1.7 Five coulombs of charge pass through the element in Fig. P1.7 from point A to point B. If the energy absorbed by the element is 150 J, determine the voltage across the element.

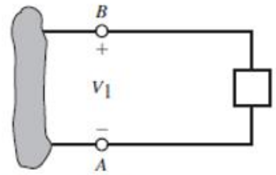
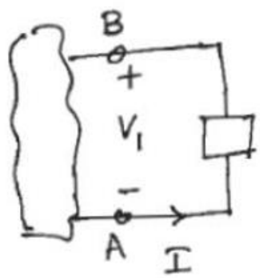


Figure P1.7

SOLUTION:



$Q = 5\ C$

$W = 150\ J$

For passive sign convention: $W = -V_1 Q$

$$V_1 = -\frac{W}{Q} \qquad \boxed{V_1 = -30V}$$

1.8 The current that enters an element is shown in Fig. P1.8. Find the charge that enters the element in the time interval $0 < t < 20$ s.

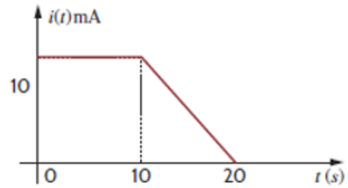


Figure P1.8

SOLUTION:

$$i(t) = m_1 t + b$$

$$m_1 = \frac{10-10}{10-20} = -1$$

$$i(t) = -t + b$$

$$10 = -10 + b$$

$$b = 20$$

$$i(t) = -t + 20 \text{ mA}$$

$$q(t) = \int_0^{20} i(t)\, dt$$

$$q(t) = \int_0^{10} 10 \times 10^{-3}\, dt + \int_{10}^{20} \frac{20-t}{1000}\, dt$$

$$q(t) = 10 \times 10^{-3} t \Big]_0^{10} + \frac{1}{1000}\left[20t - \frac{t^2}{2}\right]_{10}^{20}$$

$$q(t) = 0.1 + \frac{1}{1000}\left[20(20) - \frac{(20)^2}{2} - 20(10) + \frac{(10)^2}{2}\right]$$

$$q(t) = 0.1 + \frac{1}{1000}\left[200 - 200 + 50\right]$$

$$q(t) = 0.15\text{C}$$

1.16 The energy absorbed by the BOX in Fig. P1.16 is given below. Calculate and sketch the current flowing into the BOX. Also calculate the charge which enters the BOX between 0 and 12 seconds.

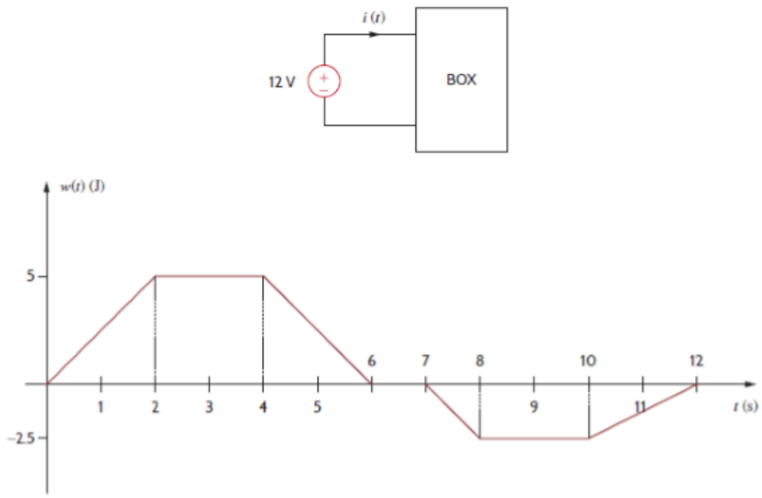


Figure P1.16

SOLUTION:

$$P = \frac{dW}{dt} \text{ (slope of the curve)}$$

$$P = vi \Rightarrow i = \frac{P}{V} = \frac{P}{12}$$

$\underline{0 \le t \le 2s:}$

$$P = \frac{5-0}{2-0} = 2.5\ W \quad , \quad i = \frac{2.5}{12} = 0.21\ A$$

$\underline{2 \le t \le 4s}$:

$$P = \frac{5-5}{4-2} = 0, \quad i = 0$$

$\underline{4 \le t \le 6s}$:

$$P = \frac{0-5}{6-4} = -2.5\,W, \quad i = \frac{-2.5}{12} = -0.21\,A$$

$\underline{6 \le t \le 7s}$:

$$P = \frac{0-0}{7-6} = 0, \quad i = 0$$

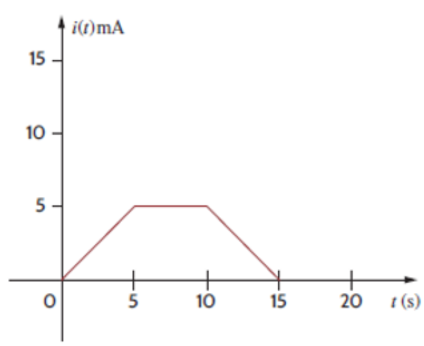
$\underline{7 \le t \le 8s}$:

$$P = \frac{-2.5-0}{8-7} = -2.5\,W, \quad i = \frac{-2.5}{12} = -0.21\,A$$

$\underline{8 \le t \le 10s}$:

$$P = \frac{-2.5-(-2.5)}{10-8} = 0, \quad i = 0$$

1.17 The plot of current entering an element is shown in the figure. Find the charge that enters the element from 5 to 15 seconds.



SOLUTION:

The charge through the element can be found by finding the area under the curve from 5 to 15 seconds.

Thus charge flown = 5 x (10-5) + ½ x 5 x (15-10)

= 37.5mC

1.37 Find I_x in the circuit in Fig. P1.37 using Tellegen's theorem.

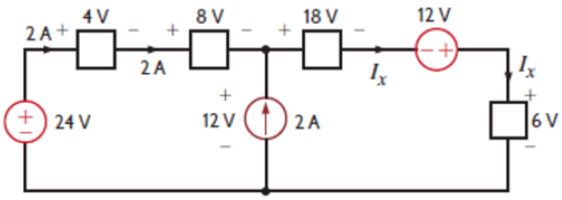


Figure P1.37

SOLUTION:

$$P_{24V} = (24)(-2) = -48W$$
$$P_{24V} = 48W \text{ supplied}$$
$$P_{4V} = (4)(2) = 8W \text{ absorbed}$$
$$P_{8V} = (8)(2) = 16W \text{ absorbed}$$

$$P_{2A} = 12(-2) = -24W$$
$$P_{2A} = 24W \text{ supplied}$$

$$P_{18V} = 18 I_x \text{ absorbed}$$
$$P_{12V} = 12(-I_x) = -12 I_x$$
$$P_{12V} = 12 I_x \text{ supplied}$$

$$P_{6V} = 6 I_x \text{ absorbed}$$

Power supplied = Power absorbed

$$P_{24V} + P_{2A} + P_{12V} = P_{4V} + P_{8V} + P_{18V} + P_{6V}$$

$$48 + 24 + 12 I_x = 8 + 16 + 18 I_x + 6 I_x$$
$$12 I_x = 48$$
$$I_x = 4A$$

2.20 In the network in Fig. P2.20, Find I_1, I_2 and I_3 and show that KCL is satisfied at the boundary.

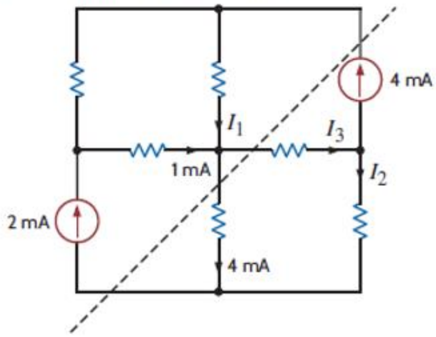


Figure P2.20

SOLUTION:

$$2mA - 1mA + 4mA = I_1$$

$$I_1 = 5mA$$

$$I_2 + 4mA = 2mA$$

$$I_2 = -2mA$$

$$I_3 = I_2 + 4mA$$

$$= 2mA$$

Across the Boundary (left -, Right +)

$$-2mA + 4mA + 2mA - 4mA = 0$$

2.30 The 10-V source absorbs 2.500 mW of power. Calculate (a) V_{ba} and (b) the power absorbed by the dependent voltage source in Fig. P2.30.

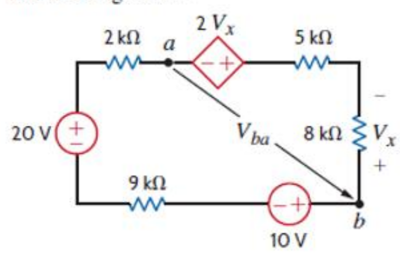
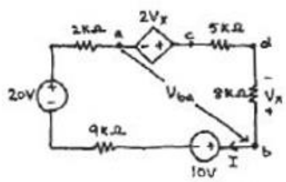


Figure P2.30

SOLUTION:



$$P_{10V} = 2.50 \text{ mW absorbed}$$

$$P_{10V} = 10 I$$

$$\Rightarrow I = \frac{P_{10V}}{10} = 250\ \mu A$$

KVL for 'bacdb' : $V_{ba} - V_{ca} - V_{dc} - V_{bd} = 0$

$$\Rightarrow V_{ba} = V_{ca} + V_{dc} + V_{bd} \quad \text{— (1)}$$

$$V_{bd} = -I\,(8 \times 10^3) = -(250 \times 10^{-6})(8 \times 10^3)$$

$$\Rightarrow V_{bd} = -2\text{ V} \quad \text{— (2)}$$

$$V_{dc} = -I\,(5 \times 10^3) \Rightarrow V_{dc} = -1.25\text{ V} \quad \text{— (3)}$$

$$V_x = V_{bd} = -2\text{ V}$$

$$V_{ca} = 2V_x = -4\text{V} \quad \text{— (4)}$$

Substituting (2), (3), (4) in (1) : $\boxed{V_{ba} = -7.25\text{ V}}$

$$P_{DS} = -2V_x I = -2(-2)(250 \times 10^{-6})$$

$$\Rightarrow \boxed{P_{DS} = 1\text{mW}}$$

2.57 Find R_{AB} in the network in Fig. P2.57.

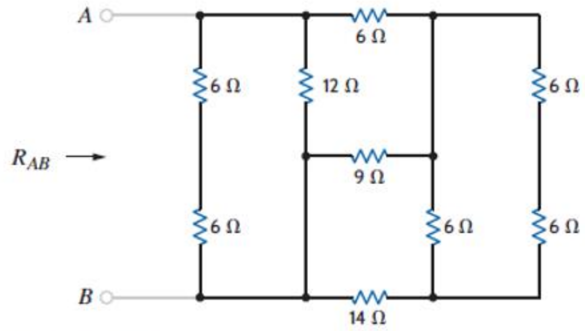
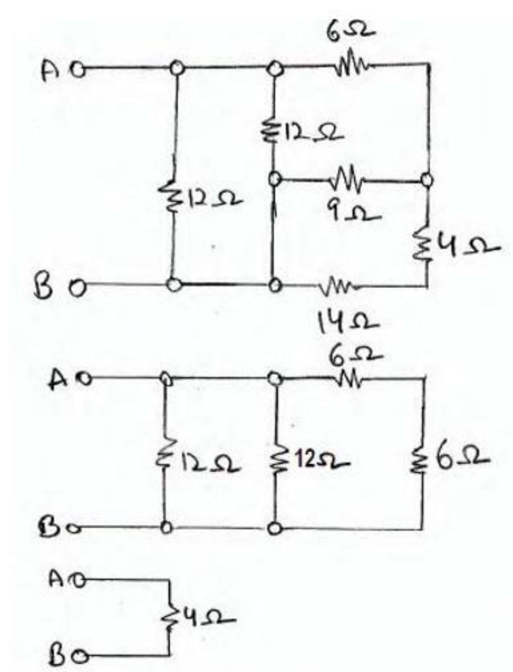


Figure P2.57

SOLUTION:



2.67 Determine I_o in the circuit in Fig. P2.67.

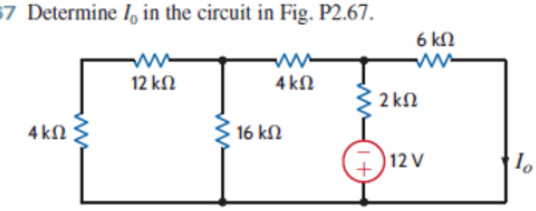
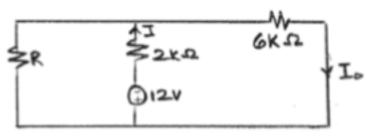


Figure P2.67

SOLUTION:

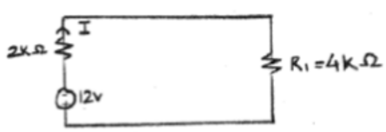


$$R = [(4K + 12K) \,||\, 16K] + 4K$$

$$R = 8K + 4K = 12K\,\Omega$$

$$R_1 = 12K \,||\, 6K$$

$$R_1 = 4K\Omega$$



$$I = \frac{-12}{2K + 4K} = -2mA$$

Current divison:

$$I_o = \left(\frac{12k}{12k + 6k}\right)(-2m)$$

$$I_o = -1.33\,mA$$

2.69 Calculate V_{AB} in Fig. P2.69.

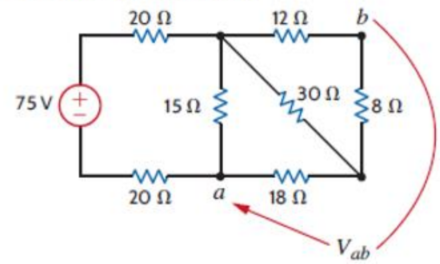
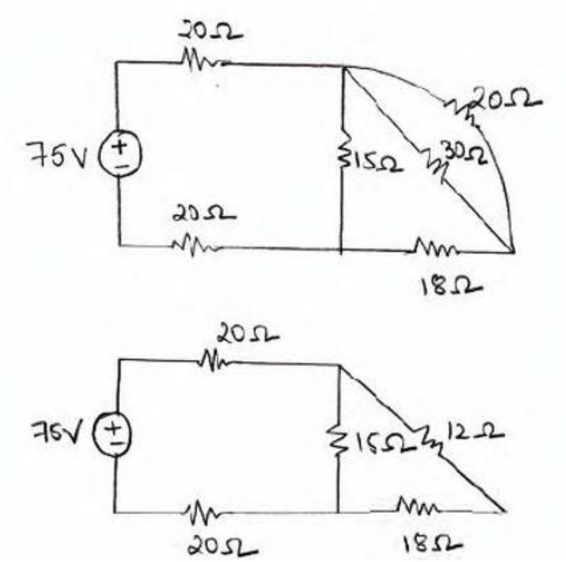
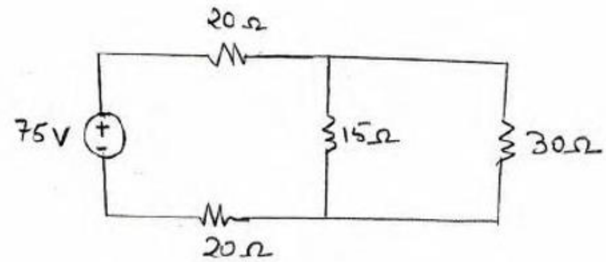
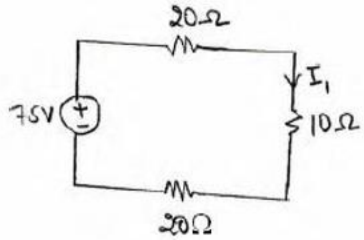


Figure P2.69

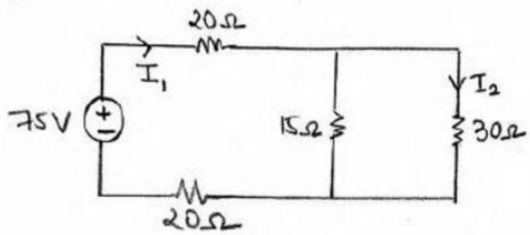
SOLUTION:





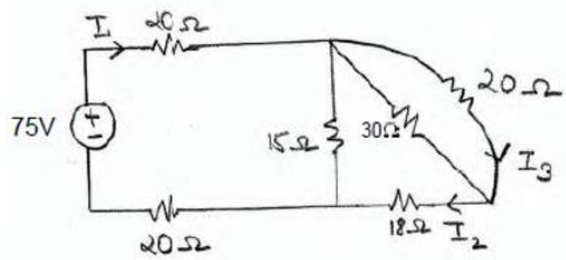


$$I_1 = \frac{75}{20+10+20} = 1.5A$$

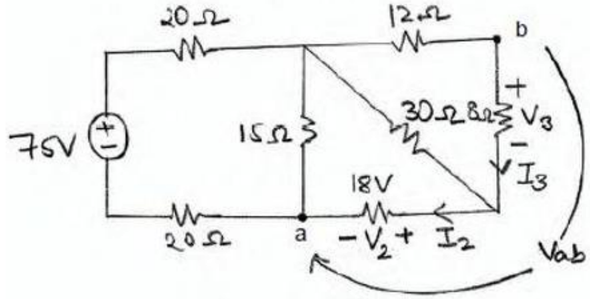


$$I_2 = 1.5\left(\frac{15}{15+30}\right)$$

$$= 0.5A$$



$$I_3 = 0.5\left(\frac{30}{30+20}\right) = 0.3A$$



$$V_3 = 8I_3 = 8(0.3) = 2.4V$$

$$V_2 = 18\,I_2 = 18(0.5) = 9V$$

$$V_{ab} = -V_2 - V_3 = -9 - 2.4 = -11.4V$$

2.71 Calculate V_{ab} and V_1 in Fig. P2.71.

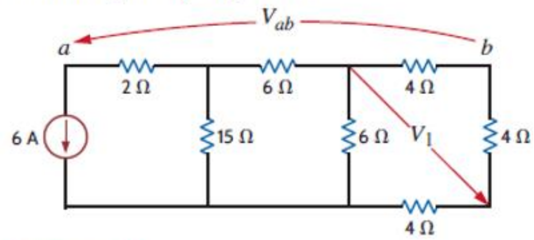
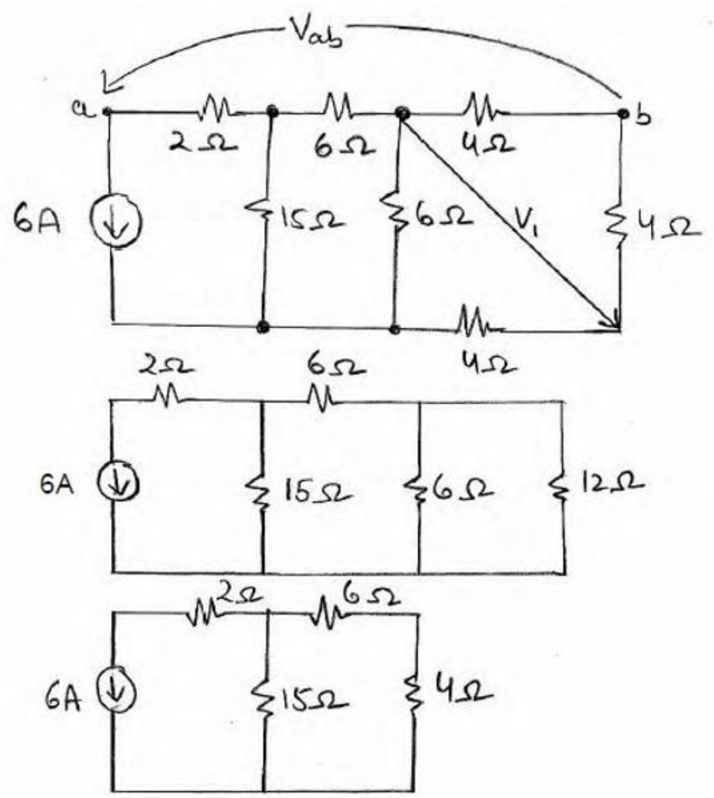
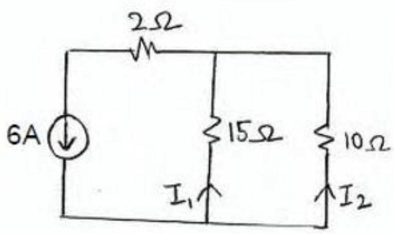


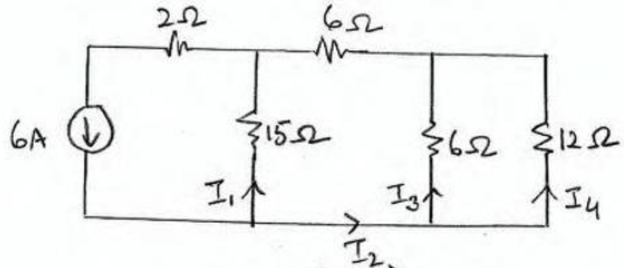
Figure P2.71

SOLUTION:



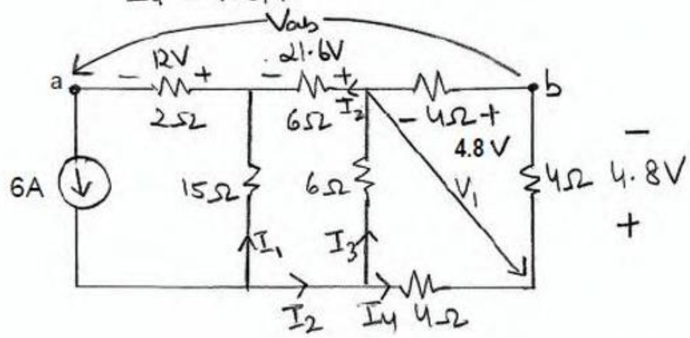


$$I_1 = 6\left(\frac{10}{10+15}\right)$$
$$= 2.4A$$
$$I_2 = 3.6A$$



$$I_3 = 3.6\left(\frac{12}{12+6}\right) = 2.4A$$

$$I_4 = 1.2A$$



$$V_1 = 4.8 + 4.8 = \underline{9.6V}$$

$$V_{ab} = -12 - 21.6 - 4.8 = \underline{-38.4V}$$

2.83 In the circuit in Fig. P2.83.

(a) Calculate V_y if $I_z = -3$ A

(b) What voltage would need to replace the 5 V source to obtain $v_y = -6$ V if $I_z = 0.5$ A.

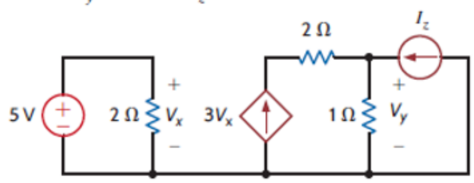


Figure P2.83

SOLUTION:

a. $v_y = 1(3v_x + i_z)$

$v_x = 5$ V and given that $i_z = -3$ A, we find that

$v_y = 3(5) - 3 = 12$ V

b. $v_y = 1(3v_x + i_z) = -6 = 3v_x + 0.5$

Solving, we find that $v_z = (-6 - 0.5)/3 = -2.167$ V.

2.86 If $V_2 = 4$ V in Fig. P2.86, calculate V_x.

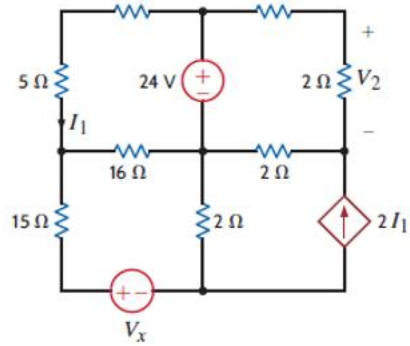
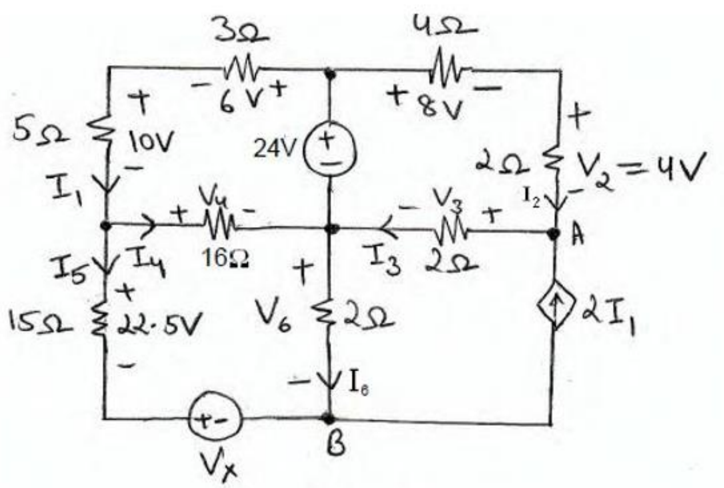


Figure P2.86

SOLUTION:



$$I_2 = \frac{4}{2} = 2A$$

$V_3 = -4 - 8 + 24 = 12V \quad I_3 = \frac{V_3}{2} = 6A$

KCL @ node A: $I_2 + 2I_1 = I_3$

$2 + 2I_1 = 6 \quad 2I_1 = 4 \quad I_1 = 2A$

$V_4 = -10 - 6 + 24 = 8V \quad I_4 = \frac{8}{16} = 0.5A$

$I_5 = I_1 - I_4 = 2 - 0.5 = 1.5A$

KCL @ node B: $I_6 + I_5 = 2I_1 = 4$

$I_6 = 4 - 1.5 = 2.5A \quad V_6 = 2I_6 = 5V$

$V_x = -22.5 + 8 + 5 = \underline{-9.5V}$

2.92 The 5-A current source in Fig. P2.92 supplies 150 W. Calculate V_A.

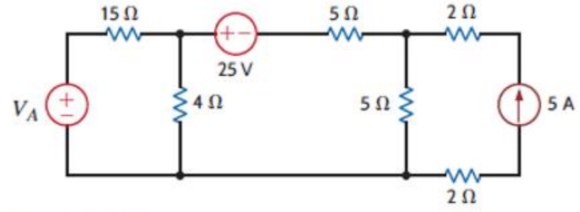
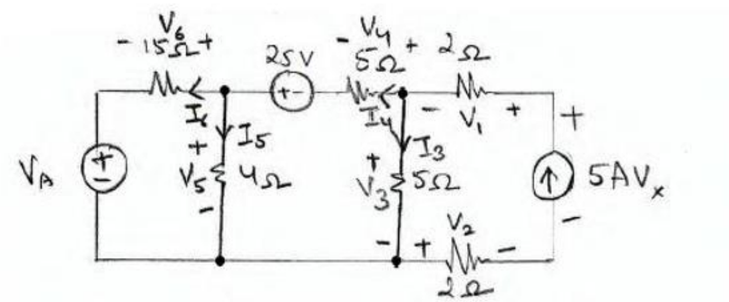


Figure P2.92

SOLUTION:



$$V_1 = (5)(2) = 10V \qquad V_x = \frac{150}{5} = 30V$$

$$V_2 = (5)(2) = 10V$$

$$V_3 = -V_1 + V_x - V_2 = -10 + 30 - 10 = 10V$$

$$I_3 = \frac{V_3}{5} = \frac{10}{5} = 2A$$

$$I_4 = 5 - I_3 = 5 - 2 = 3A$$

$$V_4 = 5I_4 = (5)(3) = 15V$$

$$V_5 = 25 - V_4 + V_3 = 25 - 15 + 10 = 20V$$

$$I_5 = \frac{V_5}{4} = \frac{20}{4} = 5A$$

$$I_6 = I_4 - I_5 = 3 - 5 = -2A$$

$$V_6 = 15I_6 = 15(-2) = -30V$$

$$V_A = -V_6 + V_5 = -(-30) + 20 = \underline{50V}$$

3.4 Use nodal analysis to find V_1 in the circuit in Fig. P3.4.

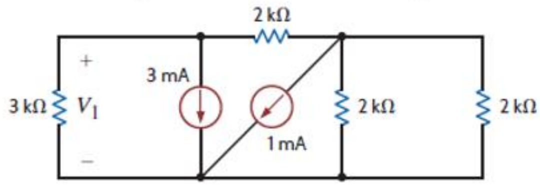
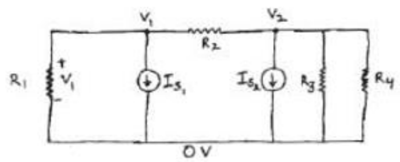


Figure P3.4

SOLUTION:



$R_1 = 3\,k\Omega$, $R_2 = R_3 = R_4 = 2\,k\Omega$, $I_{s_1} = 3\,mA$, $I_{s_2} = 1\,mA$

KCL @ V_1 : $\frac{V_1}{R_1} + I_{s_1} + \frac{V_1 - V_2}{R_2} = 0$

$$\frac{V_1}{3\times10^3} + 3\times10^{-3} + \frac{V_1 - V_2}{2\times10^3} = 0$$

$$5V_1 - 3V_2 = -18 \quad \text{———} \quad (1)$$

KCL @ V_2 : $\frac{V_2 - V_1}{R_2} + I_{s_2} + \frac{V_2}{R_3} + \frac{V_2}{R_4} = 0$

$$\frac{V_2 - V_1}{2\times10^3} + 1\times10^{-3} + \frac{V_2}{2\times10^3} + \frac{V_2}{2\times10^3} = 0$$

$$3V_2 - V_1 = -2 \quad \text{———} \quad (2)$$

Substituting equation (2) in (1), we get

$$V_2 = -\frac{28}{12}$$

$$V_1 = \frac{3V_2 - 18}{5} \Rightarrow \boxed{V_1 = -5V}$$

3.11 Find V_o in the network in Fig. P3.11 using nodal analysis.

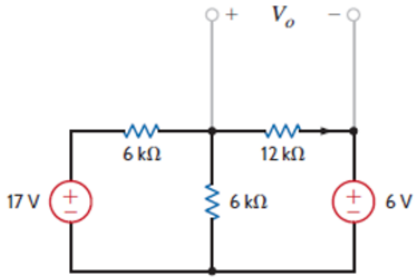
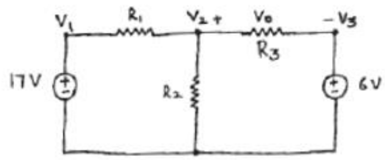


Figure P3.11

SOLUTION:



$R_1 = R_2 = 6\ k\Omega \quad , \quad R_3 = 12\ k\Omega$

@ V_1 : $\quad V_1 = 17\ V$

KCL @ V_2 : $\quad \frac{V_2 - V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_2 - V_3}{R_3} = 0$ — ①

@ V_3 : $\quad V_3 = 6\ V$

Substituting values of V_1 and V_3 in equation ①, we get

$$\frac{V_2}{R_1} - \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_2}{R_3} - \frac{V_3}{R_3} = 0$$

$$V_2\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right] - \frac{V_1}{R_1} - \frac{V_3}{R_3} = 0$$

$$V_2\left[\frac{1}{6} + \frac{1}{6} + \frac{1}{12}\right] - \frac{17}{6} - \frac{6}{12} = 0$$

$$V_2 = 8\ V$$

$$V_o = V_2 - V_3$$

$$\boxed{V_o = 2V}$$

3.18 Find I_o in the circuit in Fig. P3.18 using nodal analysis.

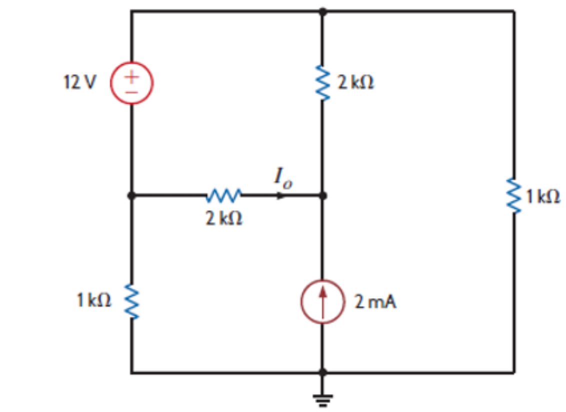
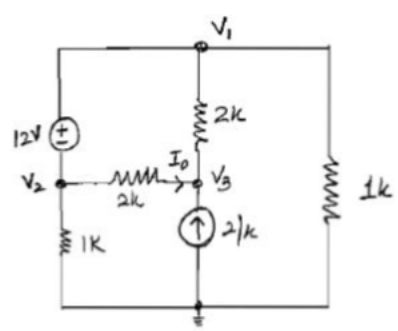


Figure P3.18

SOLUTION:



$$V_1 - V_2 = 12$$

$$\frac{V_1 - V_3}{2k} + \frac{V_1}{1k} + \frac{V_2}{1k} + \frac{V_2 - V_3}{2k} = 0$$

$$\frac{V_3 - V_1}{2k} + \frac{V_3 - V_2}{2k} = 2/k$$

$$\frac{V_1}{2k} - \frac{V_3}{2k} + \frac{V_1}{1k} + \frac{V_2}{1k} + \frac{V_2}{2k} - \frac{V_3}{2k} = 0$$

$$\frac{V_3}{2k} - \frac{V_1}{2k} + \frac{V_3}{2k} - \frac{V_2}{2k} = \frac{2}{k}$$

$$V_1 = V_2 + 12$$

$$\cancel{\frac{V_2}{2k}} + \frac{12}{2k} - \frac{V_3}{2k} + \cancel{\frac{V_2}{2k}} + \frac{12}{1k} + \cancel{\frac{V_2}{1k}} + \cancel{\frac{V_2}{2k}} - \frac{V_3}{2k} = 0$$

$$\frac{V_3}{2k} - \cancel{\frac{V_2}{2k}} - \frac{12}{2k} + \frac{V_3}{2k} - \cancel{\frac{V_2}{2k}} = \frac{2}{k}$$

$$V_2\left(\frac{1}{2k} + \frac{1}{1k} + \frac{1}{1k} + \frac{1}{2k}\right) - V_3\left(\frac{1}{2k} + \frac{1}{2k}\right) = -18/k$$

$$-V_2\left(\frac{1}{2k} + \frac{1}{2k}\right) + V_3\left(\frac{1}{2k} + \frac{1}{2k}\right) = \frac{8}{k}$$

$$V_2\left(\frac{3}{k}\right) - V_3\left(\frac{1}{k}\right) = -18/k$$

$$-V_2\left(\frac{1}{k}\right) + V_3\left(\frac{1}{k}\right) = \frac{8}{k}$$

$$\begin{bmatrix} 3 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} -18 \\ 8 \end{bmatrix}$$

$$\Delta = 3 - 1 = 2$$

$$\begin{bmatrix} V_2 \\ V_3 \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 1 & 1 \\ 1 & 3 \end{bmatrix}\begin{bmatrix} -18 \\ 8 \end{bmatrix} = \frac{1}{2}\begin{bmatrix} -10 \\ 6 \end{bmatrix} = \begin{bmatrix} -5 \\ 3 \end{bmatrix}$$

$$I_0 = \frac{V_2 - V_3}{2k} = \frac{-5-3}{2k} = \frac{-8}{2k} = -4mA$$

3.20 For the circuit in Fig. P3.20, find the node voltages using nodal analysis.

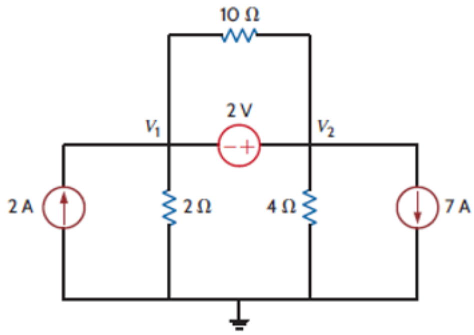
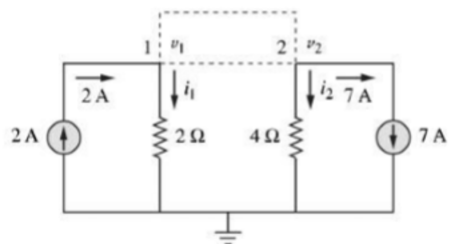


Figure P3.20

SOLUTION:

The supernode contains the 2-V source, nodes 1 and 2, and the 10-Ω resistor.Applying KCL to the supernode as shown in the figure below gives,

$$2 = i_1 + i_2 + 7$$



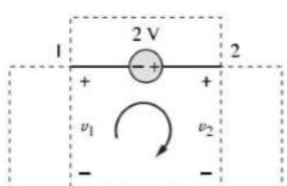
Expressing i_1 andi_2 in terms of the node voltages, we get,

$$2 = \frac{v_1 - 0}{2} + \frac{v_2 - 0}{4} + 7 \qquad => \qquad 8 = 2v_1 + v_2 + 28$$

Or, $\qquad v_2 = -20 - 2v_1 \qquad$ (i)

To get the relationship between $v_1$and v_2, we apply KVL to the circuit shown in figure below. Going around the loop, we obtain,

$$-v_1 - 2 + v_2 = 0 \qquad => \qquad v_2 = v_1 + 2 \qquad \text{(ii)}$$



From (i) and (ii), we get,

$v_1 = -7.333\ V \qquad$ And $\qquad v_2 = -5.333\ V.$

3.34 Find V_o in the circuit in Fig. P3.34 using nodal analysis.

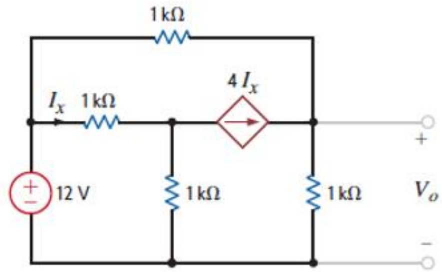


Figure P3.34

SOLUTION:

$$\frac{V_1 - 12}{k} + \frac{V_1}{k} + 4I_X = 0$$

$$\frac{V_0 - 12}{k} + \frac{V_0}{k} = 4I_X \qquad I_X = \frac{12 - V_1}{k}$$

$$V_1 - 12 + V_1 + 48 - 4V_1 = 0$$

$$V_0 - 12 + V_0 = 48 - 4V_1$$

$$-2V_1 + 36 = 0$$

$$2V_0 + 4V_1 = 60$$

$$V_1 = 18\text{V}$$

$$2V_0 = 60 - 72 = -12$$

$$V_0 = -6\text{V}$$

3.62 Find V_o in the network in Fig. P3.62 using loop analysis.

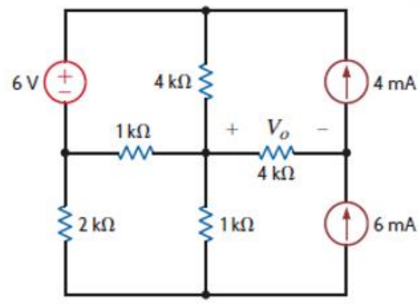
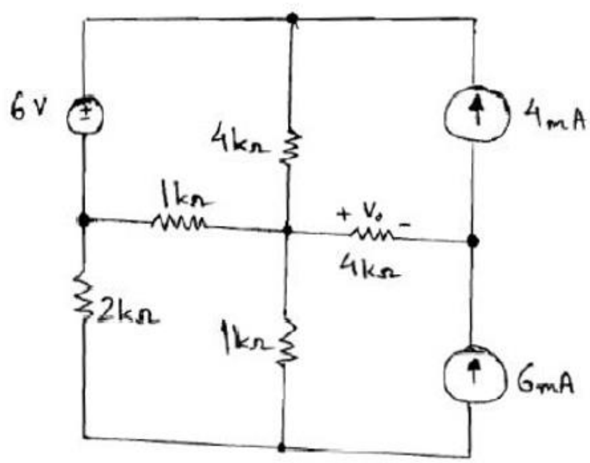


Figure P3.62

SOLUTION:



$$V_o = -(4k)\left(\frac{2}{2k}\right) = -4\,V$$

3.66 Find V_o in the network in Fig. P3.66 using loop analysis.

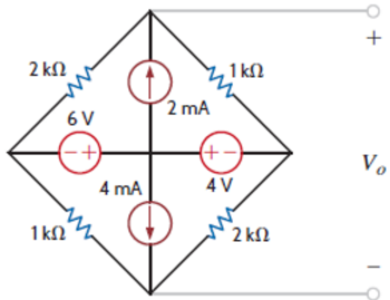
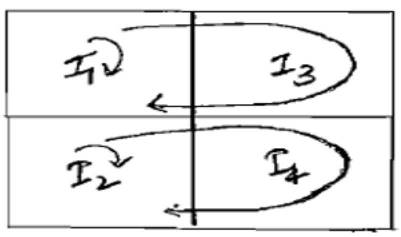


Figure P3.66

SOLUTION:



$$I_1 = -2/k$$
$$I_2 = 4/k$$

$$2k(I_1 + I_3) + 1k\, I_3 + 2 = 0$$
$$2k(I_4) + 1k(I_2 + I_4) - 2 = 0$$

$$2k\, I_1 + 3k\, I_3 = -2$$
$$3k\, I_4 + 1k\, I_2 = 2$$

$$3k\, I_3 = 2 \qquad I_3 = 2/3k$$
$$3k\, I_4 = -2 \qquad I_4 = -2/3k$$

$$V_o = 1k\, I_3 + 2k\, I_4 = \frac{2}{3} - \frac{4}{3} = -2/3\,V$$

3.83 Find the currents in the three meshes in Fig. P3.83.

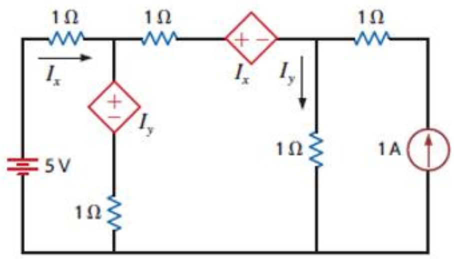
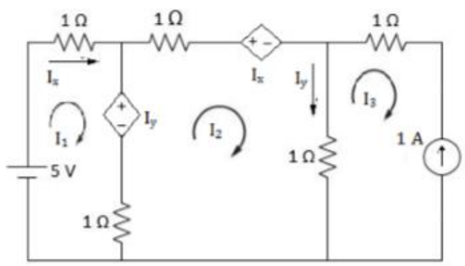


Figure P3.83

SOLUTION:

Assigning clockwise currents in three meshes, we get,



From the figure,

$I_x = I_1$ $\qquad$ $I_y = I_2 - I_3$

But $I_3 = -1\ A$, so

$I_y = I_2 + 1$

Applying KVL to Mesh 1,

$5 - I_1 - I_y - (I_1 - I_2) = 0$ $\qquad$ => $\qquad$ $-I_1 - I_2 - I_1 + I_2 = -5 + 1$

=> $\quad$ $I_1 = 2\ A$

Applying KVL to Mesh 2,

$-(I_2 - I_1) + I_y - I_2 - I_x - (I_2 - I_3) = 0$

=> $\quad$ $-I_2 + I_1 + (I_2 + 1) - I_2 - I_1 - I_2 + I_3 = 0$

=> $\quad$ $-2I_2 + 1 - 1 = 0$ $\qquad$ => $\qquad$ $I_2 = 0$

3.89. Use both nodal analysis and mesh analysis to find V_o in the circuit in Fig. P3.89.

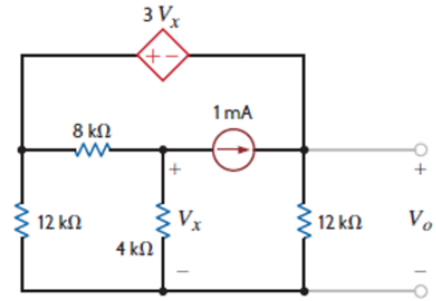
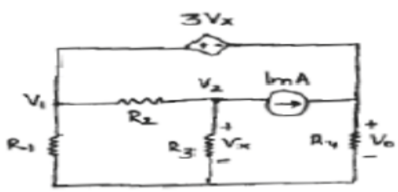


Figure P3.89

SOLUTION:

a)



$R_1 = R_4 = 12\,k\Omega$, $R_2 = 8\,k\Omega$, $R_3 = 4\,k\Omega$, $V_x = V_2$

$V_1 - V_o = 3V_x$

$\Rightarrow V_1 - V_o = 3V_2$ —— ①

KCL @ V_2 : $\dfrac{V_2 - V_1}{R_2} + \dfrac{V_2}{R_3} + 1 \times 10^{-3} = 0$

$3V_2 - V_1 = -8$

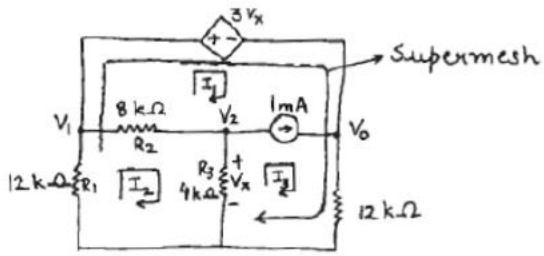
$V_2 = \dfrac{-8 + V_1}{3}$ —— ②

Substituting equation ② in ①, we get

$V_1 - V_o = \dfrac{3(V_1 - 8)}{3}$

$\boxed{V_o = 8.00\ V}$

b)



$R_1 = R_4 = 12\,k\Omega$, $R_2 = 8\,k\Omega$, $R_3 = 4\,k\Omega$

$I_3 - I_1 = 10^{-3}\,A$ — (1)

$V_x = (I_2 - I_3)\,R_3$

$V_0 = I_3\,R_4$

KVL @ Supermesh: $3V_x + I_3R_4 + I_2R_1 = 0$

$3\,I_2R_3 - 3I_3R_3 + I_3R_4 + I_2R_1 = 0$

$I_2 = 0\,A$ — (2)

KVL @ I_2 : $I_2R_1 + (I_2 - I_1)R_2 + (I_2 - I_3)R_3 = 0$

$2I_1 + I_3 = 0$

$I_1 = -\frac{I_3}{2}$ — (3)

Substituting equation (3) in (2), we get

$I_3 = \frac{2}{3} \times 10^{-3}\,A$

$V_0 = I_3\,R_4$

$\boxed{V_0 = 8.00\,V}$

3.90 Using mesh analysis, find V_o in the circuit in Fig. P3.90.

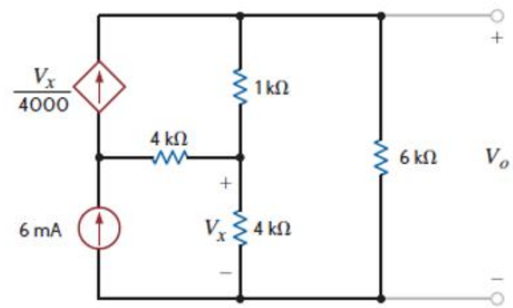
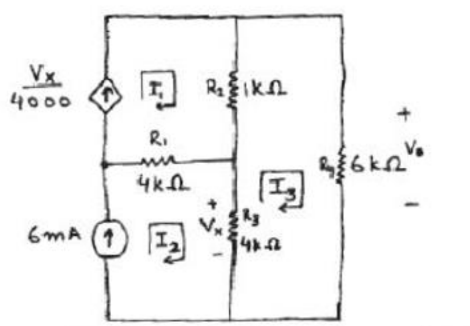


Figure P3.90

SOLUTION:



$R_1 = R_3 = 4\,k\Omega$, $R_2 = 1\,k\Omega$, $R_4 = 6\,k\Omega$

$I_2 = 6 \times 10^{-3}$ A ——— (1)

$V_x = (I_2 - I_3) R_3$ ——— (2)

$I_1 = \dfrac{V_x}{4000}$ ——— (3)

$V_0 = I_3 R_4$

KVL @ I_3: $(I_3 - I_1) R_2 + I_3 R_4 + (I_3 - I_2) R_3 = 0$

$11 I_3 - I_1 = 24 \times 10^{-3}$ ——— (4)

Substituting equations (1) and (2) in (3), we get

$I_1 = 6 \times 10^{-3} - I_3$ ——— (5)

Substituting equation (5) in (4), we get

$I_3 = \dfrac{30}{12} \times 10^{-3}$ A

$V_0 = I_3 R_4$

$= \dfrac{30}{12} \times 10^{-3} \times 6 \times 10^{3}$

$\boxed{V_0 = 15.0\,V}$

3.91 Find V_o in the network in Fig. P3.91.

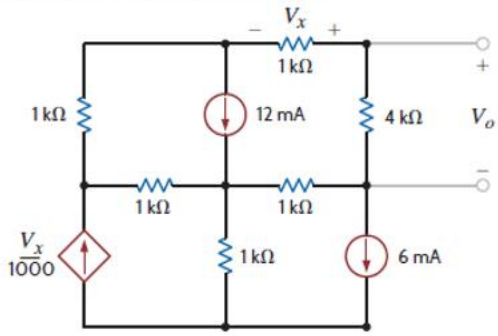
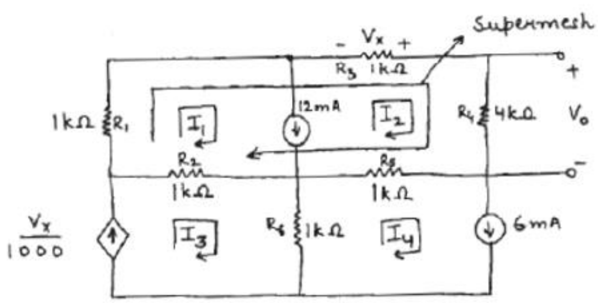


Figure P3.91

SOLUTION:



$R_1 = R_2 = R_3 = R_5 = R_6 = 1k\Omega, \; R_4 = 4k\Omega$

$I_1 - I_2 = 12 mA$ —— ①

$I_4 = 6mA$

$V_x = -I_2 R_3$

$I_3 = \frac{V_x}{1000}$

$V_o = I_2 R_4$

KVL @ supermesh: $I_1 R_1 + I_2 R_3 + I_2 R_4 + (I_2 - I_4) R_5 + (I_1 - I_3) R_2 = 0$

$I_1(R_1 + R_2) + I_2(R_3 + R_4 + R_5) - I_3 R_2 - I_4 R_5 = 0$

$$2\times10^{3} I_1 + 6\times10^{3} I_2 - 10^{3} I_3 - 10^{3} I_4 = 0$$

$$2I_1 + 6I_2 - I_3 - I_4 = 0$$

Substituting $I_3 = \frac{V_x}{1000}$ and $V_x = -I_2 R_3$

$$2I_1 + 7I_2 = 6\times10^{-3} \quad \text{—} \quad (2)$$

From equations (1) and (2), we get

$$I_2 = -2\,mA$$

$$V_0 = I_2 R_4$$

$$V_0 = -2\times10^{-3} \times 4\times10^{3}$$

$$\boxed{V_0 = -8.00\ V}$$