|12 + 5.2)\|30 = 7.5\,\Omega$$



4.68 Determine i_o and v_o in the circuit shown in Fig. P4.68 when R_o is a resistor from Appendix H whose value is less than 100 Ω.
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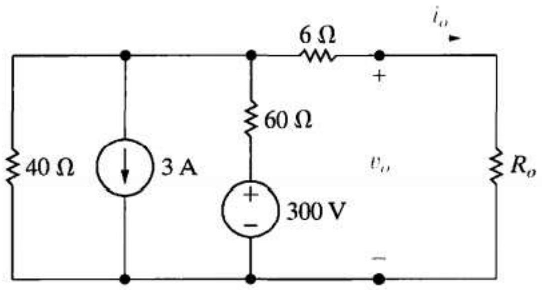
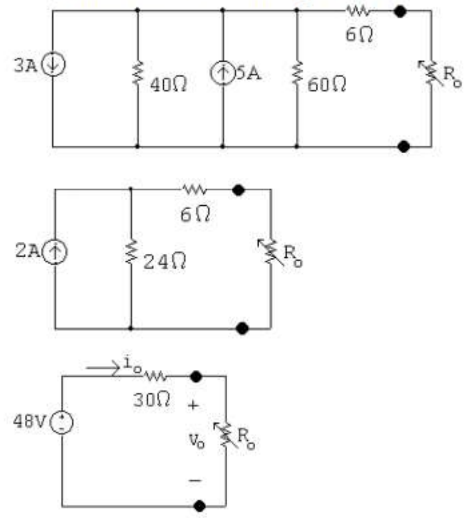
Figure P4.68



P 4.68 First, find the Thévenin equivalent with respect to R_o.



$R_o(\Omega)$	$i_o(\mathrm{A})$	$v_o(\mathrm{V})$
10	1.2	12
15	1.067	16
22	0.923	20.31
33	0.762	25.14
47	0.623	29.30
68	0.490	33.31

4.73 Find the Norton equivalent with respect to the terminals a,b for the circuit seen in Fig. P4.73.

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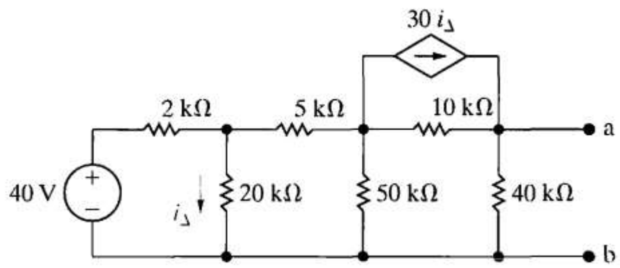
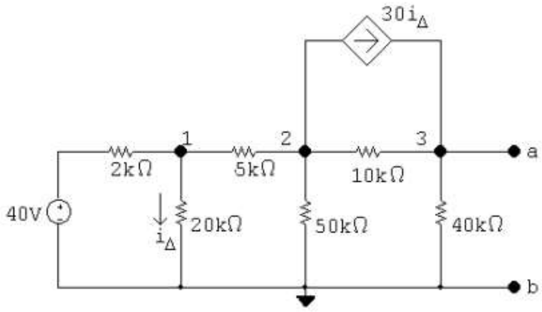
Figure P4.73



P 4.73



The node voltage equations are:

$$\begin{aligned}
\frac{v_1 - 40}{2000} + \frac{v_1}{20{,}000} + \frac{v_1 - v_2}{5000} &= 0 \\
\frac{v_2 - v_1}{5000} + \frac{v_2}{50{,}000} + \frac{v_2 - v_3}{10{,}000} + 30\frac{v_1}{20{,}000} &= 0 \\
\frac{v_3 - v_2}{10{,}000} + \frac{v_3}{40{,}000} - 30\frac{v_1}{20{,}000} &= 0
\end{aligned}$$

In standard form:

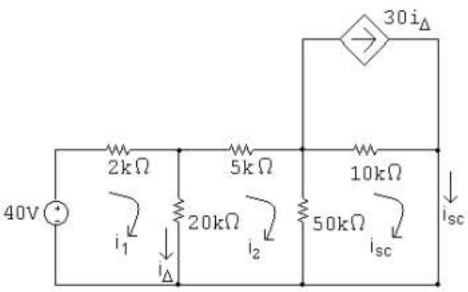
$$v_1\left(\frac{1}{2000} + \frac{1}{20{,}000} + \frac{1}{5000}\right) + v_2\left(-\frac{1}{5000}\right) + v_3(0) = \frac{40}{2000}$$

$$v_1\left(-\frac{1}{5000} + \frac{30}{20{,}000}\right) + v_2\left(\frac{1}{5000} + \frac{1}{50{,}000} + \frac{1}{10{,}000}\right) + v_3\left(-\frac{1}{10{,}000}\right) = 0$$

$$v_1\left(-\frac{30}{20{,}000}\right) + v_2\left(-\frac{1}{10{,}000}\right) + v_3\left(\frac{1}{10{,}000} + \frac{1}{40{,}000}\right) = 0$$

Solving, $v_1 = 24$ V; $v_2 = -10$ V; $v_3 = 280$ V

$V_{\text{Th}} = v_3 = 280$ V



The mesh current equations are:

$$\begin{aligned}
-40 + 2000i_1 + 20{,}000(i_1 - i_2) &= 0\\
5000i_2 + 50{,}000(i_2 - i_{sc}) + 20{,}000(i_2 - i_1) &= 0\\
50{,}000(i_{sc} - i_2) + 10{,}000(i_{sc} - 30i_\Delta) &= 0
\end{aligned}$$

The constraint equation is:

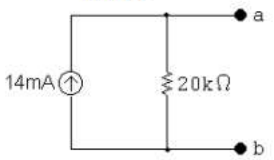
$$i_\Delta = i_1 - i_2$$

Put these equations in standard form:

$$\begin{aligned}
i_1(22{,}000) + i_2(-20{,}000) + i_{sc}(0) + i_\Delta(0) &= 40\\
i_1(-20{,}000) + i_2(75{,}000) + i_{sc}(-50{,}000) + i_\Delta(0) &= 0\\
i_1(0) + i_2(-50{,}000) + i_{sc}(60{,}000) + i_\Delta(-300{,}000) &= 0\\
i_1(-1) + i_2(1) + i_{sc}(0) + i_\Delta(1) &= 0
\end{aligned}$$

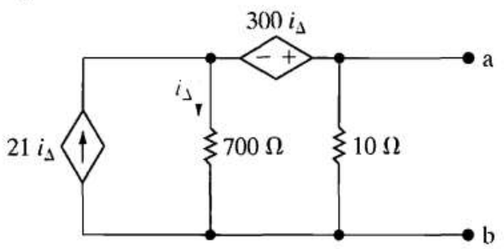
Solving, $\quad i_1 = 13.6$ mA; $\quad i_2 = 12.96$ mA; $\quad i_{sc} = 14$ mA; $\quad i_\Delta = 640\,\mu$A

$$R_{Th} = \frac{280}{0.014} = 20\text{ k}\Omega$$

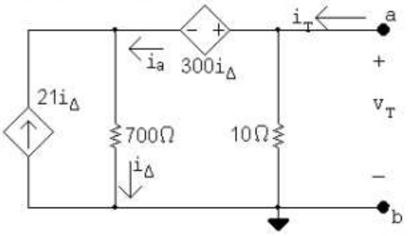


4.78 Find the Norton equivalent with respect to the terminals a,b for the circuit seen in Fig. P4.78.

Figure P4.78



P 4.78 $V_{\rm Th} = 0$ since there are no independent sources in the circuit. Thus we need only find $R_{\rm Th}$.



$$i_{\rm T} = \frac{v_{\rm T}}{10} + i_{\rm a}$$

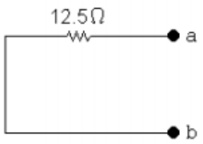
$$i_{\rm a} = i_\Delta - 21 i_\Delta = -20 i_\Delta$$

$$i_\Delta = \frac{v_{\rm T} - 300 i_\Delta}{700}, \qquad 1000 i_\Delta = v_{\rm T}$$

$$\therefore \quad i_{\rm T} = \frac{v_{\rm T}}{10} - 20\frac{v_{\rm T}}{1000} = 0.08 v_{\rm T}$$

$$\frac{v_{\rm T}}{i_{\rm T}} = 1/0.08 = 12.5\,\Omega$$

$$\therefore \quad R_{\rm Th} = 12.5\,\Omega$$



4.79 The variable resistor in the circuit in Fig. P4.79 is adjusted for maximum power transfer to R_o.

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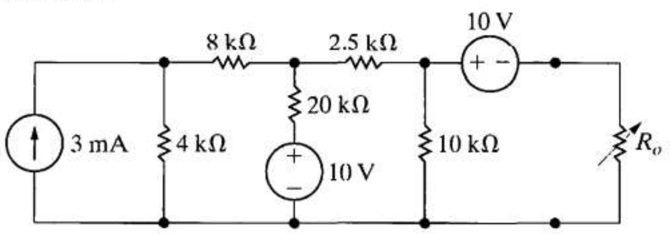
a) Find the value of R_o.

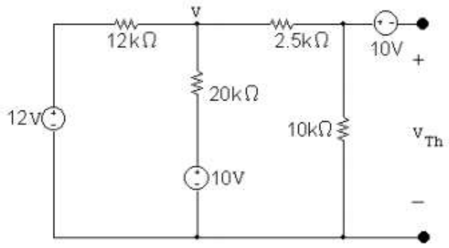
b) Find the maximum power that can be delivered to R_o.

c) Find a resistor in Appendix H closest to the value in part (a). How much power is delivered to this resistor?

Figure P4.79



P 4.79 [a]

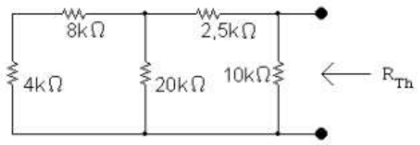


$$\frac{v-12}{12{,}000}+\frac{v-10}{20{,}000}+\frac{v}{12{,}500}=0$$

Solving, $\quad v = 7.03125$ V

$$v_{10k}=\frac{10{,}000}{12{,}500}(7.03125)=5.625 \text{ V}$$

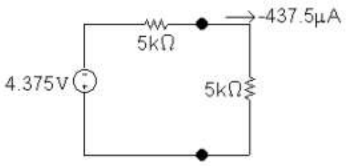
$$\therefore \quad V_{Th}=v-10=-4.375 \text{ V}$$



$$R_{Th}=[(12{,}000\|20{,}000)+2500]=5 \text{ k}\Omega$$

$$R_o=R_{Th}=5 \text{ k}\Omega$$

[b]



$$p_{max}=(-437.5\times10^{-6})^2(5000)=957\,\mu\text{W}$$

[c] The resistor closest to 5 kΩ from Appendix H has a value of 4.7 kΩ. Use voltage division to find the voltage drop across this load resistor, and use the voltage to find the power delivered to it:

$$v_{4.7k}=\frac{4700}{4700+5000}(-4.375)=-2.12 \text{ V}$$

$$p_{4.7k}=\frac{(-2.12)^2}{4700}=956.12\,\mu\text{W}$$

The percent error between the maximum power and the power delivered to the best resistor from Appendix H is

$$\%\text{ error}=\left(\frac{956}{957}-1\right)(100)=-0.1\%$$

4.87 The variable resistor (R_L) in the circuit in Fig. P4.87 is adjusted for maximum power transfer to R_L.

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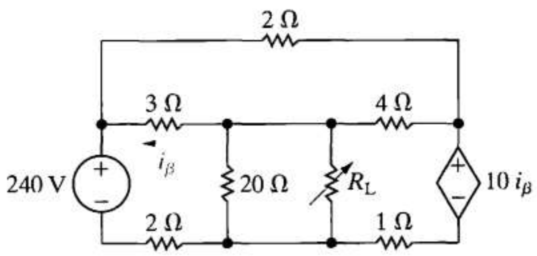
a) Find the numerical value of R_L.

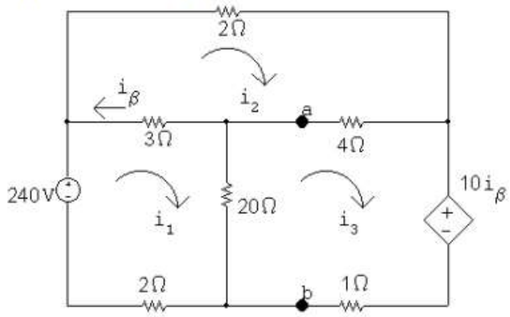
b) Find the maximum power transferred to R_L.

Figure P4.87



P 4.87 **[a]** Find the Thévenin equivalent with respect to the terminals of R_L.

Open circuit voltage:



The mesh current equations are:

$$
\begin{aligned}
-240 + 3(i_1 - i_2) + 20(i_1 - i_3) + 2i_1 &= 0 \\
2i_2 + 4(i_2 - i_3) + 3(i_2 - i_1) &= 0 \\
10i_\beta + 1i_3 + 20(i_3 - i_1) + 4(i_3 - i_2) &= 0
\end{aligned}
$$

The dependent source constraint equation is:

$i_\beta = i_2 - i_1$

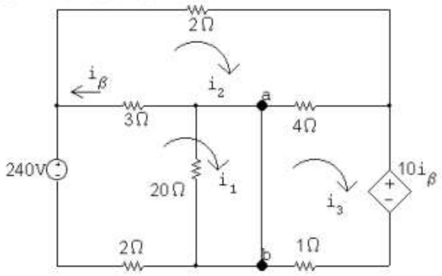
Place these equations in standard form:

$$
\begin{aligned}
i_1(3 + 20 + 2) + i_2(-3) + i_3(-20) + i_\beta(0) &= 240 \\
i_1(-3) + i_2(2 + 4 + 3) + i_3(-4) + i_\beta(0) &= 0 \\
i_1(-20) + i_2(-4) + i_3(1 + 20 + 4) + i_\beta(10) &= 0 \\
i_1(-1) + i_2(1) + i_3(0) + i_\beta(-1) &= 0
\end{aligned}
$$

Solving, $\quad i_1 = 99.6$ A; $\quad i_2 = 78$ A; $\quad i_3 = 100.8$ A; $\quad i_\beta = 21.6$ A

$V_{\mathrm{Th}} = 20(i_1 - i_3) = -24$ V

Short-circuit current:



The mesh current equations are:

$$\begin{aligned}
-240 + 3(i_1 - i_2) + 2i_1 &= 0\\
2i_2 + 4(i_2 - i_3) + 3(i_2 - i_1) &= 0\\
10i_\beta + 1i_3 + 4(i_3 - i_2) &= 0
\end{aligned}$$

The dependent source constraint equation is:

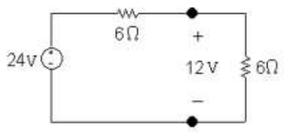
$i_\beta = i_2 - i_1$

Place these equations in standard form:

$$\begin{aligned}
i_1(3+2) + i_2(-3) + i_3(0) + i_\beta(0) &= 240\\
i_1(-3) + i_2(2+4+3) + i_3(-4) + i_\beta(0) &= 0\\
i_1(0) + i_2(-4) + i_3(4+1) + i_\beta(10) &= 0\\
i_1(-1) + i_2(1) + i_3(0) + i_\beta(-1) &= 0
\end{aligned}$$

Solving, $\quad i_1 = 92$ A; $\quad i_2 = 73.33$ A; $\quad i_3 = 96$ A; $\quad i_\beta = 18.67$ A

$i_{sc} = i_1 - i_3 = -4$ A; $\qquad R_{Th} = \dfrac{V_{Th}}{i_{sc}} = \dfrac{-24}{-4} = 6\,\Omega$



$R_L = R_{Th} = 6\,\Omega$

[b] $p_{max} = \dfrac{12^2}{6} = 24$ W

4.96 Use the principle of superposition to find the voltage v in the circuit of Fig. P4.96.

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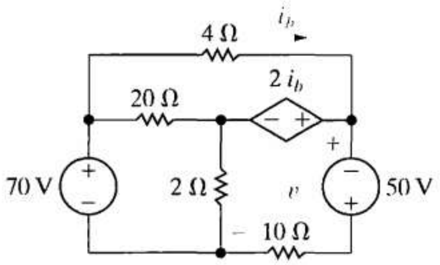
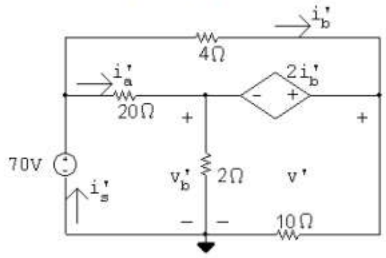
Figure P4.96



P 4.96 70-V source acting alone:



$$v' = 70 - 4i_b'$$

$$i_s' = \frac{v_b'}{2} + \frac{v'}{10} = i_a' + i_b'$$

$$70 = 20i_a' + v_b'$$

$$i_a' = \frac{70 - v_b'}{20}$$

$$\therefore \quad i_b' = \frac{v_b'}{2} + \frac{v'}{10} - \frac{70 - v_b'}{20} = \frac{11}{20}v_b' + \frac{v'}{10} - 3.5$$

$$v' = v_b' + 2i_b'$$

$$\therefore \; v_b' = v' - 2i_b'$$

$$\therefore \; i_b' = \frac{11}{20}(v' - 2i_b') + \frac{v'}{10} - 3.5 \quad \text{or} \quad i_b' = \frac{13}{42}v' - \frac{70}{42}$$

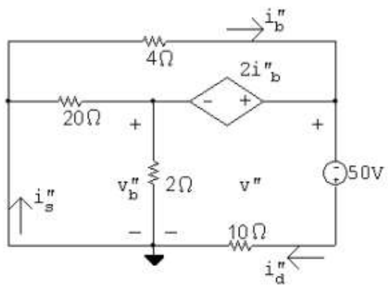
$$v' = v_b' + 2i_b'$$

$$\therefore \; v_b' = v' - 2i_b'$$

$$\therefore \; i_b' = \frac{11}{20}(v' - 2i_b') + \frac{v'}{10} - 3.5 \quad \text{or} \quad i_b' = \frac{13}{42}v' - \frac{70}{42}$$

$$\therefore \; v' = 70 - 4\left(\frac{13}{42}v' - \frac{70}{42}\right) \quad \text{or} \quad v' = \frac{3220}{94} = \frac{1610}{47}\text{ V} = 34.255\text{ V}$$

50-V source acting alone:



$$v'' = -4i_b''$$

$$v'' = v_b'' + 2i_b''$$

$$v'' = -50 + 10i_d''$$

$$\therefore \quad i_d'' = \frac{v'' + 50}{10}$$

$$i_s'' = \frac{v_b''}{2} + \frac{v'' + 50}{10}$$

$$i_b'' = \frac{v_b''}{20} + i_s'' = \frac{v_b''}{20} + \frac{v_b''}{2} + \frac{v'' + 50}{10} = \frac{11}{20}v_b'' + \frac{v'' + 50}{10}$$

$$v_b'' = v'' - 2i_b''$$

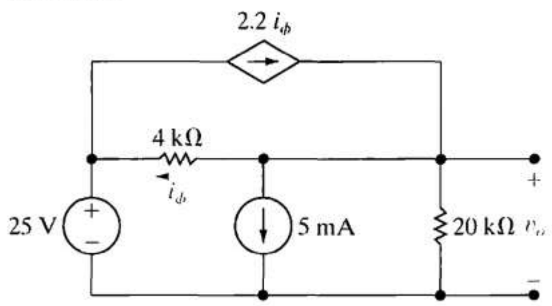
$$\therefore \quad i_b'' = \frac{11}{20}(v'' - 2i_b'') + \frac{v'' + 50}{10} \quad \text{or} \quad i_b'' = \frac{13}{42}v'' + \frac{100}{42}$$

Thus, $\quad v'' = -4\left(\frac{13}{42}v'' + \frac{100}{42}\right) \quad$ or $\quad v'' = -\frac{200}{47}\text{ V} = -4.255\text{ V}$

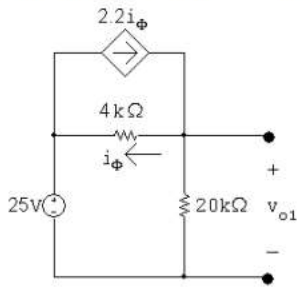
Hence, $\quad v = v' + v'' = \frac{1610}{47} - \frac{200}{47} = \frac{1410}{47} = 30\text{ V}$

4.97 Use the principle of superposition to find v_o in the circuit in Fig. P4.97.
PSPICE
MULTISIM

Figure P4.97



P 4.97 Voltage source acting alone:

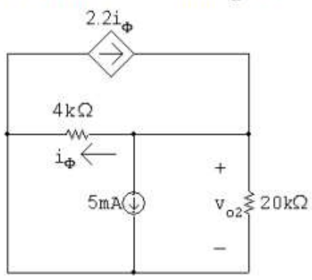


$$\frac{v_{o1}-25}{4000}+\frac{v_{o1}}{20{,}000}-2.2\left(\frac{v_{o1}-25}{4000}\right)=0$$

Simplifying $\quad 5v_{o1}-125+v_{o1}-11v_{o1}+275=0$

$\therefore \quad v_{o1}=30$ V

Current source acting alone:



$$\frac{v_{o2}}{4000}+\frac{v_{o2}}{20{,}000}+0.005-2.2\left(\frac{v_{o2}}{4000}\right)=0$$

Simplifying $\quad 5v_{o2}+v_{o2}+100-11v_{o2}=0$

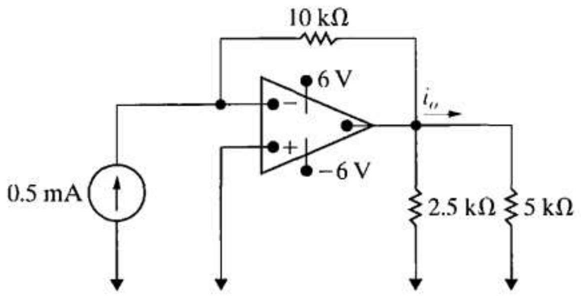
$\therefore \quad v_{o2}=20$ V

$v_o=v_{o1}+v_{o2}=30+20=50$ V

CHAPTER 5

5.2 Find i_o in the circuit in Fig. P5.2 if the op amp is ideal.

PSPICE
MULTISIM **Figure P5.2**



P 5.2 $\quad v_o = -(0.5 \times 10^{-3})(10{,}000) = -5 \text{ V}$

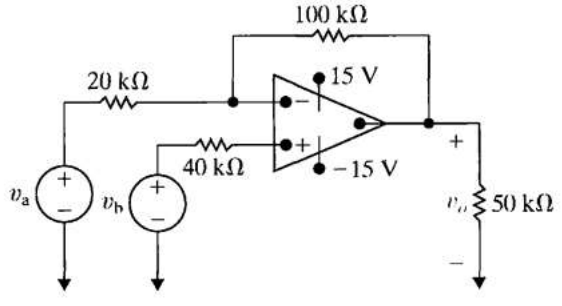
$$\therefore \quad i_o = \frac{v_o}{5000} = \frac{-5}{5000} = -1\,\text{mA}$$

5.3 The op amp in the circuit in Fig. P5.3 is ideal.

PSPICE
MULTISIM

a) Calculate v_o if $v_a = 4$ V and $v_b = 0$ V.
b) Calculate v_o if $v_a = 2$ V and $v_b = 0$ V.
c) Calculate v_o if $v_a = 2$ V and $v_b = 1$ V.
d) Calculate v_o if $v_a = 1$ V and $v_b = 2$ V.
e) Calculate v_o if $v_a = 1.5$ V and $v_b = 4$ V.
f) If $v_b = 1.6$ V, specify the range of v_a such that the amplifier does not saturate.

Figure P5.3



P 5.3 $\quad \dfrac{v_b - v_a}{20{,}000} + \dfrac{v_b - v_o}{100{,}000} = 0, \qquad$ therefore $\quad v_o = 6v_b - 5v_a$

[a] $v_a = 4$ V, $\quad v_b = 0$ V, $\quad v_o = -15$ V (sat)

[b] $v_a = 2$ V, $\quad v_b = 0$ V, $\quad v_o = -10$ V

[c] $v_a = 2$ V, $\quad v_b = 1$ V, $\quad v_o = -4$ V

[d] $v_a = 1$ V, $\quad v_b = 2$ V, $\quad v_o = 7$ V

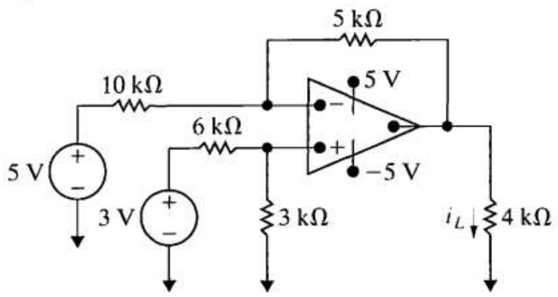
[e] $v_a = 1.5$ V, $\quad v_b = 4$ V, $\quad v_o = 15$ V (sat)

[f] If $v_b = 1.6$ V, $\quad v_o = 9.6 - 5v_a = \pm 15$

$$\therefore \quad -1.08 \text{ V} \le v_a \le 4.92 \text{ V}$$

5.4 Find i_L (in microamperes) in the circuit in Fig. P5.4.

PSPICE
MULTISIM **Figure P5.4**



P 5.4 $\quad v_p = \dfrac{3000}{3000 + 6000}(3) = 1 \text{ V} = v_n$

$$\frac{v_n - 5}{10{,}000} + \frac{v_n - v_o}{5000} = 0$$

$$(1 - 5) + 2(1 - v_o) = 0$$

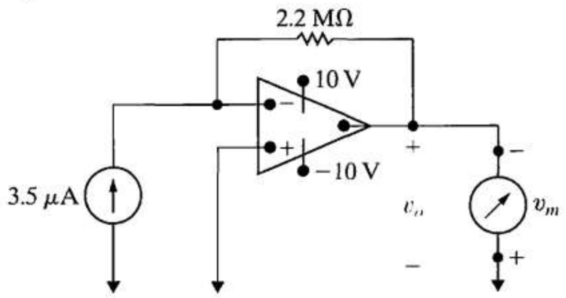
$$v_o = -1.0 \text{ V}$$

$$i_L = \frac{v_o}{4000} = -\frac{1}{4000} = -250 \times 10^{-6}$$

$$i_L = -250\,\mu\text{A}$$

5.5 A voltmeter with a full-scale reading of 10 V is used to measure the output voltage in the circuit in Fig. P5.5. What is the reading of the voltmeter? Assume the op amp is ideal.
PSPICE
MULTISIM

Figure P5.5



P 5.5 Since the current into the inverting input terminal of an ideal op-amp is zero, the voltage across the 2.2 MΩ resistor is $(2.2 \times 10^6)(3.5 \times 10^{-6})$ or 7.7 V. Therefore the voltmeter reads 7.7 V.

5.6 The op amp in the circuit in Fig. P5.6 is ideal. Calculate the following:
PSPICE
MULTISIM

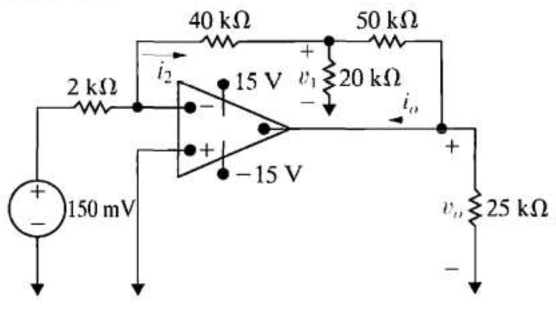
a) v_1

b) v_o

c) i_2

d) i_o

Figure P5.6



P 5.6 [a] $i_2 = \dfrac{150 \times 10^{-3}}{2000} = 75\,\mu\text{A}$

$$v_1 = -40 \times 10^3 i_2 = -3\,\text{V}$$

[b] $\dfrac{v_1}{20{,}000} + \dfrac{v_1}{40{,}000} + \dfrac{v_1 - v_o}{50{,}000} = 0$

$$\therefore \quad v_o = 4.75 v_1 = -14.25 \text{ V}$$

[c] $i_2 = 75\,\mu\text{A}$, (from part [a])

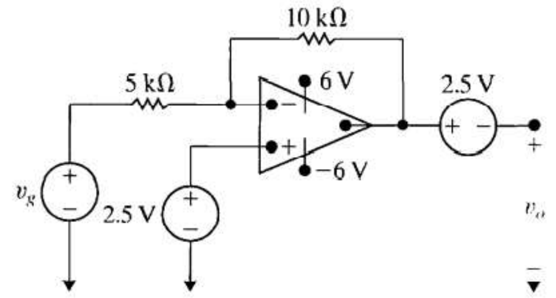
[d] $i_o = \dfrac{-v_o}{25{,}000} + \dfrac{v_1 - v_o}{50{,}000} = 795\,\mu \text{ A}$

5.7 A circuit designer claims the circuit in Fig. P5.7 will produce an output voltage that will vary between ±5 as v_g varies between 0 and 5 V. Assume the op amp is ideal.

PRACTICAL PERSPECTIVE
PSPICE
MULTISIM

a) Draw a graph of the output voltage v_o as a function of the input voltage v_g for $0 \le v_g \le 5$ V.

b) Do you agree with the designer's claim?

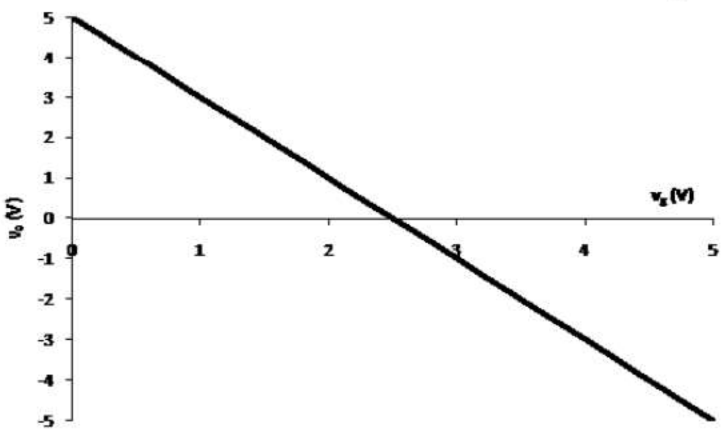


P 5.7 **[a]** First, note that $v_n = v_p = 2.5$ V

Let v_{o1} equal the voltage output of the op-amp. Then

$$\frac{2.5 - v_g}{5000} + \frac{2.5 - v_{o1}}{10{,}000} = 0, \qquad \therefore \quad v_{o1} = 7.5 - 2v_g$$

Also note that $v_{o1} - 2.5 = v_o, \qquad \therefore \quad v_o = 5 - 2v_g$



[b] Yes, the circuit designer is correct!