Circuit Analysis with PSpice A Simplified Approach 1st edition Sabah Solutions Manual

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Chapter 2 – Fundamentals of Resistive Circuits

PE2.1 $R = \frac{24}{3} = 8\ \Omega,\ G = \frac{1}{R} = \frac{3}{24} = 0.125\ \text{S},\ P = 24\times3 = 72\ \text{W}.$

PE2.2 $I = \sqrt{\frac{180}{5}} = 6\ \text{A},\ V = \frac{180}{6} = 30\ \text{V}.\ W = \frac{(30)^2}{5} = 180\ \text{W};\ G = 1/5 = 0.2\ \text{S};$

$W = (30)^2 \times 0.2 = 180\ \text{W}.$

PE2.3 (a) Power dissipated in the interval $t = 0$ to $t = 3$ s is $(2)^2\times5 = 20$ W (Figure 2.3); energy dissipated is $20\times3 = 60$ J; power dissipated in the interval $t = 3$ s to $t = 5$ s is $(1)^2\times5 = 5$ W; energy dissipated is $5\times2 = 10$ J; total energy dissipated is 60 + 10 = 70 J.

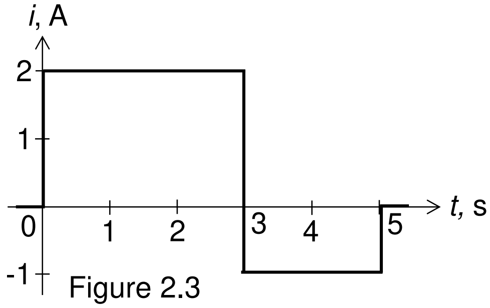


Figure 2.3

(b) Average power dissipated is 70/5 = 14 W.

PE2.4 (a) $p = 0\times I = 0$; (b) $p = V\times0 = 0$.

PE2.5 To have the largest voltage across terminals 'ab' in Figure 2.6, there should be no voltage drop across the 2 Ω resistor, which means no current in this resistor. This will be the case when terminals 'ab' are open circuited.

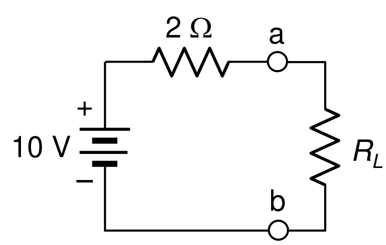


Figure 2.6

PE2.6 In accordance with the passive sign convention and its physical interpretation, the ideal voltage source delivers (12 V)×(2 A) = 24 W in (a), when the source current is in the direction of a voltage rise across the source, and absorbs 24 W in (b), when the source current is in the direction of a voltage drop across the source.

PE2.7 As illustrated in Figure 2.8c, the 5 A current is in the direction of a voltage drop across the battery and in the direction of a voltage rise through the charging circuit. According to the passive sign convention, a power of (24 V)×(5 A) = 120 W is absorbed by the battery (a) and delivered by the charging circuit (b). Equivalently, a power of -120 W is delivered by the battery (c) and absorbed by the charging circuit (d).

PE2.8 (a) The current source forces 0.1 A through the battery, directed from the + terminal to the – terminal of the battery in Figure 2.12.

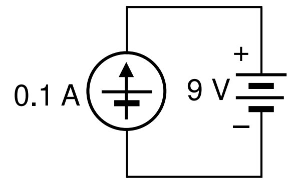


Figure 2.12

(b) The battery impresses 9 V across the current source, the voltage being of the same polarity as the battery.

(c) Current flows through the current source in the direction of a voltage rise, so that this source delivers (9 V)×(0.1 A) = 0.9 W.

(d) Current flows through the battery in the direction of a voltage drop, so that the battery absorbs (9 V)×(0.1 A) = 0.9 W.

(a′) The current source forces 0.1 A through the battery, directed from the – terminal to the + terminal of the battery.

(b′) The battery impresses 9 V across the current source, the voltage being of the same polarity as the battery.

(c′) Current flows through the current source in the direction of a voltage drop, so that this source absorbs (9 V)×(0.1 A) = 0.9 W.

(d′) Current flows through the battery in the direction of a voltage rise, so that the battery delivers (9 V)×(0.1 A) = 0.9 W.

PE2.9 (a) At the positive peaks of the sinusoid, the current through the source is in the direction of a voltage rise. Hence, $p_{max(del)}$ = 10×(4) = 40 W. These peaks occur at $t = \pi/2$ s plus an integer multiple of 2π.

(b) At the negative peaks of the sinusoid, the power delivered is p = 10×(-4) = -40 W. $p_{max(abs)}$ = 40 W, since the current through the source is in the direction of a voltage drop. The negative peaks occur at $t = 3\pi/2$ s plus an integer multiple of 2π.

(c) The average power over a cycle is $\int_0^{2\pi} 40 \sin t dt = -40[\cos \omega t]_0^{2\pi} = -40[1-1] = 0$.

PE2.10 In Figure 2.13A, the voltage of the VCVS is $2V_X = 2\times1.8 = 3.6$ V. The voltage of the CCVS is $3I_Y = 3\times2.4 = 7.2$ V.

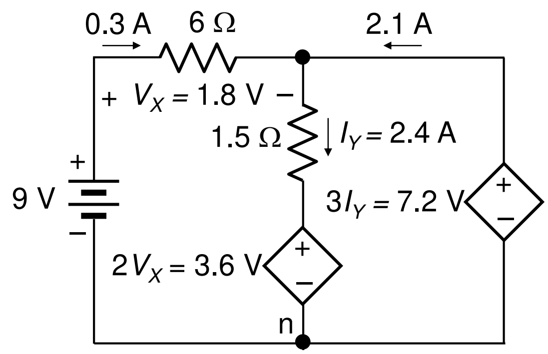


Figure 2.13A

(a) From Ohm's law, the current through the 6 Ω resistor is 1.8/6 = 0.3 A in the direction of the voltage drop V_X.

(b) From Ohm's law, the voltage across the 1.5 Ω resistor is $1.5\times2.4 = 3.6$ V and is a voltage drop in the direction of the current.

(c) The 0.3 A is in the direction of a voltage rise across the 9 V source. Hence, this source delivers $9\times0.3 = 2.7$ W. The 2.4 A current through the VCVS is in the direction of a voltage drop across the source. Hence, this source absorbs $3.6\times2.4 = 8.64$ W.

(d) The power dissipated in the resistors is $1.8\times0.3 + 3.6\times2.4 = 9.18$ W.

(e) Power absorbed by the VCVS and the resistors is 8.64 + 9.18 = 17.82 W. Power delivered by the independent source is 2.7 W. From conservation of power, the CCVS must deliver 17.82 – 2.7 = 15.12 W.

(f) The total voltage across the CCVS is 3.6 + 3.6 = 7.2 V. Current though the CCVS is 15.12/7.2 = 2.1 A. It is seen that charge is conserved at the upper and lower junctions. This is because in 1s, 2.1 C enter the upper junction and 2.1 C leave the junction.

PE2.11 (a) In Figure 2.14A, the current through the 1 Ω resistor is 3.6/1 = 3.6 A in the direction of the voltage drop V_X.

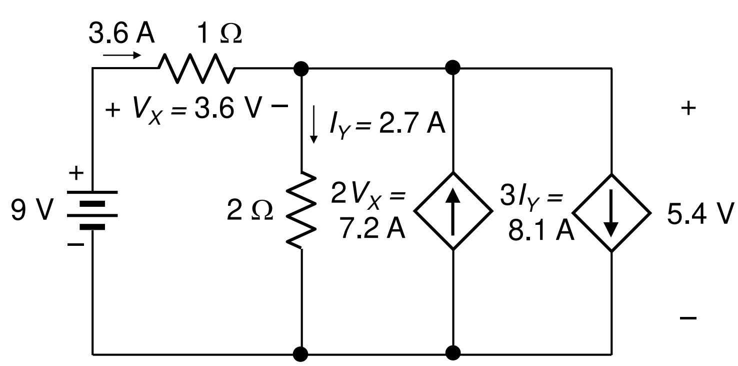


Figure 2.14A

(b) Voltage across the 2 Ω resistor is $2\times2.7 = 5.4$ V drop in the direction of I_Y.

(c) 3.6 A current is in the direction of a voltage rise across the battery. Hence, battery delivers $9\times3.6 = 32.4$ W. The 7.2 A current through VCCS is in the direction of a voltage rise across the source. Hence, VCCS delivers 5.4×7.2 = 38.88 W. The 8.1 A current through CCCS is in the direction of a voltage drop across the source. Hence, CCCS absorbs 5.4×8.1 = 43.74 W.

(d) Power absorbed by 1 Ω resistor is 3.6×3.6 = 12.96 W. Power absorbed by 2 Ω resistor is 5.4×2.7 = 14.58 W.

(e) Total power delivered: 32.4 + 38.88 = 71.28 W. Total power absorbed: 43.74 + 12.96 + 14.58 = 71.28 W. Charge is conserved at the upper and lower junctions, because in 1 s, 3.6 + 7.2 = 10.8 C enter the upper junction and 2.7 + 8.1 = 10.8 A.

E2.12 If V_X is the voltage across the VCCS, the definition of an ideal current source is violated. In fact, such a source can be replaced by a resistor. If I_Y is the current through the CCCS, then $I_Y = 3I_Y$, so that $I_Y = 0$, and the CCCS is equivalent to an open circuit.

PE2.13

(a) 7 nodes, labelled ‘a’ to ‘g’ in Figure 2.17A.

(b) 4 essential nodes, labelled ‘b’, ‘d’, ‘e’, and ‘f’.

(c) 9 branches, each element being a branch.

(d) 6 essential branches, ‘bf’, ‘bd’, ‘be’, ’de’, ‘ef’, and ‘df.

(e) 3 meshes, ‘abfa’, ‘bcedb’, and ‘degfd’.

(f) 4 loops, ‘bcgfb’, ‘abdegfa’, ‘acedfa’, and ‘acgfa’.

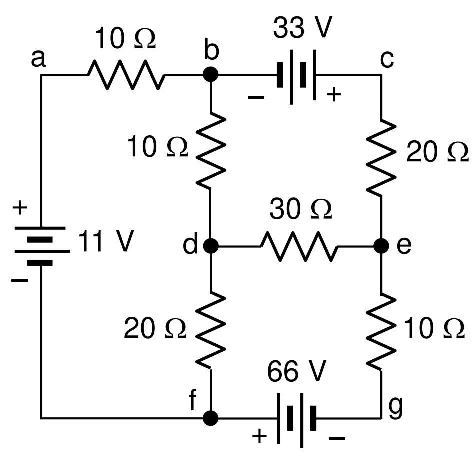


Figure 2.17A

PE2.14 $i_1 + i_2 + i_3 + i_4 = 0$ (Figure 2.18A); substituting given values: $1.5 - 2 + 1.25 + i_4 = 0$, or, $0.75 + i_4 = 0$, or, $i_4 = -0.75$ A.

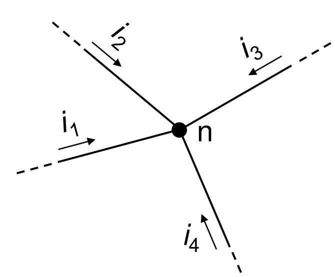


Figure 2.18A

PE2.15 In Figure P2.1A,

Node 'a': current entering = 1.5 A; current leaving = 0.5 + 1 = 1.5 A.

Node 'b': current entering = 1 + 2 = 3 A; current leaving = 3 A.

Node 'c': current entering = 2 A; current leaving = 1.5 + 1 = 2 A.

Node 'n': current entering 0.5 + 1.5 = 2 A; Current leaving = 2 A.

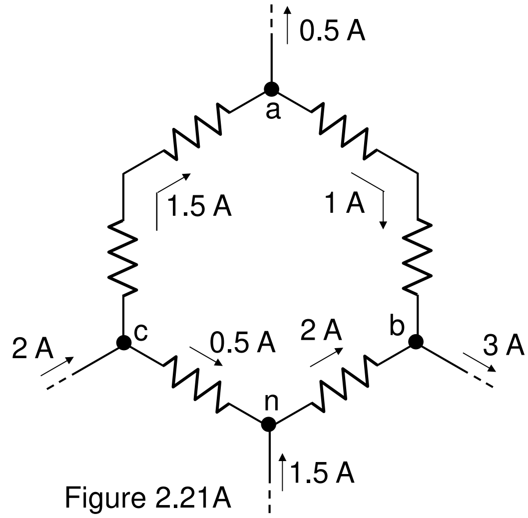


Figure 2.21A

PE2.16 The mesh with the voltages doubled is as shown in Figure P2.21B.

(a) Starting at node 'n' and going clockwise,

$$+8 - 5 - 6 - 1 - 3 + 7 = 0$$

KVL is satisfied.

(b) Starting at node 'n' and going counterclockwise,

$$-7 + 3 + 1 + 6 + 5 - 8 = 0$$

KVL is satisfied.

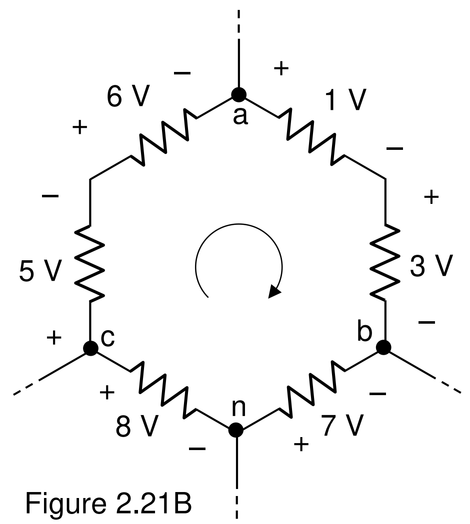


Figure 2.21B

PE2.17 (a) From KCL at the upper node, right-hand node in Figure 2.23 $I + 1 = 0$, or $I = -1$ A.

(b) From KVL around the mesh, starting from the bottom node and going clockwise, $12 - 2 + V_S = 0$, or $V_S = -10$ V.

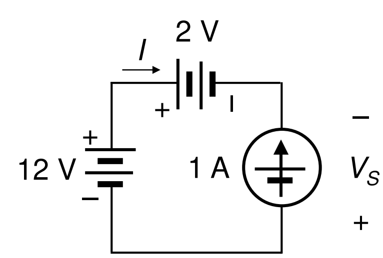


Figure 2.23

(c) Power delivered by 12 V source is $12I = -12$ W, so that this source absorbs 12 W; power absorbed by 2 V source is $2I = -2$ W, so that this source delivers 2 W; power absorbed by current source is $V_S \times 1 = -10$ W, so that this source delivers 10 W.

PE2.18 In Figure 2.17A,

(a) Number of independent KCL equations = Number of essential nodes – 1 = 4 – 1 = 3.

(b) Number of independent KVL equations = Number of meshes = 3.

(c) Number of essential branches = 6 = 3 + (4 – 1).

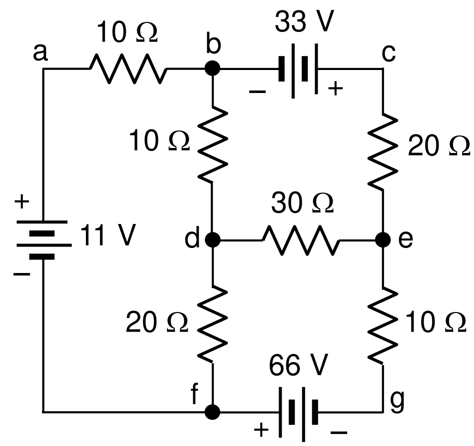


Figure 2.17A

PE2.19 In Figure 2.42, three wires are connected in parallel between common nodes. The three sets of three wires each are connected in series, since they carry the same total current (Figure 2.43).

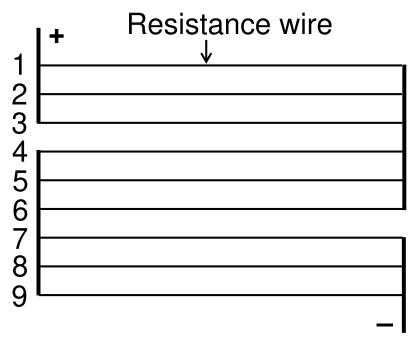


Figure 2.42

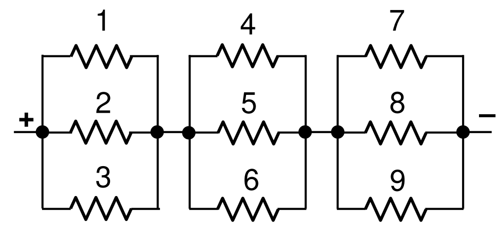


Figure 2.43

PE2.20 From KVL in Figure 2.44, $2.5 = 3I + V_X = 5I$; $I = 0.5$ A, and $V_X = 2I = 1$V.

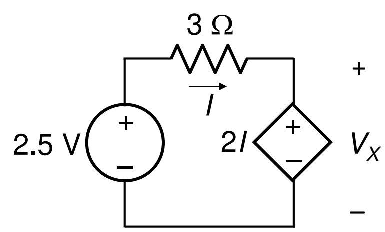


Figure 2.44

PE2.21 The current through 'A' in Figure 2.45A is (3 – 2) = 1 A; $V_A = 4/1 = 4$ V; the power absorbed by the 2 A source is $P_{2abs} = 4 \times 2 = 8$ W.

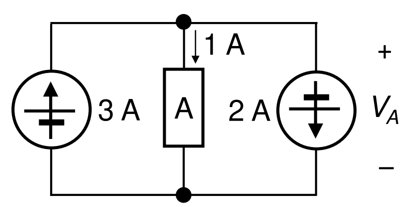


Figure 2.45A

PE2.22 Power dissipated in 6 Ω resistor in Figure 2.46A = $6(0.5)^2 = 1.5$ W. Current in 3 Ω resistor = 0.5 + 1.5 = 2 A. Power dissipated in 3 Ω resistor = $3(2)^2 = 12$ W. Total power dissipated = 13.5 W. Power delivered by 9 V source = $9 \times 0.5 = 4.5$ W. Voltage across current source = $3 \times 2 = 6$ V.

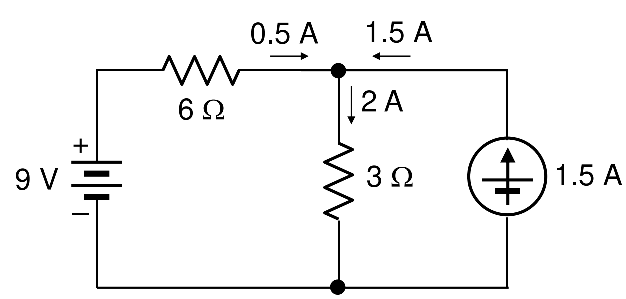


Figure 2.46A

Power delivered by 1.5 A source is 6×1.5 = 9 W. Total power delivered is 13.5 W.

PE2.23 Power dissipated in 10 Ω resistor in Figure 2.48A = $10(7)^2$ = 490 W. Current in 4 Ω resistor = 7 – 2 = 5 A. Power dissipated in 4 Ω resistor = $4(5)^2$ = 100 W. Power absorbed by 2 A source = 30×2 = 60 W. Power absorbed by 10 V source = 10×5 = 50 W. Total power absorbed = 490 + 100 + 60 + 50 = 700 W. Power delivered by dependent source = 100×7 = 700 W.

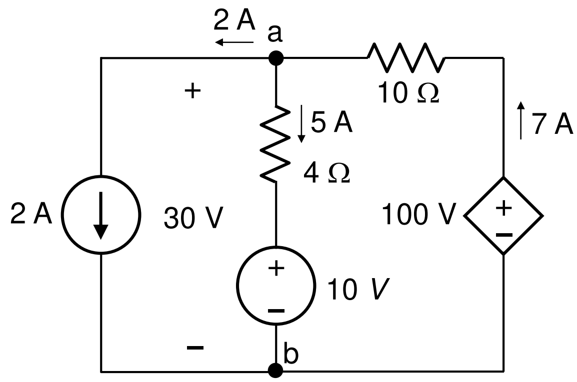


Figure 2.48A

P2.1 $P = \dfrac{V^2}{R}$, $V^2 = R \times P = 1.5 \times 10^6 \times 0.5 = 0.75 \times 10^6 = 75 \times 10^4$, $V = 500\sqrt{3}$ = 866.0 V.

P2.2 (a) At 120 V the current of a 60 W lamp is $\dfrac{60}{120} = 0.5$ A.

(b) Four lamps in parallel (Figure P2.2) draw 0.5×4 = 2 A from the supply, which is the current through *R*.

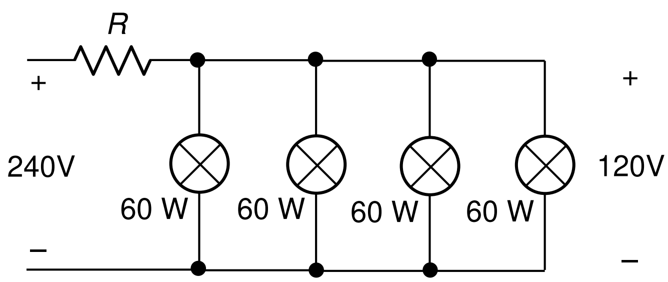


Figure P2.2

(c) The voltage across *R* is 120 V; $R = \dfrac{120}{2} = 60\ \Omega$.

(d) The power rating of the resistor is $60(2)^2$ = 240 W, the same as the total power rating of the lamps, since the voltage and current are the same.

P2.3 (a) $\dfrac{60\sin 100\pi t}{4\sin 100\pi t} = 15\ \Omega$.

(b) $p(t) = v(t)i(t) = 240\sin^2 100\pi t = 120(1 - \cos 200\pi t)$ W.

(c) $P = \dfrac{120}{\pi}\int_0^{\pi}(1-\cos 2\omega t)d(\omega t) = \dfrac{120}{2\pi}\left[(\omega t) - \dfrac{1}{2}\sin 2(\omega t)\right]_0^{\pi}$ = 120 W.

(d) No. The average of the voltage and the current is zero, because they are alternately positive and negative in successive half cycles. But negative voltage multiplied by negative current gives a positive value of power, so that the power does not average to zero.

P2.4 $v\ (\text{V}) = \begin{cases} t/12 \\ 5 \\ 0 \end{cases}$ (Figure P2.4)

$0 \le t \le 60$ s

$60 \le t < 180$ s

$t > 180$ s

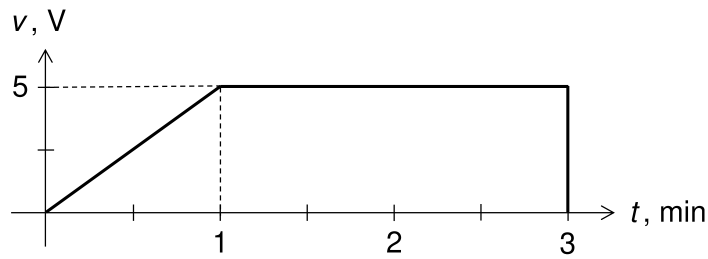


Figure P2.4

(a) $i = v/R$; $i = t/60$ A, $0 \le t \le 60$ s; $i = 1$ A, $60 \le t < 180$ s; $i = 0$, $t > 80$ s.

(b) $0 \le t \le 60$ s; $p(t) = \dfrac{v^2}{R} = \dfrac{1}{5}\left(\dfrac{t}{12}\right)^2 = \dfrac{t^2}{720}$ W, where t is in s.

(c) $w = \int_0^{180} p dt = \int_0^{60} \dfrac{t^2}{720} dt + \int_{60}^{180} \dfrac{25}{5} dt = 700$ J.

P2.5 $v(t) = 10\cos 100\pi t = 10\cos\omega t$, where $\omega = 100\pi$ rad/s, so that the supply frequency is $\dfrac{100\pi}{2\pi} = 50$ Hz, and the supply period is $\dfrac{1}{50} \equiv 20$ ms.

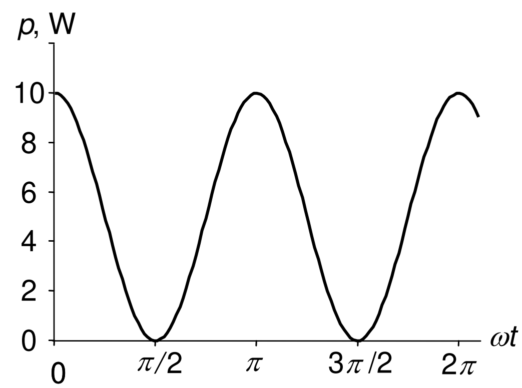


Figure P2.5A

(a) $p = \dfrac{v^2}{R} = \dfrac{(10\cos 100\pi t)^2}{10}$

$= 10\cos^2 100\pi t = 5(1 + \cos 2\omega t)$ W, as shown in Figure P2.5A

(b) $P = \dfrac{5}{\pi}\int_0^{\pi}(1+\cos 2\omega t)d(\omega t) = \dfrac{5}{\pi}\times\pi = 5$ W.

$$w = \int_0^{0.01} p dt = \int_0^{0.01} 10\cos^2 100\pi t dt = 5\int_0^{0.01}(1+\cos 200\pi t)dt = 5\left[t + \frac{\sin 200\pi t}{200\pi}\right]_0^{0.01} = 0.05 \text{ J.}$$

Since the average power dissipated is 5 W, the energy dissipated during one half cycle is 5(W)×0.01(s) = 0.05 J. Note that the average power, that is, average energy per unit time, is independent of the time scale, but the energy is the integral of instantaneous power with respect to time.

P2.6 In Figure P2.6, $v = 10t$ V, $0 \le t \le 1$ min;
$v = -10t + 20$ V, $1 \le t \le 3$ min;
$v = 10t - 40$ V, $3 \le t \le 4$ min.

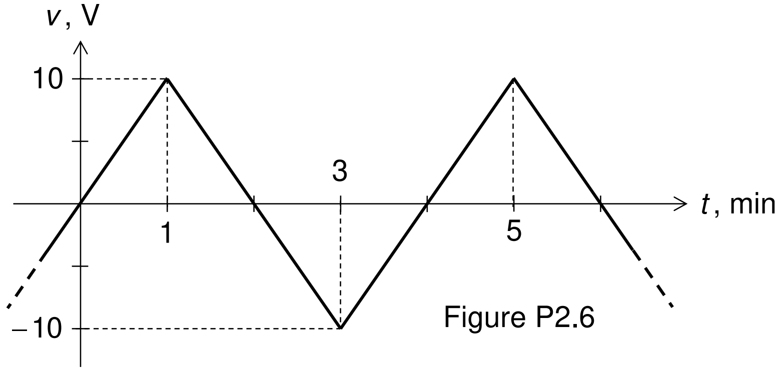


Figure P2.6

(a) $i = \dfrac{v}{100} = 0.1t$ A, $0 \le t \le 1$ min;
$i = -0.1t + 0.2$ A, $1 \le t \le 3$ min;
$i = 0.1t - 0.4$ A, $3 \le t \le 4$ min.

(b) $p(t) = \dfrac{v^2}{R} = t^2$ W, $0 \le t \le 1$ min, $p(t) = \dfrac{(-10t+20)^2}{100}$ W, $1 \le t \le 3$ min,

$p(t) = \dfrac{(10t-40)^2}{100}$ W, $3 \le t \le 4$ min.

(c) $P = \dfrac{1}{T}\int_0^T p\,dt = \dfrac{1}{4}\left[\int_0^1 t^2 dt + \int_1^3 \left(t^2 - 4t + 4\right)dt + \int_3^4 \left(t^2 - 8t + 16\right)dt\right]$

$= \dfrac{1}{4}\left\{\left[\dfrac{t^3}{3}\right]_0^1 + \left[\dfrac{t^3}{3} - 2t^2 + 4t\right]_1^3 + \left[\dfrac{t^3}{3} - 4t^2 + 16t\right]_3^4\right\} = \dfrac{1}{3}$ W. Note that it is simpler to work with t in minutes and not convert to seconds.

P2.7 $R_2 = R_1\left[1 + \alpha_m\left(T_2 - T_1\right)\right]$; $70 = 60\left[1 + 0.0039\left(T_2 - 20\right)\right]$; $T_2 = 62.7°$ C.

P2.8 $i = 10^{-9}\left(e^{20v} - 1\right)$ A.

(a) $v = 0.7\text{ V} \Rightarrow i = 10^{-9}\left(e^{20\times0.7} - 1\right) \cong 10^{-9} \times e^{20\times0.7} \equiv 1.20$ mA.

(b) $v = -0.7\text{ V} \Rightarrow i = 10^{-9}\left(e^{20\times(-0.7)} - 1\right) \cong -10^{-9} \equiv -1$ nA.

P2.9 The instantaneous power delivered by i_{SRC} in Figure P2.9 is $1\times i_{SRC}$. The average power delivered is:

$P = \dfrac{1}{T}\int_0^T (2 + 2\cos 100\pi t)dt = \dfrac{1}{T}\left[2t + \dfrac{2}{100\pi}\sin 100\pi t\right]_0^T =$

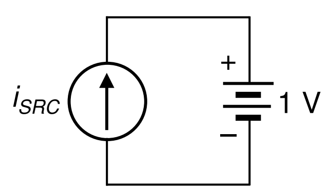


Figure P2.9

$\frac{1}{T}\left[2T + \frac{2}{100\pi}\sin 2\pi - 0\right] = 2$ W. Note that one can work with T, which is $2\pi/100\pi$ = 1/50 s, without having to substitute its numerical value.

P2.10 From KCL at the upper node in Figure P2.10A: 10 = I_x + 5, so I_x = 5 A. From KVL around the outer loop, starting at the lower node and going CW: 40 – V_y – 25 = 0, so V_y = 15 V. The voltage across the 5A current source is 40 V, and the current through the 25 V voltage source is 10 A.

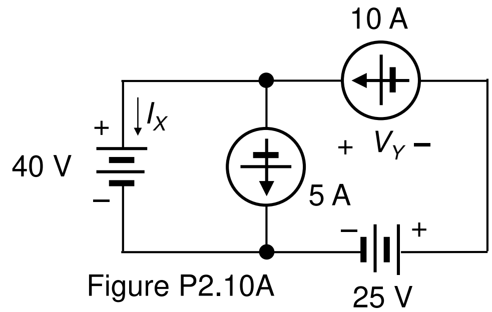


Figure P2.10A

P2.11 I_{SRC} = 5 A in Figure P2.11; from KVL, starting at the lower node and going CW: 50 – 2I_{SRC} – V_X = 0. Substituting for I_{SRC}, V_X = 40 V; power delivered by 50 V source is 50×5 = 250 W; power absorbed by dependent source is 2I_{SRC}×I_{SRC} = 50 W; power absorbed by 5 A source is 40×5 = 200 W. Total power delivered =250 W = total power absorbed.

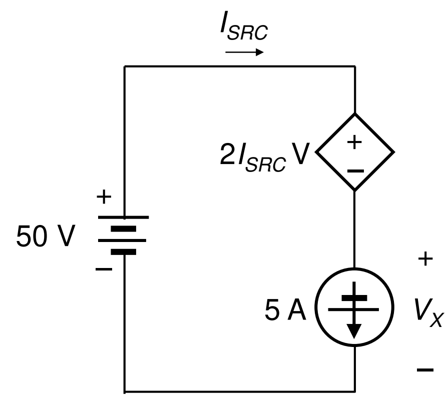


Figure P2.11

P2.12 From KVL in Figure P2.12, V_Y = 20 + (-10) = 10 V. The current of the dependent source is therefore 0.5×10 = 5 A. From KCL 10 = 5 + I_X, so that I_X = 5 A. The 10 A source delivers 100 W. The dependent source absorbs 50 W. The 10 a source absorbs 5(-10) = -50 W, so it actually delivers 50 W. The 20 V source absorbs 5×20 = 100 W. The total power delivered is 100 + 50 = 150 W, and the total power absorbed is 50 + 100 = 150 W.

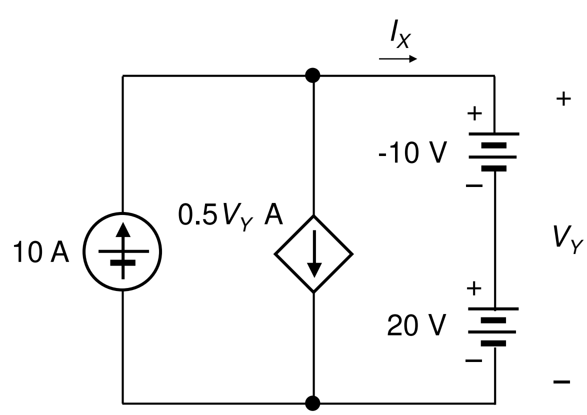


Figure P2.12

P2.13 From Figure P2.13A, $I_\Delta = -5$ A. From KCL at the upper node: $I_X = 10 + I_\Delta = 5$ A; $V_X = -10I_\Delta = 50$ V; from KVL around the outer loop: $V_\Delta + 5 - V_X = 0$, so $V_\Delta = 45$ V. From KVL around the mesh on the RHS: $-10 + V_Y - V_X = 0$, $V_Y = 60$ V. The 5 V source absorbs 25 W; the 5 A source absorbs $5\times45 = 225$ W; the 10 A source delivers 600 W; the 10 V source absorbs 100 W; the dependent source absorbs 250 W. Total power delivered = 600 W = total power absorbed.

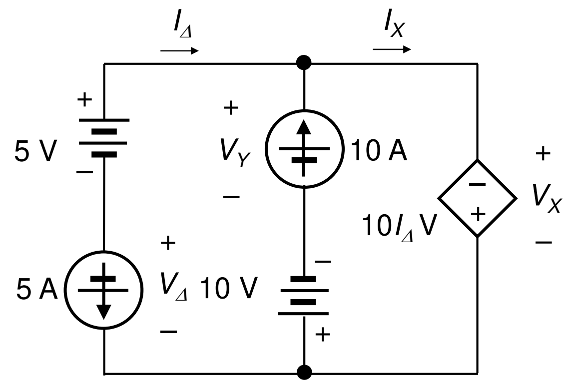


Figure P2.13A

P2.14 $V_{ab} = 20$ V in Figure P2.14A, $I_X = 0.8V_{ab} = 16$ A. From KCL at node 'a', net current flowing away from this node is $16 - 10 = 6$ A. Hence, 6A must flow into node 'a' from the 20 V source.

Voltage drop across the CCVS = $0.5I_x = 8$ V; let the voltage drop across the VCCS be V_X. From KVL the voltage drop V_{ab} is the same whether going through the 20 V source or the two dependent sources. Hence $20 = V_X + 8$, which gives $V_X = 12$ V.

The 20 V source delivers $20\times6 = 120$ W; the 10 A source delivers $20\times10 = 200$ W; VCCS absorbs $12\times16 = 192$ W; and CCVS absorbs $8\times16 = 128$ W. Total power delivered = 320 W = total power absorbed.

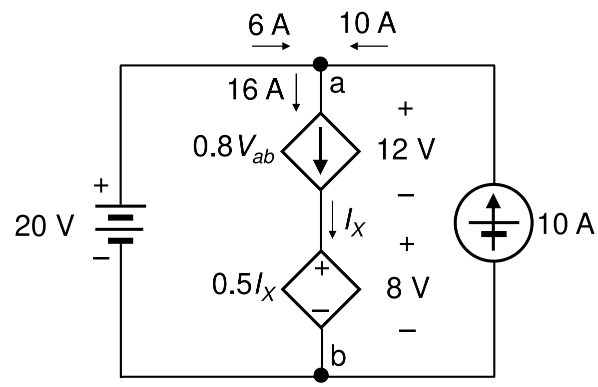


Figure P2.14A

P2.15 The current leaving node 'a' through V_1 in Figure P2.15A is $I_2 + I_3 = 1 + 1 = 2$ A. The source V_1 absorbs $1\times2 = 2$ W.

The current leaving node 'b' through V_2 is $I_1 - I_3 = 2 - 1 = 1$ A. The source V_2 delivers $1\times1 = 1$ W.

The current entering node 'c' through V_3 is $I_1 + I_2 = 3$ A. V_3 absorbs $1\times3 = 3$ W.

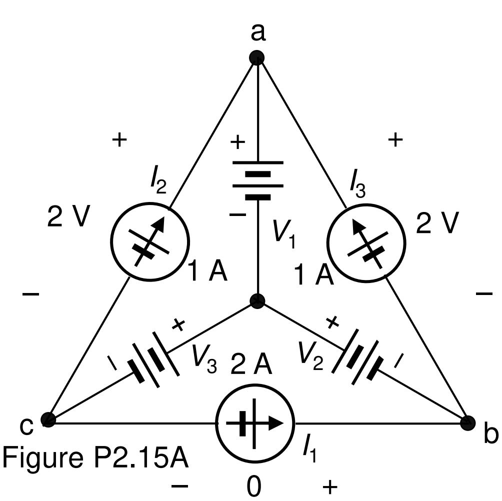


Figure P2.15A

From KVL, V_{ab} = 2 V, V_{ac} = 2 V, and V_{bc} = 0. The source I_1 neither absorbs nor delivers power; the source I_2 delivers 2 W; the source I_3 delivers 2 W.

Total power delivered = 5 W = total power absorbed.

P2.16 From KCL at node ‘d’ in Figure P2.16A : 10 = 5 + I_Δ, so I_Δ = 5 A. From KCL at node ‘b’: I_Y = 10 + 3 = 13 A. From KCL at node ‘a’: 3 + 5 = 8 A = I_X. As a check, KCL at node ‘c’ is: 13 = 8 + 5 A.

From KVL around the outer loop: $-V_{cd}$ + 10 = 0, so that V_{cd} = 10 V. From KVL around the mesh on the RHS: 10 – V_{ba} = 0, so that V_{ba} = 10 V. From KVL around the mesh ‘abda’: $-V_{ba}$ – 10 + V_{bd} = 0, so that V_{bd} = 20 V. As a check, KVL around the mesh ‘bcdb’ gives: -10 – V_{cd} + V_{bd} = -10 – 10 + 20 = 0. Upper 10 V source delivers 50 W; lower 10 V source delivers 130 W; 5 A source delivers 50 W; 10 A source absorbs 200 W; 3 A source absorbs 30 W. Total power delivered = 230 W = total power absorbed.

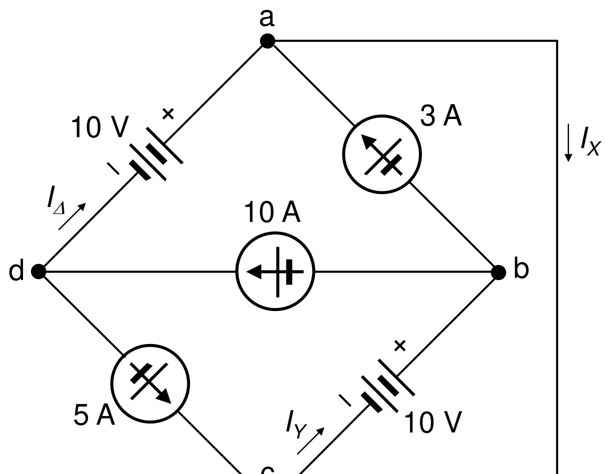


Figure P2.16A

P2.17 The resistance seen by the source in Figure P2.17 is 5||5 = 2.5 Ω; V_O = 2.5×0.2 = 0.5 V. The grounding does not affect V_O.

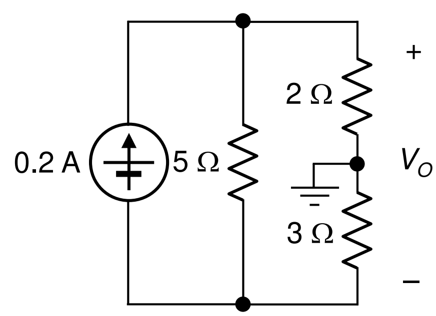


Figure P2.17

P2.18 When I_S = 0 in Figure P2.18, I_{SRC} flows through the 6 kΩ resistor, producing a voltage of 6I_{SRC} across this resistor. To have I_S = 0, this voltage must equal 3 V, which gives: I_{SRC} = 3/6 = 0.5 mA.

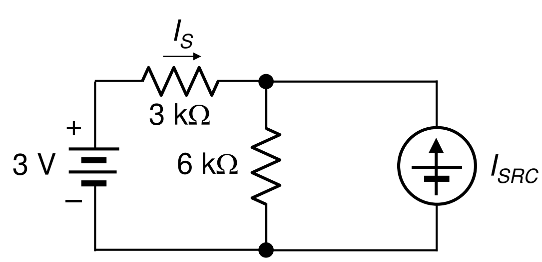


Figure P2.18

P2.19 The voltage across the 10 Ω resistor in Figure P2.19A is 20 V, as set by the voltage source. The current through this resistor is therefore 2 A. From KCL at the upper node, the current through the voltage source is 3 A downwards. Since the 5 A current of the current source is in the direction of a 20 V voltage rise across the source, this source delivers 20×5 = 100 W. The 3 A current of the voltage source is in the direction of a 20 V voltage drop across the source. This source absorbs 20×3 = 60 W. As a check, the resistor absorbs 20×2 = 40 W, so that the power delivered = 100 W = the total power absorbed.

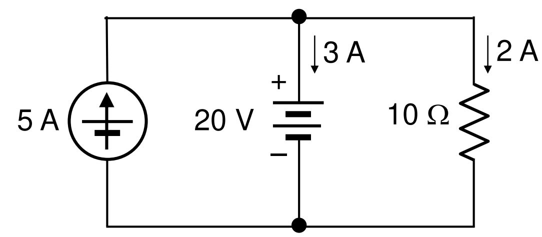


Figure P2.19A

P2.20 The current in the mesh in Figure P2.20A is the 6 A of the current source. The voltage drop across the resistor is 30 V. From KVL, starting at the lower node and going clockwise: $-V_S + 50 - 30 = 0$, which gives $V_S = 20$ V. Since the 6A current of the current source is in the direction of a 20 V voltage drop across the source, this source absorbs 20×6 = 120 W. The 6 A current of the voltage source is in the direction of a 50 V voltage rise across the source. This source delivers 50×6 = 300 W. As a check, the resistor absorbs 30×6 = 180 W, so that the power delivered = 300 W = the total power absorbed.

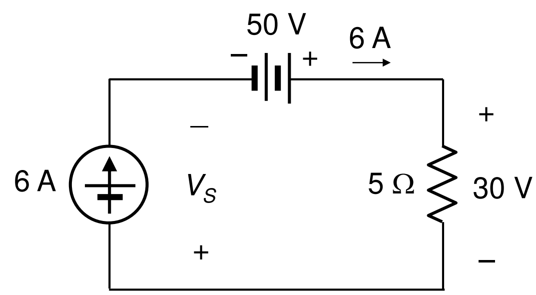


Figure P2.20A

P2.21 From Ohm's law, the current in the 1 Ω resistor in series with the 6 V source in Figure P2.21A is 6 A. From Ohm's law, the current in the 1 Ω resistor in series with the dependent source is $0.9I_X$ A. From KCL, $I_X = 6 + 0.9I_X$, which gives $I_X = 6/0.1 = 60$ A.

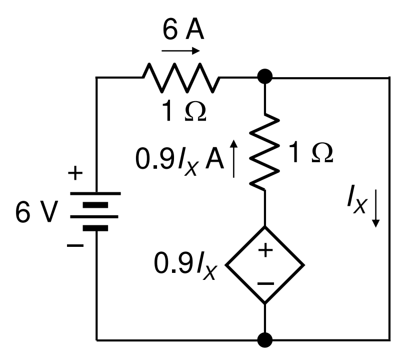


Figure P2.21A

P2.22 The 6 V source in Figure P2.22A appears across the two 2 Ω resistors in series. The current in these resistors is therefore 6/4 = 1.5 A in the direction shown. As a two-essential node circuit, KCL at node 'b' gives, $\frac{12+6}{6}+1.5=I_X$, or, I_X = 3 + 1.5 = 4.5 A.

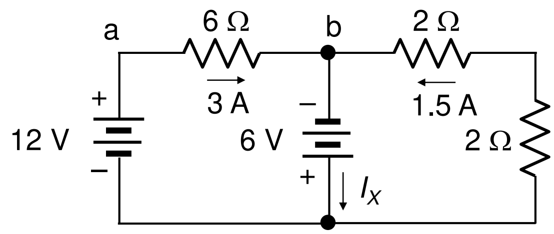


Figure P2.22A

P2.23 **Initialize.** The circuit is already marked with the given values and the required V_X. The nodes may be labelled 'a' and 'b' as in Figure P2.2.3A.

Simplify. The circuit is in a simple enough form.

Deduce. From KCL: 7 A enter node 'a' from R_2. From Ohm's law: voltage drop across the 3 Ω resistor is 45 V in the direction of 15 A; voltage drop across the 2 Ω resistor is 12 V in the direction of 6 A. From KVL around the outer loop, starting at node 'b' and going CW: -12 + 37 + V_X – 45 = 0, which gives V_X = 20 V. Note that this 20 V is a voltage rise across R_2 in the direction of 7A. This means that R_2 = -20/7 Ω and does not obey Ohm's law because it is a negative resistance.

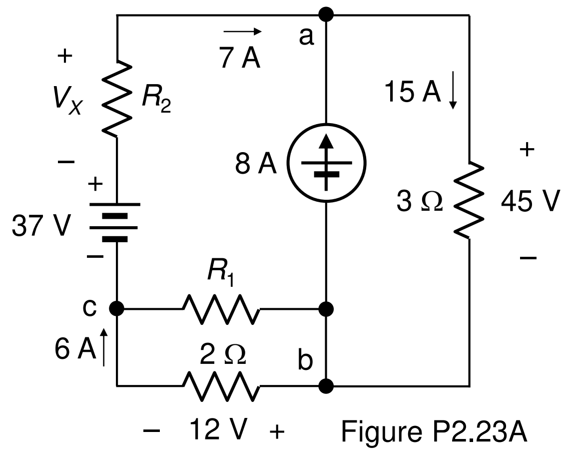


Figure P2.23A

P2.24 From current division in figure P2.24A,

$I\times\frac{25}{25+75}=1$, which gives: I = 4 A.

From KVL around the outer loop, 100 = R×4 + 75×1, or R = 25/4 = 6.25 Ω.

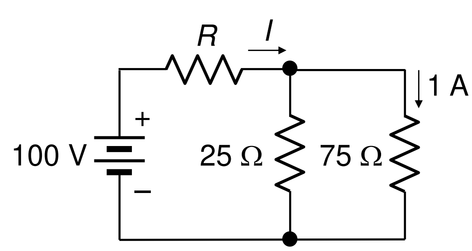


Figure P2.24A

P2.25 Since the voltage source in Figure P2.25A does not deliver or absorb power, $I = 0$. The voltage across R is 6 V, and the current through R and the 3 Ω resistor is 1 A. It follows that there is a voltage rise of 9 V across the current source in the direction of current. The source therefore delivers 9 W.

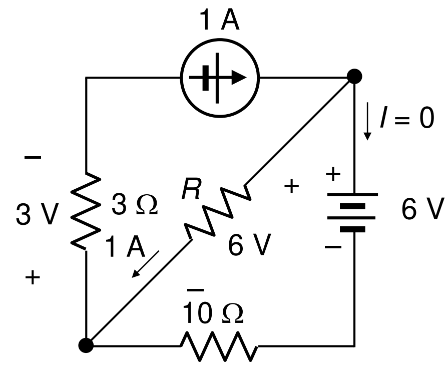


Figure P2.25A

P2.26 Since the current source in Figure P2.26A does not deliver or absorb power, the voltage across it is zero. The voltage across R is 3 V, the same as across the 3 Ω resistor, and the voltage across the 10 Ω resistor is 9 V. The current through the voltage source is 0.9 A in the direction of a voltage rise through the source. This source therefore delivers 0.9×6 = 5.4 W.

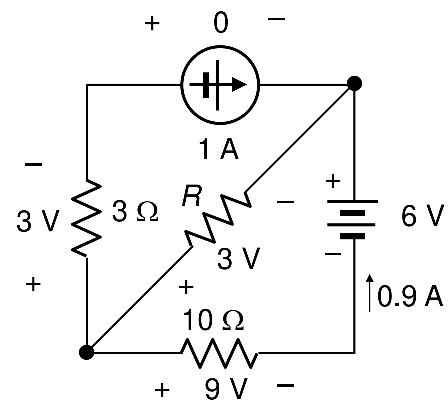


Figure P2.26A

P2.27 The voltage across the 20 Ω resistor in Figure P2.27A is V_{SRC} = 100 V, so the current through it is 5 A. The current of the dependent source is $0.2V_{SRC}$ = 20 A. From KCL at the upper node, the current flowing into the voltage source is 20 – 5 = 15 A. The voltage drop across the 2 Ω source is 40 V. From KVL, the voltage across the dependent source is 100 + 40 = 140 V. It follows that this source delivers 140×20 = 2,800 W, and the voltage source absorbs 100×15 = 1,500 W. The power absorbed in the 2 Ω resistor is 40×20 = 800 W, and the power absorbed in the 20 Ω resistor is 100×5 = 500 W. Total power delivered = 2,800 W = total power absorbed.

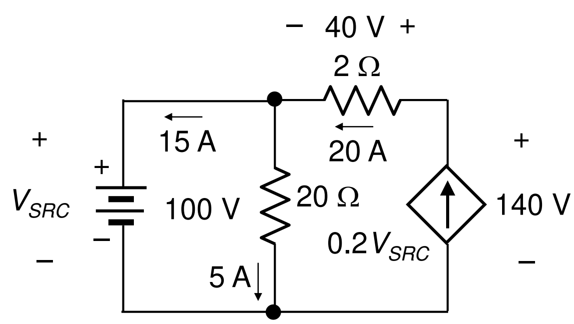


Figure P2.27A

P2.28 The voltage of the dependent source in Figure P2.28A is $0.6\times100 = 60$ V. The current in the 1.5 Ω resistor is $60/1.5 = 40$ A. From KCL, the current in the dependent source is $100 - 40 = 60$ A. The voltage across the 0.2 Ω resistor is $0.2\times100 = 20$ V. From KVL, the voltage across the current source is $60 + 20 = 80$ V. It follows that the current source delivers 8,000 W, and the voltage source absorbs $60\times60 = 3{,}600$ W. The 0.2 Ω resistor absorbs $20\times100 = 2{,}000$ W, and the 1.5 Ω resistor absorbs $60\times40 = 2{,}400$ W. Total power delivered = 8000 W = total power absorbed.

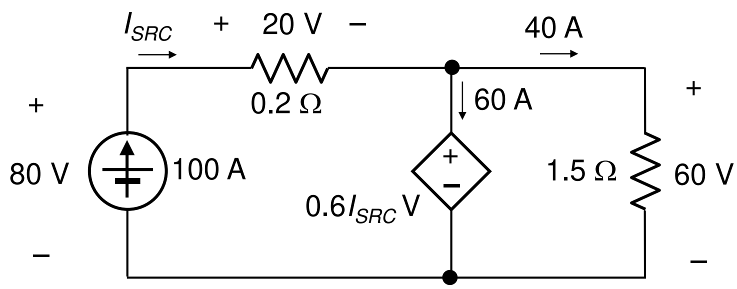


Figure P2.28A

P2.29 As a two-essential-node circuit, with $V_O = 2I_X$, KCL in Figure P2.29 gives: $\dfrac{3I_X - 2I_X}{3} + 0.5 = I_X$, so that $I_X + 1.5 = 3I_X$, or, $I_X = 1.5/2 = 0.75$ mA. Hence, $V_O = 1.5$ V.

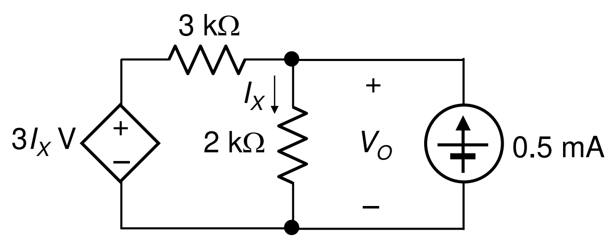


Figure P2.29

P2.30 The current of the dependent source in Figure P2.30A is $0.4\times20 = 8$ A. From KCL, the current through the 2.5 Ω resistor is 12 A, so that the voltage across it and the dependent source is 30 V. The current in the 1 Ω resistor is I_{SRC} = 20 A, so that the voltage across it is 20 V. From KVL, the voltage across the independent source is 50 V. It follows that the independent source delivers 1,000 W, and the dependent source absorbs 240 W. The 2.5 Ω resistor absorbs 360 W, and the 1 Ω resistor absorbs 400 W. Total power delivered = 1,000 W = total power absorbed.

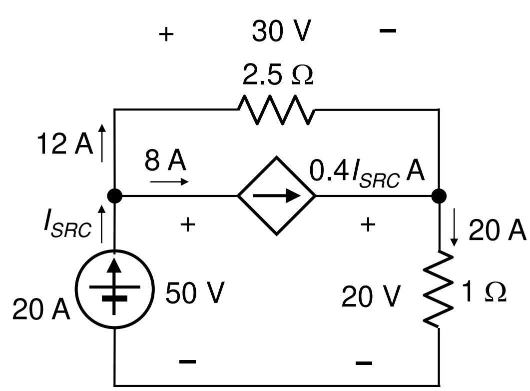


Figure P2.30A

P2.31 The voltage of the dependent source in Figure P2.31A is 0.5×60 = 30 V, so that the voltage across the 7.5 Ω resistor is 30 V, and the current in this branch is 30/7.5 = 4 A. From Ohm's law, the current in the 10 Ω resistor is 6 A. From KCL, the current in the independent source is 10 A. The power delivered by this source is 600 W and that absorbed by the dependent source is source is 30×4 = 120 W. The power absorbed by the 7.5 Ω resistor is 120 W, and the power absorbed by the 10 Ω resistor is 360 W. Total power delivered = 600 W = total power absorbed.

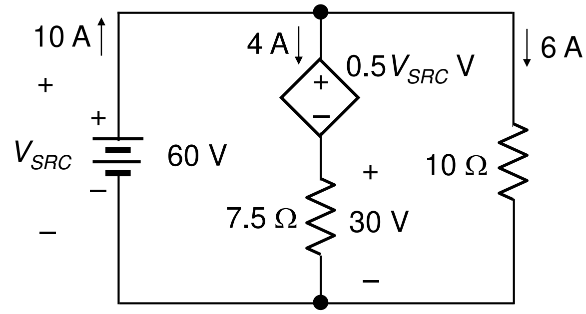


Figure P2.31A

P2.32 From KVL around the RHS mesh in Figure P2.32, $I_Y\times1 + V_X - 2I_Y = 0$, or $V_X = I_Y$ V; from KCL at the upper node, with I_Y replaced by V_X, $3V_X = V_X + 1$, which gives $V_X = 0.5$ V; independent source delivers a power $P = 0.5\times1 = 0.5$ W.

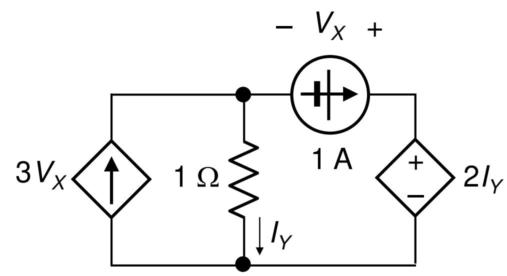


Figure P2.32

P2.33 **Initialize:** All given parameters and variables are entered. The nodes are labelled in Figure P2.33A.

Simplify: The circuit is already in a simple enough form.

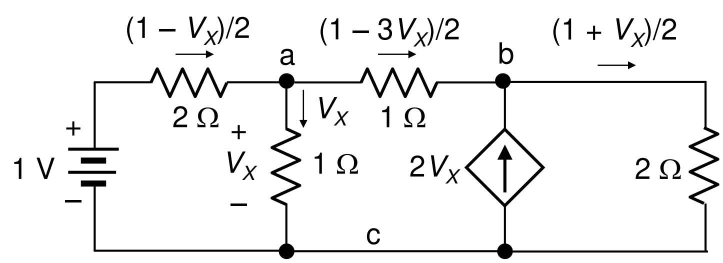


Figure P2.33A

Deduce: From Ohm's law, the current I_{ac} is V_X A; from KVL around the mesh on the LHS, the voltage drop across the 2 Ω resistor is $(1 - V_X)$, and the current flowing from V_{SRC} to node 'a' is $(1 - V_X)/2$. From KCL at node 'a', $I_{ab} = (1 - V_X)/2 - V_X = (1 - 3V_X)/2$. From KCL at node 'b', the current through the 2 Ω resistor on the RHS is $I_{bc} = (1 - 3V_X)/2 + 2V_X = (1 + V_X)/2$. From KVL around the loop 'abca' $V_X - 1\times(1 - 3V_X)/2 -$

$2\times(1 + V_X)/2 = 0$, or $2V_X - 1 + 3V_X - 2 - 2V_X = 0$, which gives $V_X = 1$ V. Hence, $V_{bc} = 2\times(1 + V_X)/2 = 2$ V. The power delivered by the dependent source is $P = 2\times 2 = 4$ W.

P2.34 The current in the 2 kΩ resistor in Figure P2.34A is $0.5V_X$ mA, and the current in the 10 kΩ resistor is V_X mA. From KVL, the voltage drop across the 1 kΩ resistor on the left is $(25 - V_X)$ V, so that

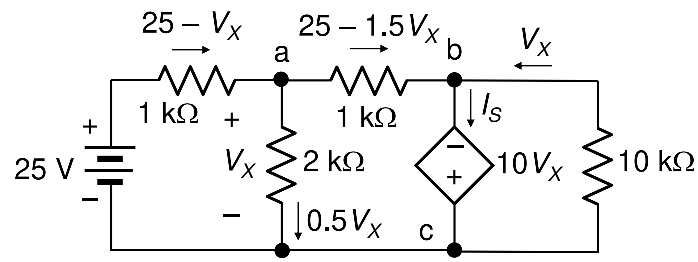


Figure P2.34A

the current through it is $(25 - V_X)$ mA. It follows from KCL at node 'a' that the current in the 1 kΩ resistor in the middle is $(25 - 1.5V_X)$ mA. From KVL around the mesh 'abca', $V_X - (25 - 1.5V_X) + 10V_X = 0$, or $12.5V_X = 25$, or $V_X = 2$ V. From KCL at node 'b', $I_S = (25 - 3) + 2 = 24$ mA.

P2.35 From KVL around the mesh the middle mesh in Figure P2.35A, $12 - 5V_x - V_x = 0$, which gives $V_x = 2$ V. Hence, the current in the 1 Ω resistor is 2 A, downwards. From KCL, $I_X = 2 - 2 = 0$. Hence, the dependent source neither delivers nor absorbs power. As a check,

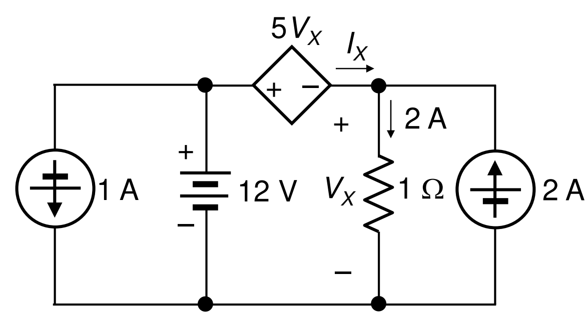


Figure P2.35A

the 1 A source absorbs 12 W, the 12 V source delivers 12 W. The 2 A source delivers 4 W and the 1 Ω resistor absorbs 4 W.

P2.36 Considering the circuit as a two-essential-node circuit, the current entering the upper node from the left in Figure P2.36 is: $I = \dfrac{24 + 3V_1}{2}$. KCL at this node gives: $\dfrac{24 + 3V_1}{2} + \dfrac{V_1}{4} + 3 = 0$, or, $48 + 7V_1 + 12 = 0$, or $V_1 = -60/7$ V. It follows that $V_1 = -4(I + 3)$, or, $I = -V_1/4 - 3 = 15/7 - 3 = -6/7$ A.

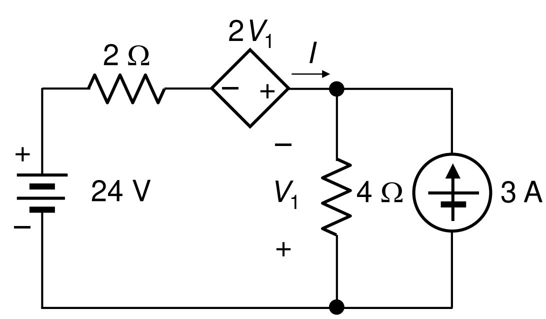


Figure P2.36

P2.37 As a two-essential-node circuit, KCL In Figure P2.37A gives: $5I_X = I_X + (10I_X - 4)/2$, or $8I_X = 10I_X - 4$, or $I_X = 2$ A.

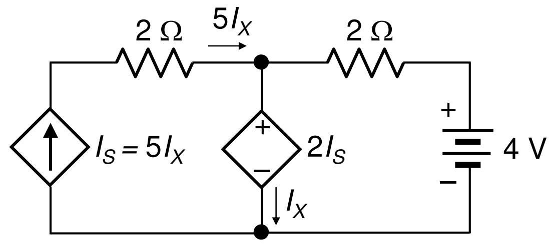


Figure P2.37A

P2.38 The circuit is a two-essential-node circuit. The voltage across the middle branch in Figure P2.38 is $10 + V_A$. KCL at the upper node gives:

$2 + \dfrac{V_A}{4} + \dfrac{10 + V_A - 5V_A}{10} = 0$, or,

$40 + 5V_A + 20 - 8V_A = 0$, or $V_A = 20$ V. $I_X = \dfrac{4V_A - 10}{10} = 7$ A.

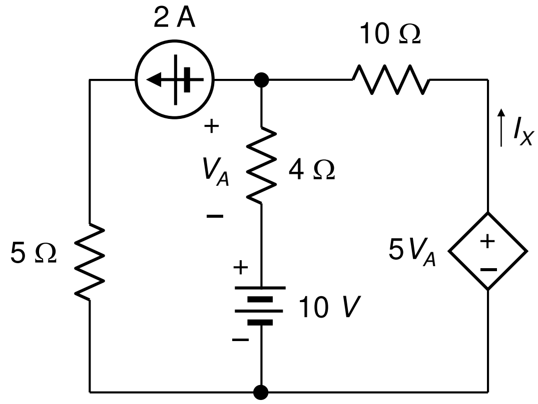


Figure P2.38

P2.39 $50\text{ W} = 2(I_x)^2$, so that $I_X = 5$ A in Figure P2.39A, and the source voltage of the dependent source is $5K$. From KCL at the upper left node, the current through the 4 Ω resistor is 6 – 5 = 1 A. Applying KVL to the loop consisting of the 2 Ω resistor, the 4 Ω resistor, the dependent source, and the 16 V source, $+10 - 4 + 5K - 16 = 0$, which $5K = 10$, and $K = 2$.

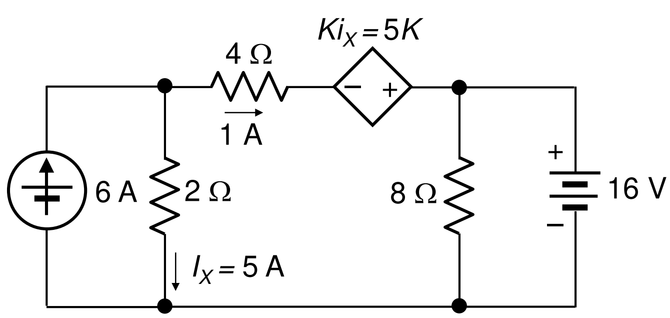


Figure P2.39A

P2.40 The current entering node 'b' in Figure P2.40A is $2(V_X/10) = 0.2V_X$. From KCL, this makes $2V_X = 0.2V_X$, which means that $V_X = 0$. Hence, the current source is zero, and the voltage across the two 10 Ω resistors is zero, From KVL, $V_{ab} - 1 - 0 = 0$, so that $V_{ab} = 1$ V.

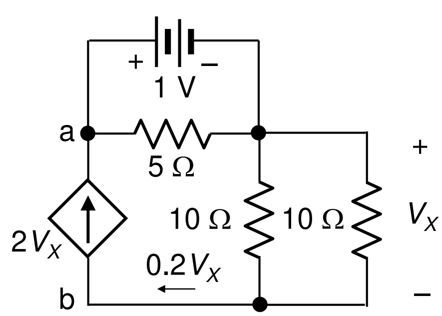


Figure P2.40A

P2.41 **Initialize.** The circuit is marked with given values (Figure P2.41). To determine the power delivered or absorbed by the dependent source, the voltage V_X should be determined.

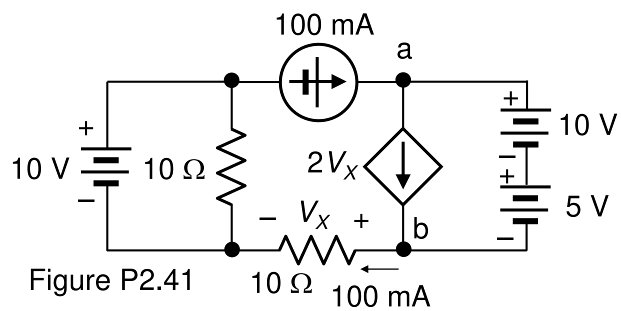


Figure P2.41

Simplify. The circuit is in a simple enough form.

Deduce. From KCL around a surface enclosing the dependent source and the two batteries, the current through the lower 10 Ω resistor is 100 mA in the direction shown. From Ohm's law, $V_X = 10 \times 0.1 = 1$ V. The source current of the dependent source is 2 A. Since the voltage across the source is 15 V, and the 2 A is in the direction of a 15 V drop across the source, the source absorbs $15 \times 2 = 30$ W.

P2.42 From KCL at node 'a' in Figure P2.3.42A, the current in the 4 Ω resistor is $10 - I_X$, and from KCL at node 'b', the current in the 2 Ω resistor is $10 - 3I_X$. Taking KVL around the mesh consisting of the three resistors,

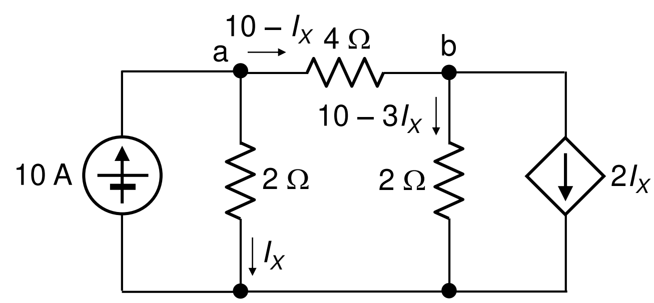


Figure P2.3.42A

$2I_X - 4(10 - I_X) - 2(10 - 3I_X) = 0$, or $12I_x = 60$, $I_X = 5$ A, $10 - I_x = 5$ A, and the power dissipated in the 4 Ω resistor is $4(5)^2 = 100$ W.

P2.43 The 1 A current flows through the 2 Ω resistor away from the lower node in Figure P2.43A. Hence, $V_A = -2$ V. The VCCS is $2V_a = -4$ A. From KCL at the upper node, $1 + (-4) + I_B = 0$, or $I_B = 3$ A. The CCVS is $5I_B =$ 15 V. The 4 A current flows in the direction of a voltage drop through the source. It follows that the dependent voltage source absorbs 60 W.

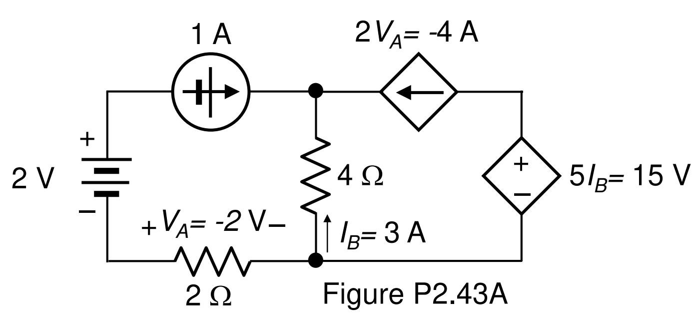


Figure P2.43A

P2.44 The $0.5I_X$ current flows in the 20 Ω Resistor in Figure P2.44A. From KCL at node 'a', the current in the 40 Ω resistor is $1.5I_X$. From KVL around the mesh on the left-hand-side, $30 - 60I_X - 30I_X = 0$, which gives $I_X = 1/3$ A. From KVL around the upper mesh, $-V_Y - 10I_X + 60I_X = 0$, so that $V_Y = 60\ I_X - 10I_X = 50I_X = 50/3$ V.

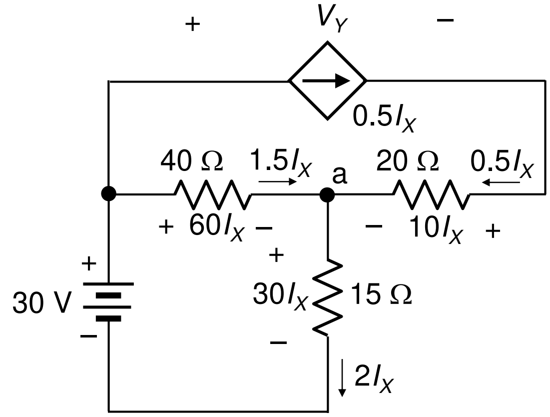


Figure P2.44A

P2.45 **Initialize.** The circuit is marked with given values and the nodes labelled, as in Figure P2.45A. To determine the power delivered or absorbed by the dependent source, the current through the source should be determined.

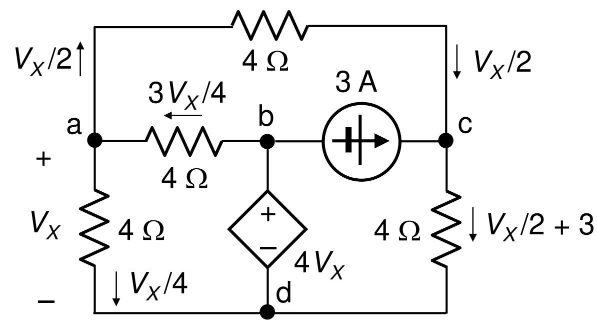


Figure P2.45A

Simplify. The circuit is in a simple enough form.

Deduce. $I_{ad} = V_X/4$; $V_{bd} = 3V_X$; $I_{ba} = 3V_X/4$; $I_{ac} = V_X/2$; $I_{cd} = V_X/2 + 3$. From KVL around the outer loop, $V_X - 2V_X - 2V_X - 12 = 0$, which gives $V_X = -4$ V. Hence, $I_{ab} = -3$ A, so that the current through the dependent source is zero.

P2.46 In going from node 'a' to node 'b' in Figure P2.46A, there is a voltage drop of $5I_X$ and an equal and opposite voltage rise of $5I_X$. Hence, nodes 'a' and 'b' are at the same voltage, and the 10 V appear across the 10 Ω resistor, producing a current of 1 A as shown. From KCL at node 'a', $I_X = 1 + 1 = 2$ A.

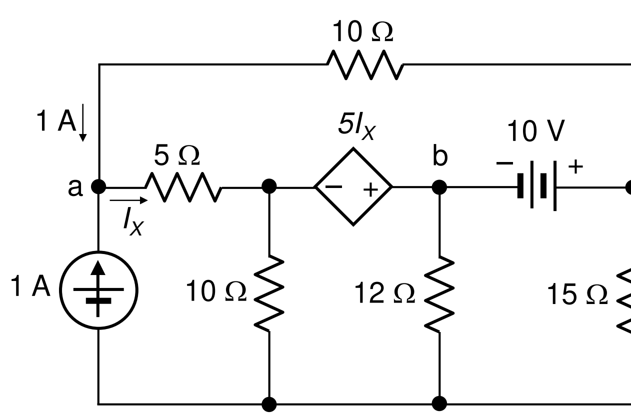


Figure P2.46A

P2.47 **Initialize.** The circuit is marked with given values, as in Figure P2.47A. To determine the power delivered or absorbed by the dependent source, the voltage V_X across the source and the source current should be determined. The nodes may be labeled 'a', 'b', and 'c'.

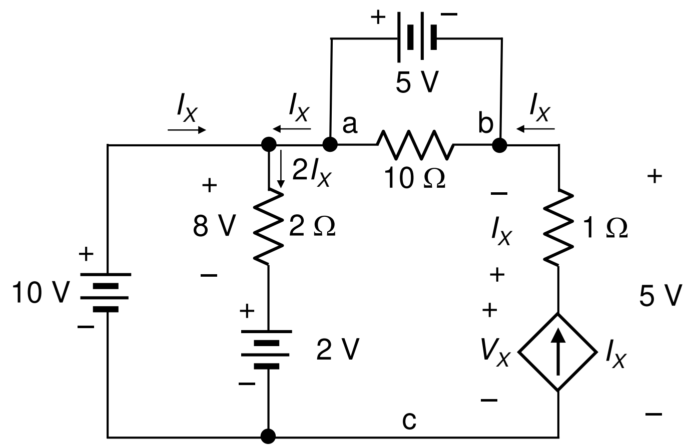


Figure P2.47A

Simplify. The circuit is in a simple enough form.

Deduce. From KVL, $V_{bc} = 10 - 5 = 5$ V and the voltage across the 2 Ω resistor is 8 V. From KCL around a surface enclosing the 5 V source and the 10 Ω resistor, a current I_X leaves node 'a'. From KCL, the current through the 2 Ω resistor is $2I_X$ in the direction of the 8 V drop. It follows from Ohm's law that $2 \times 2I_X = 8$, so that $I_X = 2$ A; $V_{bc} = 5 = V_X - I_X \times 1$. Substituting $I_X = 2$ A gives $V_X = 7$ V. It follows that the dependent source delivers $7 \times 2 = 14$ W.

P2.48 From KVL, the voltage across the 2 Ω resistor on the RHS in Figure P2.48A is 30 V, so that the current through it is 15 A. From KCL the current through the voltage source is 25 A. From KCL at the middle node, the current in the 2 Ω resistor on the LHS is 5 A and the voltage across it is 10 V.

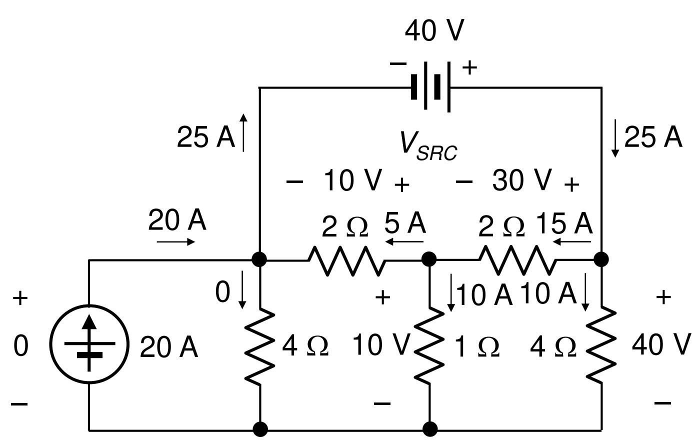


Figure P2.48A

It follows that $V_{SRC} = 40$ V, so that this source delivers $40 \times 25 = 1000$ W. From KCL at the node on the left, the current through the 4 Ω resistor is zero, and the voltage across the current source is zero. Hence, this source neither absorbs nor delivers energy.

P2.49 From KCL in Figure P2.49A, the current I_{bd} = 3 mA, and the current I_{dc} = 1 mA. $V_{bc} = V_{bd} + V_{dc} = 3{\times}1 + 1{\times}1 = 4$ V.

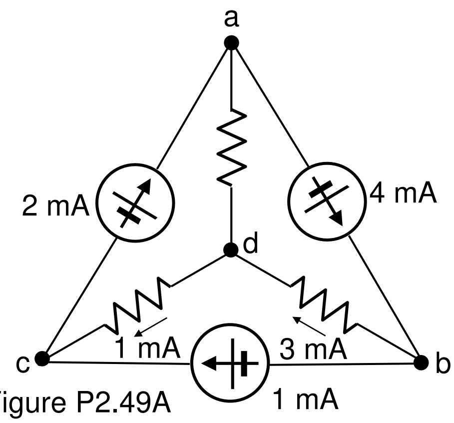


Figure P2.49A

P2.50 **Initialize.** The circuit is marked with given values. The nodes are labeled, as in Figure P2.50A. To determine R, the voltage across it and the current through it should be determined. V_X and V_Y are determined from KVL around a mesh.

Simplify. The circuit is in a simple enough form.

Deduce. From KCL at node 'b', I_{be} = 5 A; from KCL at node 'e', I_{de} = 5 A; from KCL at node 'c', I_{ca} = 15 A; from KCL at node 'a', I_{ad} = 15 A; as a check, KCL is satisfied at node 'd'. From Ohm's law, V_{be} = 30 V, V_{ad} = 15 V, and $V_{de} = 5R$. From KVL in the outer loop, $5R + 15 - 30 = 0$, which gives $R = 3\ \Omega$.

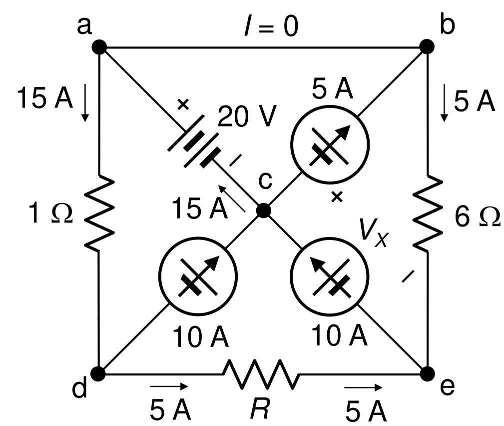


Figure P2.50A

From KVL around the mesh 'abca' in Figure P2.50B, V_{bc} = 20 V; from KVL around the mesh 'cbec', $V_{bc} + V_X - 30 = 0$, or V_X = 10 V. From KVL around the mesh 'acda', $-20 - V_{cd} + 15 = 0$, or $V_y = V_{cd} = -5$ V.

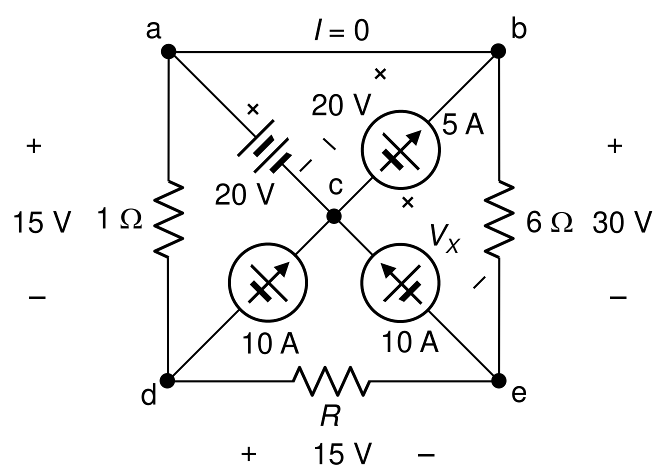


Figure P2.50B

P2.51 **Initialize.** The circuit is marked with given values. The nodes are labeled, as in Figure P2.51A.

Simplify. The circuit is in a simple enough form.

Deduce. $V_{ab} = 2I_O$, so that the current in the 2 Ω resistor is I_O. From KCL at node 'a', $I_{da} = 3I_O$. From KCL at node 'b', $I_{bc} = 0$. From KVL around the mesh 'abcd', $-2I_O + 0 + 5 - 3I_O = 0$, which gives $I_O = 1$ A.

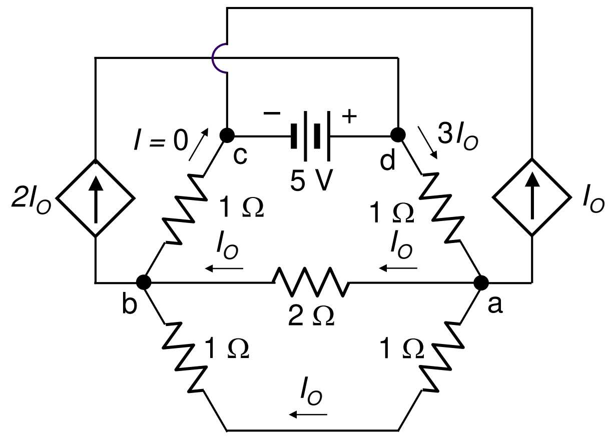


Figure P2.51A

P2.52 **Initialize.** The circuit is marked with given values. The nodes are labeled, as in Figure P2.52A.

Simplify. The circuit is in a simple enough form.

Deduce. $I_Y = 2/2 = 1$ A in Figure P2.52A. The CCVS is therefore 2 V. From KCL at node 'e', the current in the dependent source is $(I_X - 1)$ upwards. From KCL at node 'c', $I_{cd} = (3I_X - 1)$. From KVL around the mesh 'ecde', starting at node 'e' and going CW: $2 - (3I_X - 1)\times 1 - I_X \times 1 = 0$, or, $4I_X = 3$, which gives $I_X = 0.75$ A.

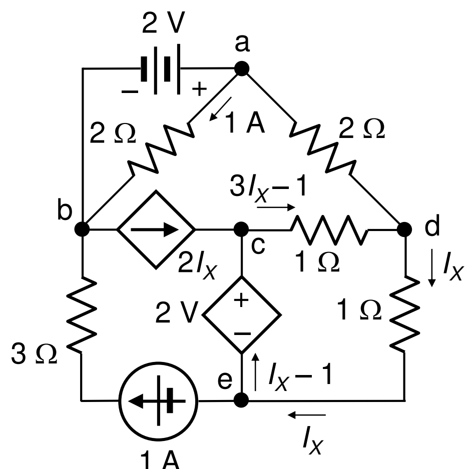


Figure P2.52A

P2.53 From KCL at node 'd' in Figure P2.53A, the current in the 5 Ω resistor is zero. The 15 A source current therefore divides equally between the 20 Ω resistor and the two 10 Ω resistors in series, resulting in $V_{ac} = 75$ V. With $V_{cd} = 0$, it follows that $V_X = V_{ac} = 75$ V.

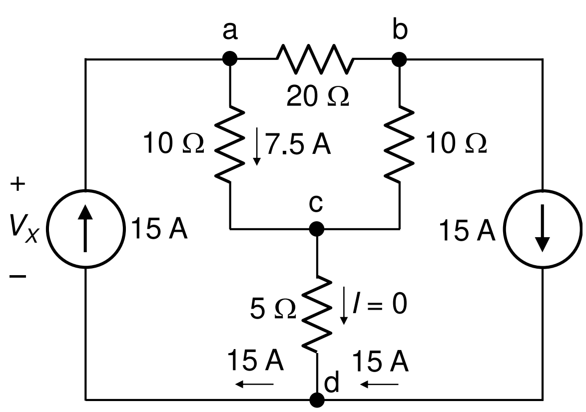


Figure P2.53A

P2.54 **Initialize.** Since $I_1 = I_2$, each of these currents is denoted by I in Figure P2.54A. The voltage sources become ρI and αRI.

Simplify. The circuit is in a simple enough form.

Deduce. Since the currents are equal, and the resistances are equal, the source voltages must be equal: $\rho I = \alpha RI$. This gives: $\rho / \alpha = R$.

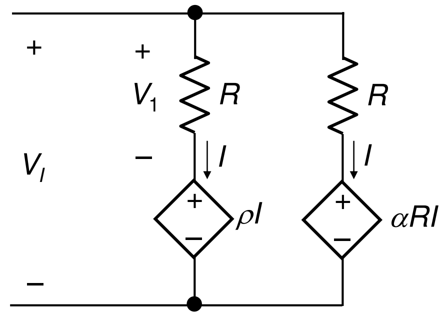


Figure P2.54A

P2.55 From KVL around the loop 'abeda' in Figure P2.55A. $5I_X - 10 + 5 - 20I_X = 0$, or $I_X = -1/3$ A; from KCL at node 'c', $1 + 1 = I_{cb}$; From KVL around the loop 'cdebc', $20 + 5 - 10 + V_X = 0$, or $V_X = -15$ V.

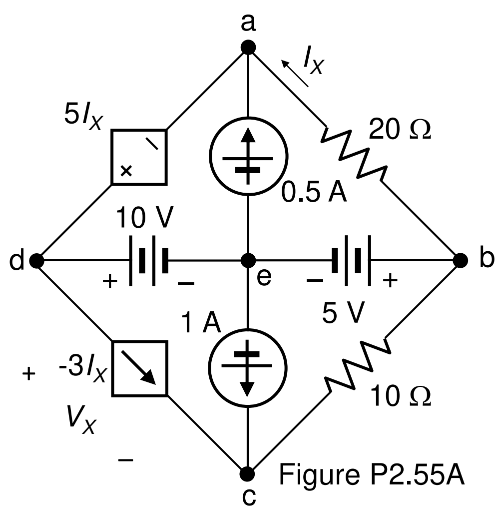


Figure P2.55A

P2.56 **Initialize.** The circuit is marked with given values. The nodes are labeled, as in Figure P2.56A.

Simplify. The circuit is in a simple enough form.

Deduce. From Ohm's law, the current in the lower 20 Ω resistor in Figure P2.56A is $0.05V_X$.

From KCL at node 'e', the current in the 10 Ω resistor is $5 + 0.05V_X$. From KVL around the mesh 'cdec', $50 - 10(5 + 0.05V_X) + V_X = 0$, or, $50 - 50 + 0.5\ V_X = 0$. This gives: $V_X = 0$. From KCL at node a, the current through the upper 20 Ω resistor is $(I_Y - 5)$. From KVL around the loop 'abcd', $50 - 20(I_Y - 5) - 25I_Y - 5I_Y = 0$, or, $150 - 50I_Y = 0$, which gives $I_Y = 3$ A.

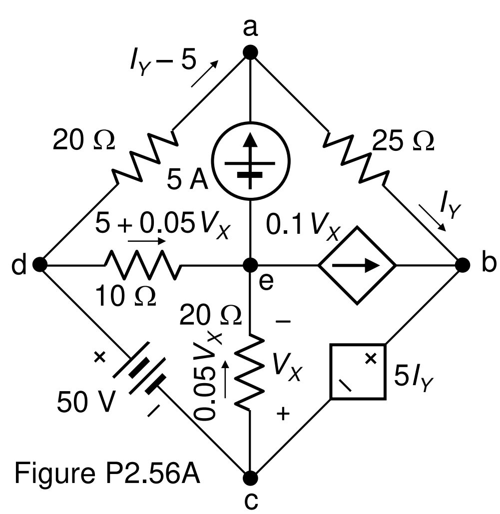


Figure P2.56A

P2.57 **Initialize.** All given parameters are entered. The nodes are labelled, as in Figure P2.57A.

Simplify. The circuit is in a simple enough form.

Deduce. From Ohm's law, the current in the 20 Ω resistor is 5 A, downward.

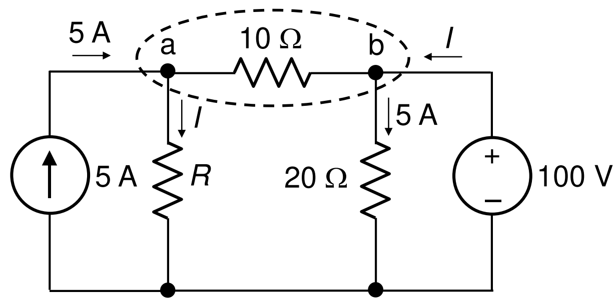


Figure P2.57A

Explore. If the 10 Ω resistor between nodes 'ab' is enclosed by a surface, 5 A enter the surface at node 'a' and leave the surface at node 'b'. It follows that if a current I enters the surface at node 'b', a current I must leave the surface at node 'a'. The power delivered by the 100 V source is $100I$, the power delivered by the 5 A source is $5RI$. Equating these powers gives $R = 100/5 = 20\ \Omega$.

P2.58 **Initialize.** The circuit is marked with the given values, as in Figure P2.58A. The nodes may be labeled 'a', 'b', and 'c'.

Simplify. The circuit is in a simple enough form.

Deduce. To determine the power delivered or absorbed by the 3 V source, the current

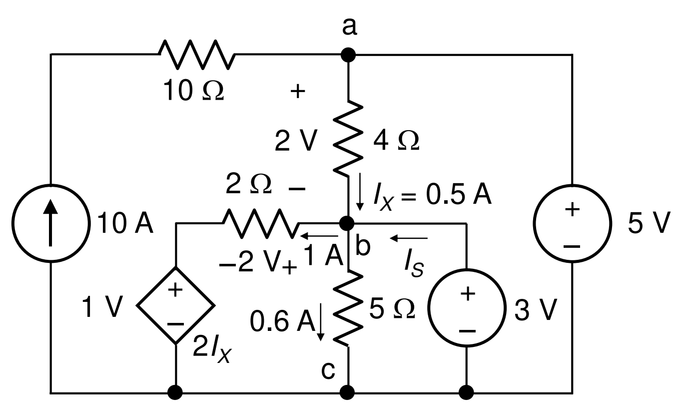


Figure P2.58A

through the source I_S should be determined. From Ohm's law, the current in the 5 Ω resistor is 3/5 = 0.6 A. From KVL, the voltage across the 4 Ω resistor is 5 – 3 = 2 V drop in the direction of I_X. It follows that $I_X = 2/4 = 0.5$ A, and the source voltage of the CCVS is 1 V. From KVL, the current through the 2 Ω resistor is 1 A.

From KCL at node 'b': $I_S + 0.5 = 1 + 0.6$. This gives $I_S = 1.1$ A, so that the power delivered by the 3 V source is 3.3 W.

P2.59 **Initialize.** All given parameters are entered. The nodes are labelled, as in Figure P2.59A.

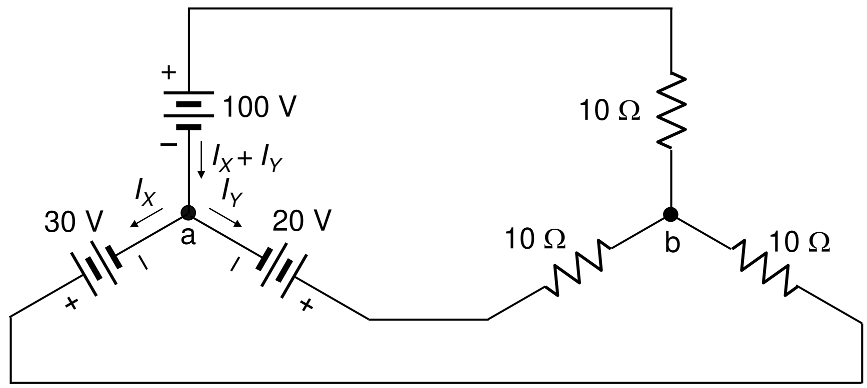


Figure P2.59A

Simplify. The circuit is in a simple enough form.

Deduce. No immediate deductions can be made.

Explore. Three branches are in parallel between nodes 'ab' If the current in the middle branch is denoted by I_Y, the current in the upper branch is $I_X + I_Y$ as shown. Two independent KVL equations can be written: $+30 - 10I_X = +20 - 10I_Y$; and $+30 - 10I_X = 100 + 10(I_X + I_Y)$. Adding these two equations: $60 - 20I_X = 120 + 10I_X$, or, $30I_X = -60$, or, $I_X = -2$ A.

P2.60 In Figure P2.60, $i_R(t) = i_{SRC1}(t) + i_{SRC1}(t)$; $v_R(t) = 5i_R(t)$ V; $v(t) = v_R(t) + 2$ V; $p_2(t) = v(t)i_{SRC2}(t)$ W, power delivered = $-v(t)$ W, as in Figure P2.60A.

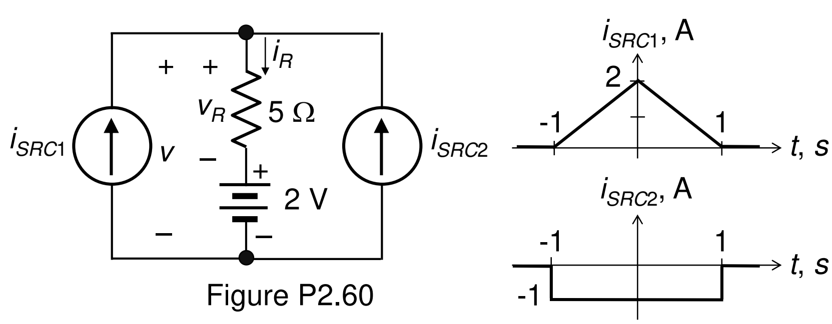


Figure P2.60

It follows that $i_{SRC2}(t)$ absorbs power $-0.7 \leq t \leq 0.7$ s, and delivers power for $-1 \leq t \leq -0.7$ s and $1 \geq t \geq 0.7$ s.

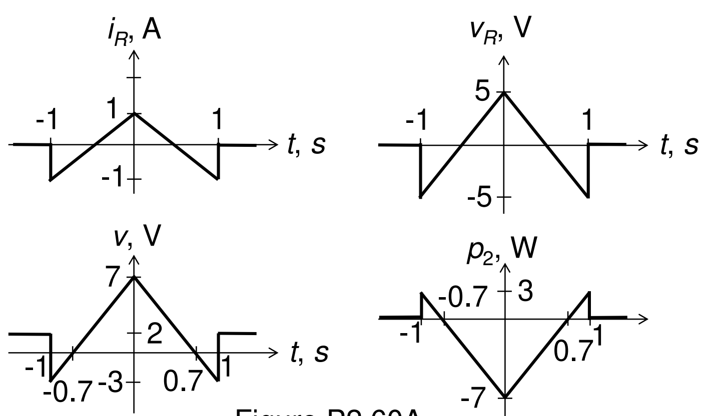


Figure P2.60A

P2.61 Consider conservation of charge first. The charge entering node 'b' in Figure 2.16 during an interval of time Δt is $(I_1 + 1.5)\Delta t$, whereas the charge leaving the node during the time interval Δt is $I_2\Delta t$. From conservation of charge,

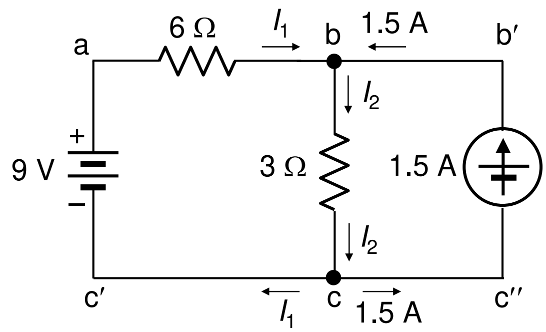


Figure 2.16

$$(I_1 + 1.5)\Delta t = I_2\Delta t \qquad (1)$$

or,
$$I_1 + 1.5 = I_2 \qquad (2)$$

The power delivered by the battery is $9I_1$, whereas that delivered by the current source is $1.5V_{bc}$, where V_{bc} is the voltage across the 3 Ω resistor, which from Ohm's law is $3I_2$. The total power delivered is therefore:

$$\text{Power delivered} = 9I_1 + 4.5I_2 \qquad (3)$$

The total power dissipated in the two resistors is:

$$\text{Power dissipated} = 6I_1^2 + 3I_2^2 \qquad (4)$$

From conservation of power,

$$9I_1 + 4.5I_2 = 6I_1^2 + 3I_2^2 \qquad (5)$$

Equations (2) and (5) are two equations in two unknowns, which can be solved to give: $I_1 = 0.5$ A and $I_2 = 2$ A. It follows that $V_{ab} = 6I_1 = 3$ V, and $V_{bc} = 3I_3 = 6$ V.

P2.62 Suppose that three branches are removed as shown in Figure P2.62A, leaving three essential branches connected between 4 essential nodes in a straight path, without any loops. This gives: $B_1 = N - 1$, since the number of essential branches left is one less than the number of essential nodes. Each restored branch introduces a mesh, so that $B = M + N - 1$.

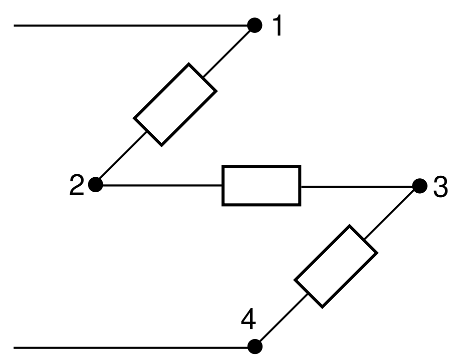


Figure P2.62A

Chapter 2 Fundamentals of Resistive Circuits

2.1 Nature of Resistance

Concept ***Resistance is fundamentally due to impediments to the movement of current carriers in a conductor in the presence of an applied electric field.***

- According to a simplified model, resistance is due to "collisions" of conduction electrons with vibrating crystal atoms (Figure 2.1).

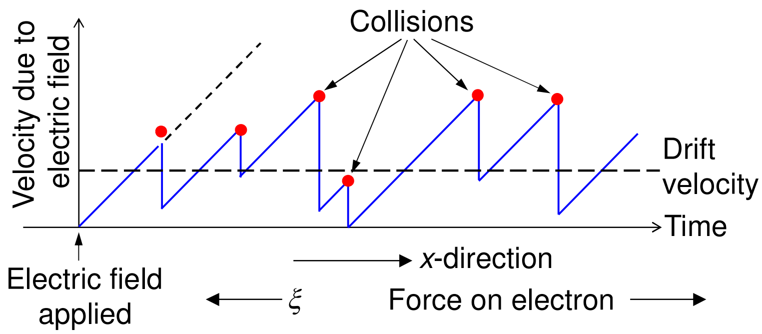


Figure 2.1

- Model, though not rigorous, explains: i) finite current due to applied voltage, ii) increase of resistance with temperature, iii) heating effect of current.

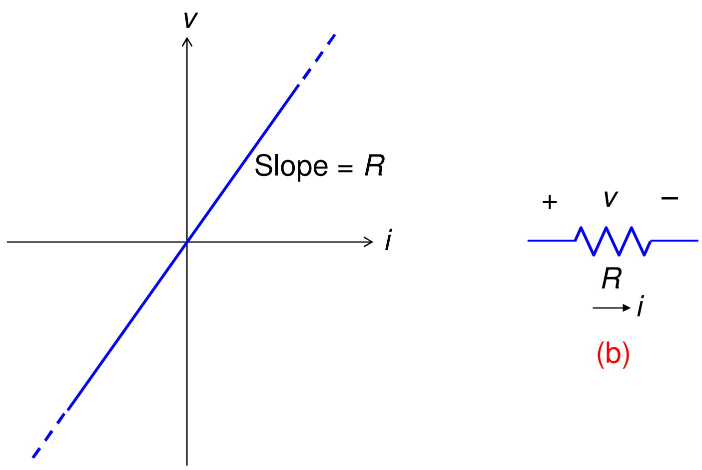
2.2 Ideal Resistors

Definition **An ideal resistor is a purely dissipative circuit element that obeys Ohm's law:**

$$v = Ri \qquad (2.1)$$

Units: v in volts i in amperes, R in ohms (Ω).

- v vs. i is a line of slope R (Figure 2.2a).
- ***Direction of current through a resistor is always in the direction of the voltage drop across the resistor***, ⇒ R is +ve in Equation 2.1.
  - Positive charges flowing down a voltage drop ⇒ loss of potential energy ⇒ heat dissipation.



(a) (b)
Figure 2.2

- Alternative form of Ohm's law: $i = \frac{1}{R}v = Gv$; $G = 1/R$ is **conductance**. Unit: siemens (S) = 1/ohm.

❖ Power dissipated in resistor: $p = vi = Ri^2 = v^2 / R = Gv^2$ (2.3)

Units: v in volts, i in amperes, R in ohms, G is in siemens, p in watts.

Example 2.1 Cold and Hot Resistance of Heating Elements

Given: 120 W, 12 V, heating element.

(a) **Required:** R and G of the filament at 12 V.

Solution: From Equation 2.3, $120 = (12)^2 / R \rightarrow R = 1.2\ \Omega$, and $G = 1/1.2 = 0.83$ S. (b)

Required: lamp current.

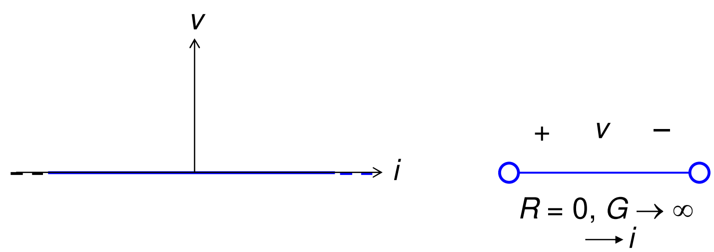
Solution: $I = (120\text{ W})/(12\text{ V}) = 10$ A. As a check $RI^2 = 1.2 \times (10)^2 = 120$ W.

(c) **Required:** resistance of filament at room T (20°C), assuming that the filament T at 12 V is 1,200°C and the temperature coefficient of resistance is 0.0045/°C.

Solution: Assuming $R_2 = R_1[1 + \alpha_m(T_2 - T_1)]$, with $R_2 = 1.2\ \Omega$, $T_1 = 20$°C, $T_2 = 1{,}200$°C, and α_m 0.0045/°C, $\rightarrow R_1 = \dfrac{1.2}{1 + 0.0045(1200 - 20)} = 0.19\ \Omega$.

2.3 Short Circuit and Open Circuit

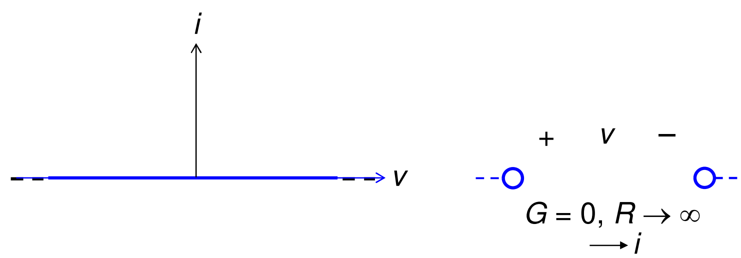
Definition ***A short circuit is a connection of zero resistance, or infinite conductance. An open circuit has infinite resistance, or zero conductance.***



(a) Figure 2.4 (b)

❖ Short circuit: $R = 0 \Rightarrow v = Ri = 0$ for all finite i. (Figure 2.4).
  - ➢ Wiring connections implicitly assumed to be short circuits.

❖ Open circuit: $G = 0 \Rightarrow i = Gv = 0$ for all finite v. (Figure 2.5).



(a) Figure 2.5 (b)

2.4 Ideal, Independent Voltage Source

Definition ***An ideal, independent voltage source maintains a <u>specified</u> voltage v_{SRC} between its terminals irrespective of the current through the source, where v_{SRC} is independent of any voltage or current in the circuit.***

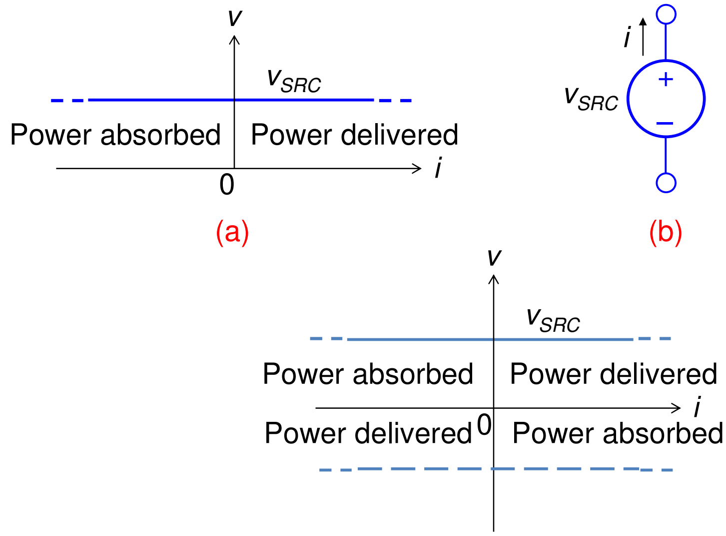


Figure 2.7 (c)

- "ideal" ⇒ v_{SRC} is as specified for all i (Figure 2.7a); "independent" ⇒ independence of any voltage or current in the circuit. Example: 12 V battery.
- Symbol: circle, except for dc it is a battery. "+" and "- " signs indicate the assigned positive direction of v_{SRC}.
- v_{SRC} and i can be +ve, -ve or zero: $V_{SRC} > 0$ and $I > 0$ (Figure 2.8a); $V_{SRC} < 0$ and $I < 0$ (Figure 2.8b) → power is delivered; $V_{SRC} >$ 0 and $I < 0$ (Figure 2.8c) → power is absorbed.
- Value and polarity of the source current depend on v_{SRC} and the circuit to which the source is connected.
- Voltage source imparts electric PE to current carriers.

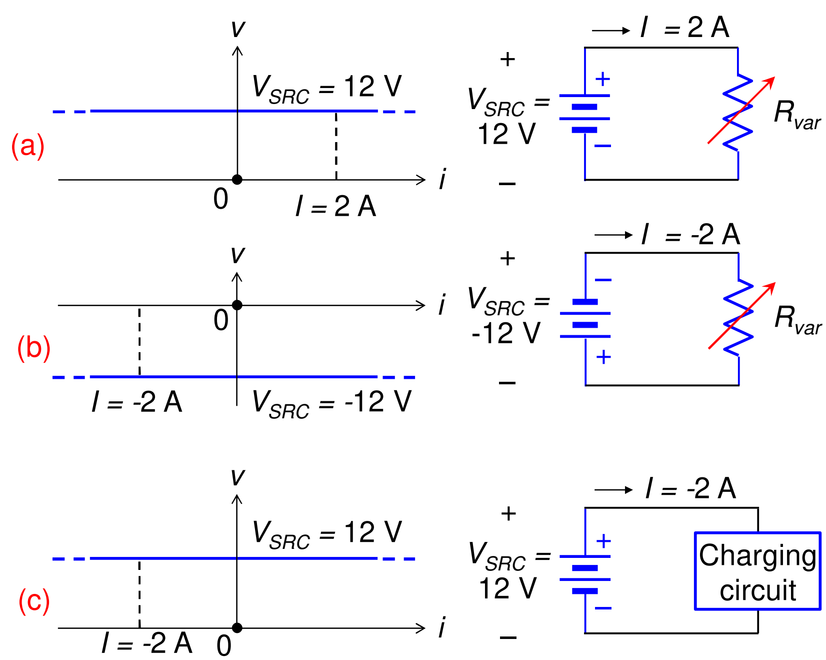
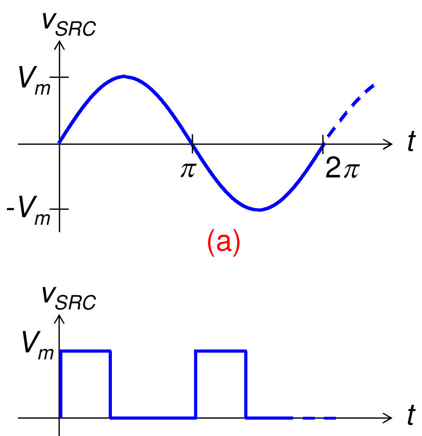


Figure 2.8



(b) Figure 2.9

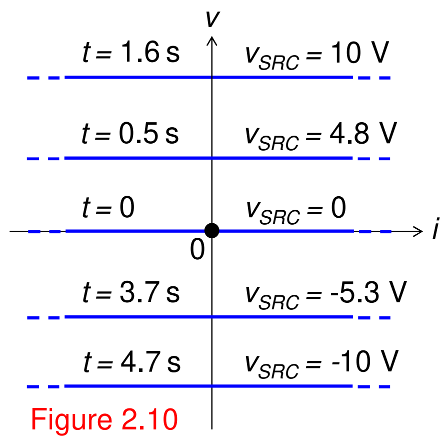


Figure 2.10

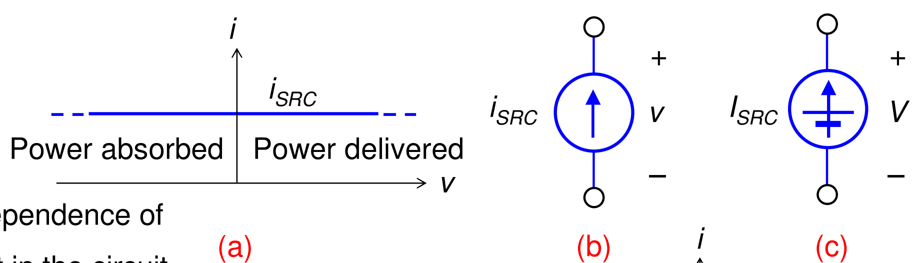
- ❖ Ideal, independent voltage sources are in general time-varying (Figure 2.9). However, ***the v-i relation is still a horizontal line (Figure 2.7a).***
  - ➢ If $v_{SRC} = 10\sin t$ V, v_{SRC} line moves up or down with time (Figure 2.10).
- ❖ When $v_{SRC} = 0$, Figure 2.7a ≡ Figure 2.5a ⇒

  an ideal voltage source is set to zero by replacing it with a short circuit.

2.5 Ideal, Independent Current Source

Definition ***An ideal, independent current source maintains a specified current i_{SRC} through the source irrespective of the voltage across the source, where i_{SRC} is independent of any voltage or current in the circuit.***

- ❖ "ideal" ⇒ i_{SRC} as specified for all v (Figure 2.11a); "independent" ⇒ independence of any voltage or current in the circuit.
- ❖ Symbol: circle with arrow, plus a battery for a dc source. Arrow points in assigned positive direction of current.



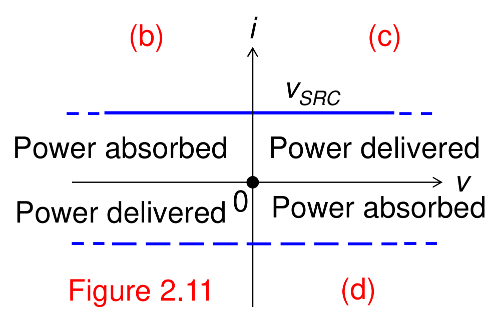


Figure 2.11 (d)

- ❖ Analogies to ideal voltage source:
  - ➢ i_{SRC} and v can be +ve, -ve, or zero.
  - ➢ For a given i_{SRC}, v depends on circuit to which the source is connected.
  - ➢ An ideal current source can deliver or absorb power (Figure 2.11d).
  - ➢ i_{SRC} is in general a function of time, but is a constant with respect to the voltage across

the source.

- Current source imparts KE to current carriers.
- When $i_{SRC} = 0$, Figure 2.11a $\equiv$ Figure 2.5a $\Rightarrow$ ***an ideal current source is set to zero by replacing it with an open circuit***.

2.6 Ideal, Dependent Sources

Concept ***Dependent sources behave exactly as independent sources in all respects except that the value of a dependent source is specified as a linear function of a voltage or a current elsewhere in the circuit.***

- Dependent sources supply energy through conversion from an electric source of energy, such as batteries, or dc supplies, used with electronic devices.
- Ideal, dependent sources are represented by a diamond symbol.

Ideal, Dependent Voltage Sources

- (i) **voltage-controlled voltage source** (VCVS): v_{SRC} controlled by a voltage in the circuit ($2V_X$ in Figure 2.13). (ii) **current-controlled voltage source** (CCVS): v_{SRC} controlled by a current in the circuit ($3I_Y$ in Figure 2.13).

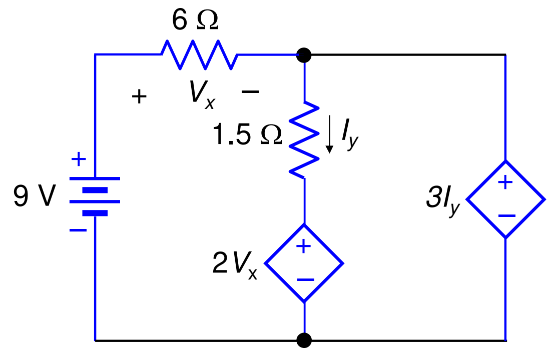


Figure 2.13

- Being ideal sources, ***the specified source voltage of an ideal, dependent voltage source is independent of the current through the source***, as in Figure 2.4a.

Ideal, Dependent Current Sources

- (i) **voltage-controlled current source** (VCCS): i_{SRC} controlled by a voltage in the circuit ($2V_X$ Figure 2.14). (ii) **current-controlled current source** (CCCS): i_{SRC} controlled by a current in the circuit ($3I_Y$ in Figure 2.14).

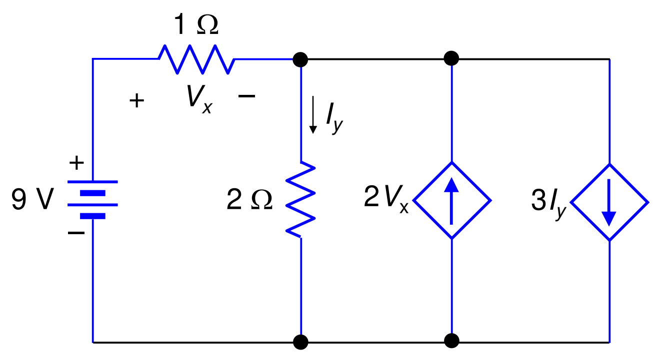


Figure 2.14

- Being ideal sources, ***the specified source current of an ideal, dependent current source is***

❖ ***independent of the voltage across the source***, as in Figure 2.5a.

❖ Summary of classification of ideal sources.

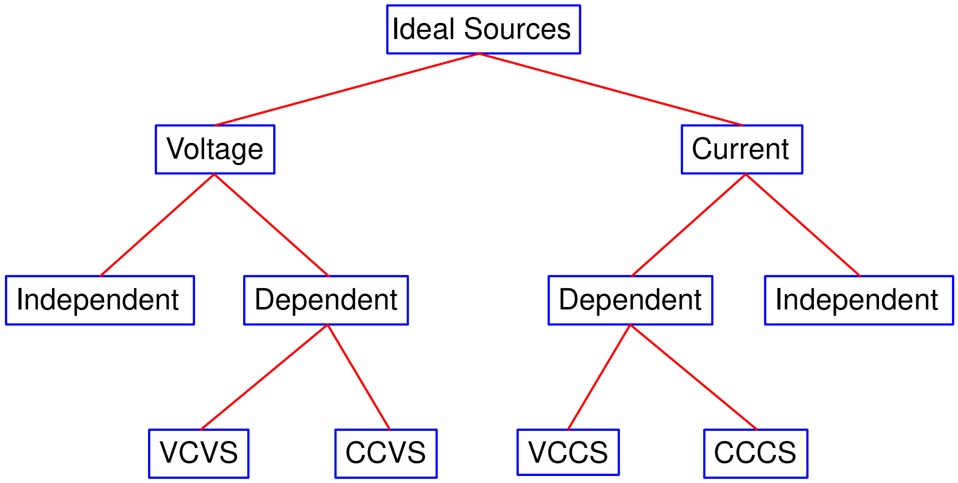


Figure 2.15

2.7 Nomenclature and Analysis of Resistive Circuits

❖ **Node:** electrical junction, or connection point, between a number of circuit elements ('a', 'b', and 'c' in Figure 2.16).

➢ **Inessential node:** node connecting two elements ('a').

➢ **Essential node:** node connecting three or more circuit elements ('b' and 'c').

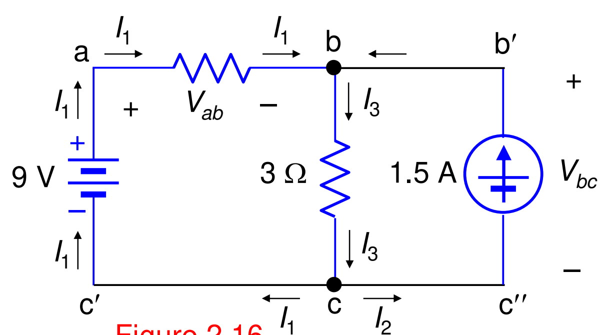


Figure 2.16

Connections 'bb′' and 'c′cc′′' are short circuits within the same nodes.

❖ **Path:** set of one or more adjoining circuit elements that may be traversed in succession without passing through the same node more than once.

➢ **Branch:** path that connects two nodes.

➢ **Essential branch:** set of adjoining circuit elements traversed in going from one essential node to an adjacent essential node, without passing another essential node. Branches: battery, and 6 Ω resistor; together they are an

essential branch between essential nodes 'b' and 'c'. 3 Ω resistor and current source are essential branches between nodes 'b' and 'c'.

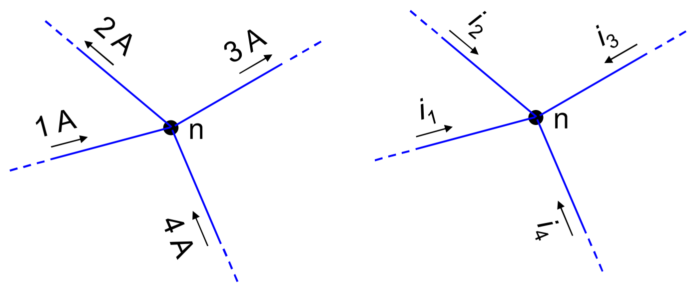
❖ **Loop:** closed path. **Mesh:** loop that does not enclose another loop. Meshes: c′abcc′, cbb′c′′c; loop: cc′abb′c′′c.

- Analysis of resistive circuits aims at determining all the voltages and currents in a given circuit given the values of the sources and resistances in the circuit, or some specified conditions in the circuit.
- Required number of equations can be written from conservation of charge and conservation of power → inconvenient to solve because of quadratic relation between *p* and *v*, or *p* and *i*. Much more convenient to have circuit equations that are linear in *v* and *i* → Kirchhoff's current and voltage laws.

2.8 Kirchhoff's laws

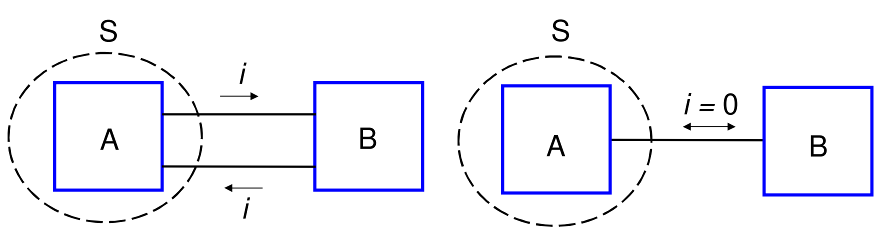
Kirchhoff's Current Law (KCL)

Statement ***At any instant of time, the sum of currents entering a node is equal to the sum of currents leaving the node.***



(a) Figure 2.18 (b)

- KCL at node 'n' in Figure 2.18a: 1 + 4 = 2 + 3.
- KCL is an expression of conservation of current, at any instant of time and at every node in a given circuit, as a consequence of conservation of charge.
  - Charge entering node during $\Delta t = \left(\sum_{\text{Entering}} i\right)\Delta t$; charge leaving node during $\Delta t = \left(\sum_{\text{Leaving}} i\right)\Delta t$; from conservation of charge these are equal; cancelling Δt → KCL.
- KCL applies not only to actual current values (Figure 2.18a), but also to arbitrarily assigned directions of currents at a node. KCL at node 'n' in Figure 2.18b: $i_1 + i_2 + i_3 + i_4 = 0$. Actual values: $i_1 = 1$ A, $i_2 = -2$ A, $i_3 = -3$ A, and $i_3 = 4$ A. Substituting, 1 – 2 – 3 + 4 = 0 or 1 + 4 = 2 + 3.
- KCL applies to whole circuit elements or to combinations of circuit elements in a circuit. In Figure 2.19a, current leaving S = current



(a) Figure 2.19 (b)

entering S. In Figure 2.19b, $I = 0$.

Kirchhoff's Voltage Law (KVL)

❖ Voltages along a path add algebraically, because changes in electric PE can be added algebraically, and voltage is electric PE/unit charge.

➢ Take Δq from ground to 'c' in Figure 2.20; PE is $6\Delta q$, $10\Delta q$, $8\Delta q$, voltages being 6, 10 and 8 V.

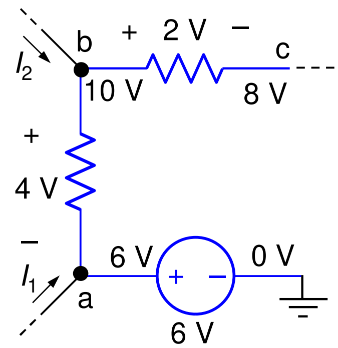


Figure 2.20

Statement ***At any instant of time, the sum of voltage rises around any loop is equal to the sum of voltage drops around the loop.***

❖ Traversing the mesh CW in Figure 2.21: sum of voltage rises is 3.5 + 4 = 7.5 V; sum of the voltage drops is 0.5 + 1.5 + 2.5 + 3 = 7.5 V, in accordance with KVL.

❖ Interpretation of KVL: Take a small charge Δq around the mesh and equate the total work done on Δq to the total work done by Δq, in accordance with conservation of energy:

$$\Delta q \sum \text{Voltage rises} = \Delta q \sum \text{Voltage drops}$$

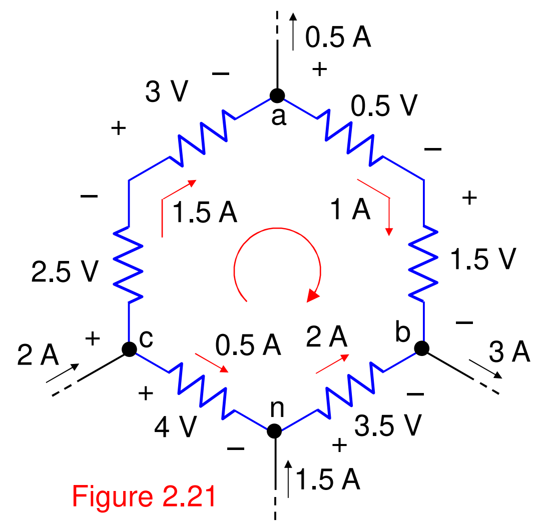


Figure 2.21

❖ Because the currents that produce the voltage rises and voltage drops across the circuit elements around the mesh must satisfy KCL → ***KCL and KVL together are an expression of conservation of energy***.

❖ Procedure for writing KVL:

➢ Choose a node as the starting point and end point in traversing the loop (node 'n' in Figure 2.21).

➢ Decide on the direction in which the loop is to be traversed, say CW.

➢ Traverse the loop in the chosen direction proceeding through all the circuit elements in succession.

➢ As each circuit element is crossed, record the voltage across the circuit element, assigning it a +ve sign if it is a voltage rise and a -ve sign if it is a voltage drop. Set the algebraic sum of the recorded voltages equal to zero: + 4

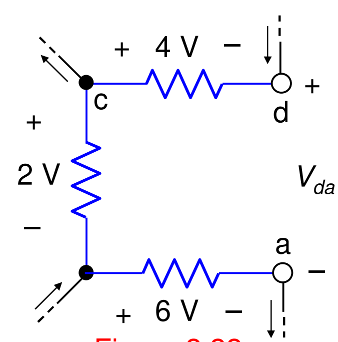


Figure 2.22

$-2.5 - 3 - 0.5 - 1.5 + 3.5 = 0.$

❖ KVL can also be applied to an open path in a circuit to determine the voltage between the two ends of the path (Figure 2.22): Starting from node 'a' and going CW → $+6 + 2 - 4 - V_{da} = 0$, → $V_{da} = 4$ V.

- ➢ By convention, V_{da}: ***voltage drop*** from node denoted by first subscript to node denoted by second subscript.

Example 2.3 Application of Ohm's law, KCL, and KVL

Required: to determine V_O in Figure 2.30.

Solution: *Step 1*: Because of open-circuit, no current flows at terminals (Figure 2.31).

Step 2: From KCL at 'a', current flowing through 10 Ω resistor is 2 A.

Step 3: From Ohm's law, voltage drop from 'a' to 'c' is 2×10 = 20 V.

Step 4: From KCL at 'c', current through 20 Ω resistor is 0. (can also be deduced by enclosing the 2 A source and 10 Ω resistor by a surface.)

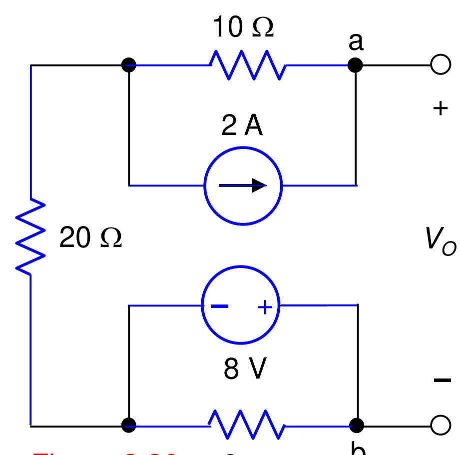


Figure 2.30

Step 5: From Ohm's law, the voltage across 20 Ω resistor is zero.

Step 6: Applying KVL in going through bdcad: $-8 + 0 + 20 - V_O = 0 \rightarrow V_O = 12$ V.

Problem-Solving Tip

❖ Always mark on the circuit diagram the directions of currents of interest and the polarities of voltages of interest, bearing in mind that the current through a resistor is in the direction of the voltage drop across the resistor.

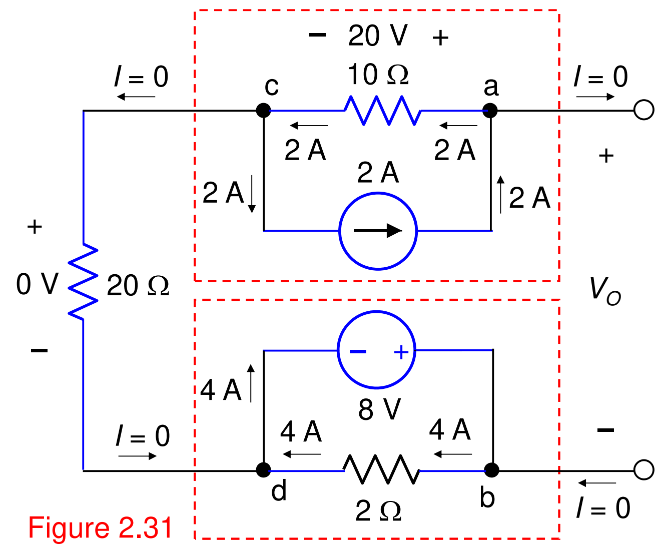


Figure 2.31

2.9 Series and Parallel Connections

Series Connection

1. Circuit elements are connected in succession, end-to-end, without branching at any of the

nodes between the elements (Figure 2.33).

2. Nodes between series-connected elements are inessential nodes.
3. Same current flows through the series-connected elements ⇒ KCL is automatically satisfied in a series connection.
4. Voltages add algebraically along the path of series-connected elements (Figure 2.34a). Voltage at ‘c’: 5 + 3 = 8; voltage at ‘d’: 8 – 6 = 2 V. KVL: 5 + 3 – 6 – V_{da} = 0 → V_{da} = 2 V.
5. If one of the series-connected elements is removed, element is replaced by an open circuit, current drops to zero (Figure 2.34b).

❖ Figure 2.35a: Three lamps connected in series; Figure 2.35b: Equivalent resistor in series.

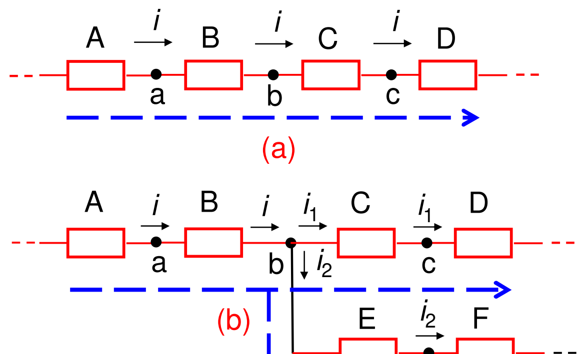


Figure 2.33

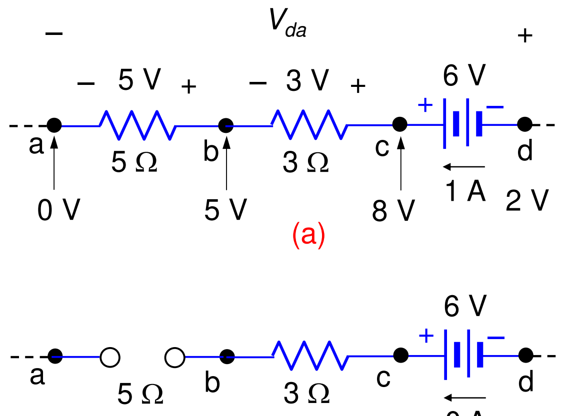


Figure 2.34

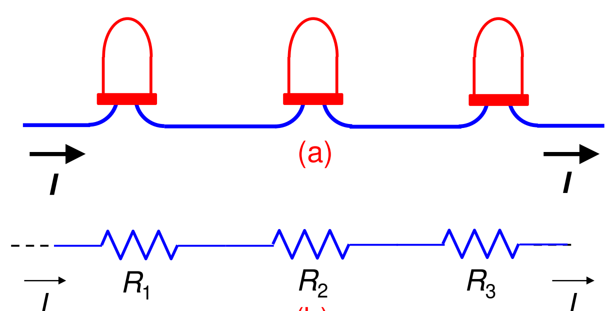


Figure 2.35

Parallel Connection

1. One end of each element, marked with ‘x’ in Figure 2.36a, is connected to a common node, ‘a ’, whereas the other end of each of these elements, marked with z in Figure 2.36a, is connected to another common node, ‘b’ ⇒ the closed path through any two

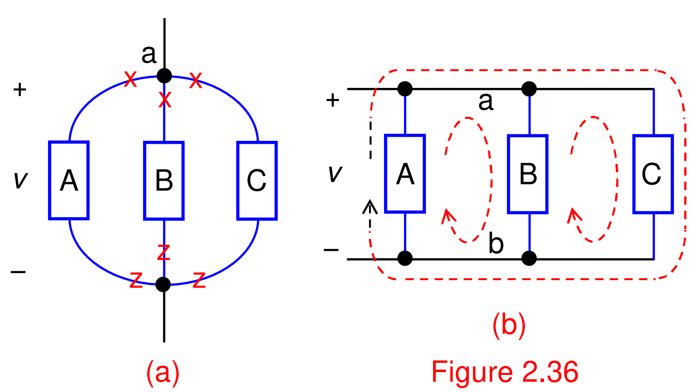
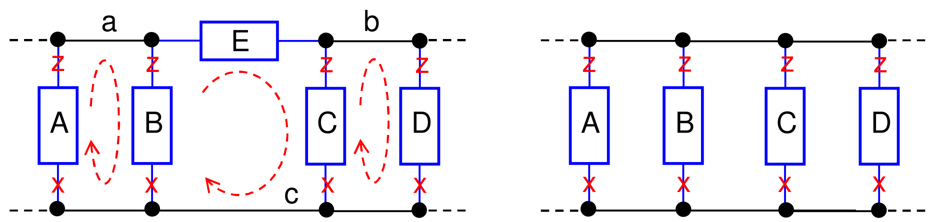
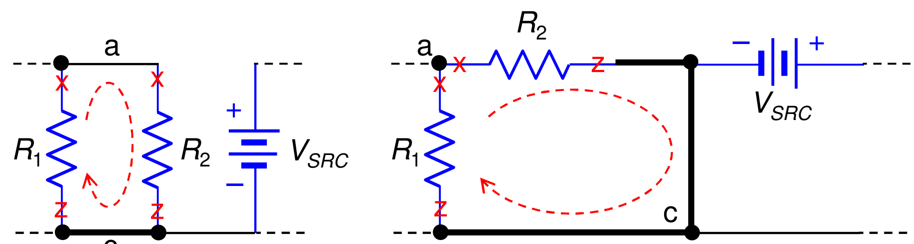


Figure 2.36

paralleled elements traverses these two elements only, and no other elements (Figure 2.36b). Examples: elements ‘A’ and ‘B’ in Figure 2.37a are in parallel, as are elements ‘C’ and ‘D’. These four elements are not in parallel in Figure 2.37a but are in parallel in Figure 2.37b. R_1 and R_2 in Figure 2.38 are in parallel. In both figures, the x-z and the closed path tests apply.



(a) Figure 2.37 (b)



(a) Figure 2.38 (b)

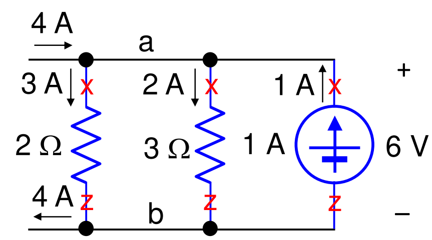


Figure 2.39

2. The nodes between which paralleled elements are connected are essential nodes.
3. Same voltage across each of the parallel-connected elements ⇒ KVL is automatically satisfied in the mesh or loop formed by any two paralleled elements (Figure 2.39)
4. Currents through paralleled elements add algebraically at either node. KCL at either node: 3 + 2 – 1 = 4 A.
5. To have zero current between end nodes ‘a’ and ‘b’, in Figure 2.39, *all* paralleled elements must be removed.

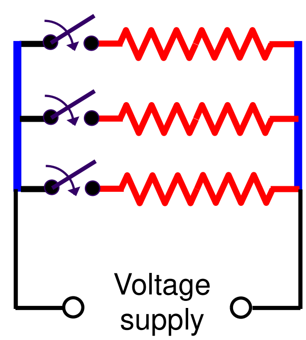


Figure 2.40

- Figure 2.40: three heating elements are connected in parallel across the mains voltage supply.
- Series and parallel connections allow building circuits of any desired complexity (Figure 2.41).

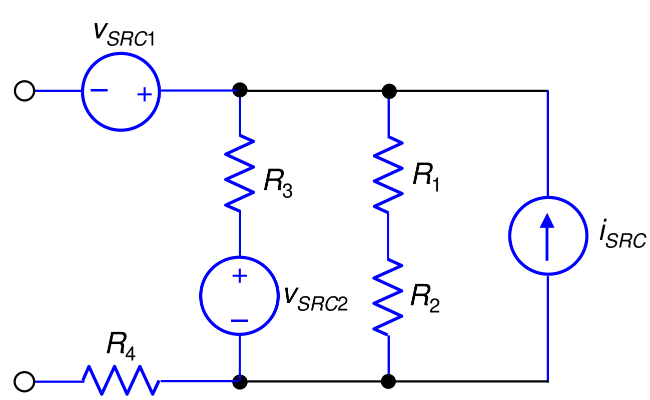


Figure 2.41

2.10 Problem-Solving Approach

The most effective engineering solution to a given problem is the one reached in minimum time, at minimum cost and effort, and which achieves the desired objectives in the simplest possible manner. (ISDEPIC):

Step 1 – Initialize. Generally, this involves the following:

(a) Mark on the circuit diagram all given values of circuit parameters, currents and voltages, as well as the unknowns to be determined, keeping in mind that every current must have a direction and every voltage must have a polarity.

(b) Label the nodes, such as 'a', 'b', 'c', etc., as this is usually helpful.

(c) If the solution requires that a given value of current or voltage be satisfied, *assume this value from the very beginning*, as this can considerably facilitate the solution.

Step 2 – Simplify. Try and reduce the circuit to a simpler form, if possible. This may be done, for example, by redrawing the circuit, or by replacing series and parallel combinations of circuit elements by an equivalent circuit element, as discussed in Chapter 3.

Step 3 – Deduce. Determine any values of current or voltage that *follow immediately from direct application of Ohm's law, KCL, or KVL, without introducing any additional unknowns*. The given unknowns, such as required outputs, as well as controlling voltages and currents of dependent sources, may be used in expressing Ohm's law, KCL, or KVL in this step.

The results of applying Ohm's law, KCL, and KVL should be entered on the circuit diagram itself, including directions of currents and polarities of voltages. This way, the correctness of these circuit laws can be readily checked visually. Bear in mind that the current through an ideal resistor that obeys Ohm's law is always in the direction of the voltage drop across the resistor.

Step 3 is often sufficient to solve the problem, as in Example 2.3. Moreover, it may be possible to repeat Steps 2 and 3 alternately in some cases. If Step 3 does not provide the solution, proceed to Step 4.

Step 4 – Explore. Consider the nodes and meshes in the circuit to see if KCL or KVL can be expressed using *a single, unknown current or voltage, AND if this unknown can then be directly determined from KCL or KVL.* If so, this step provides the solution, because, once an unknown current or voltage is determined, other required values can be derived using KCL, KVL, or Ohm's law. If Step 4 does not provide the solution, proceed to Step 5.

Step 5 – Plan. Think carefully about the problem in the light of circuit fundamentals and circuit analysis techniques. Imagination, creativity, and experience in problem-solving can play a decisive role in this Step. Try to think of alternative solutions and select what seems to be the simplest and most direct solution.

Step 6 – Implement. Carry out your planned solution, bearing in mind the following considerations:

(a) Keep the number of unknown variables to a minimum, as this minimizes the likelihood of careless mistakes. Make use of any given variables such as an unknown variable to be determined or the controlling currents or voltages of dependent sources.

(b) Mentally ascertain the correctness of equations or relations as you write them or copy them, in order to minimize careless mistakes. If in doubt about the correctness of an equation or relation, check the units on both sides of the equation or relation, or the units of numerators and denominators of expressions.

(c) Keep track of units, and label all calculated values with the appropriate units.

Step 7 – Check your calculations and results.

(a) Check that your results make sense, in terms of magnitude and sign.

(b) Check that Ohm's law is satisfied across every resistor, that KCL is satisfied at every node, and that KVL is satisfied around every mesh.

(c) A good way to check your results is to seek an alternative solution to the problem and see if it gives the same results.

(d) Whenever feasible, check your results with PSpice simulation. This is a valuable habit to acquire.

Example 2.4 Illustration of ISDEPIC Approach

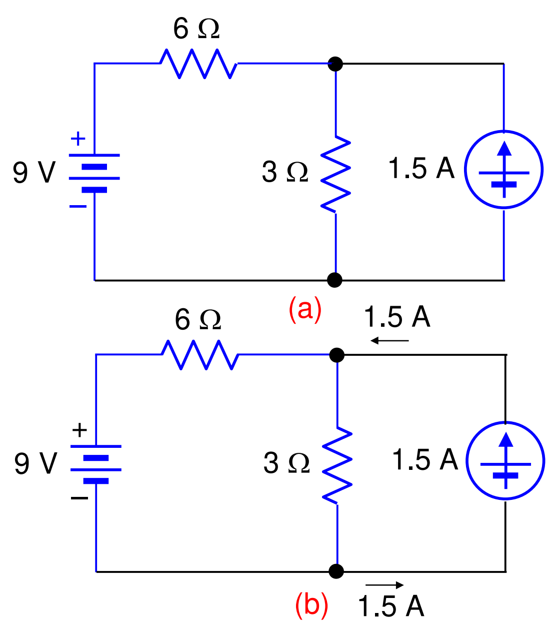
Required: analyze the circuit of Figure 2.46.

Sol: 1 – Initialize. Circuit is reproduced in Figure 2.46a, indicating values of all circuit elements.

2 – Simplify. The circuit is in a simple enough form.

3 – Deduce. 1.5 A enter the upper node and leave the lower node (Figure 2.46b).

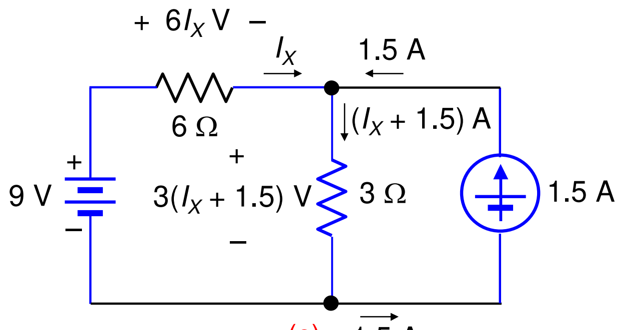
4 – Explore. KCL can be satisfied by assigning I_X entering upper node through the 6 Ω resistor (Figure 2.46c). From KCL, current leaving this node through the 3 Ω resistor is (I_X + 1.5) A. From Ohm's law, voltages across resistors are 6I_X and 3(I_X +



1.5). KVL around LHS mesh: $+9 - 6I_X - 3(I_X + 1.5) = 0 \rightarrow I_X = 0.5$ A $\rightarrow$ determining all other unknown currents and voltages. Alternatively, an unknown voltage V_X may be assigned between the nodes (Figure 2.46d). Currents in the two resistors are expressed in terms of V_X, as $V_X/3$ and $(V_X - 9)/6$ A. KCL a either node is: $1.5 = (V_X - 9)/6 + V_X/3$.

Problem-Solving Tip

❖ Circuits having only two essential nodes can generally be analyzed by applying KCL at either node.



(c)

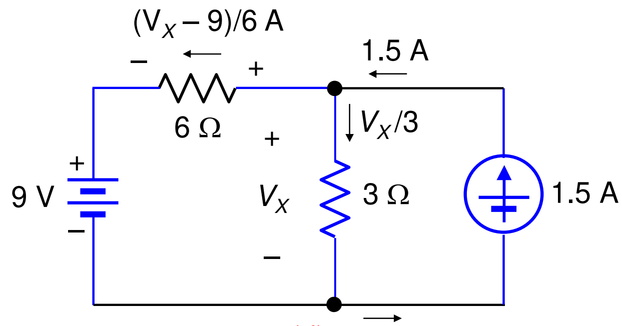


Figure 2.46 (d)

Example 2.5 Illustration of ISDEPIC Approach

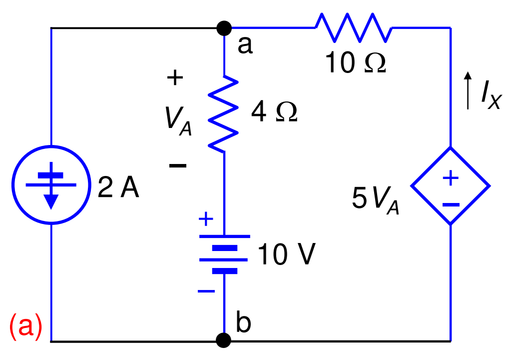
Required: determine I_X in Figure 2.48a

Solution: Circuit has two essential nodes, as in Example 2.4, but with the addition of a VCVS.

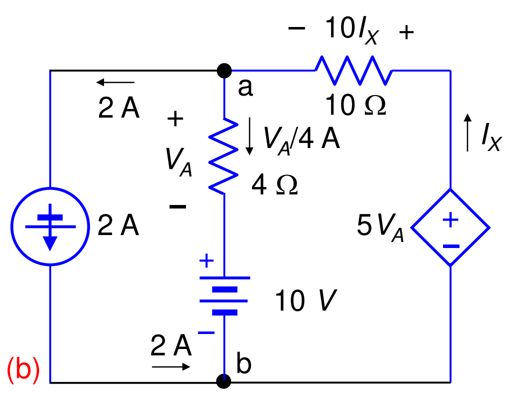
1 – Initialize. The circuit is already marked with given values and the required I_X. The nodes are labelled 'a' and 'b'.

2 – Simplify. The circuit is in a simple enough form.

3 – Deduce. 2 A and a current $V_A/4$ leave the upper node (Figure 2.48b). The voltage drop across the 10 Ω resistor is $10I_X$. KCL at node 'a' is: $I_X = 2 + V_A/4$. KVL around the mesh on the RHS, starting at node 'b' and going clockwise, gives: $+10 + V_A + 10I_X - 5V_A = 0$, or $4V_A - 10I_X = 10$. Solving these equations for V_A and I_X gives $I_X = 7$ A and $V_A = 20$ V. Alternatively, since the circuit is a two-essential node circuit, $V_{ab} = (10 + V_A)$ (Figure 2.48c). The voltage drop from node 'a' to the positive terminal of the VCVS is: $V_{ab} - 5V_A = 10 + V_A - 5V_A = 10 - 4V_A$, and the current leaving node 'a'



(a)



(b)

through the 10 Ω resistor is $(10 - 4V_A)/10 = 1 - 0.4V_A$. From KCL at node ‘a’, $2 + 0.25V_A + 1 - 0.4V_A = 0$, which gives $V_A = 20$ V. Hence, $I_X = -(1 - 0.4V_A) = 7$ A.

Problem-Solving Tip

❖ Controlling currents or voltages of dependent sources are often convenient to use as unknown variables in analyzing circuits.

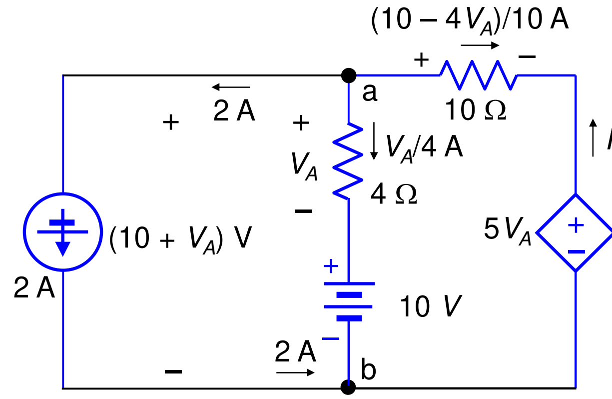


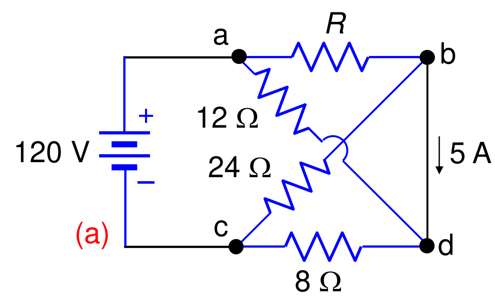
Figure 2.48 (c)

Example 2.6 Illustration of ISDEPIC Approach

Required: determine R in Figure 2.50a so that $I_{bd} = 5$ A.

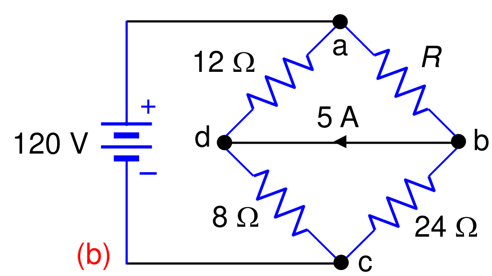
Solution: 1 – Initialize. The required value of current is ***assumed to begin with***.

2 – Simplify. Lattice circuit configuration of Figure 2.50a is redrawn as a bridge configuration: relocate nodes in the order ‘a’, ‘b’, ‘c’, and ‘d’ CW and enter the same circuit elements between the relocated nodes (Figure 2.50b).



(a)

3 – Deduce. No immediate deductions.



(b)

4 – Explore. KVL around the meshes and KCL at nodes ‘a’, ‘c’, or ‘b’ are not helpful because of too many unknowns. However, if a current I is assigned entering at ‘d’ from the 12 Ω resistor (Figure 2.50c), the current leaving node ‘d’ through the 8 Ω resistor is $(I + 5)$ A. I can then be determined from Ohm’s law and KVL around the mesh on the left: $120 - 12I - 8(I + 5) = 0 \rightarrow I = 4$ A. To determine R, we note that the 8 Ω and 24 Ω resistors are in parallel, so that the voltage across the 24 Ω resistor is $8(4 + 5) = 72$ V, and the current through it is $72/24 = 3$ A. From KCL at node ‘b’, the current in R is $(5 + 3) = 8$ A. Since R is in parallel with the 12 Ω resistor, the voltage across it is $12I = 48$ V. Hence, $R = 48/8 = 6$ Ω.

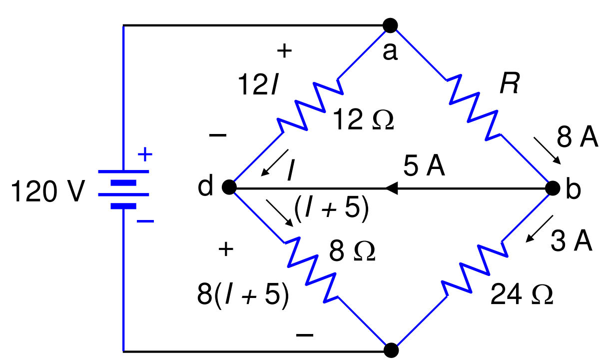


Figure 2.50 (c)

Problem-Solving Tips

❖ A circuit with rather awkward-looking connections can be redrawn, after labeling of nodes, for easier visualization of the connections.

Checking of Solutions

❖ The solution to any circuit problem can be checked by making sure that KCL is satisfied at every node and KVL is satisfied around every mesh.

❖ If a circuit has N essential nodes, then after writing KCL for ($N-1$) essential nodes, KCL at the remaining node should automatically be satisfied if KCL was written correctly at the other nodes.

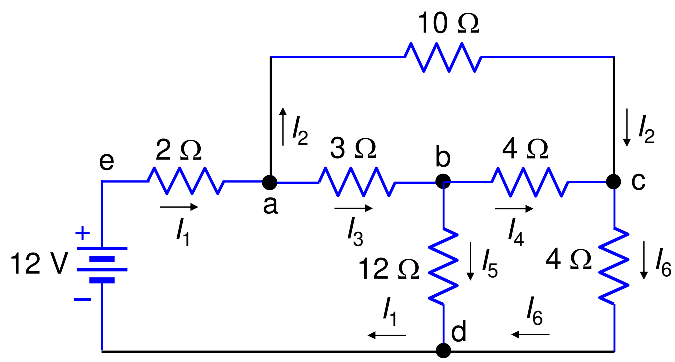


Figure 2.29

➢ Circuit of Figure 2.29 has are 4 essential nodes: ‘a’, ‘b’, ‘c’, and ‘d’. KCL for the first three nodes gives:

Node ‘a’: $I_1 = I_2 + I_3$

Node ‘b’: $I_3 = I_4 + I_5$

Node ‘c’: $I_2 + I_4 = I_6$.

➢ When these three equations are added, I_2, I_3, and I_4 cancel out, leaving $I_1 = I_5 + I_6$, which is KCL for node ‘d’.

➢ Thus, $N = 4$, and $N - 1 = 3$, so that only three independent KCL equations can be written. KCL for the remaining node is not an independent equation but can be used as a check on the KCL

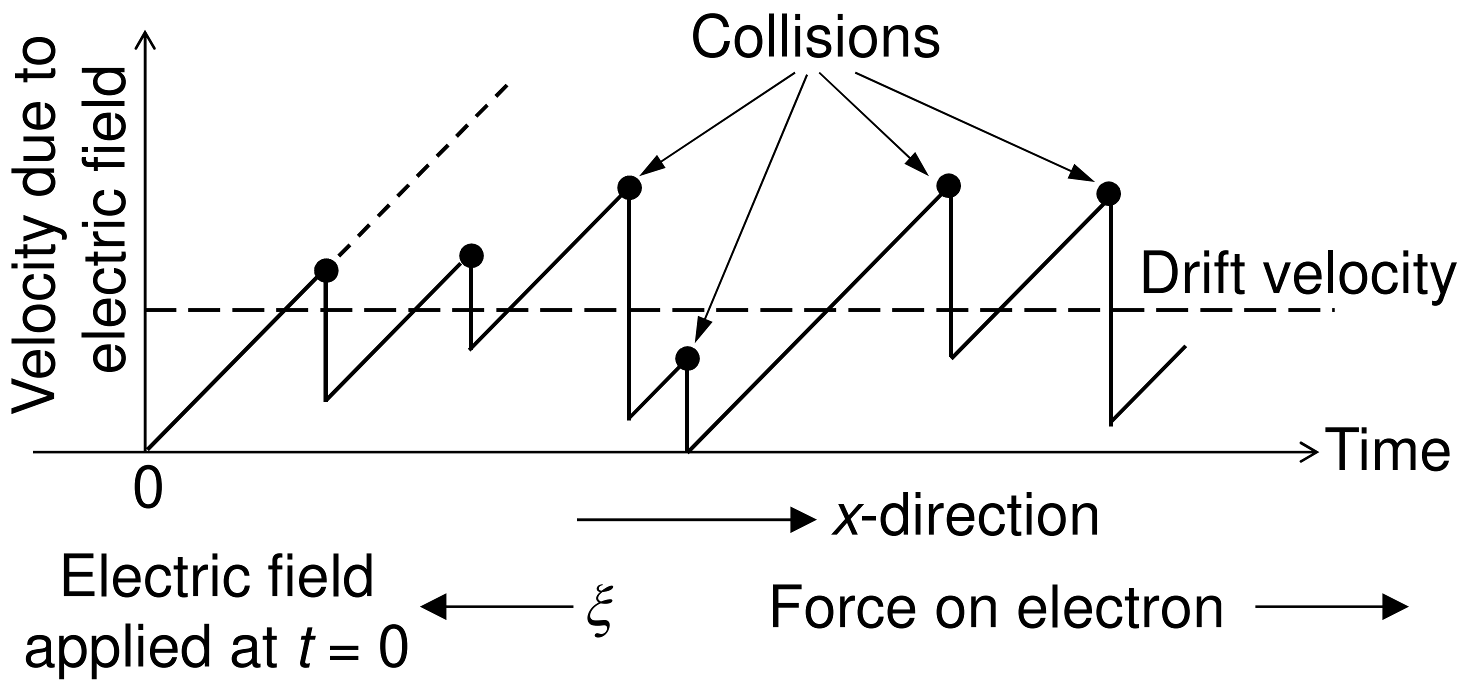

Collisions
Velocity due to electric field
Drift velocity
0
Time
x-direction
Electric field applied at t = 0
ξ
Force on electron

Figure 2.1

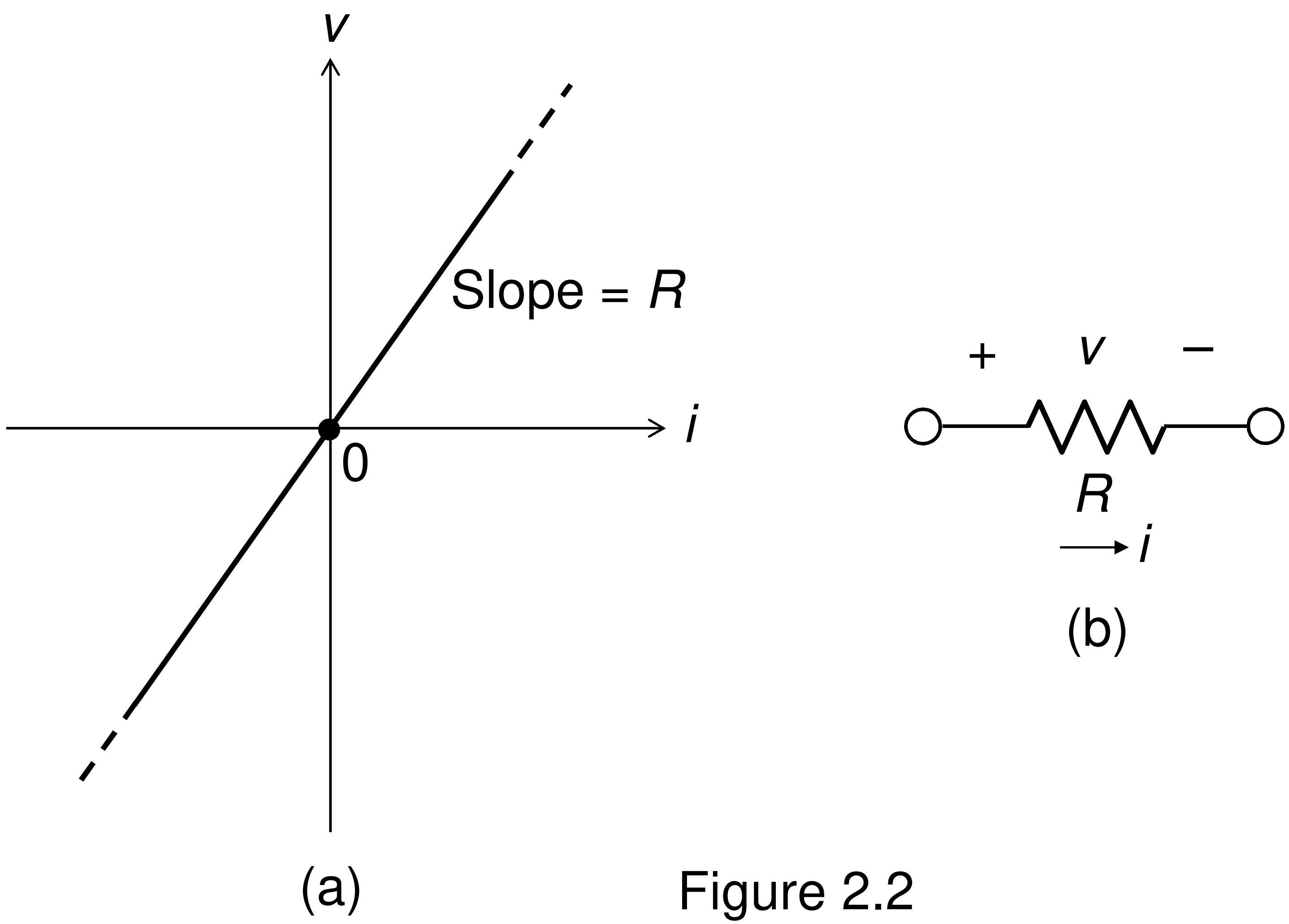


Figure 2.2

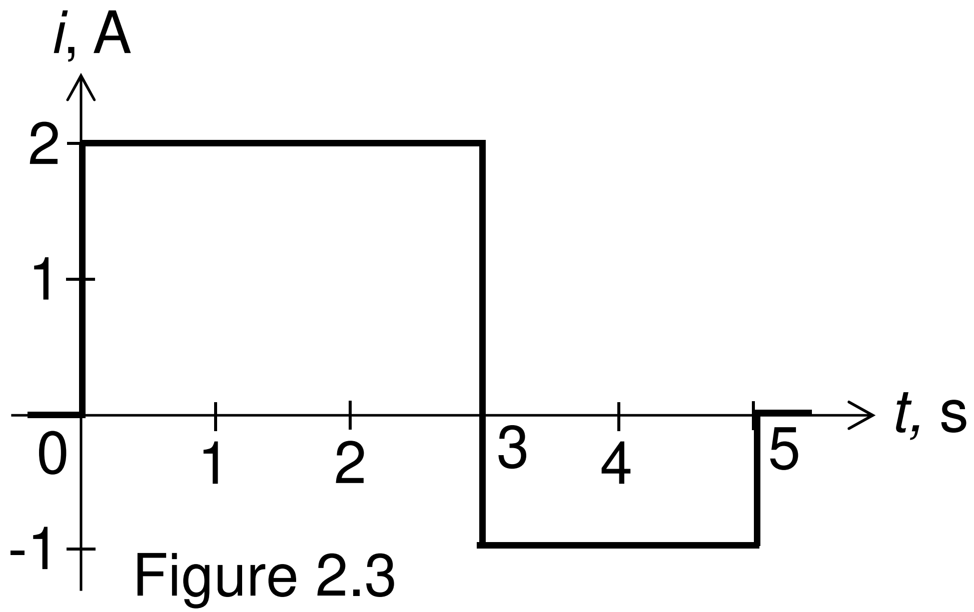
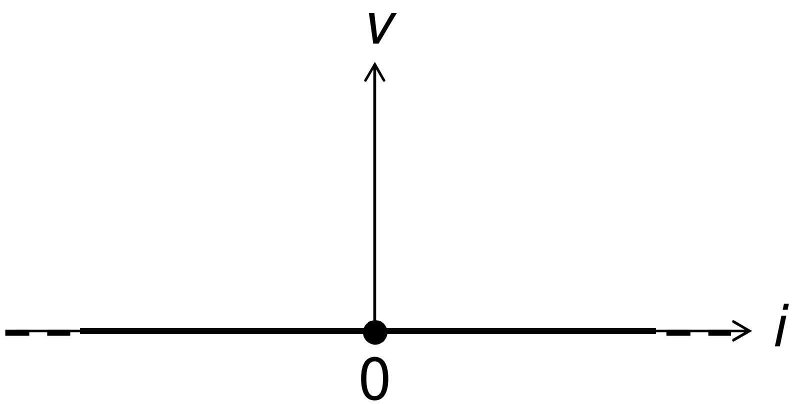
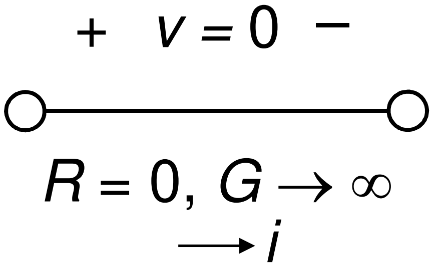


Figure 2.3

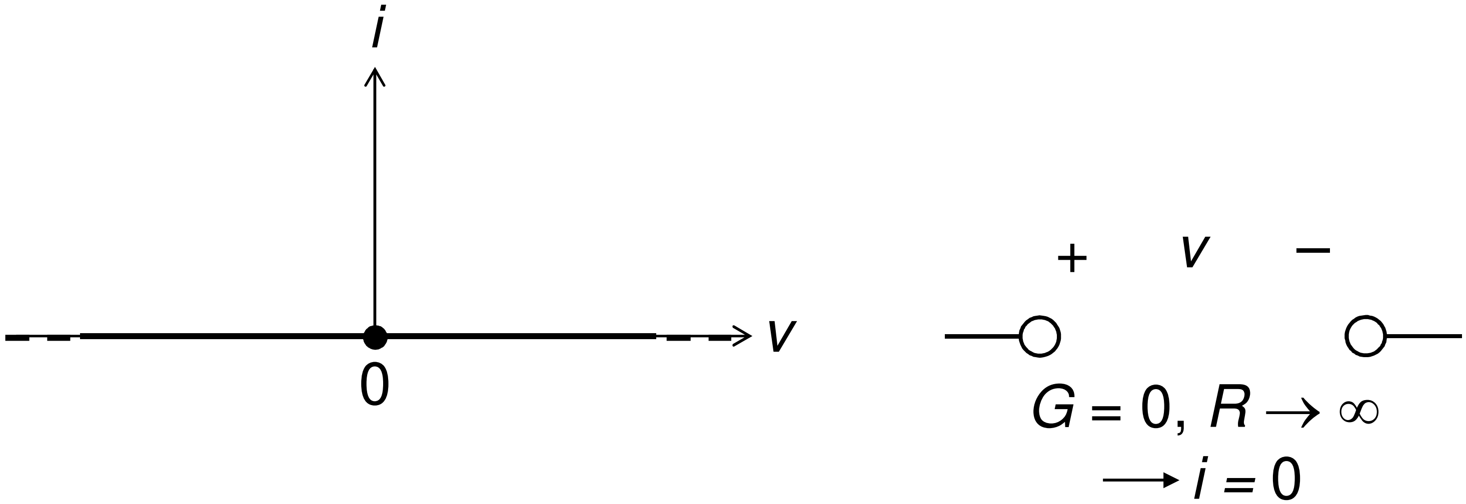


(a)



(b)

Figure 2.4



(a) (b)

Figure 2.5

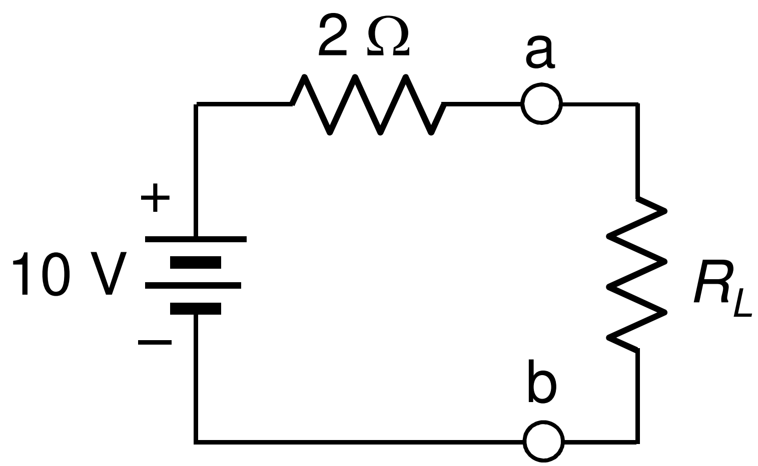


Figure 2.6

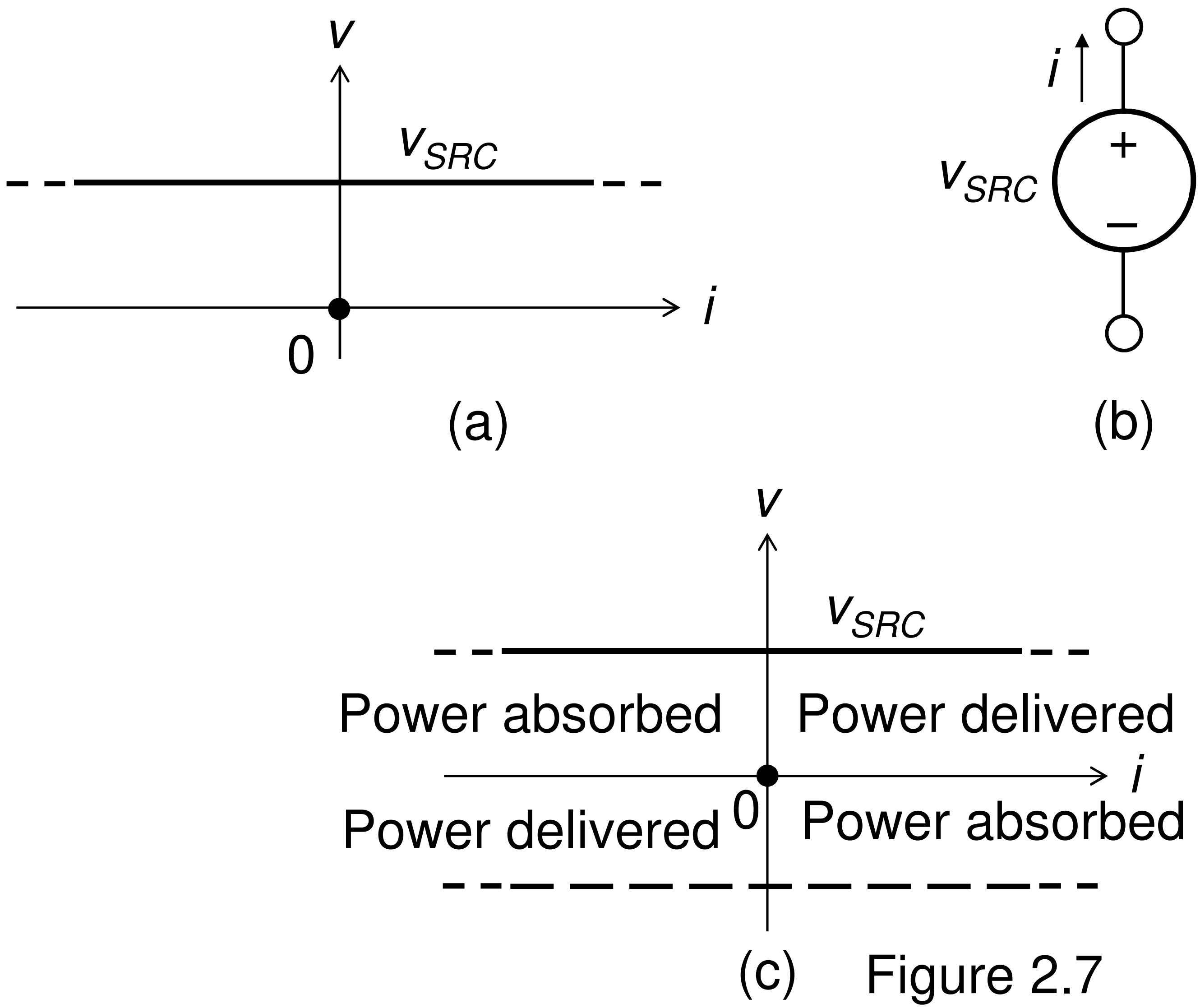

v
v_SRC
i
0
(a)
i
v_SRC
+
−
(b)
v
v_SRC
Power absorbed
Power delivered
i
0
Power delivered
Power absorbed
(c)

Figure 2.7

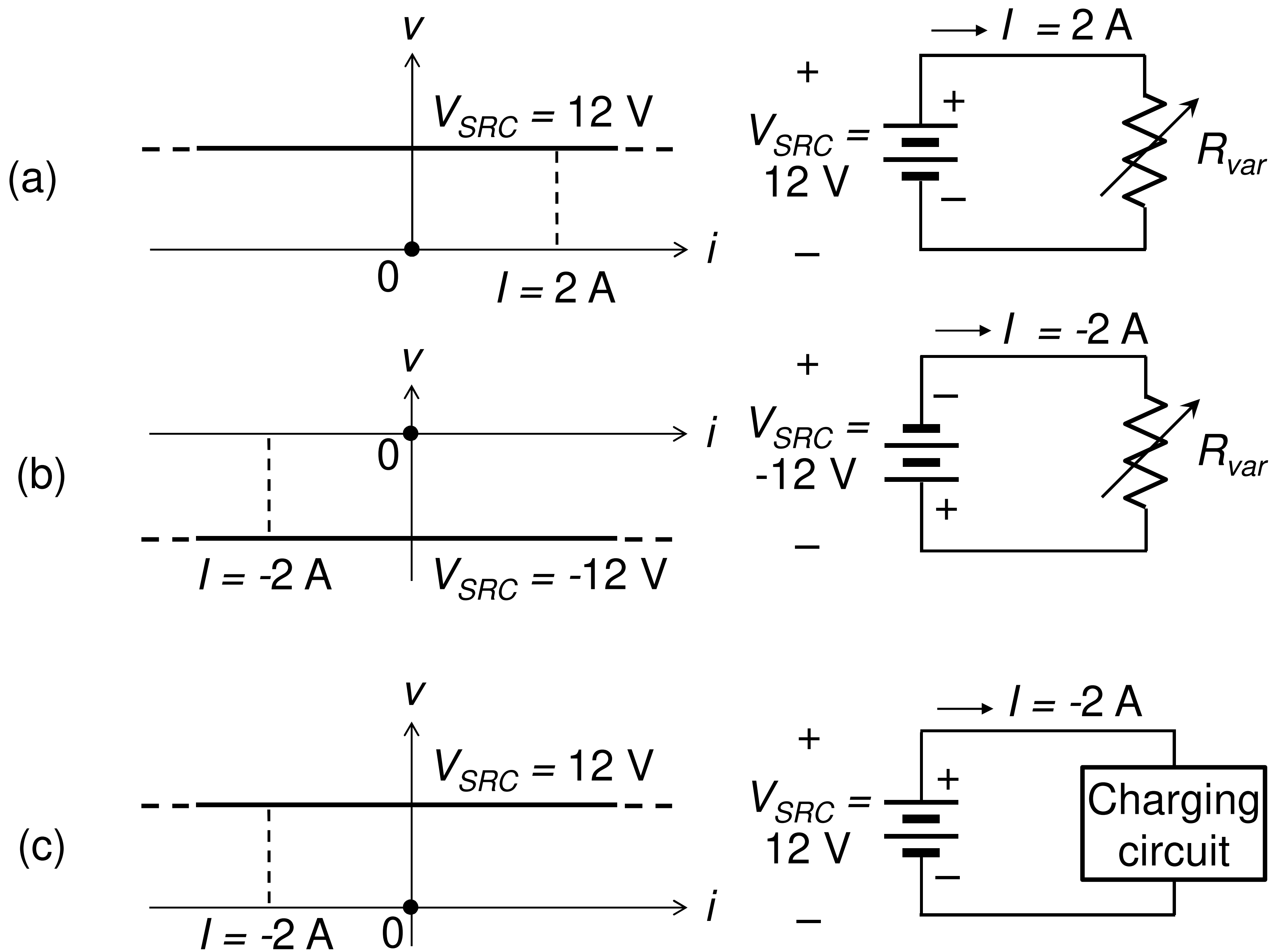

(a)
v
V_{SRC} = 12 V
i
0
I = 2 A
→ I = 2 A
+
V_{SRC} = 12 V
–
R_{var}
(b)
v
i
0
I = -2 A
V_{SRC} = -12 V
→ I = -2 A
+
V_{SRC} = -12 V
–
R_{var}
(c)
v
V_{SRC} = 12 V
i
I = -2 A
0
→ I = -2 A
+
V_{SRC} = 12 V
–
Charging circuit

Figure 2.8

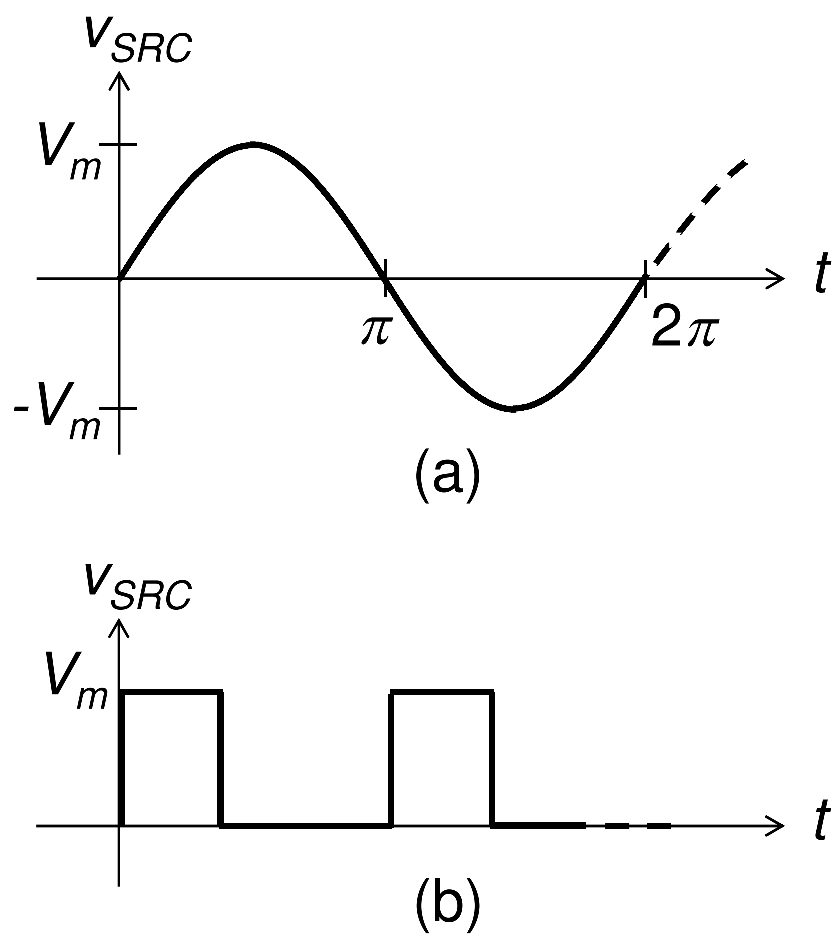


Figure 2.9

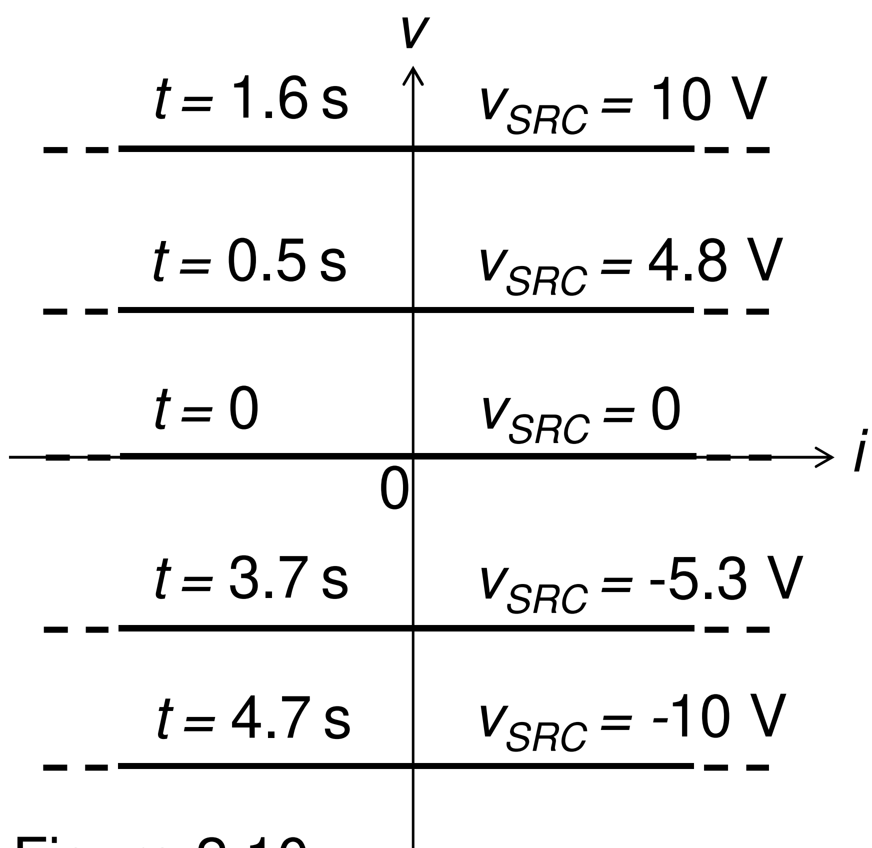
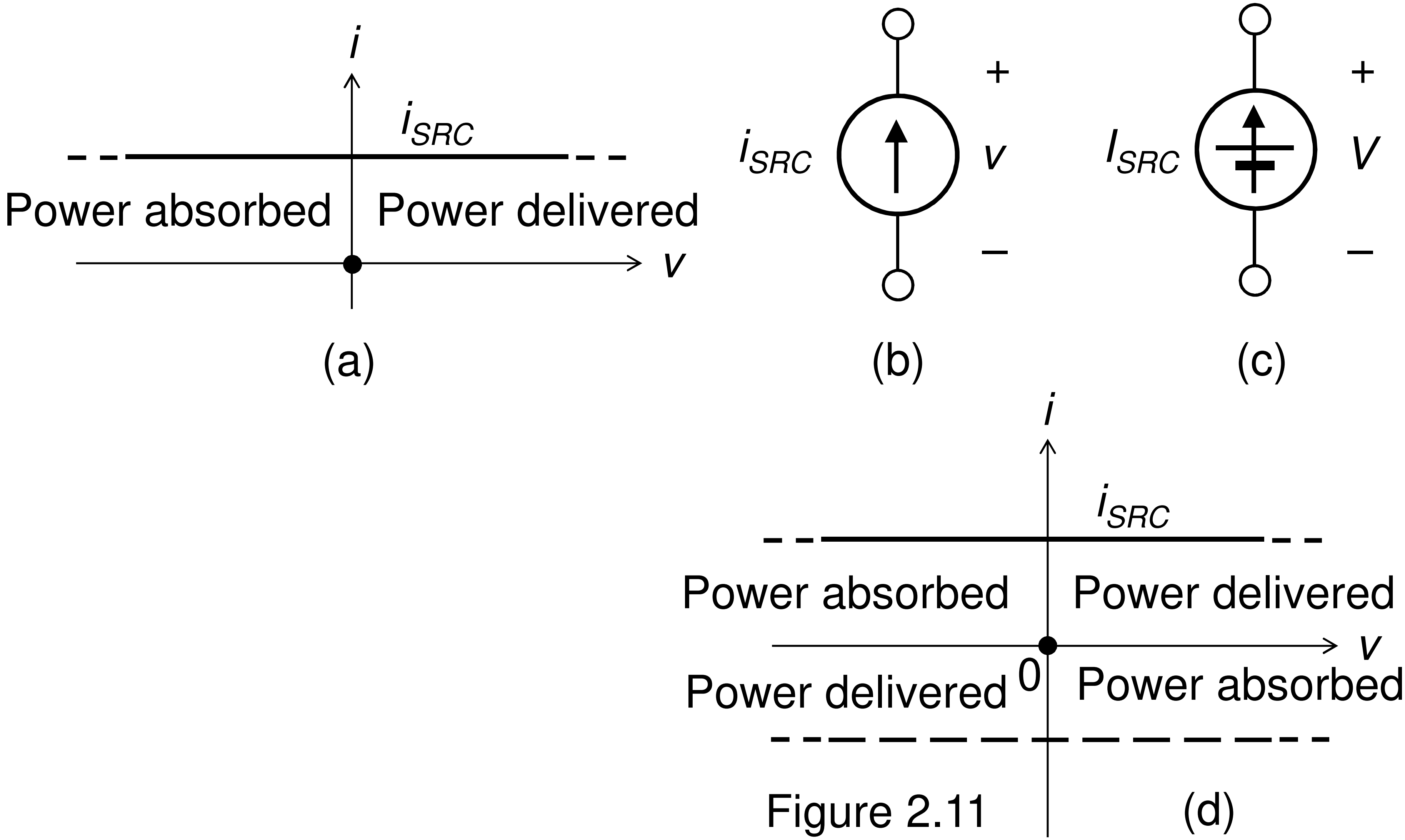

v
t = 1.6 s
v_{SRC} = 10 V
t = 0.5 s
v_{SRC} = 4.8 V
t = 0
v_{SRC} = 0
i
0
t = 3.7 s
v_{SRC} = -5.3 V
t = 4.7 s
v_{SRC} = -10 V

Figure 2.10



i
i_{SRC}
Power absorbed
Power delivered
v
(a)
+
i_{SRC}
v
–
(b)
+
I_{SRC}
V
–
(c)
i
i_{SRC}
Power absorbed
Power delivered
v
0
Power delivered
Power absorbed
(d)

Figure 2.11

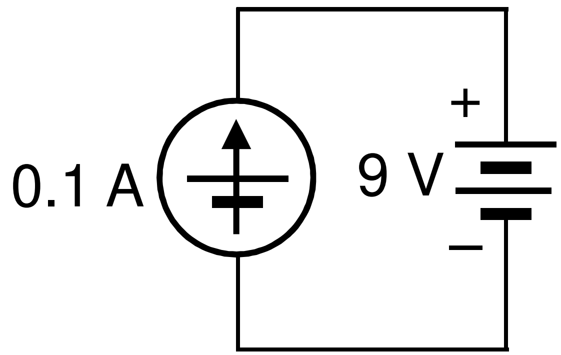


Figure 2.12

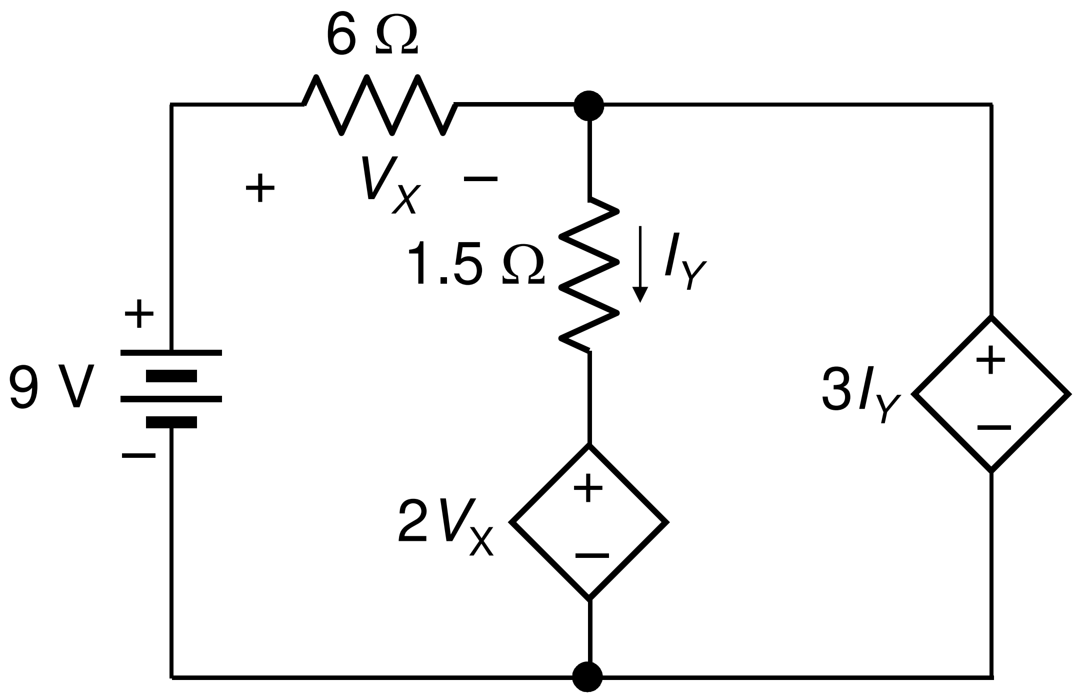


Figure 2.13

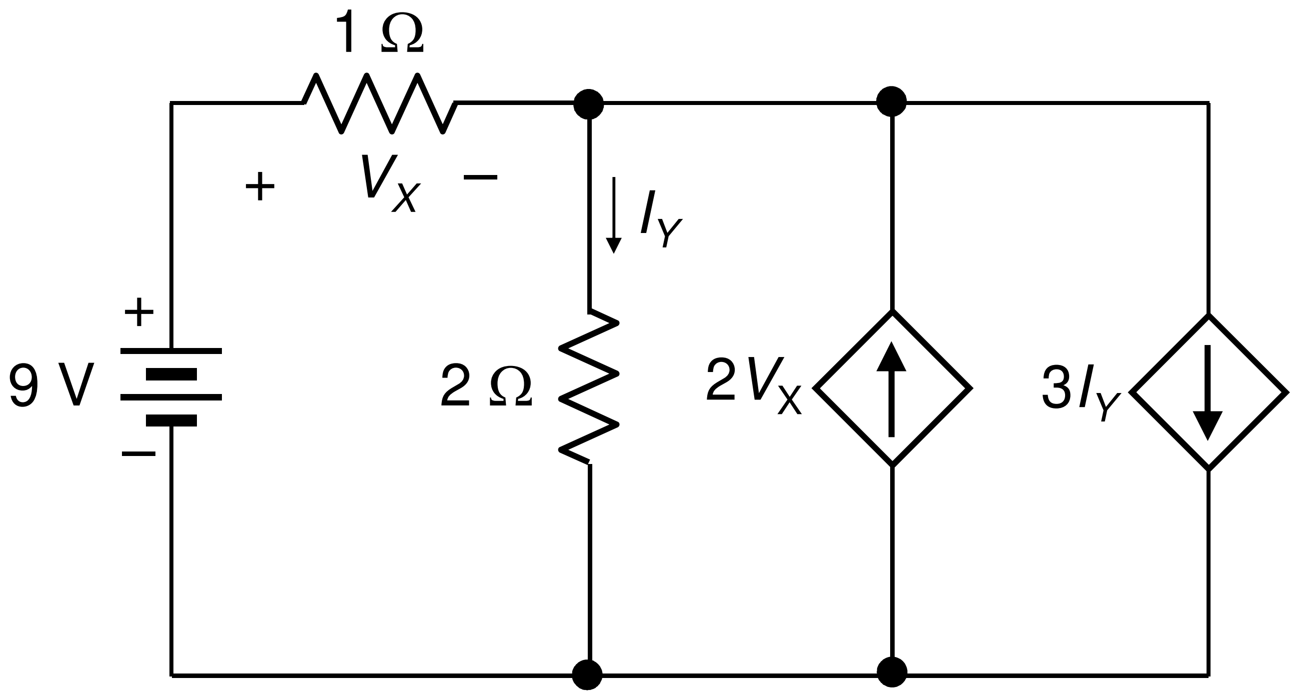
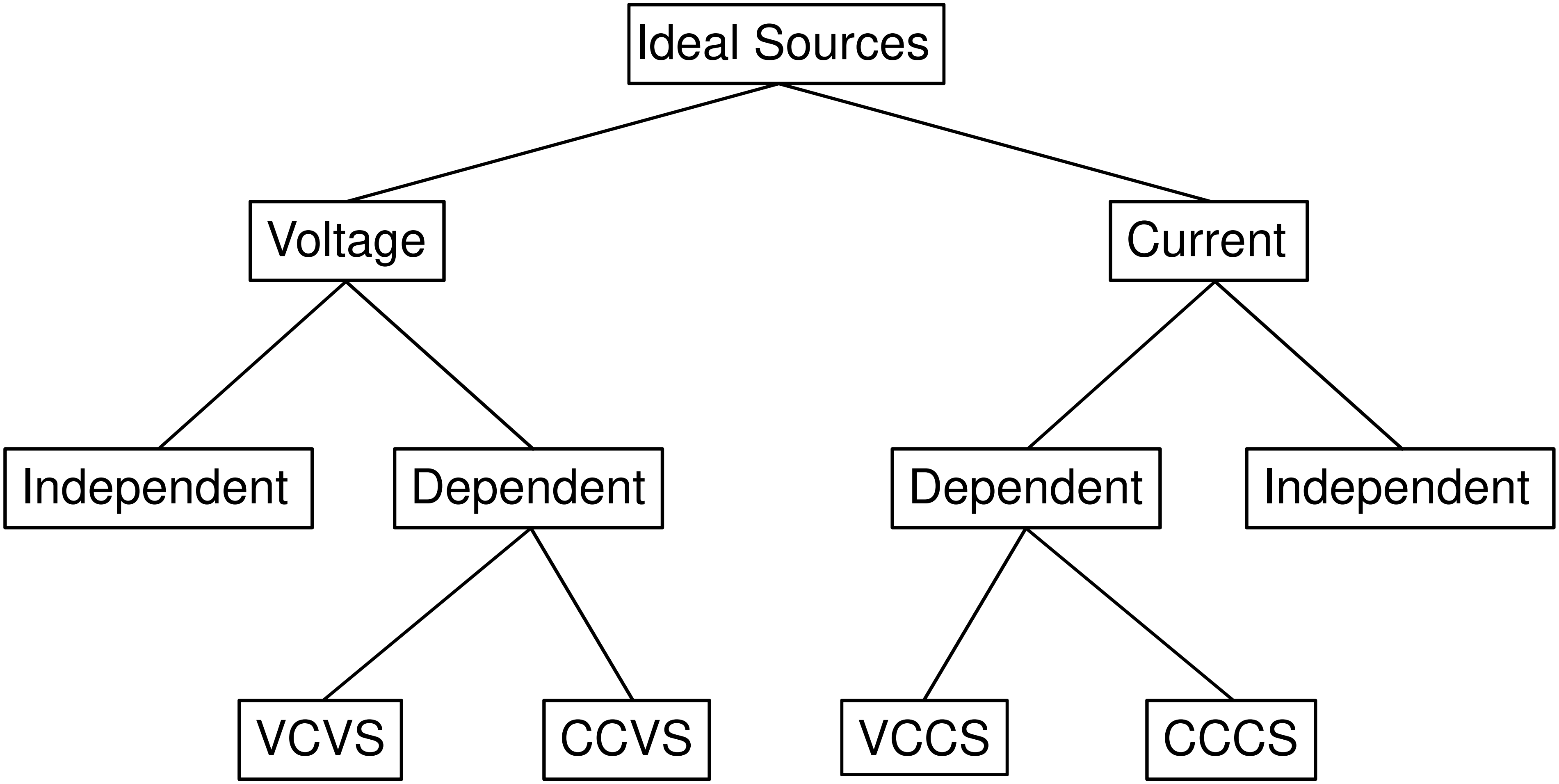


Figure 2.14


Ideal Sources
Voltage
Current
Independent
Dependent
Dependent
Independent
VCVS
CCVS
VCCS
CCCS
Figure 2.15

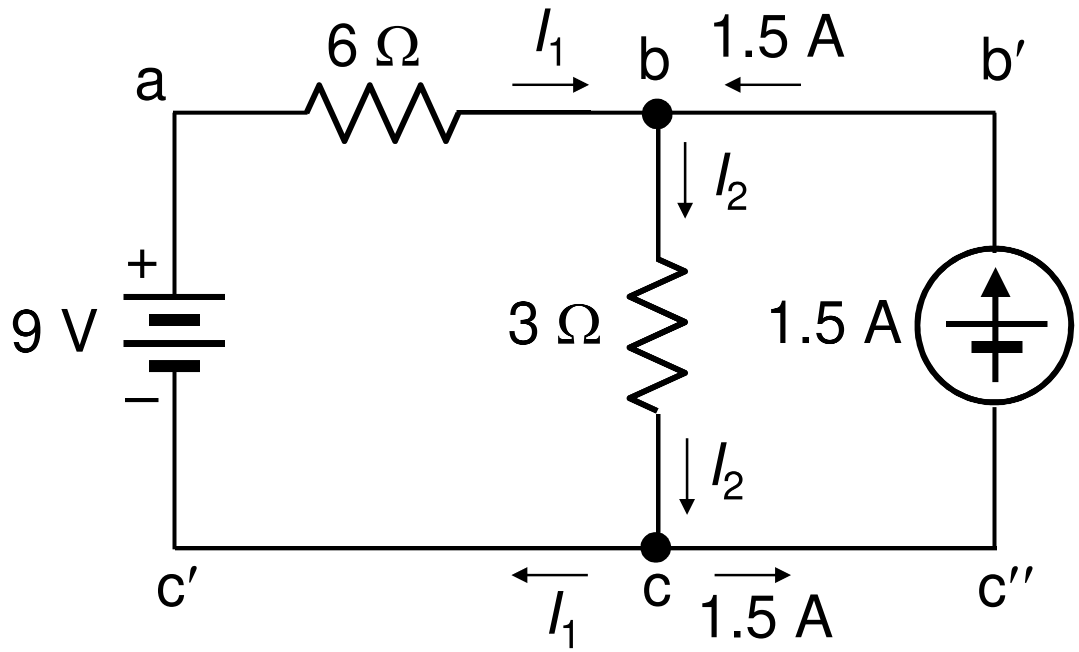


Figure 2.16

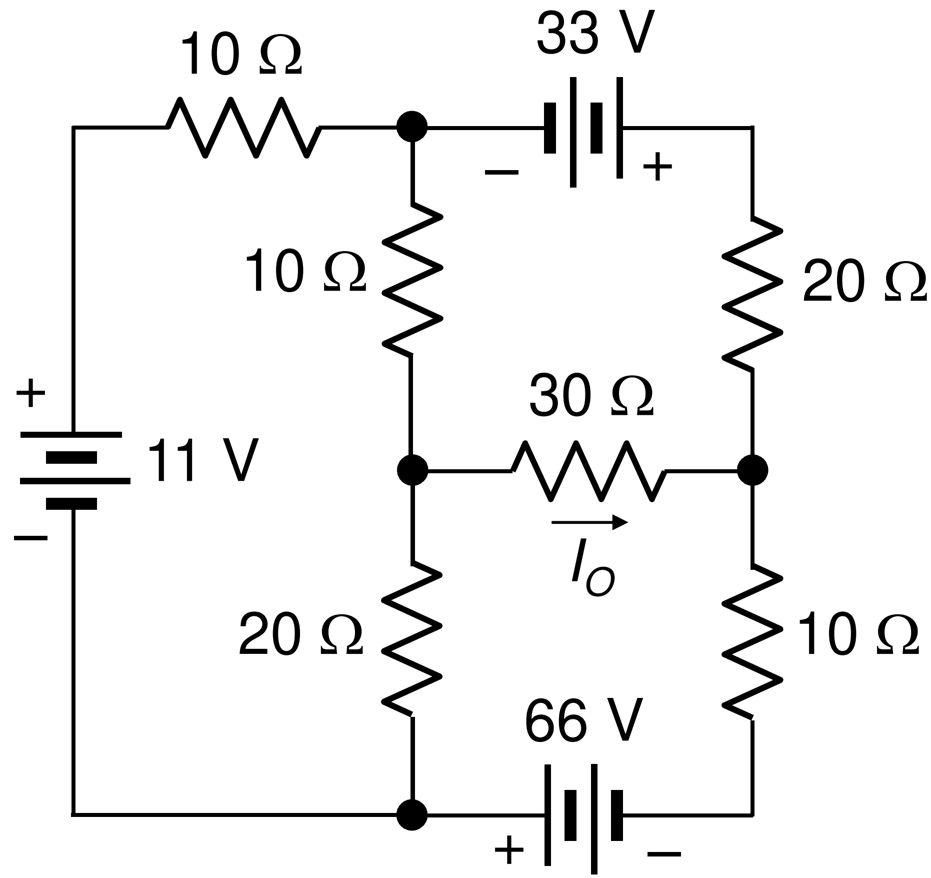


Figure 2.17

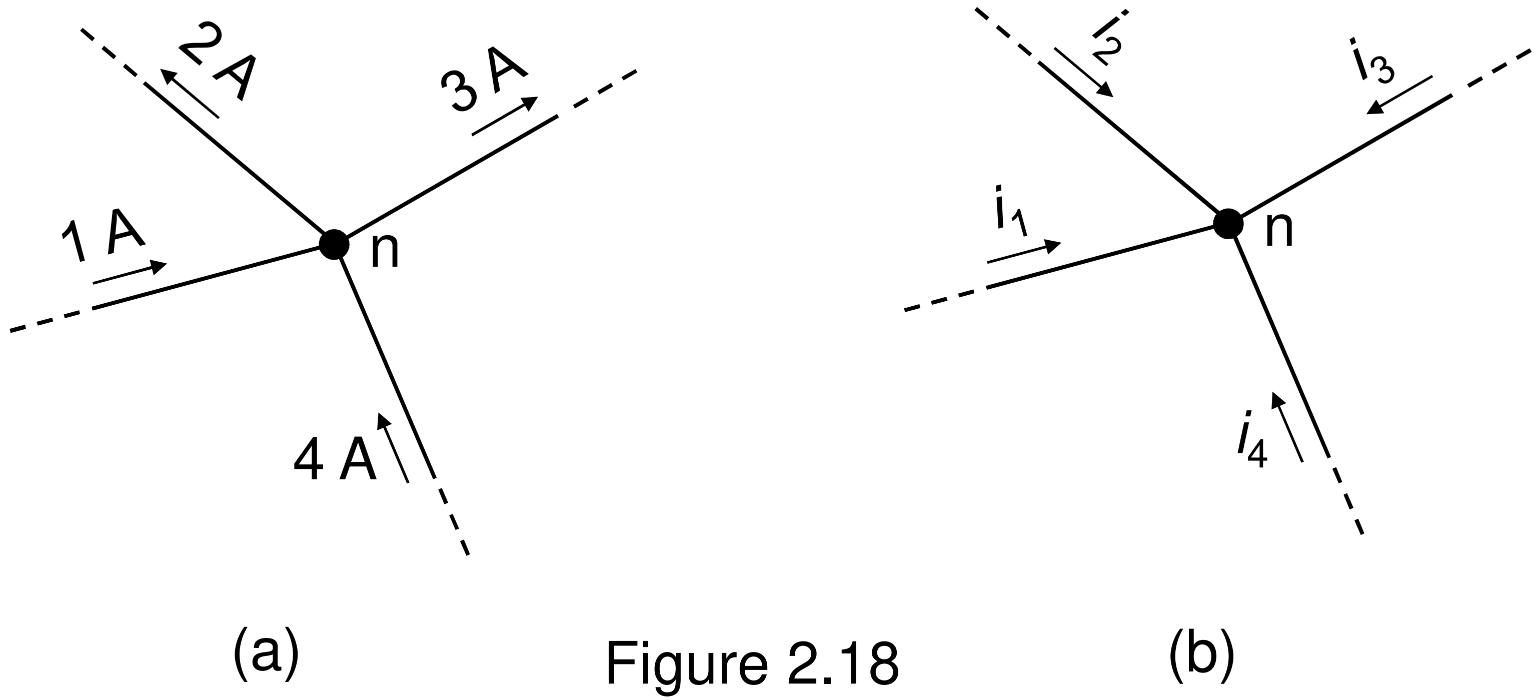
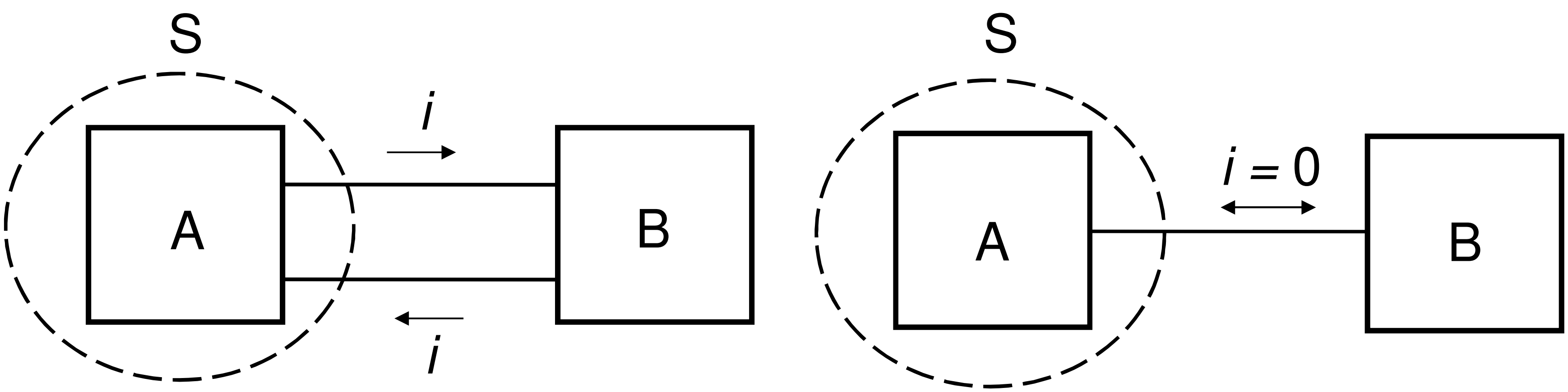


Figure 2.18



(a) Figure 2.19 (b)

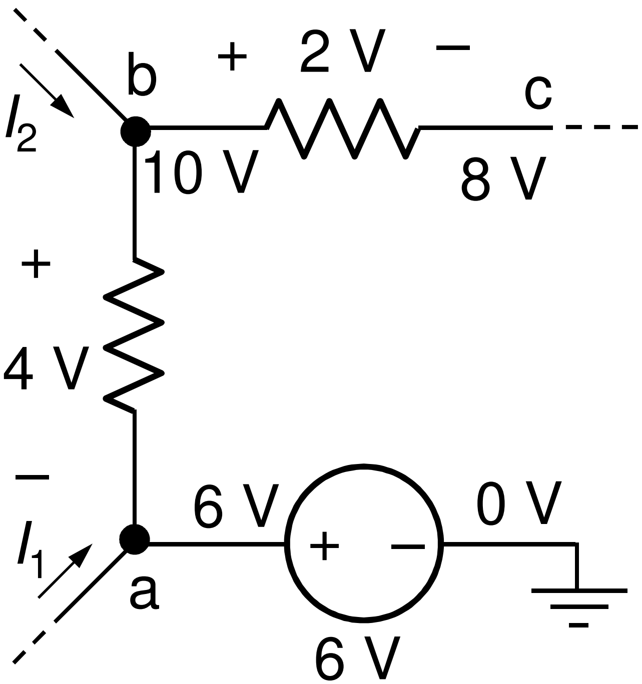


Figure 2.20

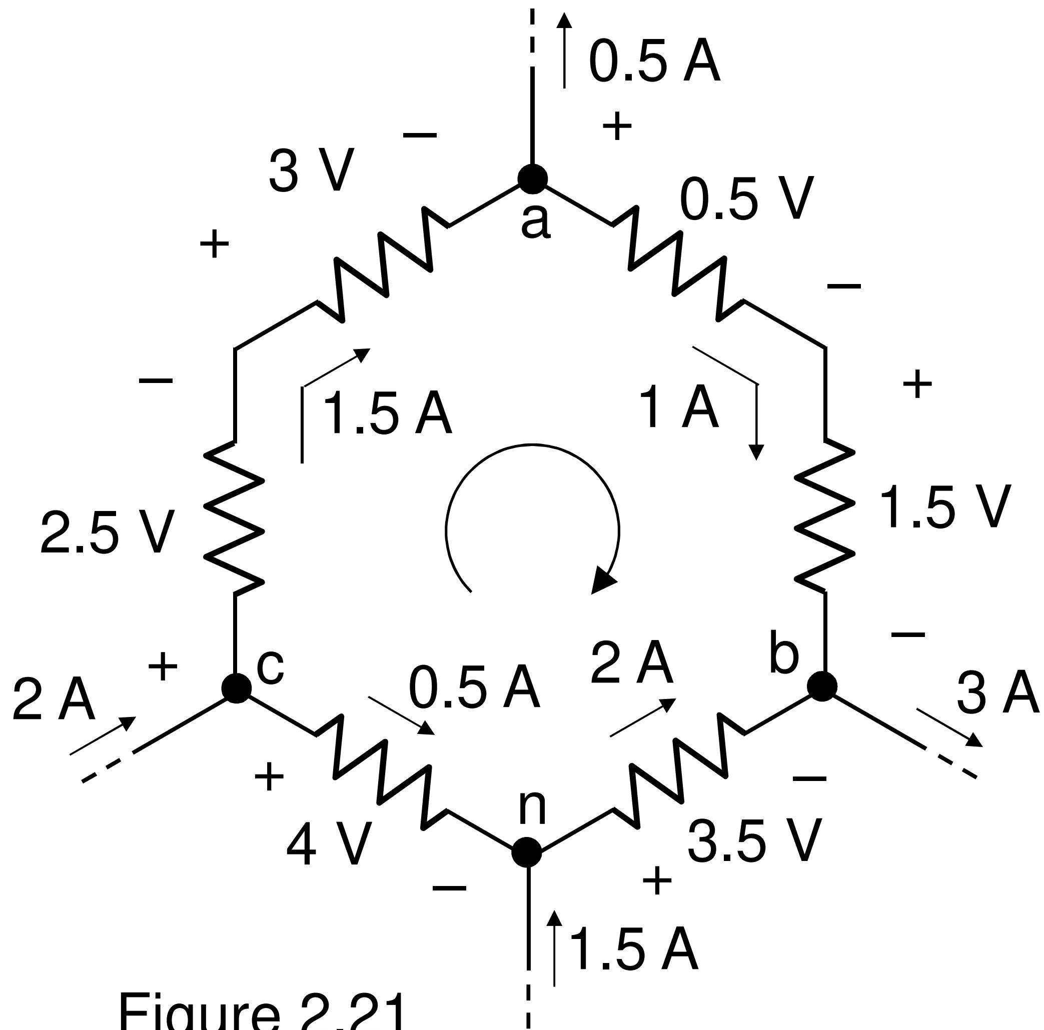


Figure 2.21

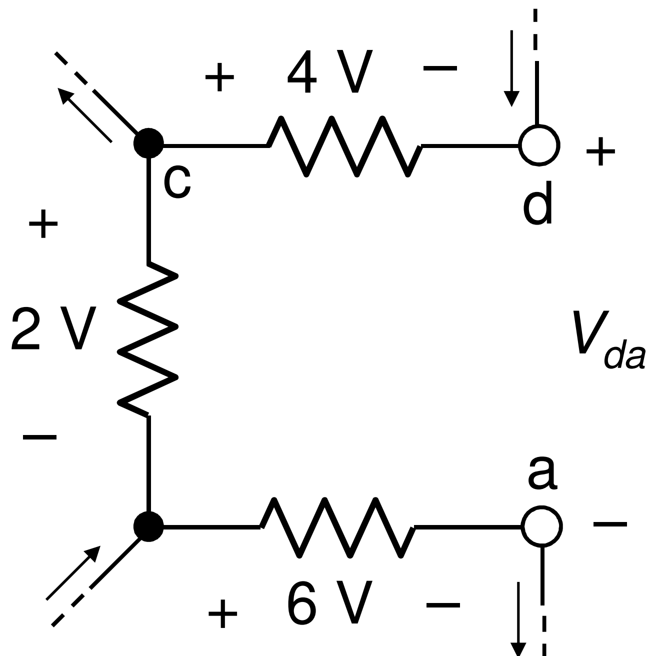


Figure 2.22

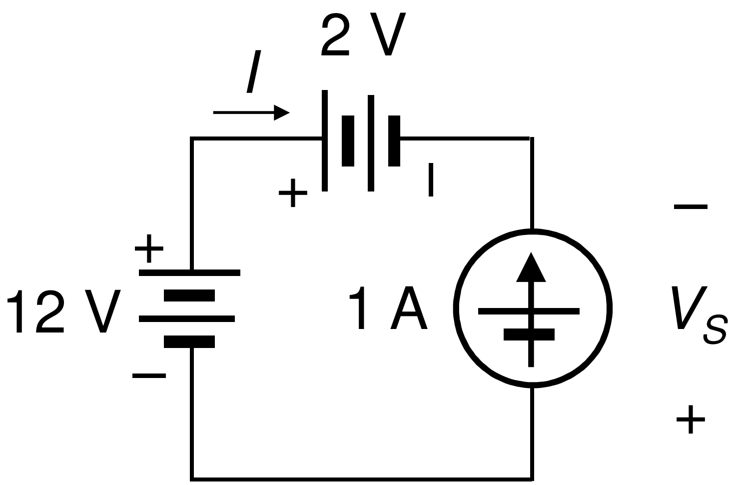


Figure 2.23

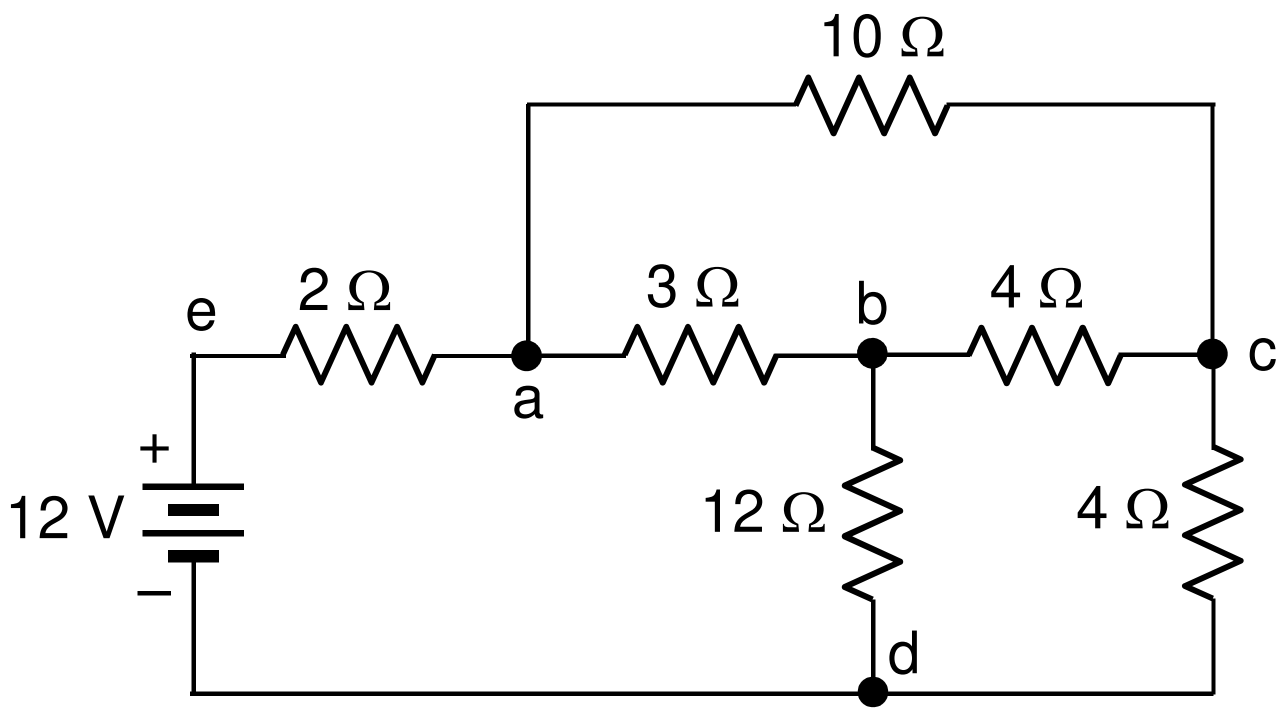


Figure 2.24

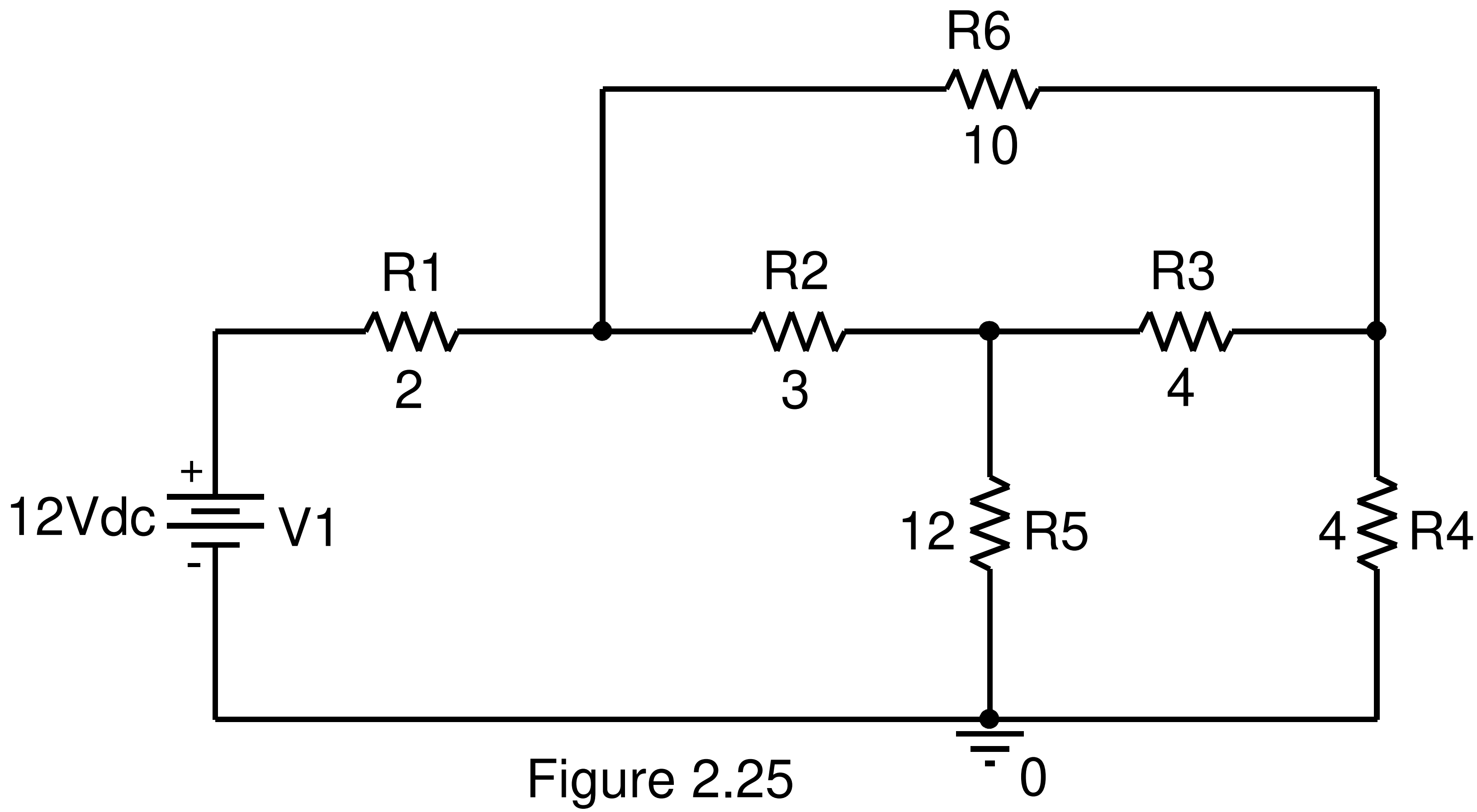


Figure 2.25

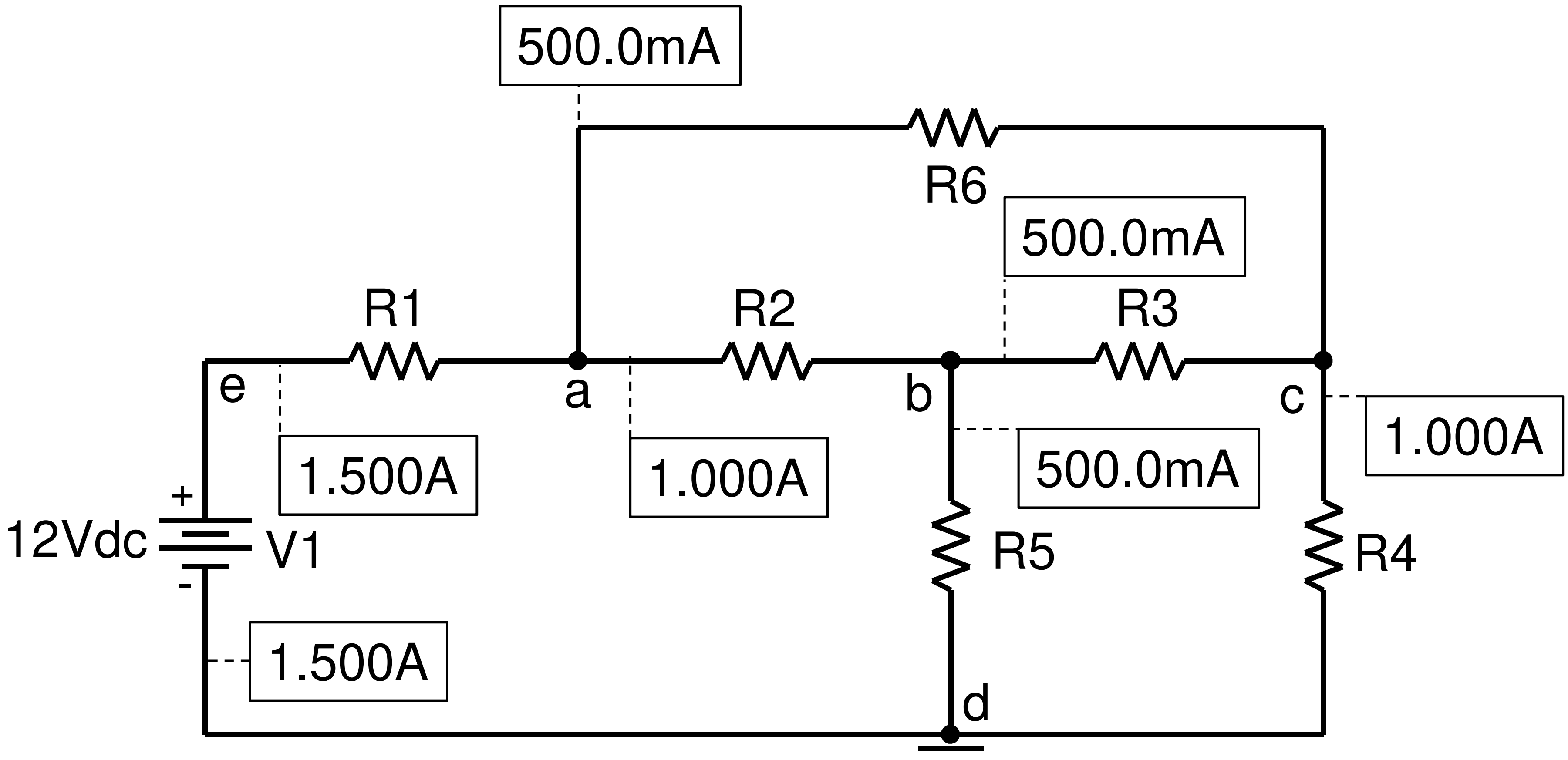

500.0mA
R6
500.0mA
R1
R2
R3
e
a
b
c
1.000A
500.0mA
1.500A
1.000A
+
12Vdc
V1
-
R5
R4
1.500A
d
0

Figure 2.26

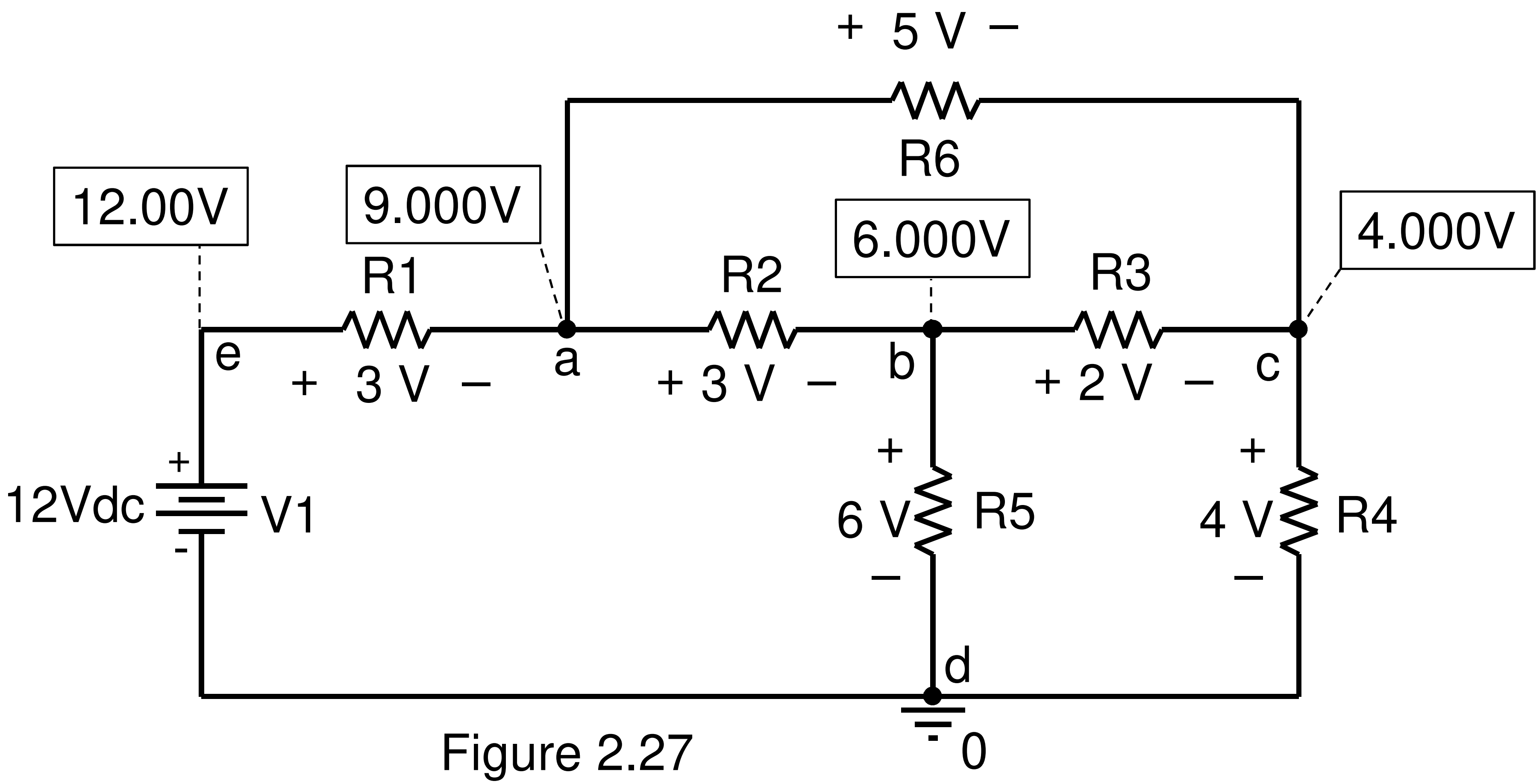

+ 5 V –
R6
12.00V
9.000V
6.000V
4.000V
R1
R2
R3
e
a
b
c
+ 3 V –
+ 3 V –
+ 2 V –
+
12Vdc
V1
-
+
6 V
R5
–
+
4 V
R4
–
d
0

Figure 2.27

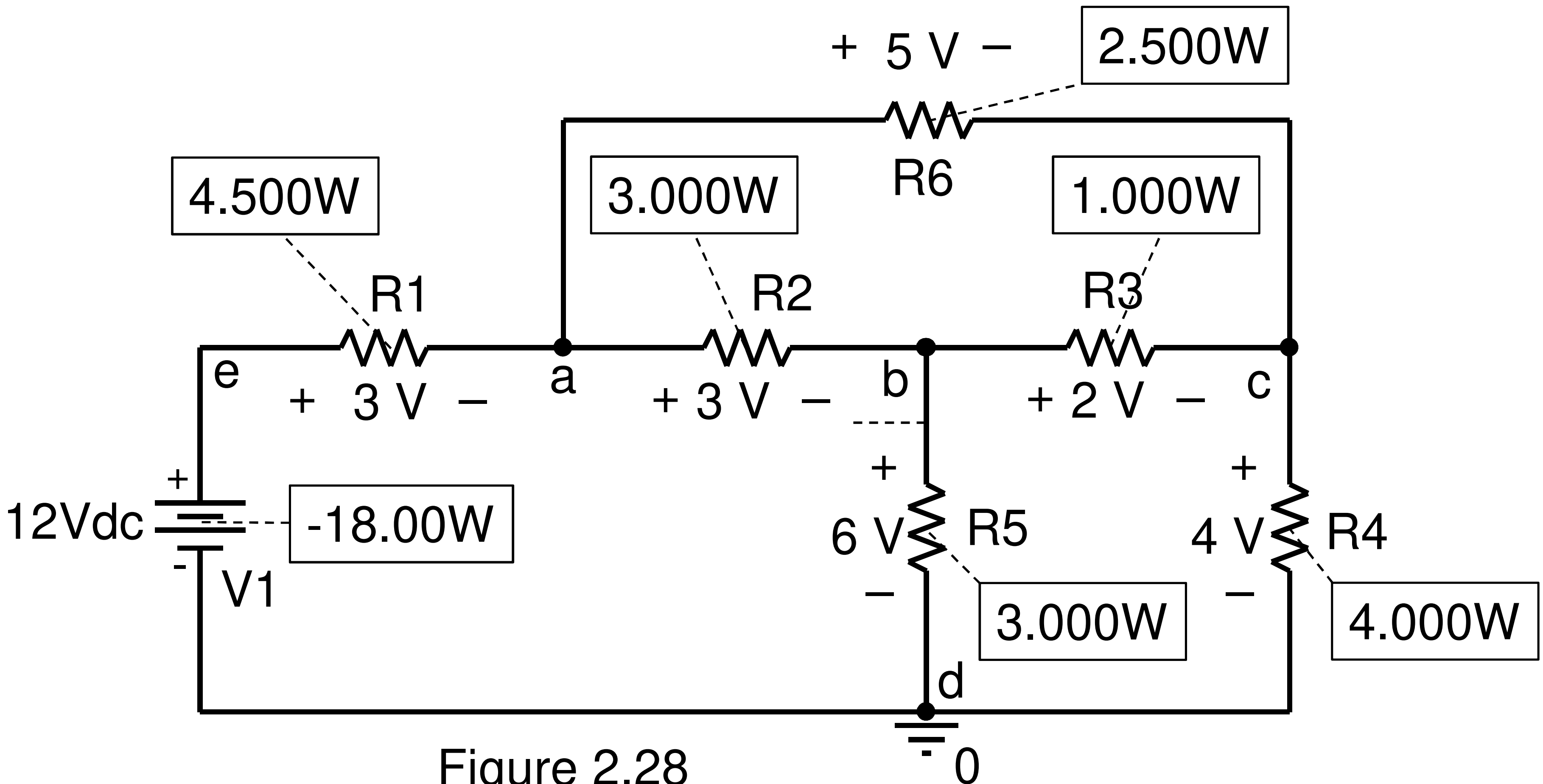

+ 5 V −
2.500W
R6
4.500W
3.000W
1.000W
R1
R2
R3
e
a
b
c
+ 3 V −
+ 3 V −
+ 2 V −
+
12Vdc
-
V1
-18.00W
+
6 V
−
R5
3.000W
+
4 V
−
R4
4.000W
d
0

Figure 2.28

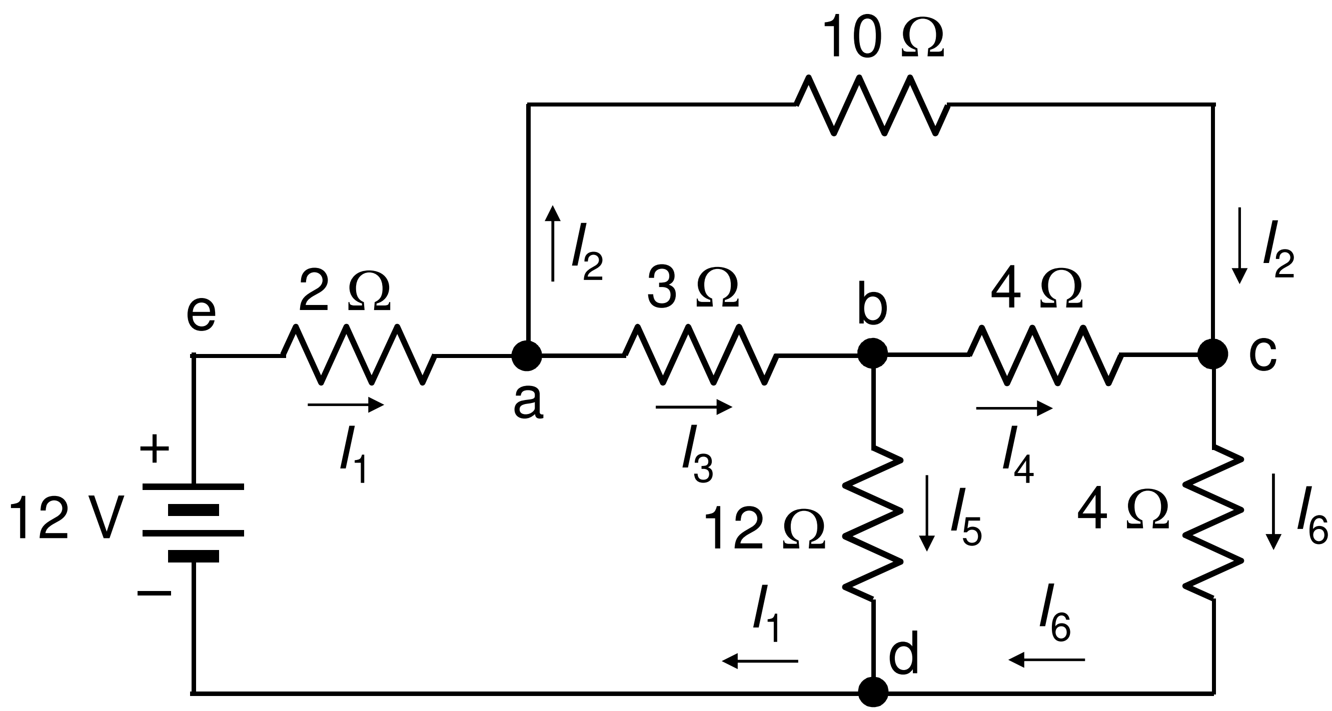


Figure 2.29

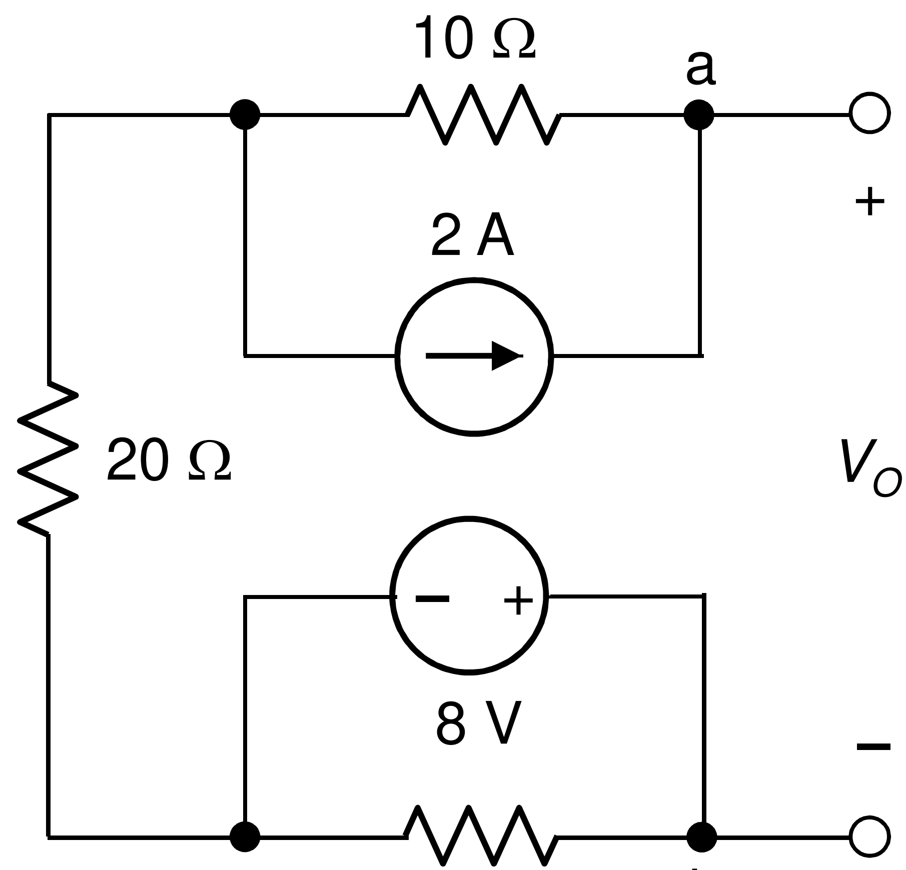


Figure 2.30

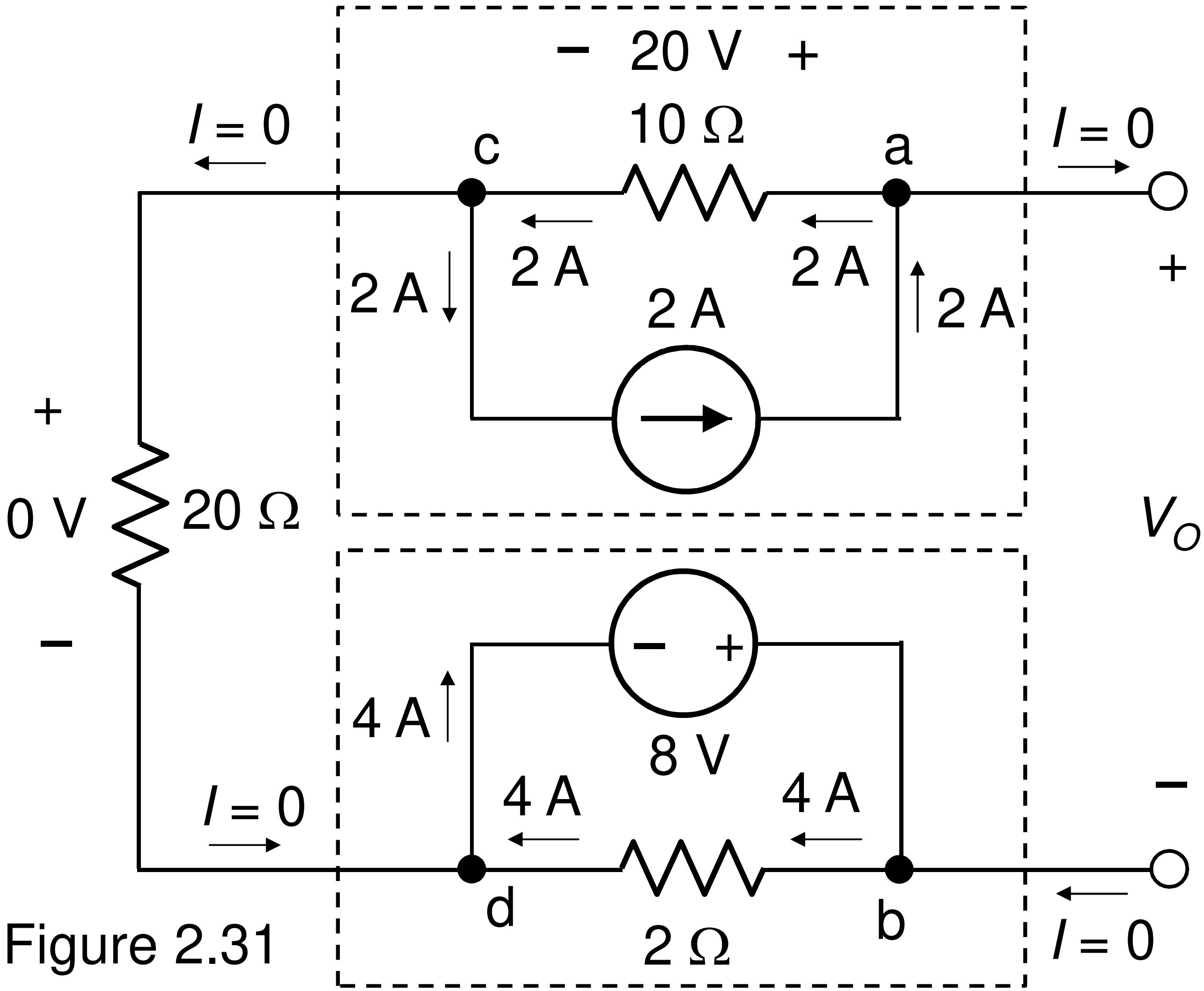


Figure 2.31

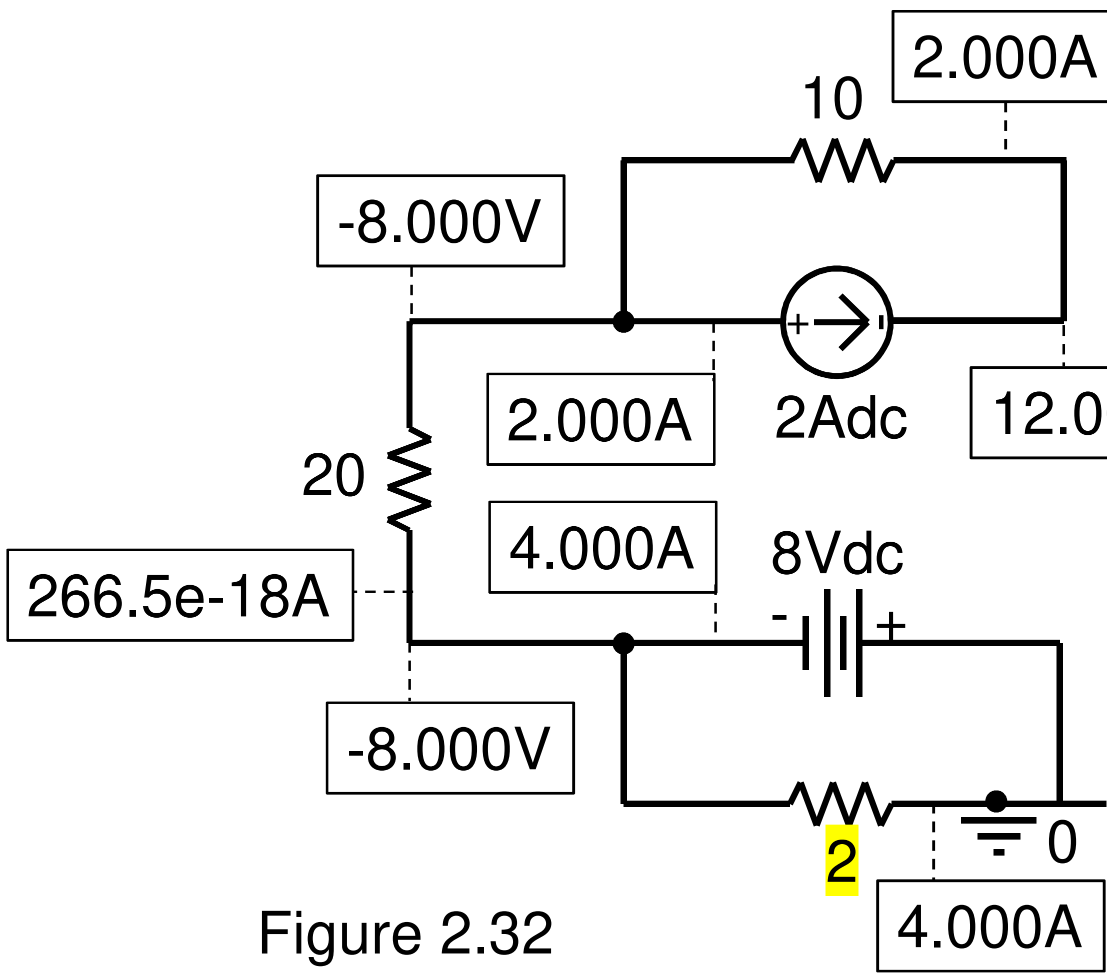

2.000A
10
-8.000V
2.000A
2Adc
12.00V
20
4.000A
8Vdc
266.5e-18A
-8.000V
2
0
4.000A

Figure 2.32

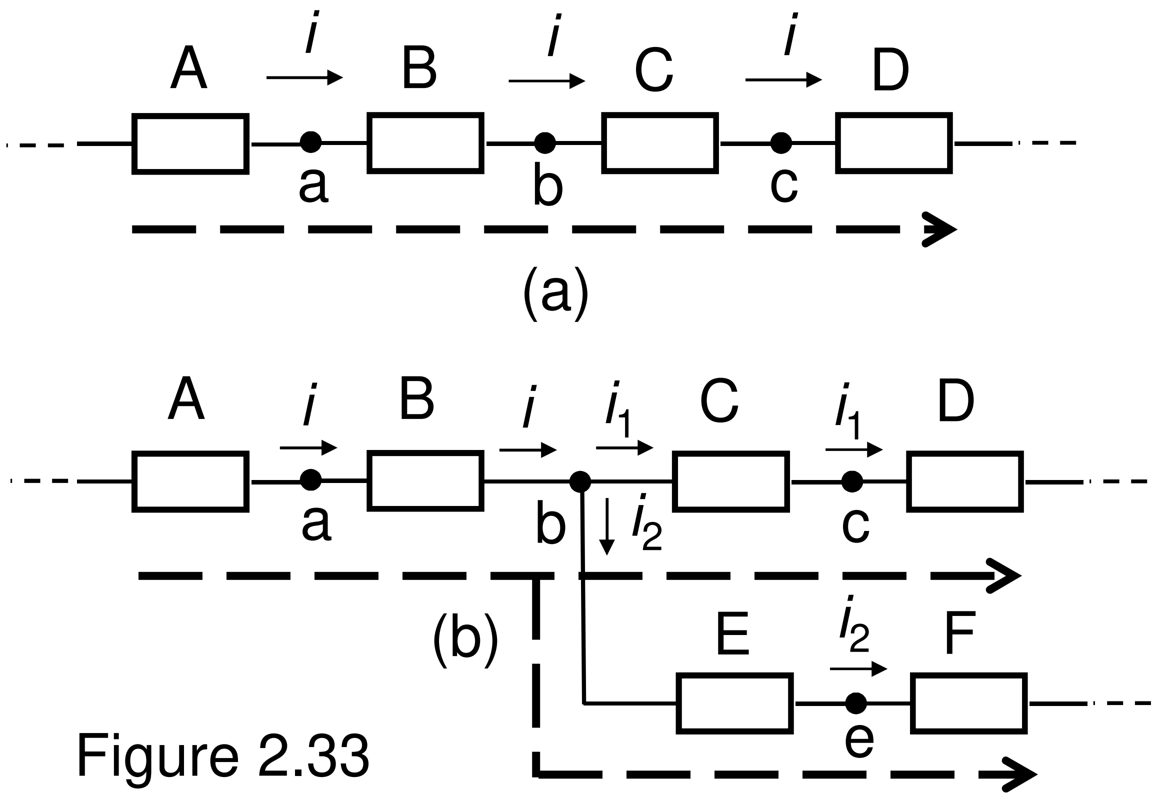


Figure 2.33

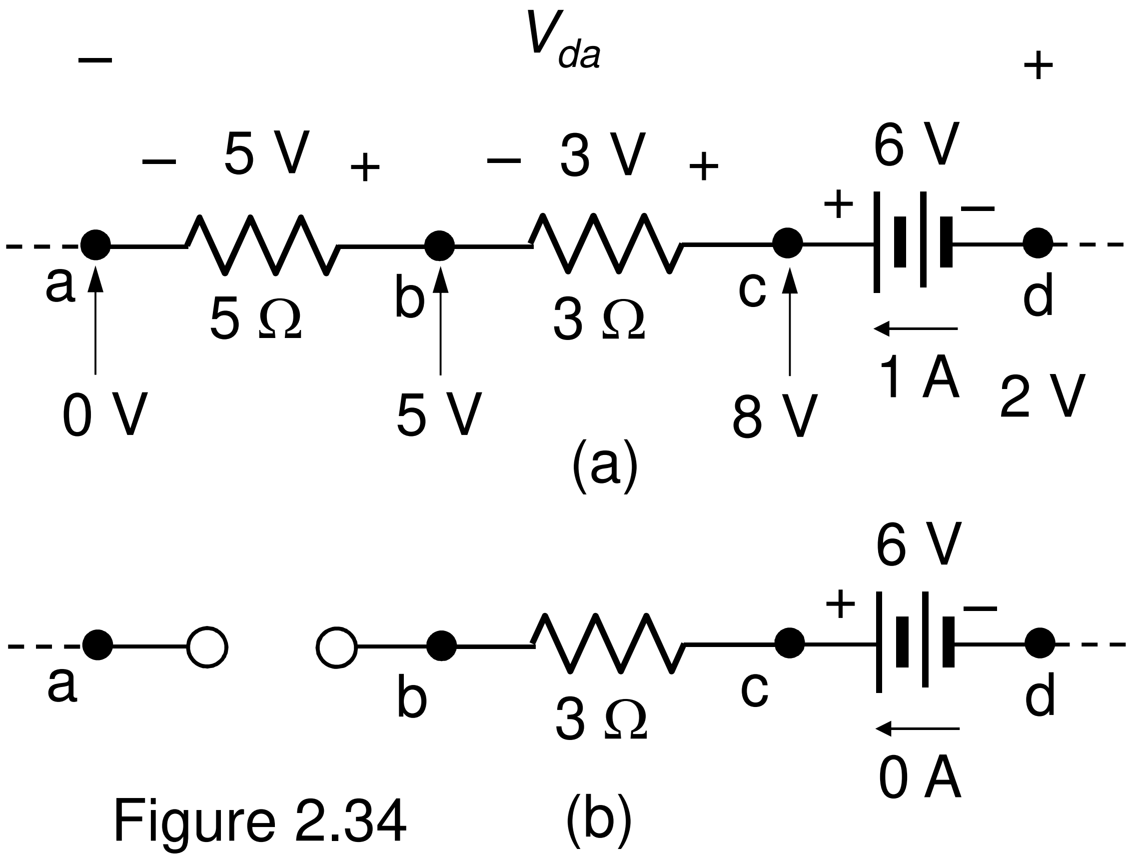


Figure 2.34

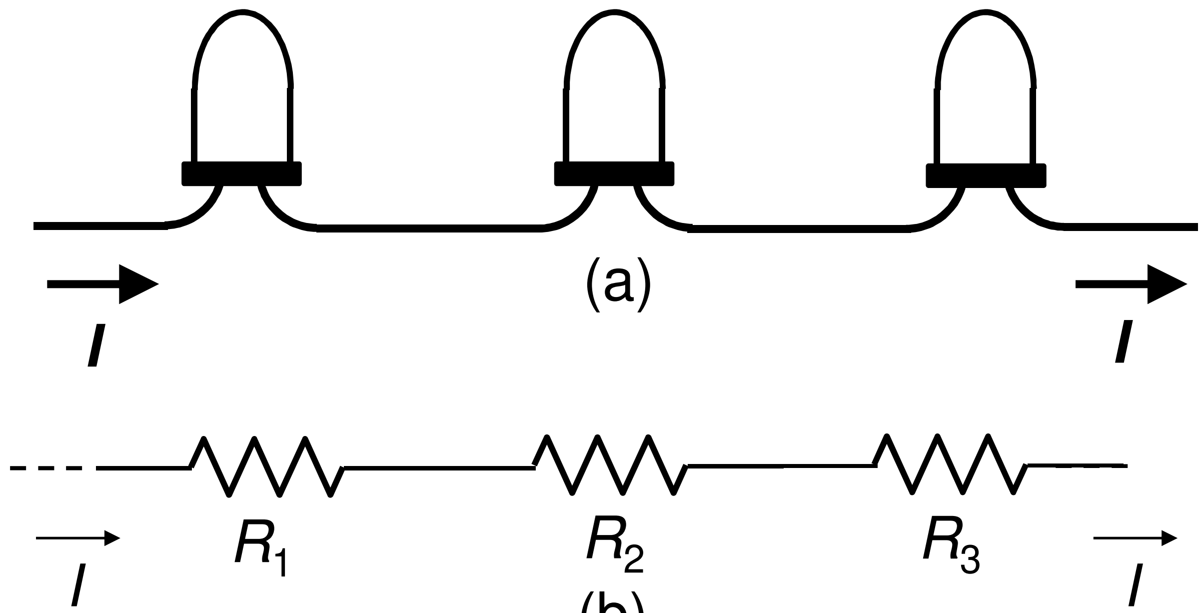


Figure 2.35

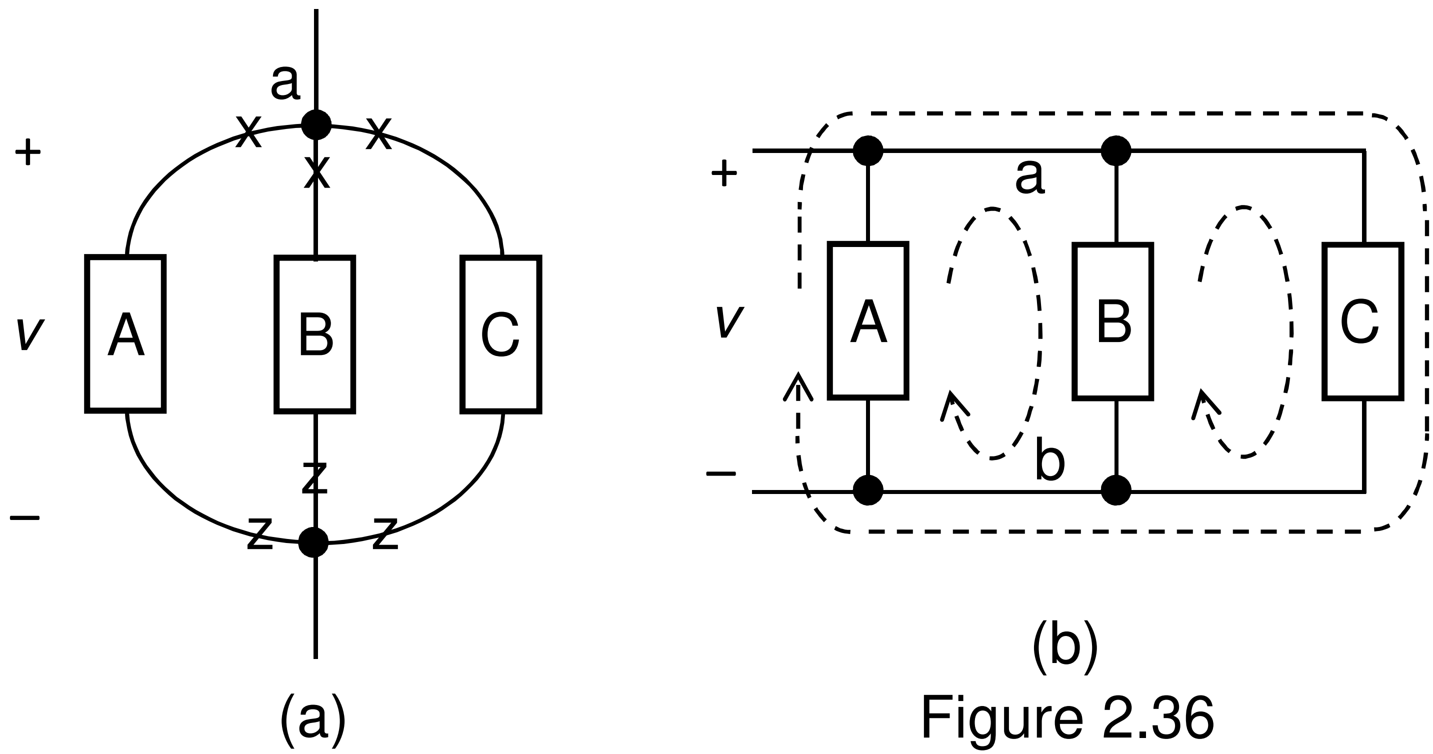


Figure 2.36

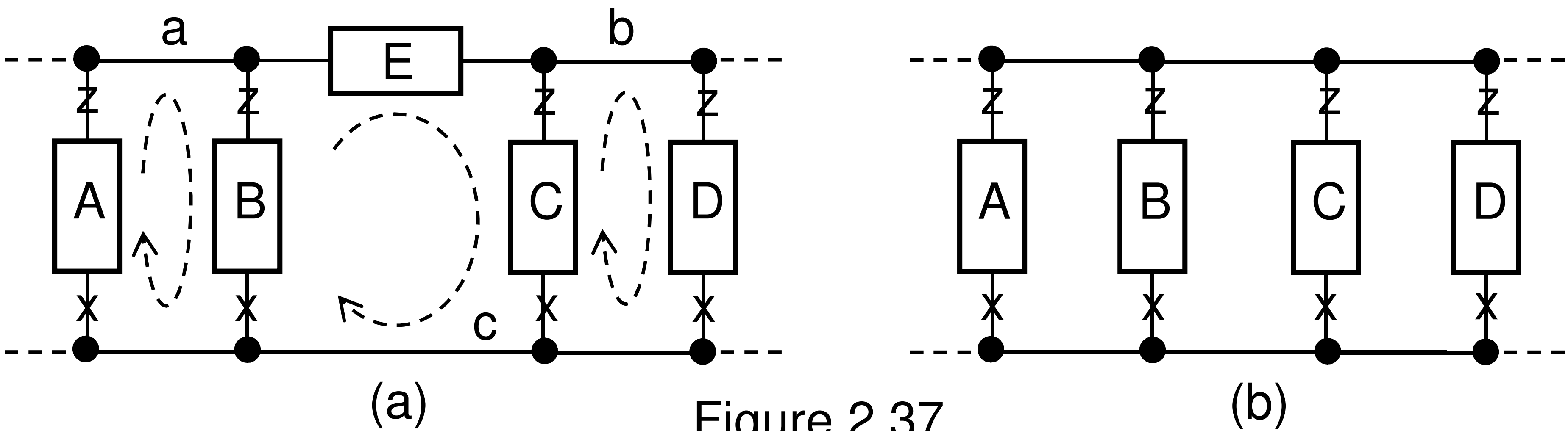


Figure 2.37

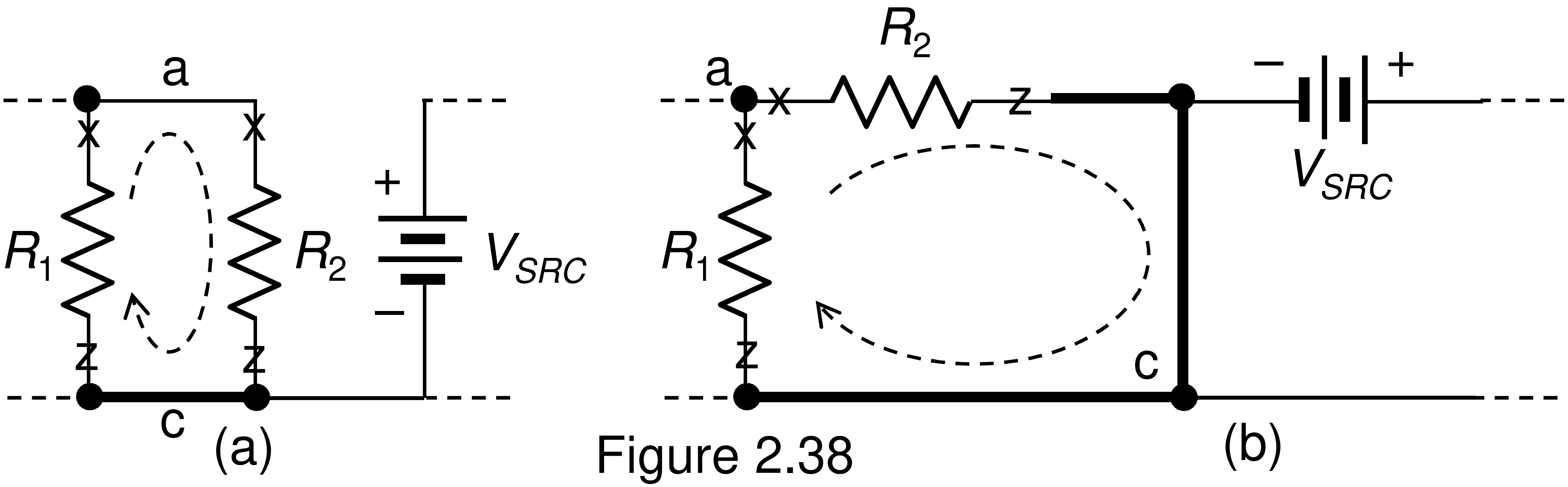


Figure 2.38

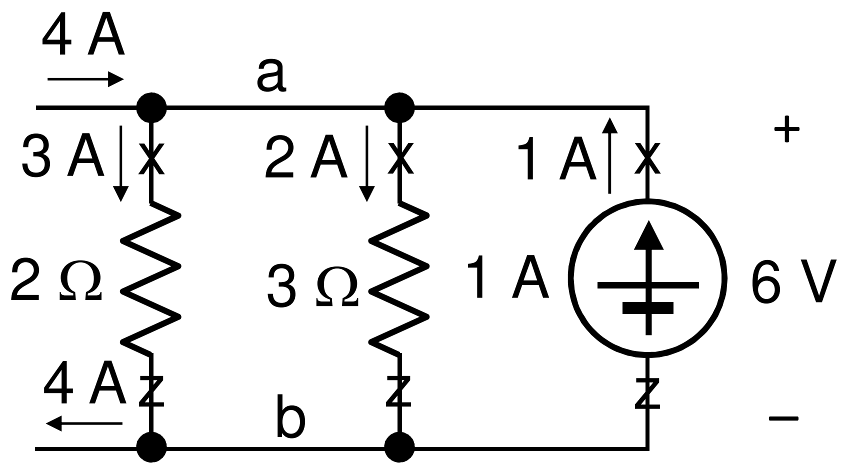


Figure 2.39

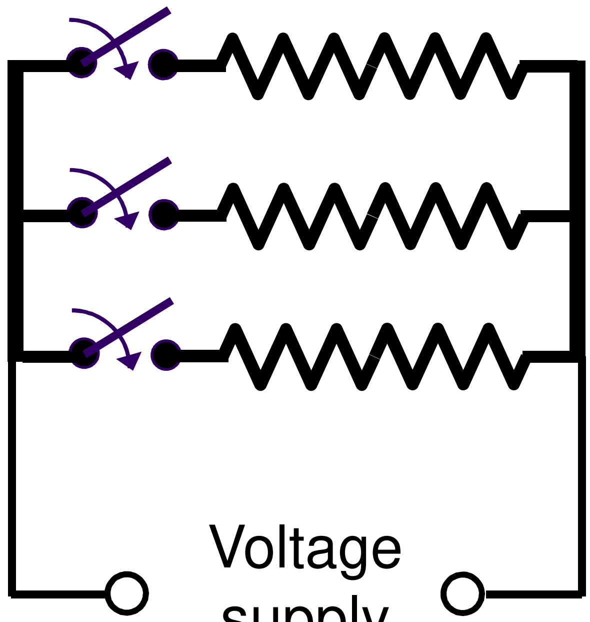


Figure 2.40

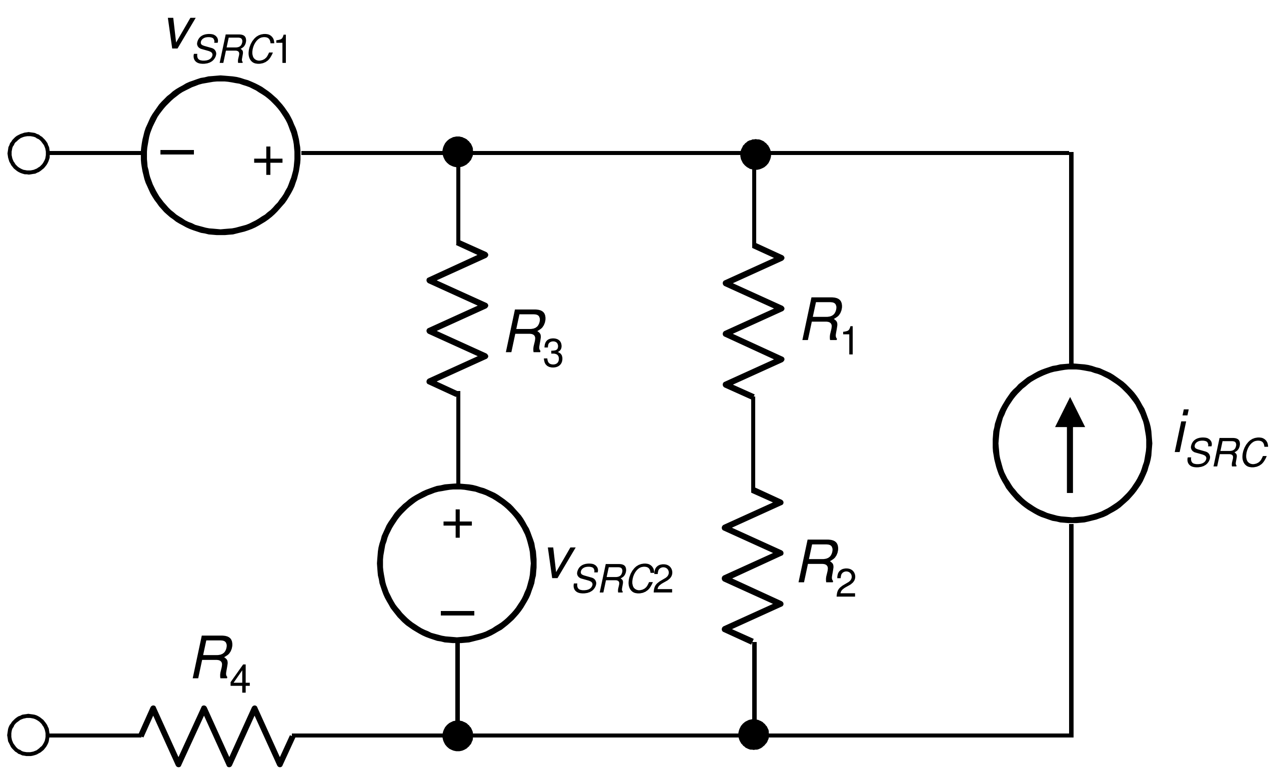


Figure 2.41

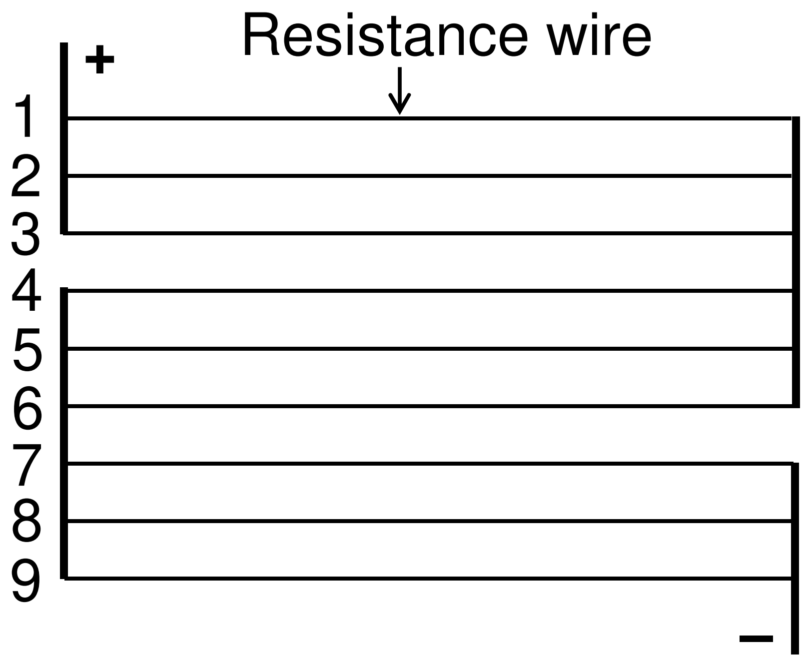


Figure 2.42

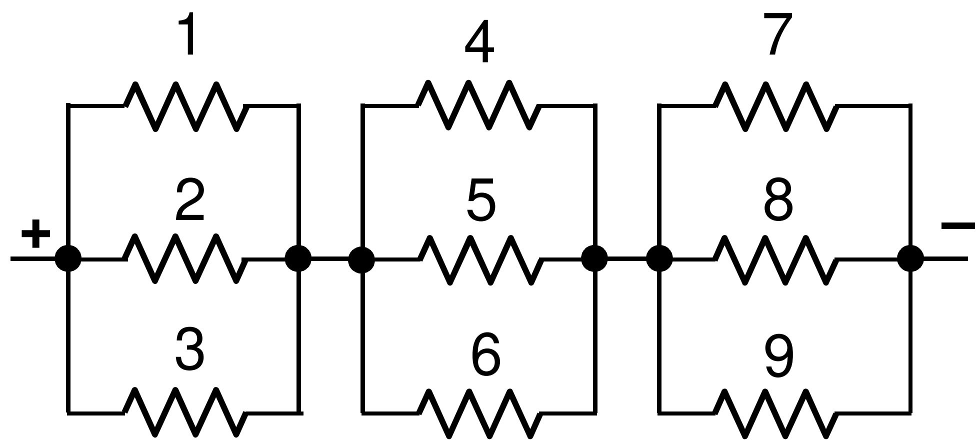


Figure 2.43

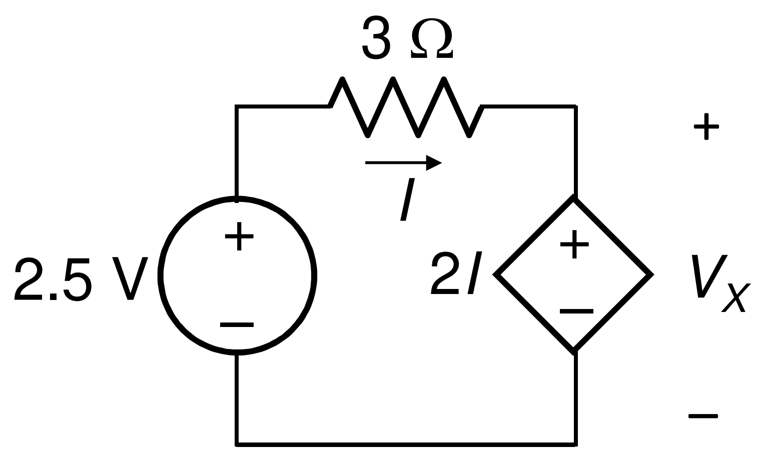


Figure 2.44

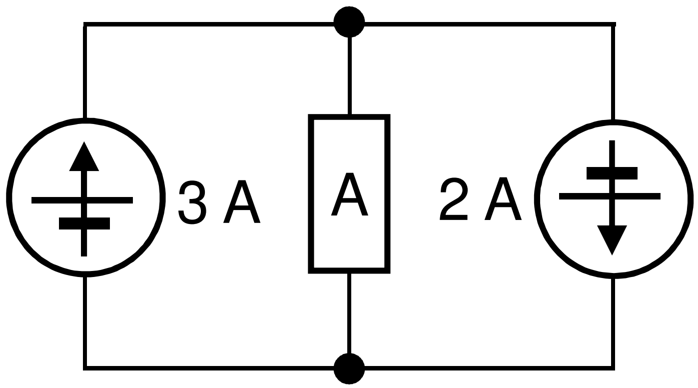
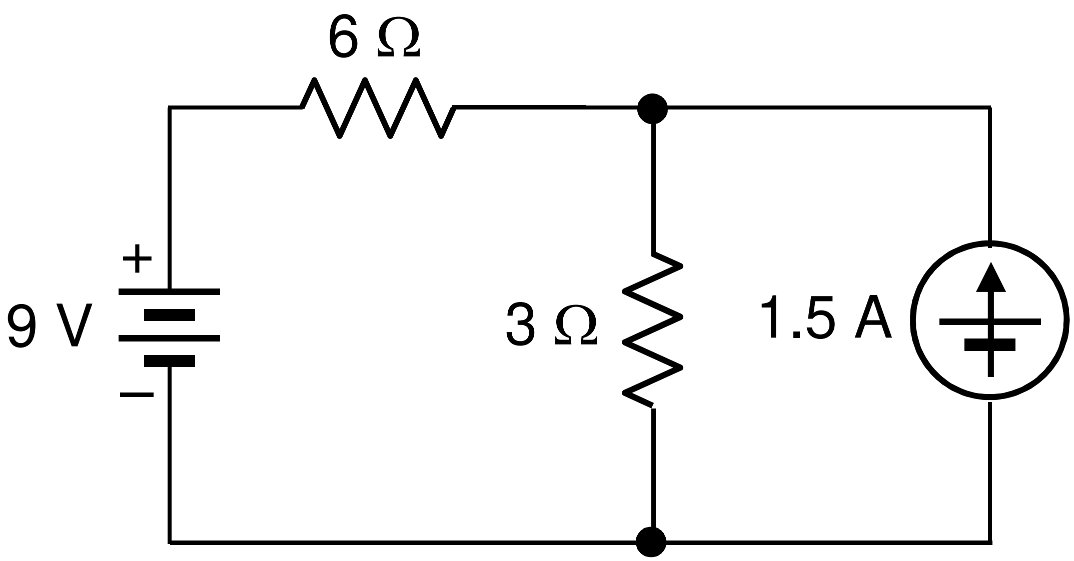
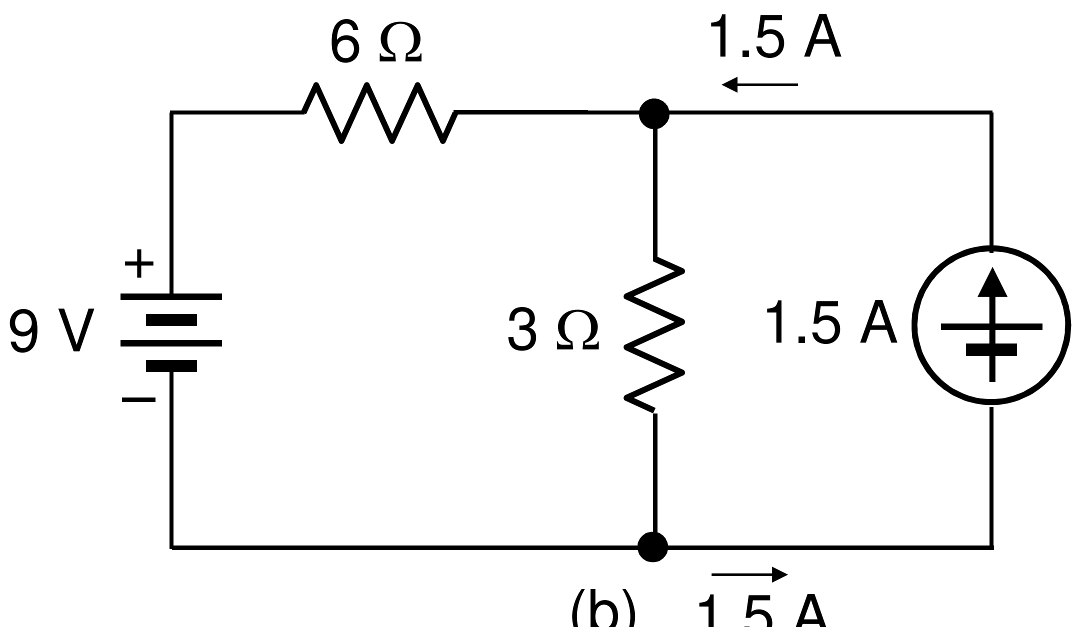


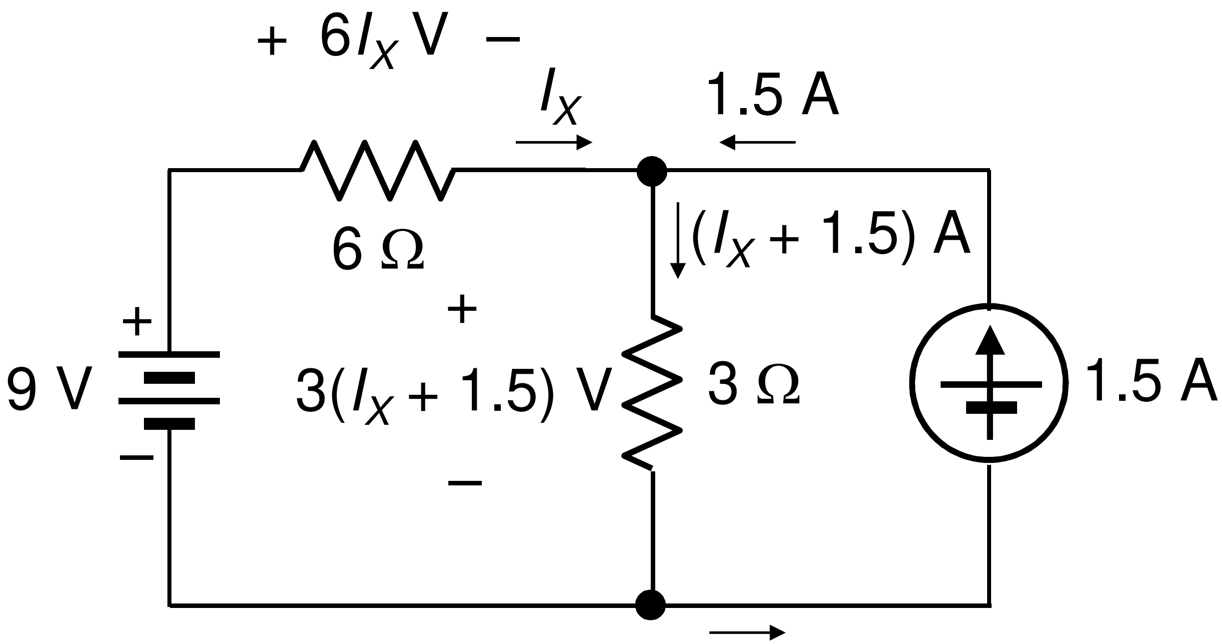
Figure 2.45



(a)



(b)



(c)

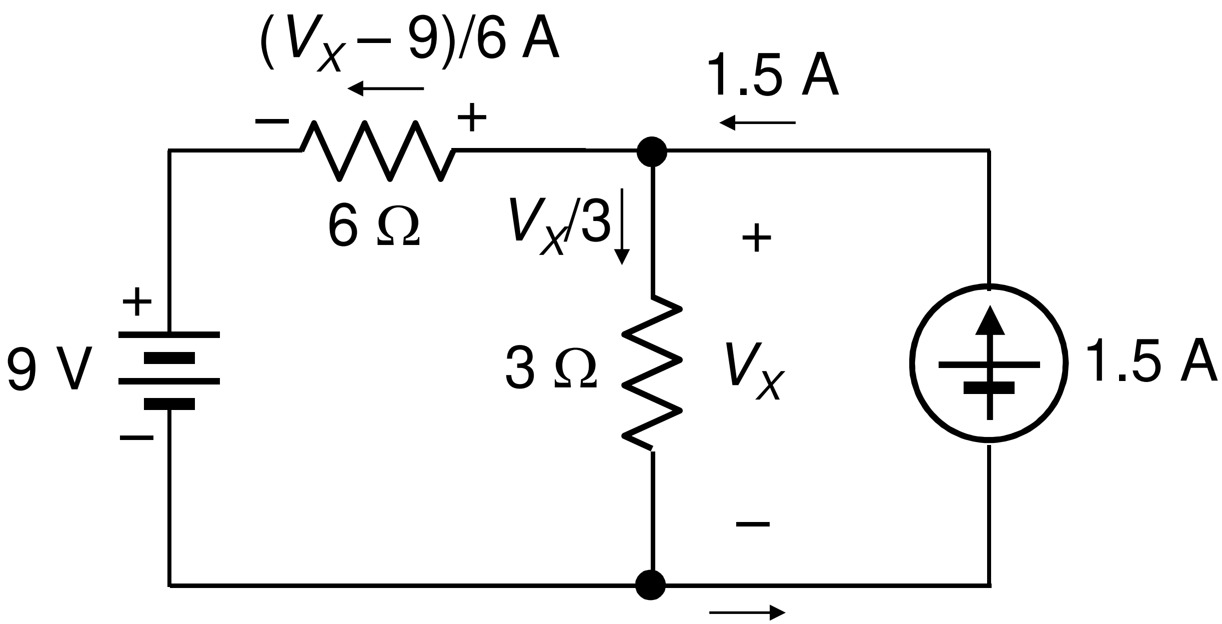


Figure 2.46 (d)

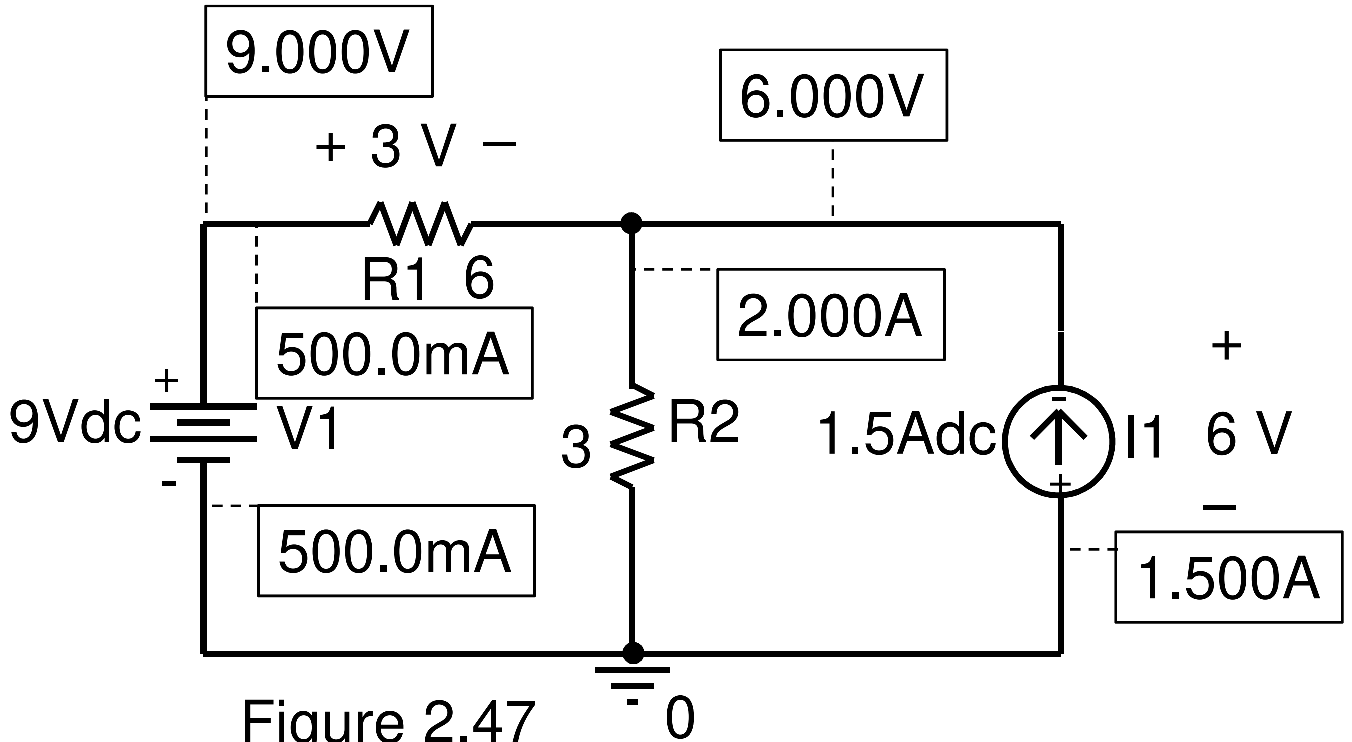
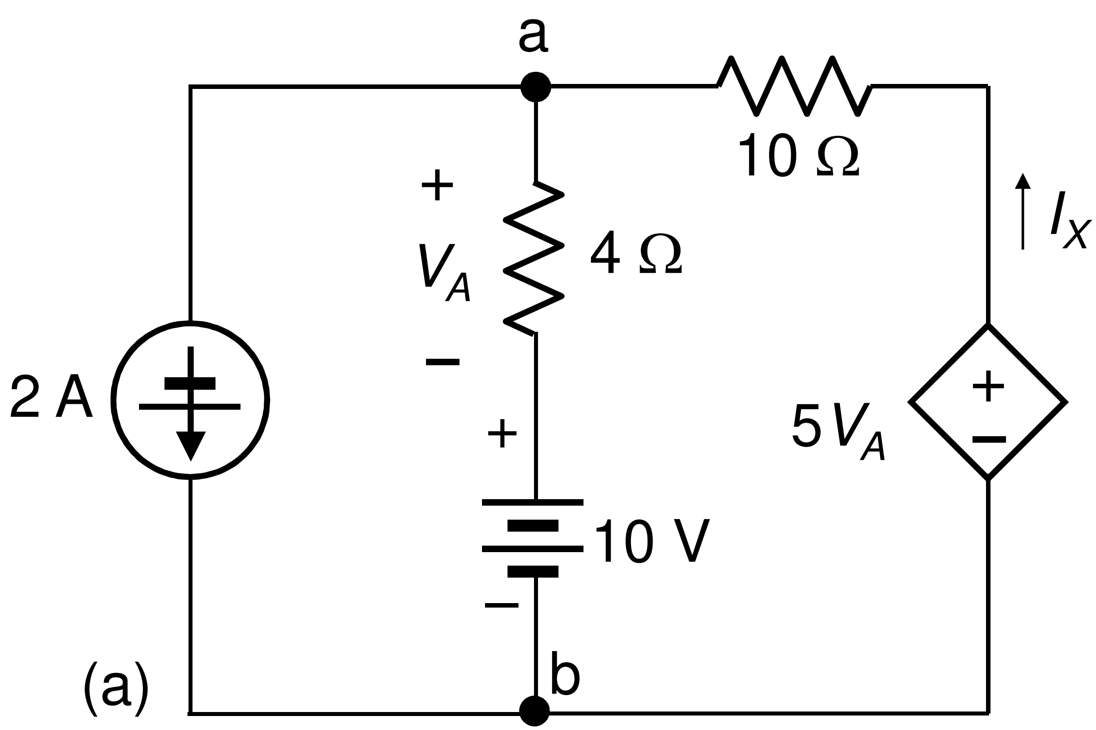
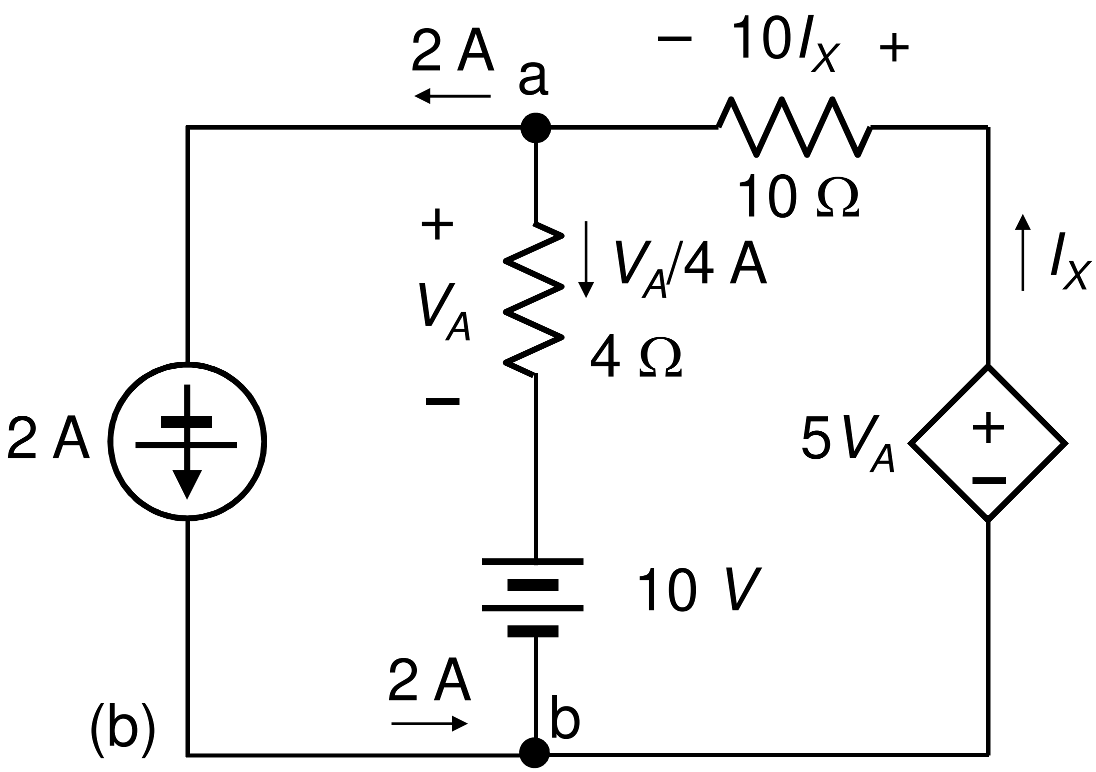

9.000V
+ 3 V −
6.000V
R1 6
2.000A
500.0mA
+
9Vdc
V1
-
3
R2
1.5Adc
I1 6 V
+
−
500.0mA
1.500A
0

Figure 2.47


a
10 Ω
+
V_A
4 Ω
I_X
−
2 A
+
5V_A
+
−
10 V
−
b
(a)


2 A
a
− 10I_X +
10 Ω
+
V_A
−
V_A/4 A
4 Ω
I_X
2 A
5V_A
+
−
10 V
2 A
b
(b)

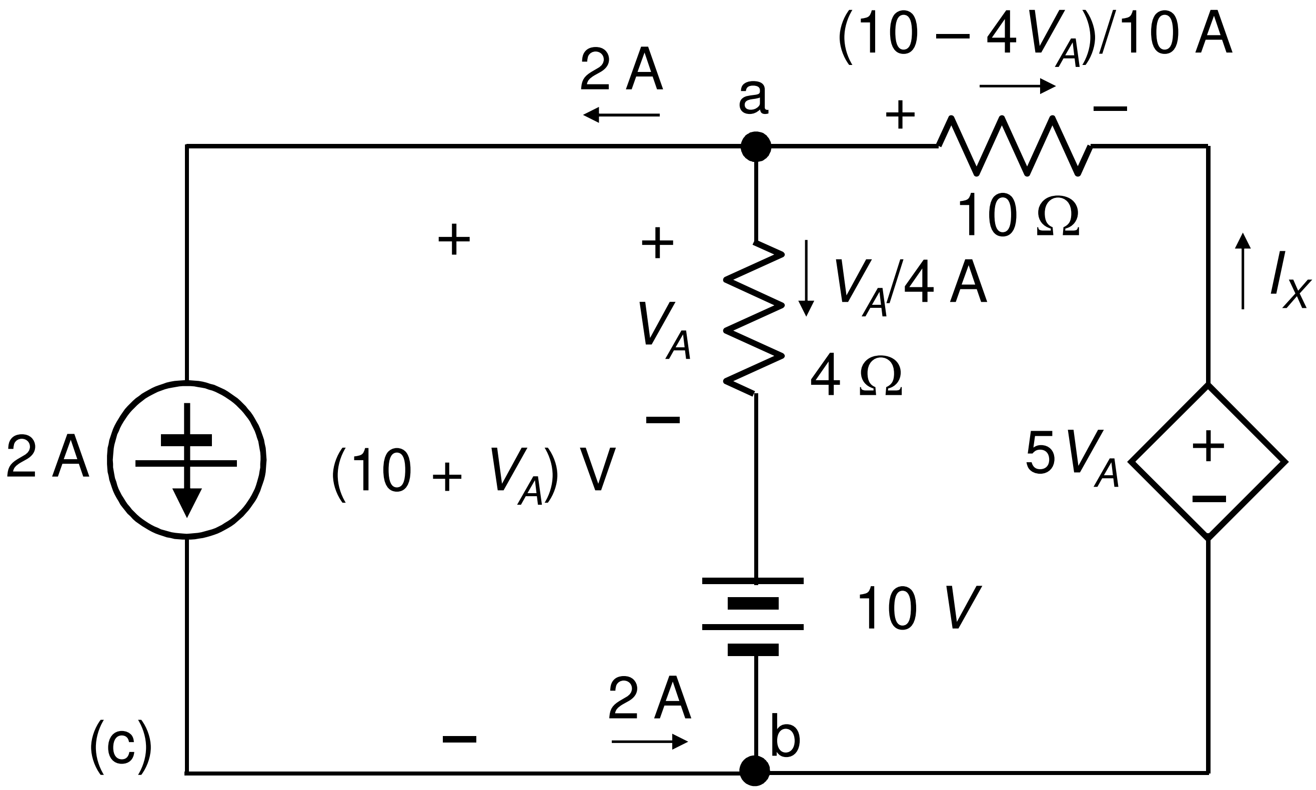


Figure 2.48

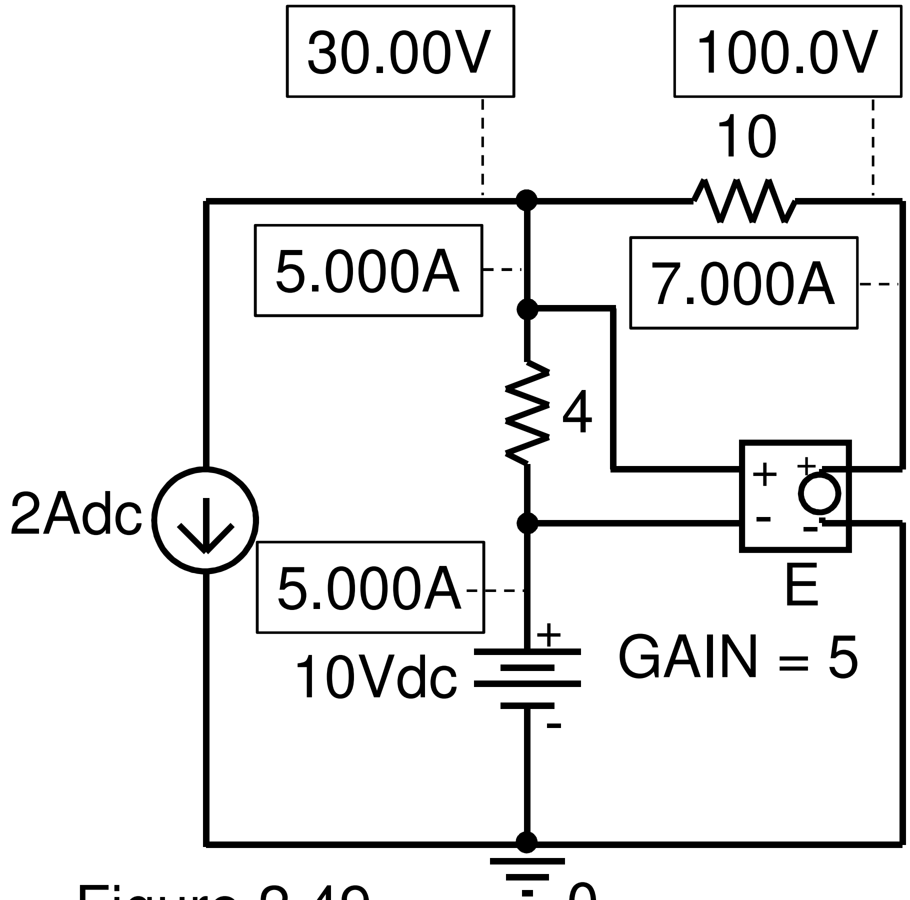
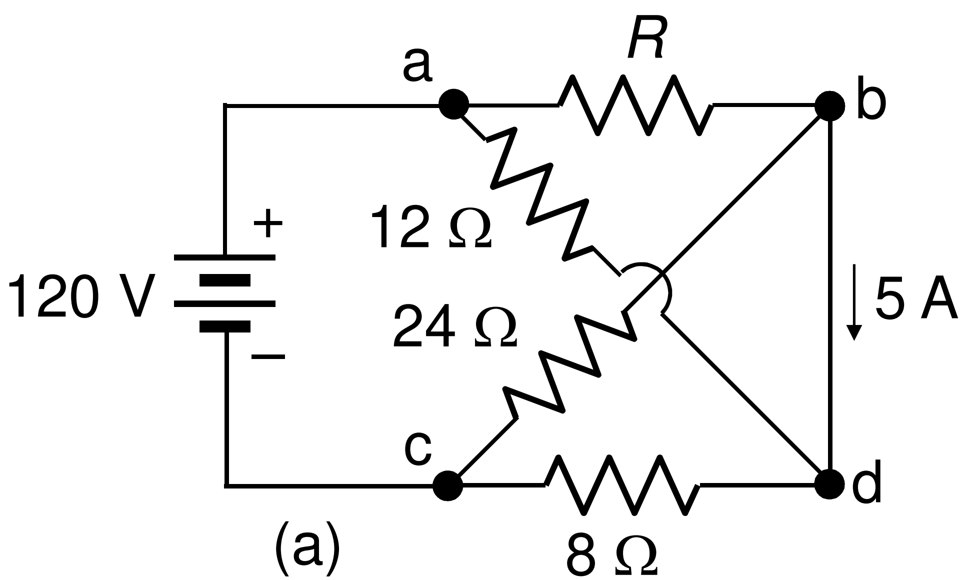
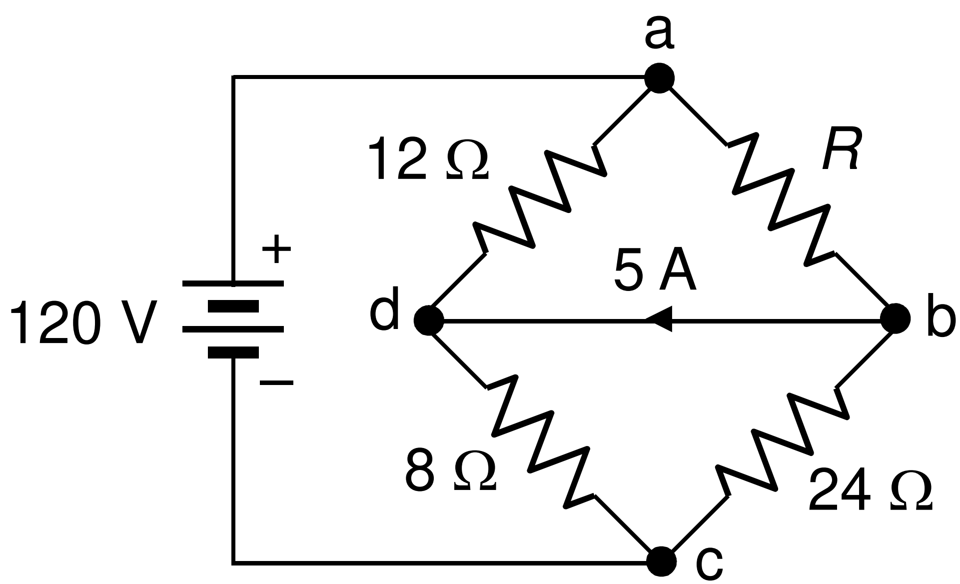


Figure 2.49



(a)



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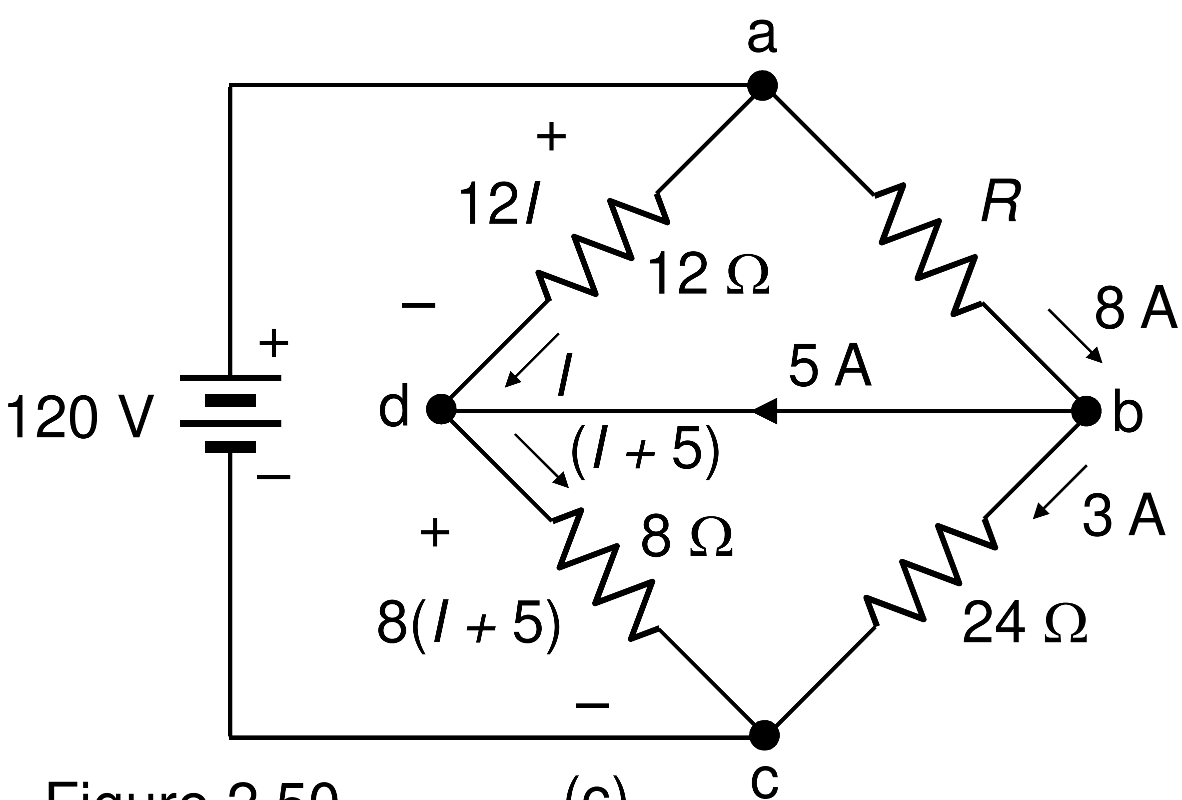
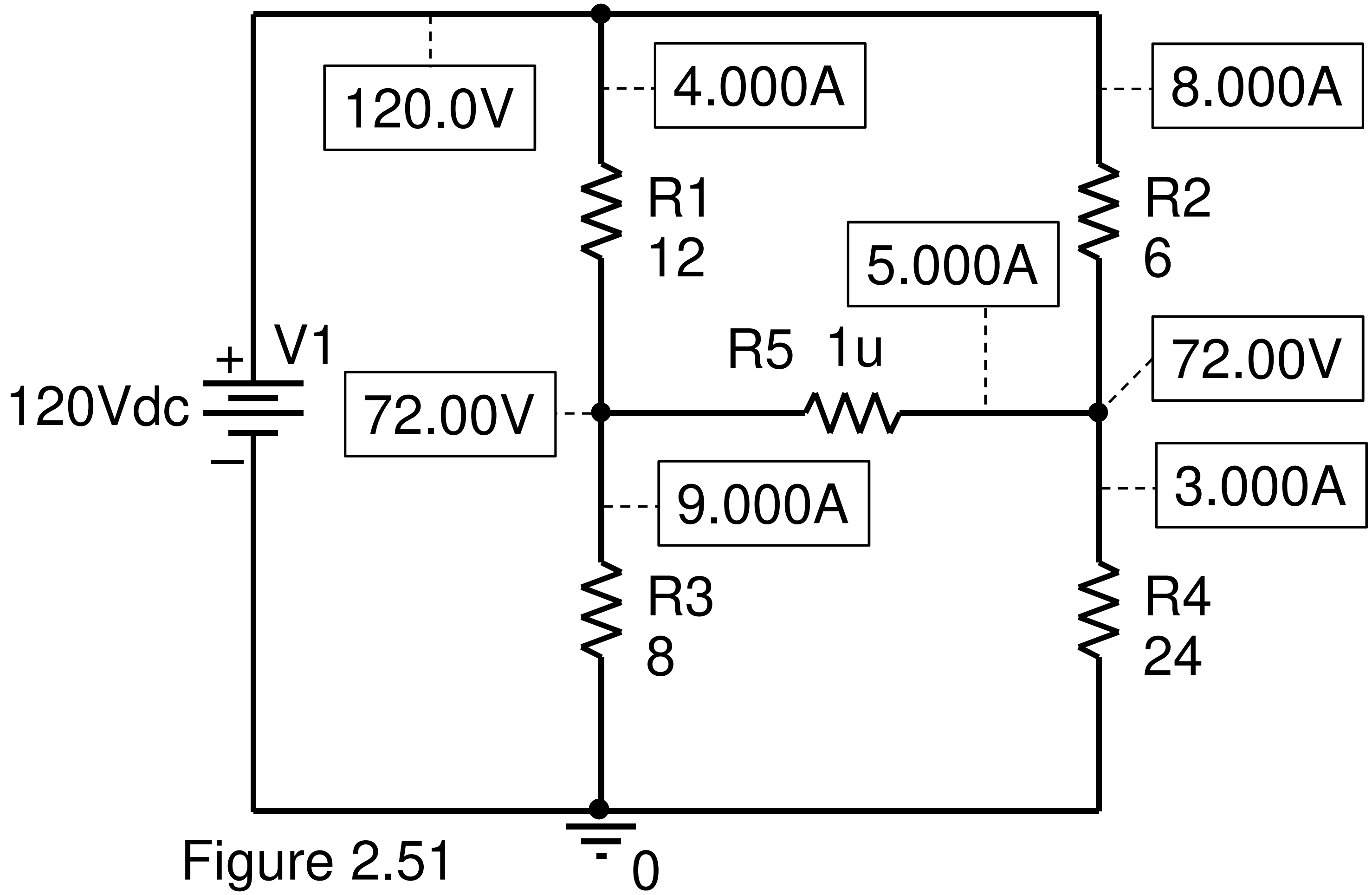


Figure 2.50 (c)



120.0V
4.000A
8.000A
R1
12
R2
6
5.000A
V1
R5 1u
72.00V
120Vdc
72.00V
9.000A
3.000A
R3
8
R4
24
0

Figure 2.51

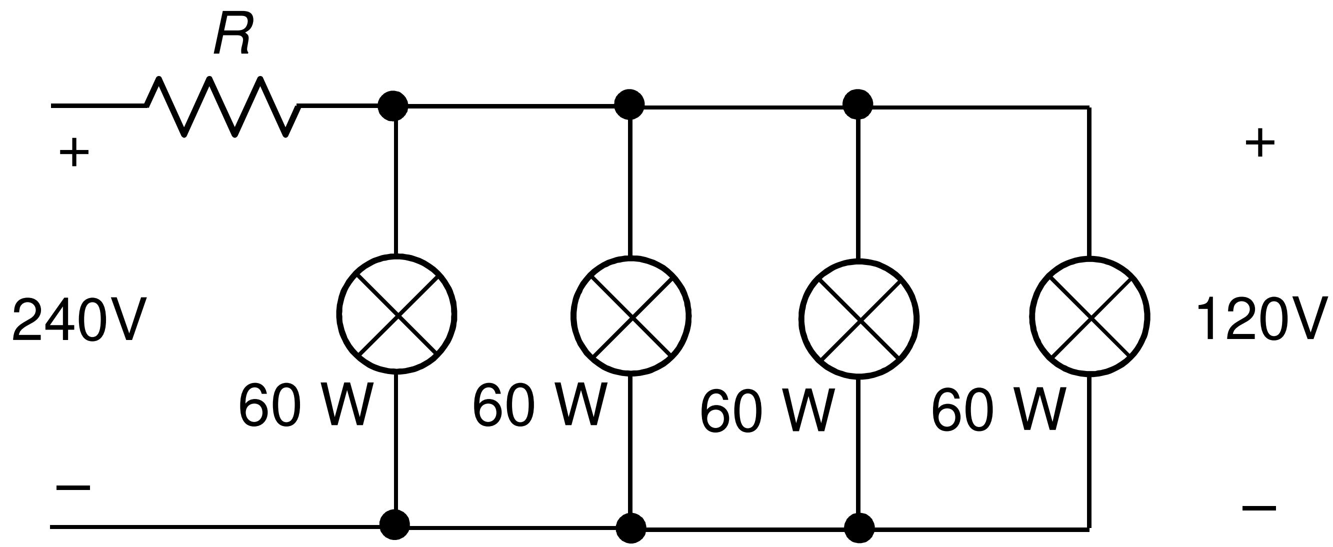
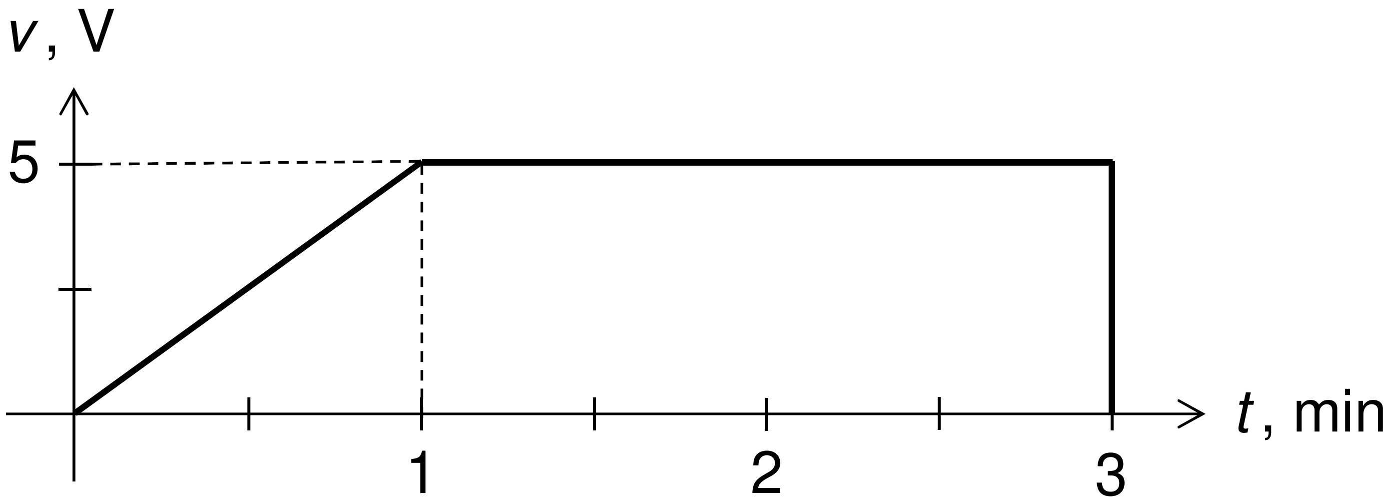


Figure P2.2



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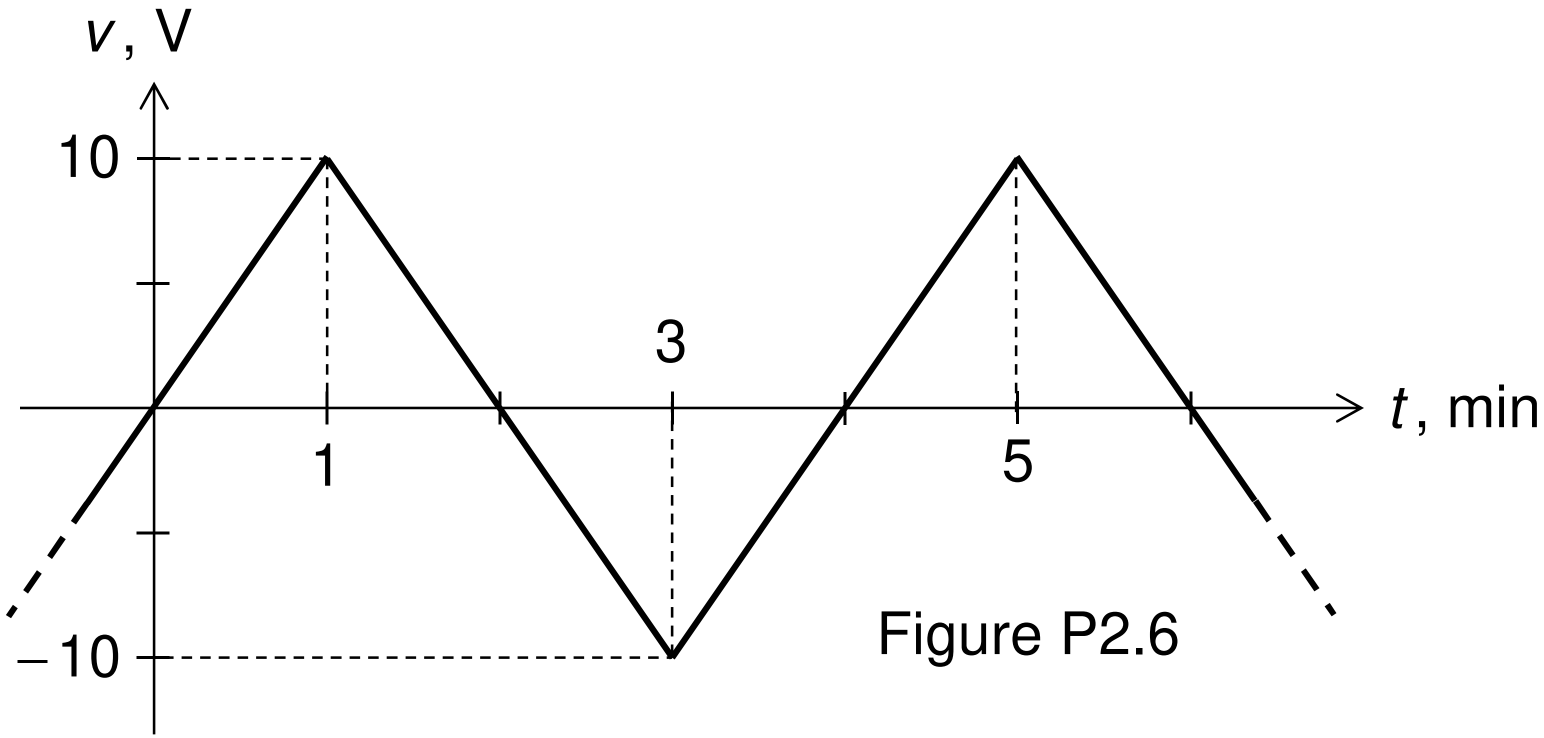
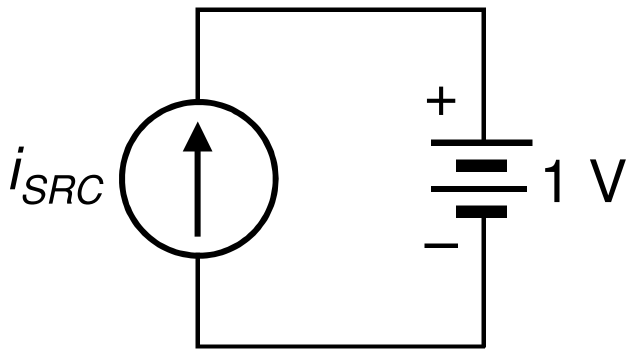


Figure P2.6



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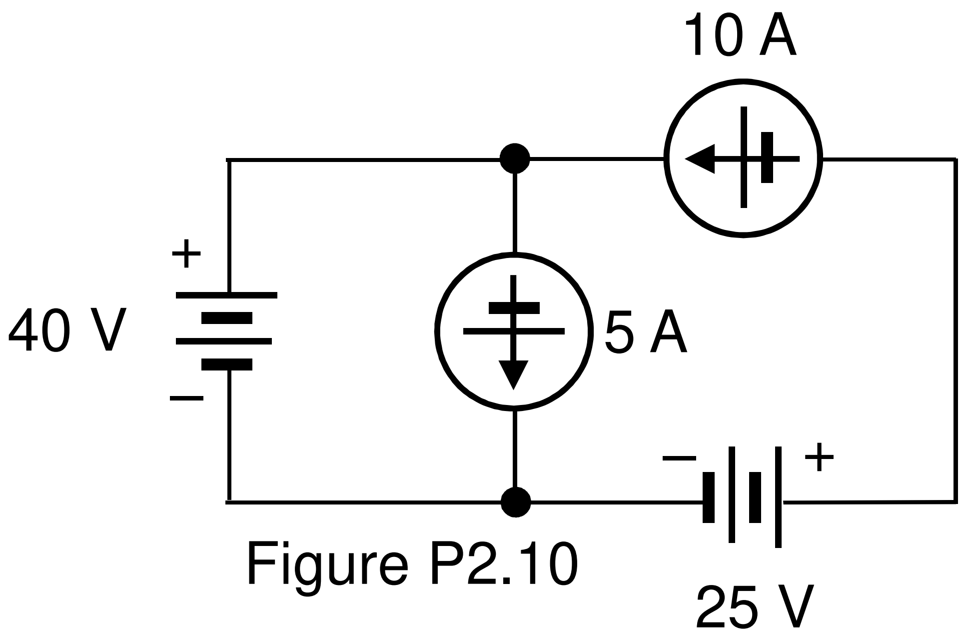


Figure P2.10

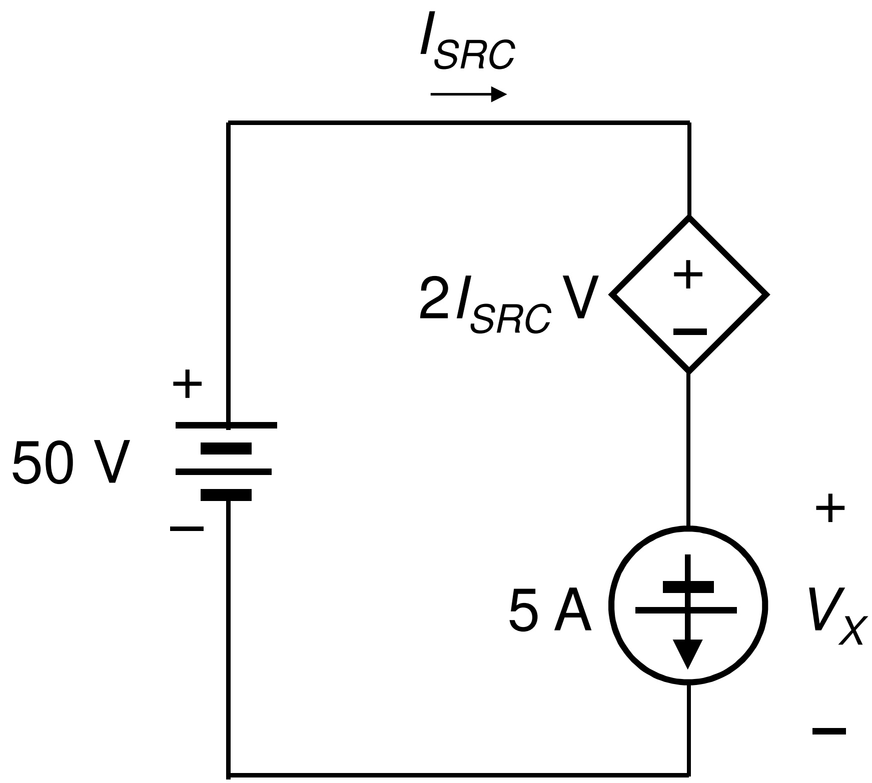


Figure P2.11

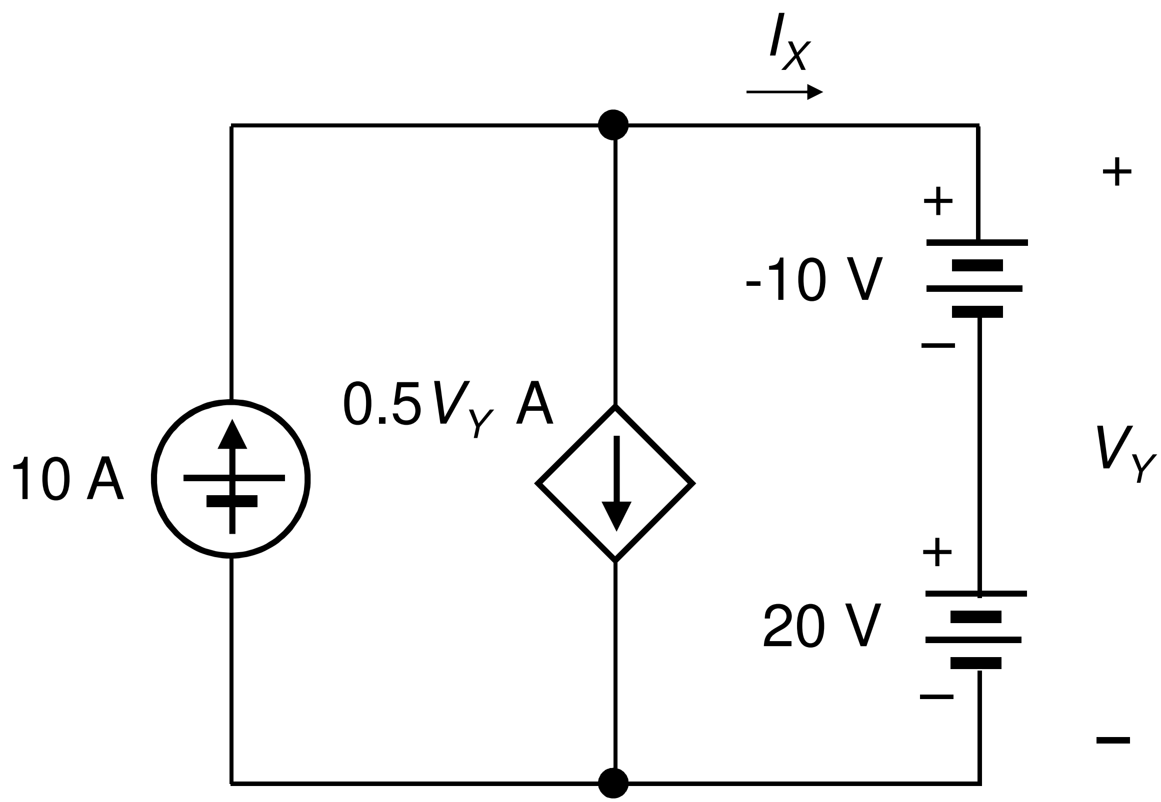


Figure P2.12

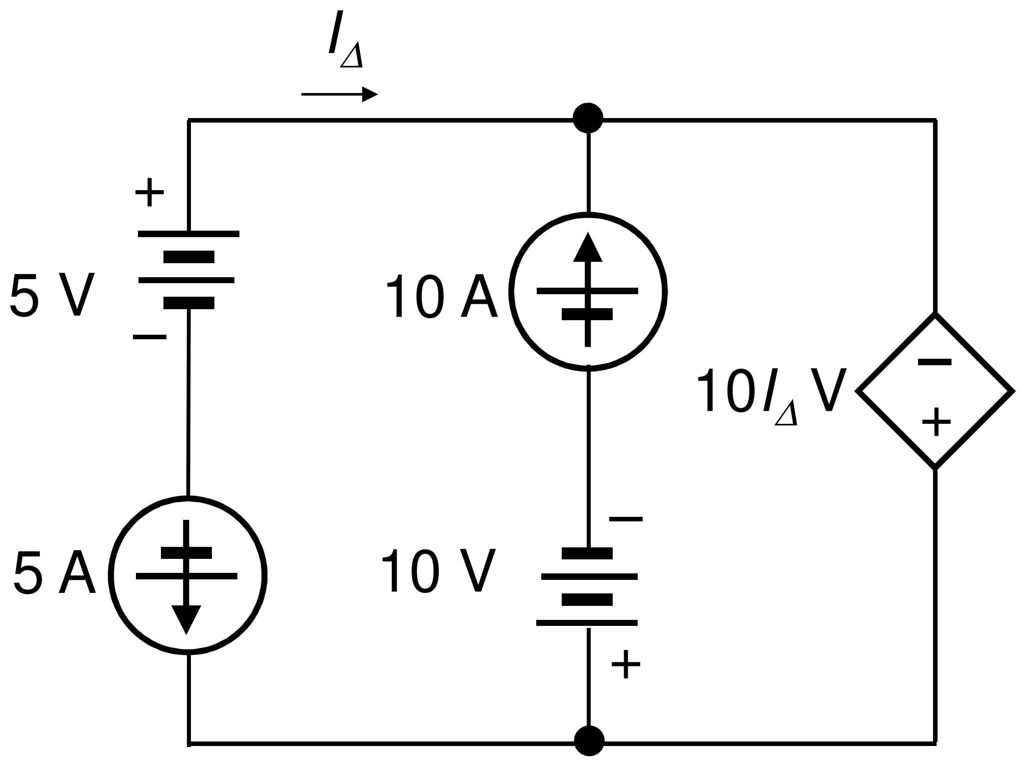


Figure P2.13

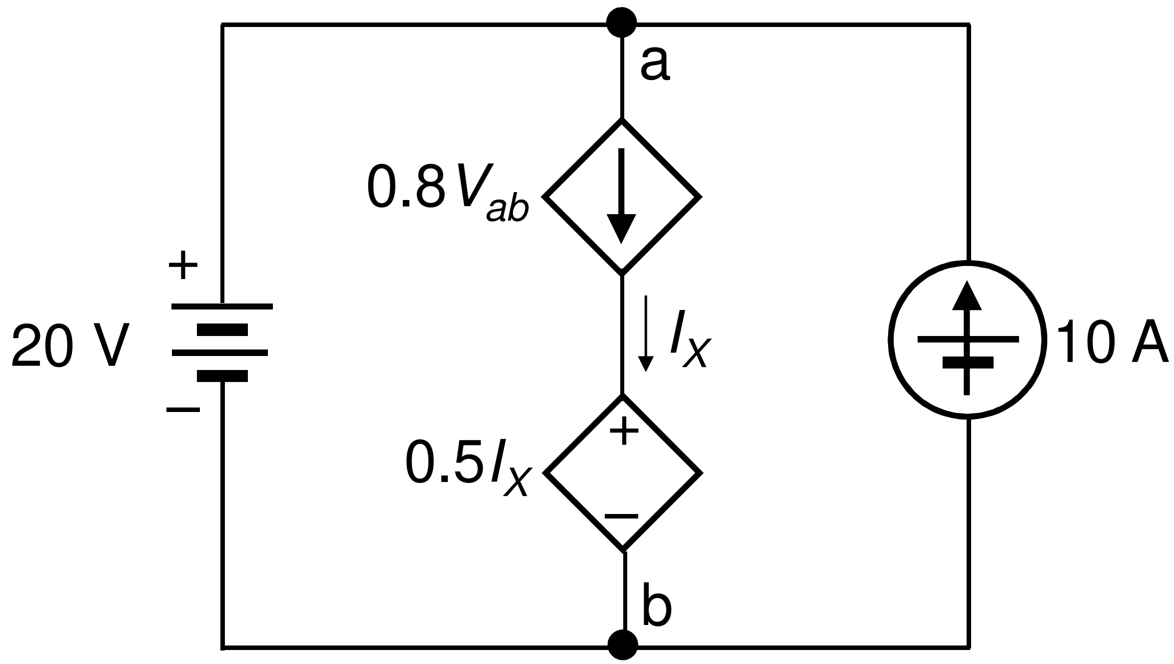


Figure P2.14

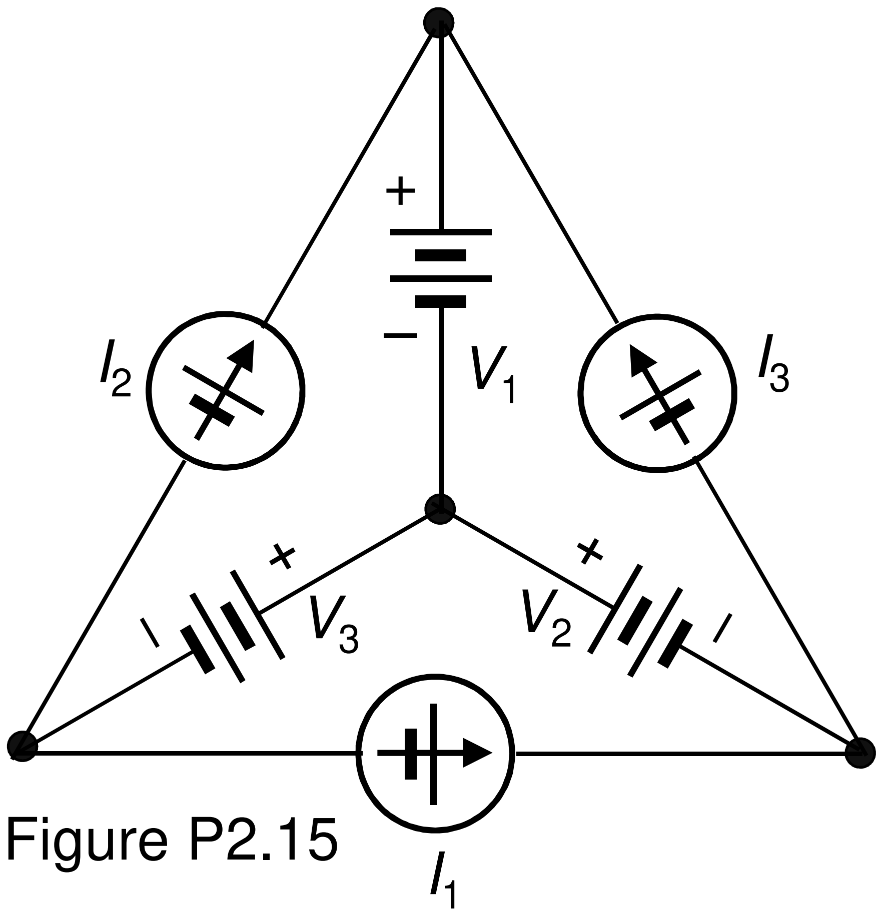


Figure P2.15

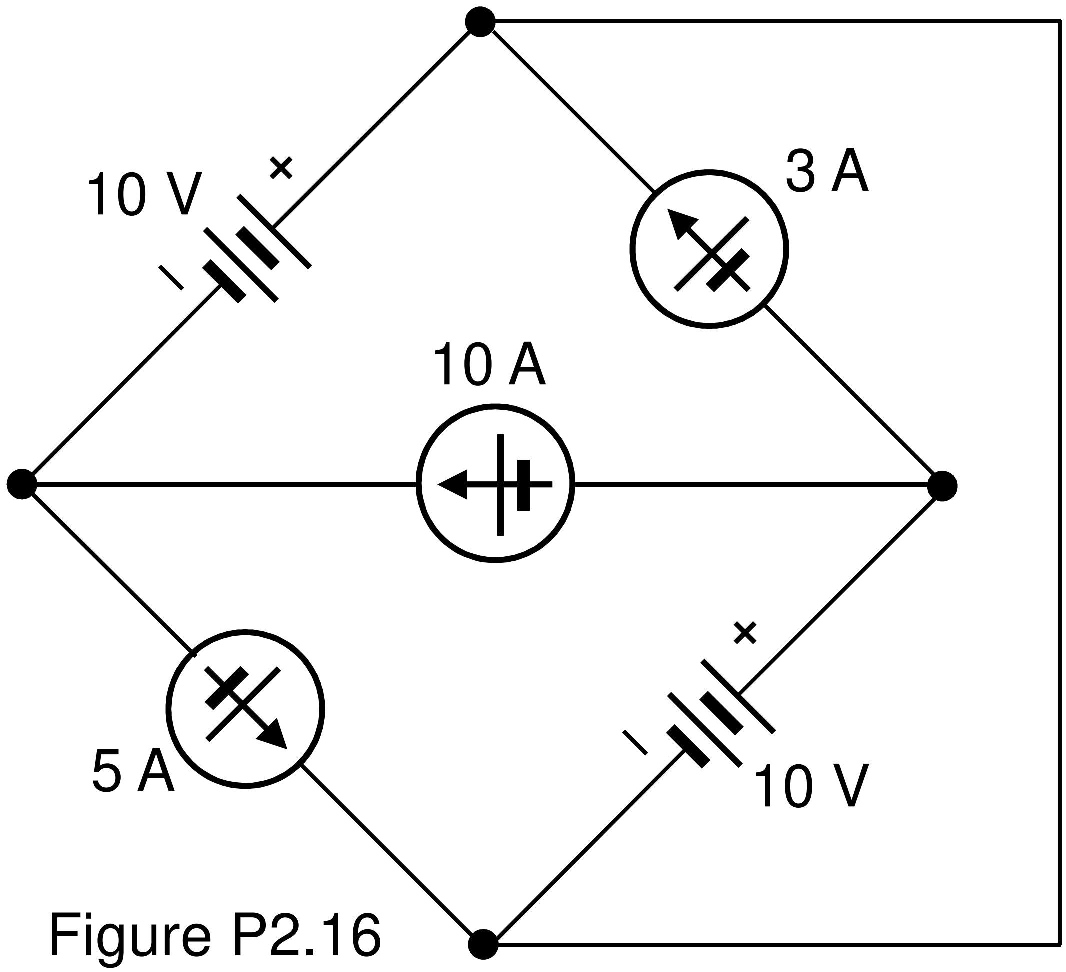


Figure P2.16

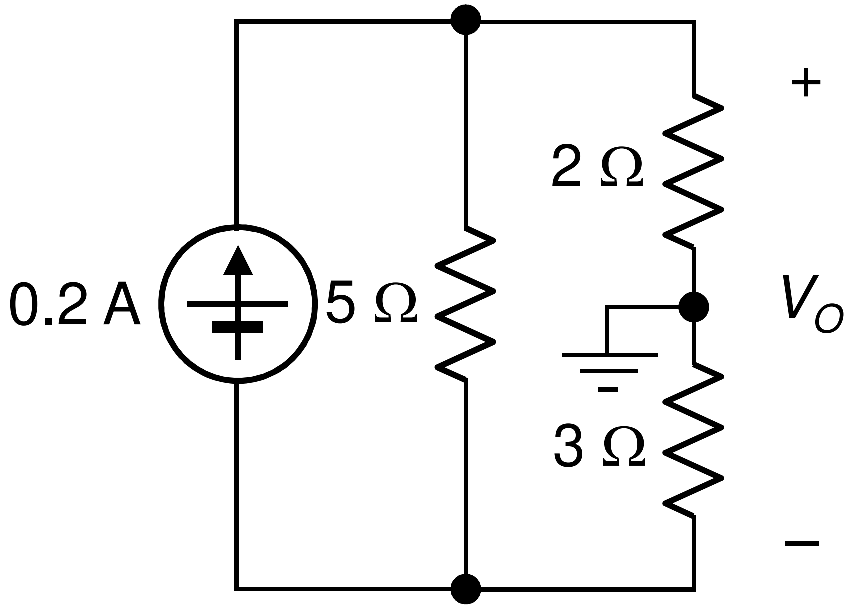


Figure P2.17

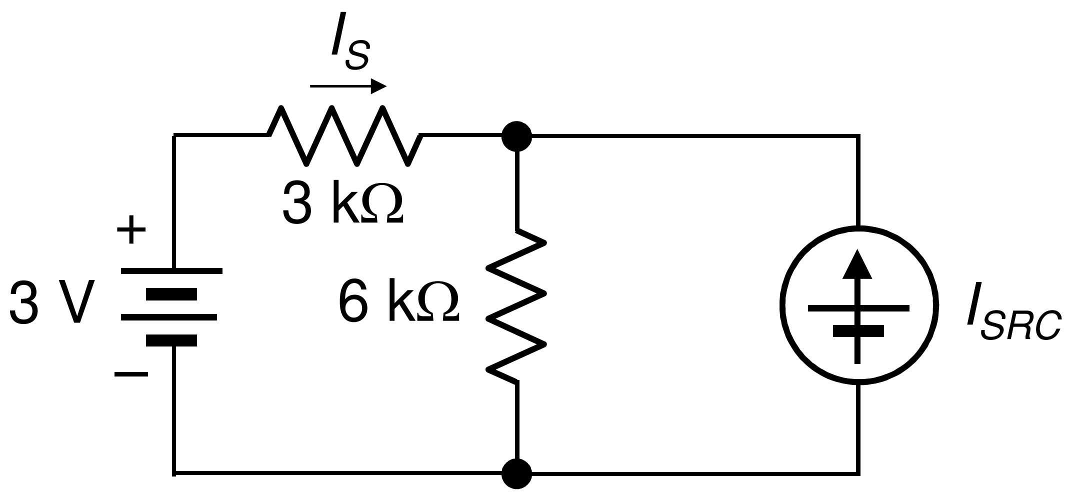


Figure P2.18

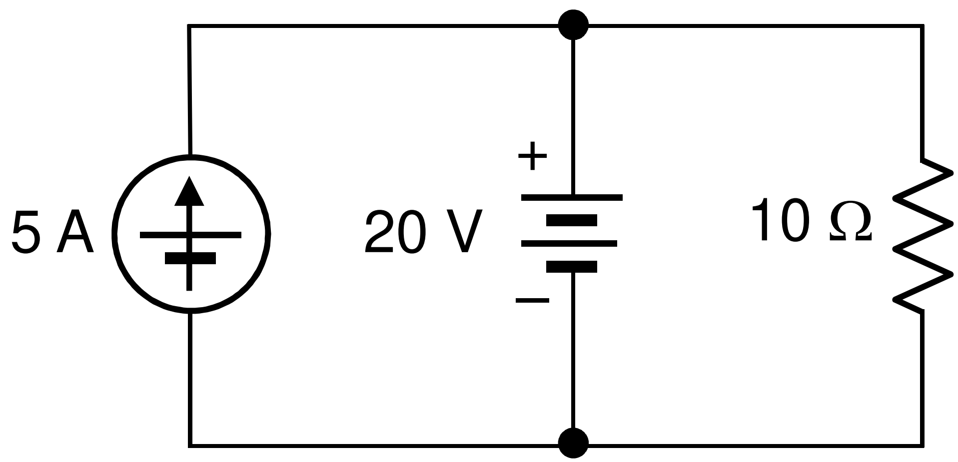


Figure P2.19

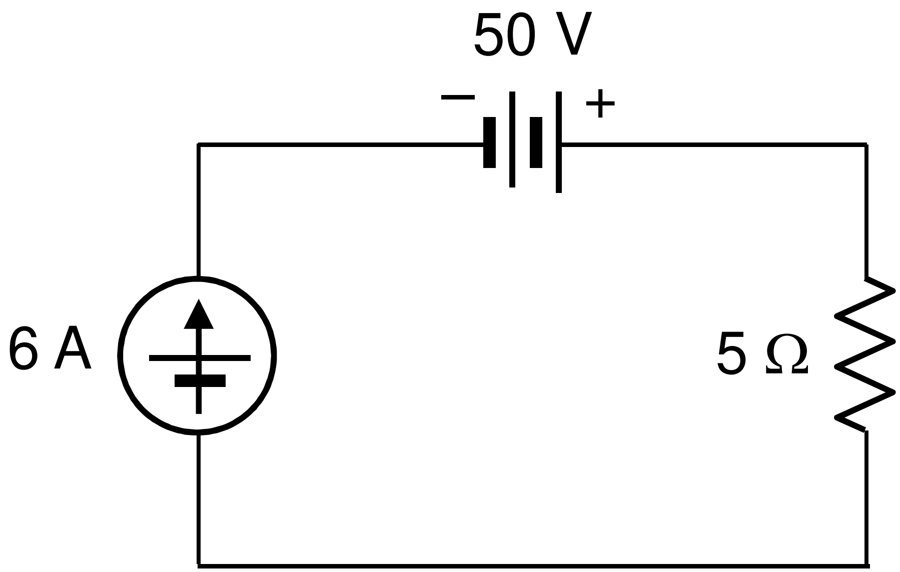


Figure P2.20

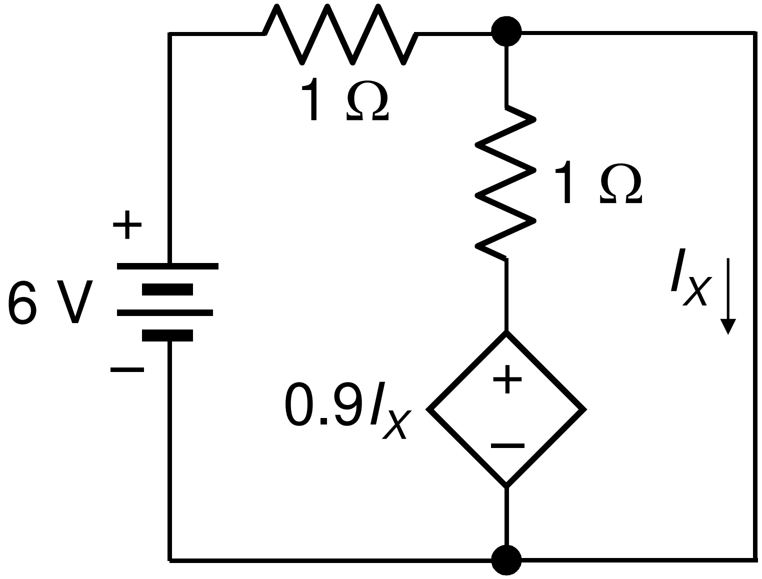


Figure P2.21

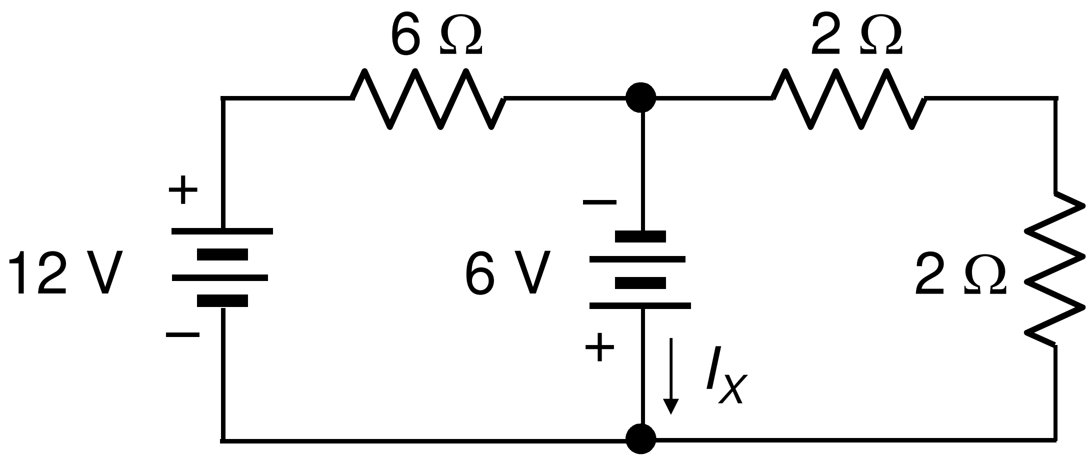


Figure P2.22

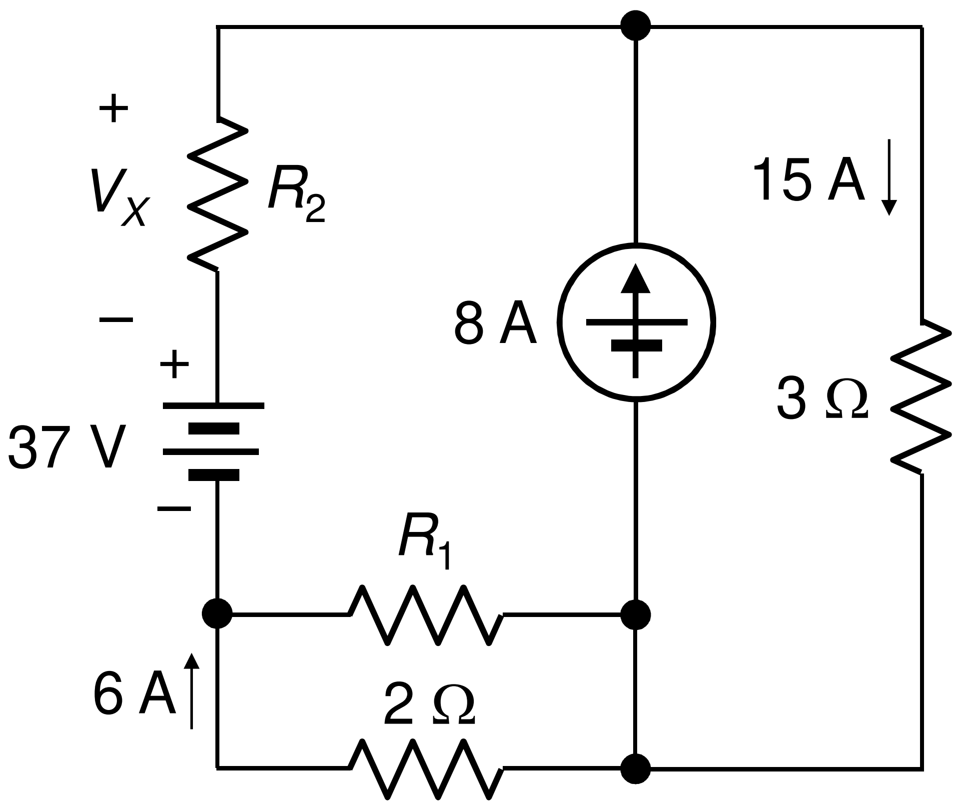


Figure P2.23

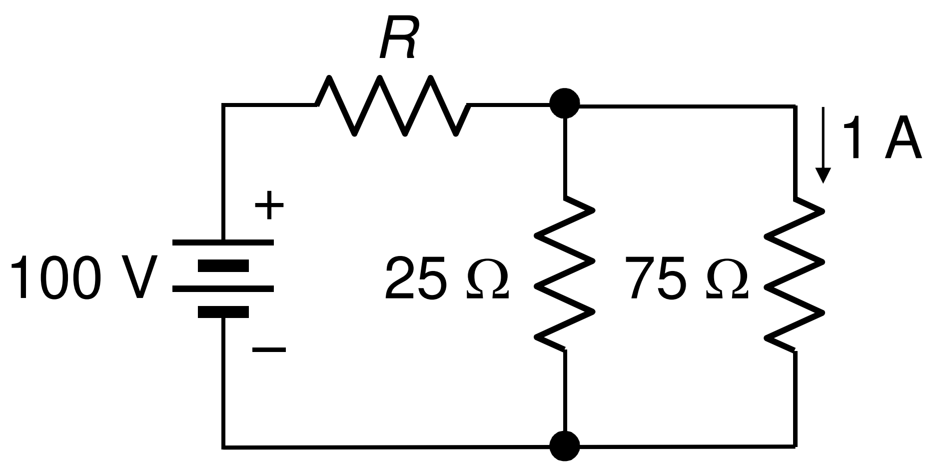


Figure P2.24

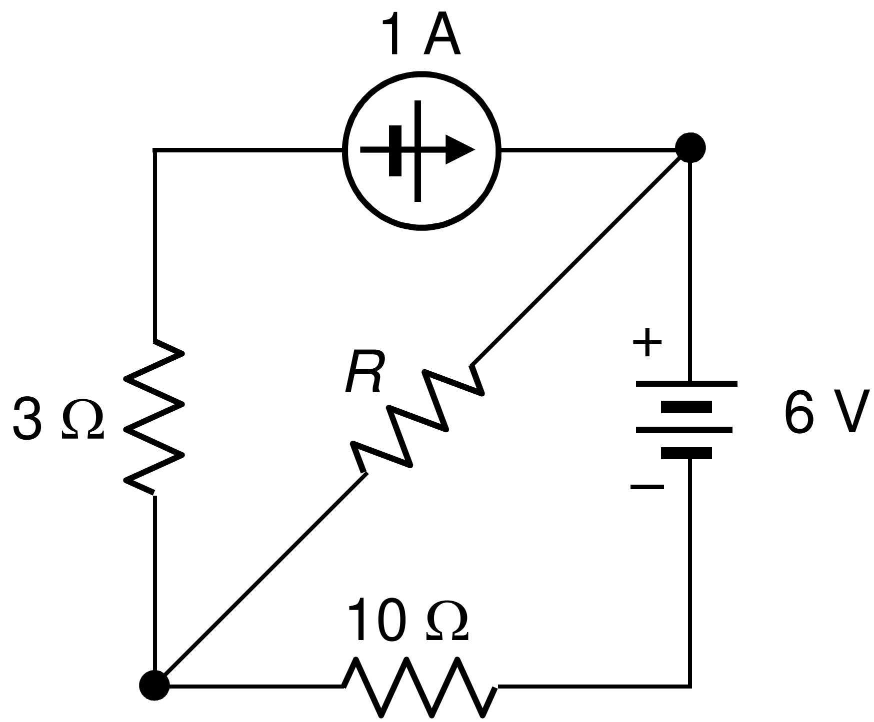


Figure P2.25

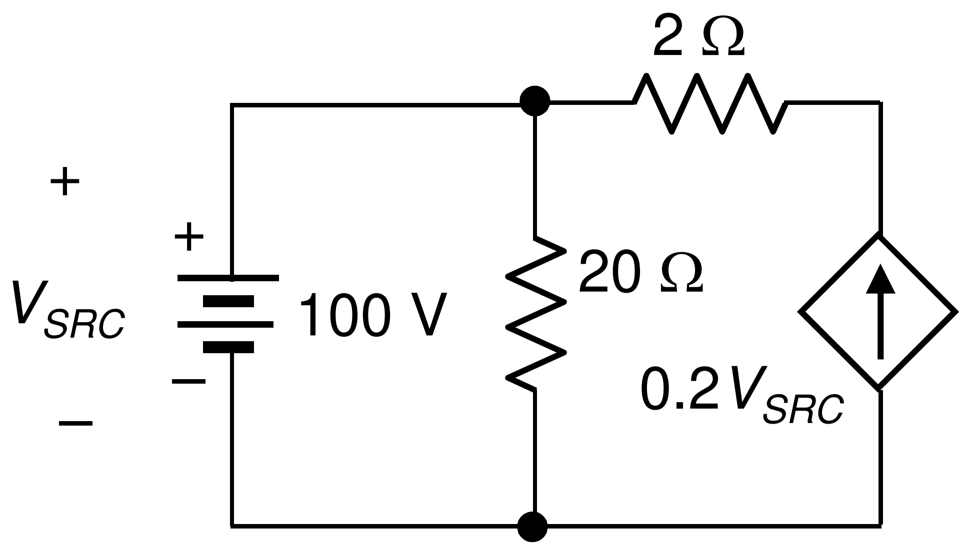


Figure P2.27

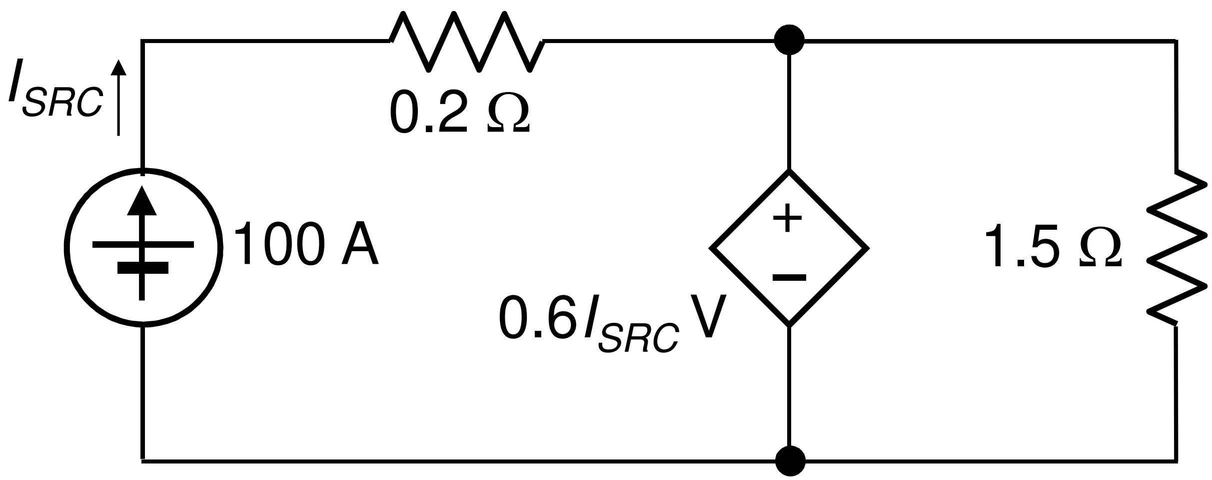


Figure P2.28

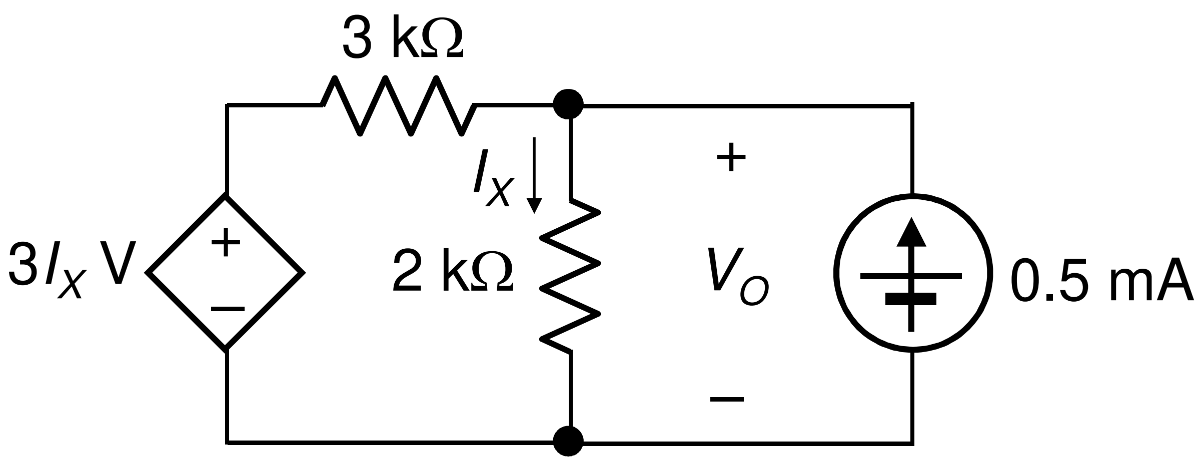


Figure P2.29

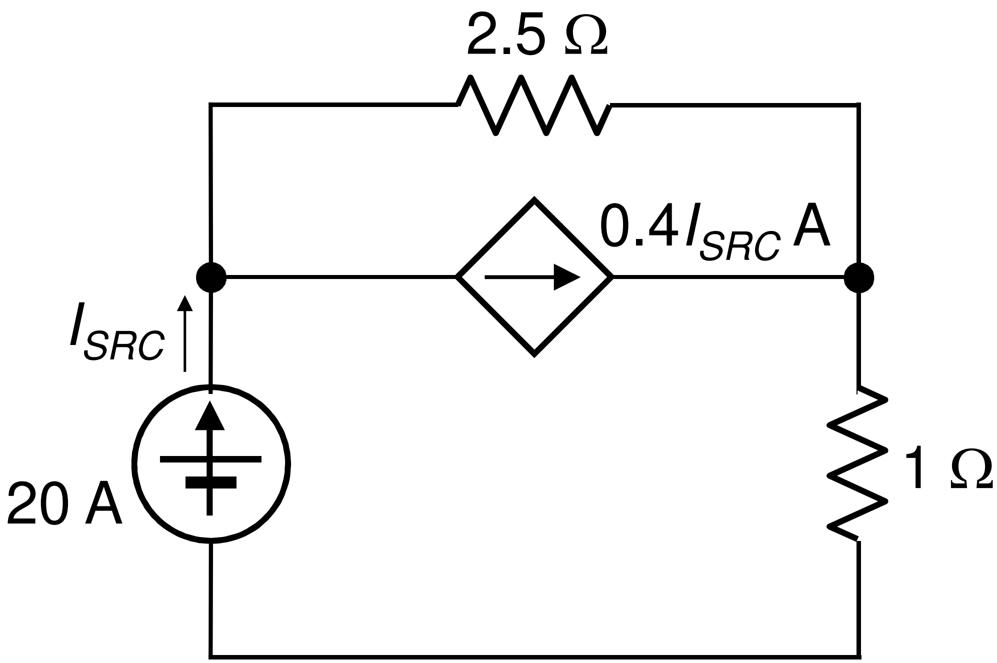


Figure P2.30

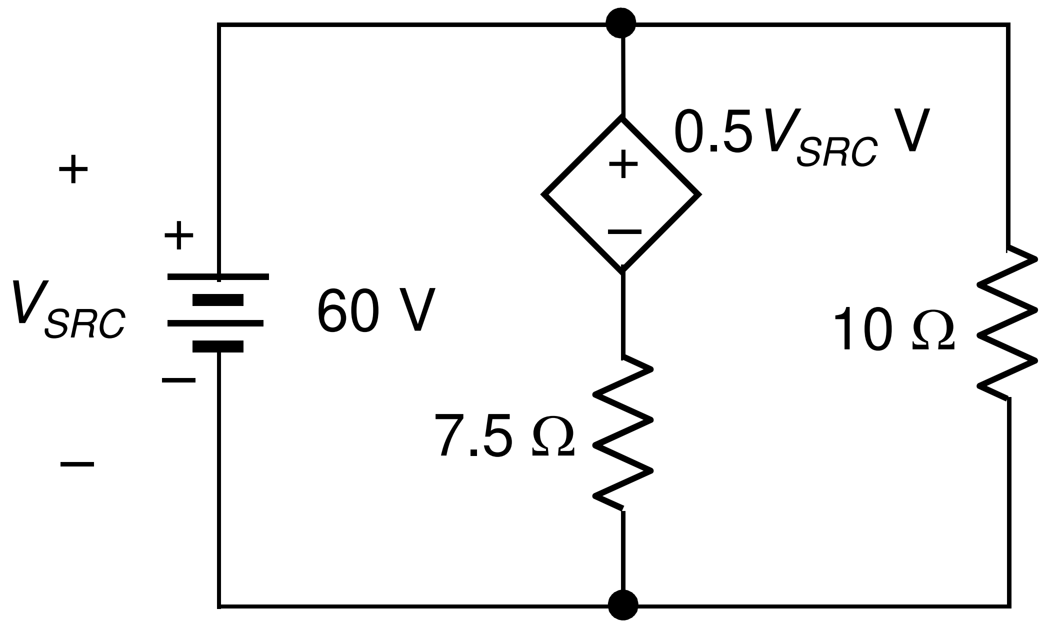


Figure P2.31

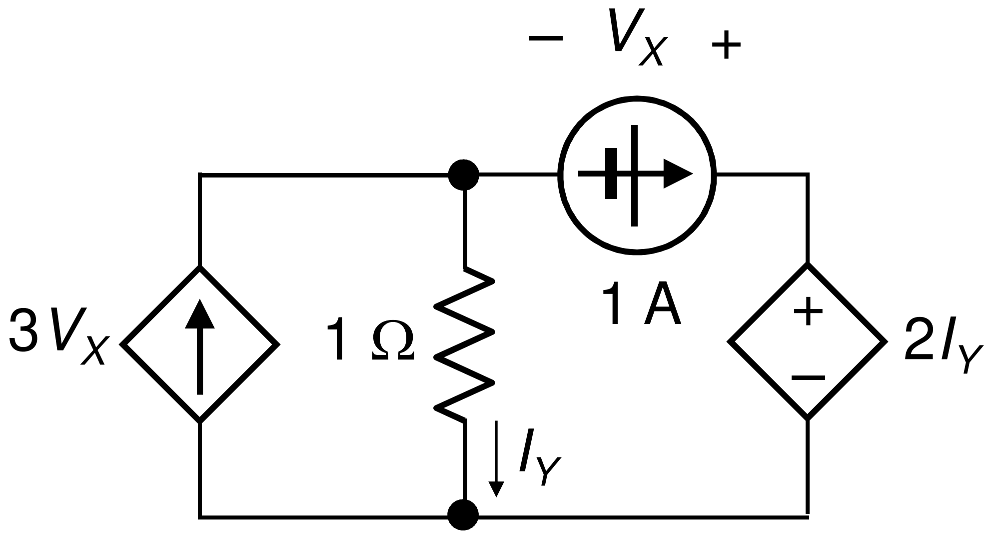


Figure P2.32

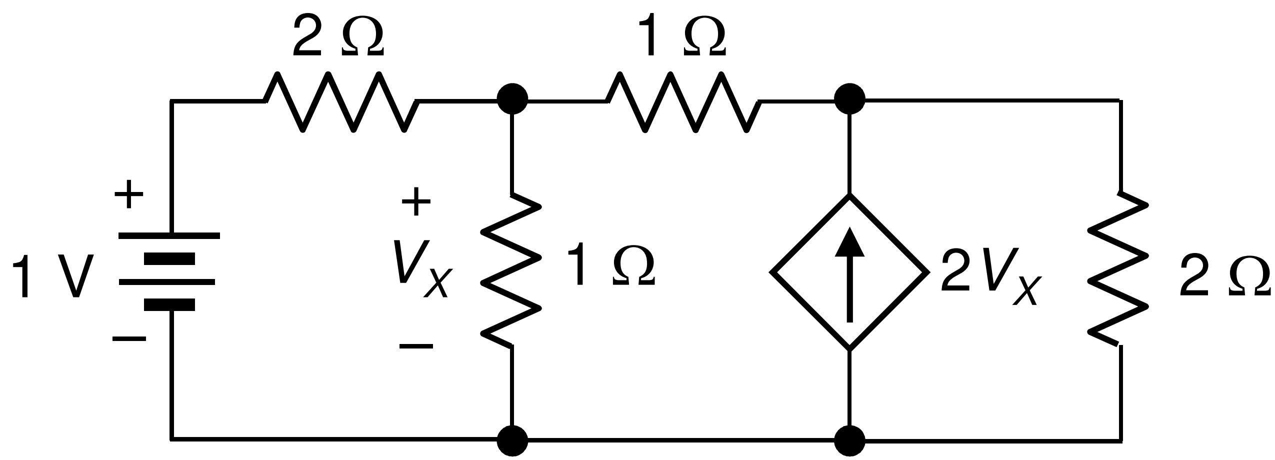


Figure P2.33

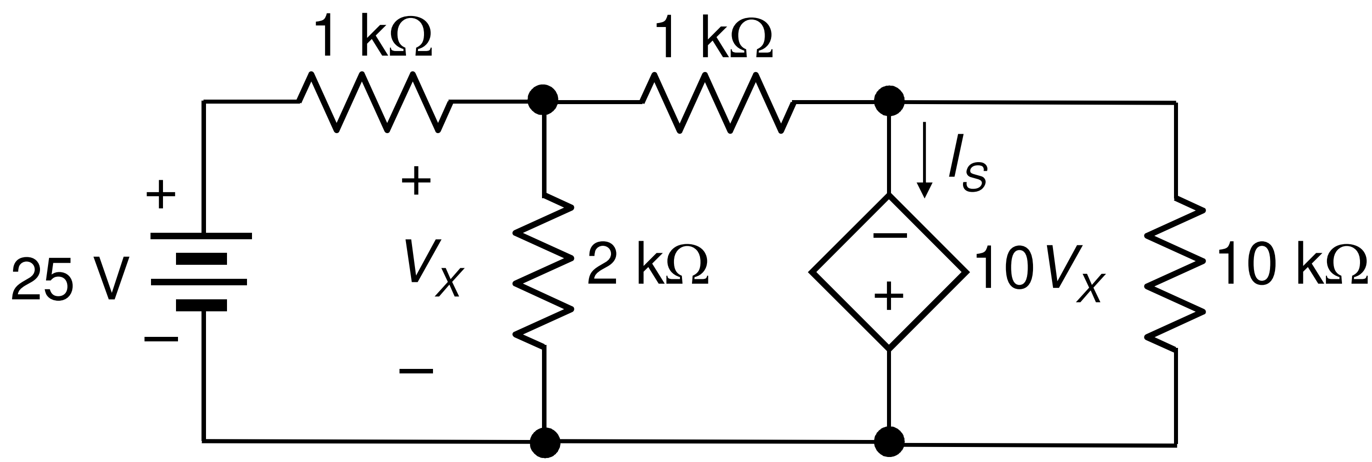


Figure P2.34

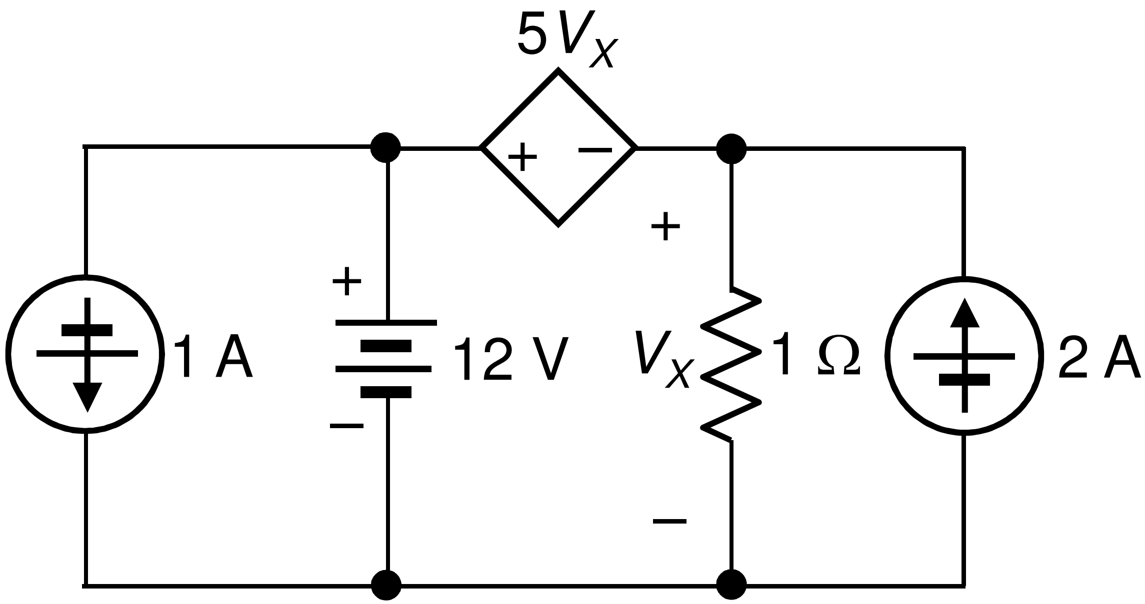


Figure P2.35

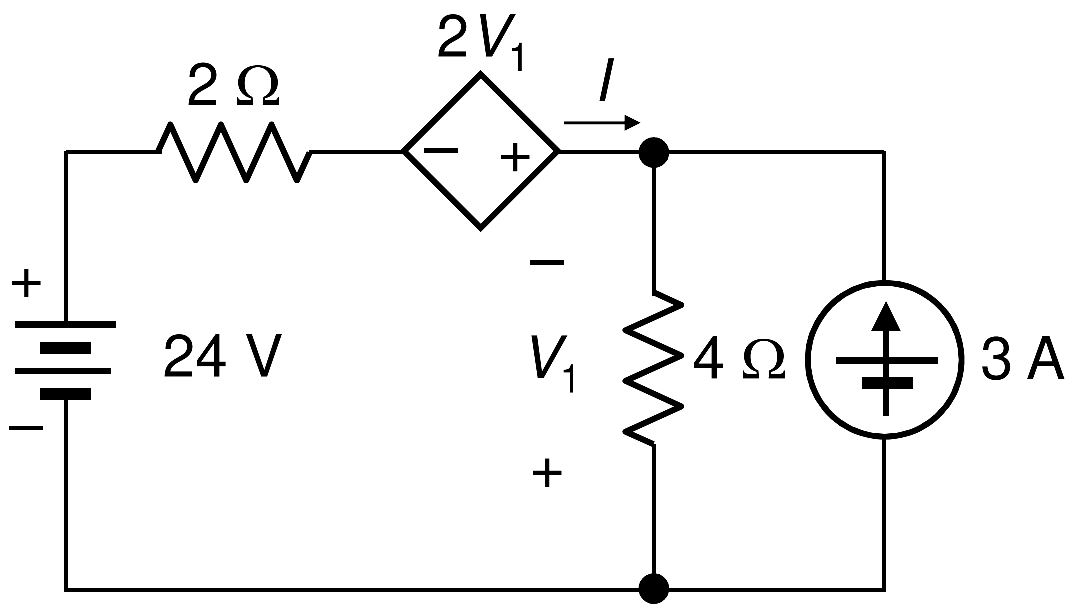


Figure P2.36

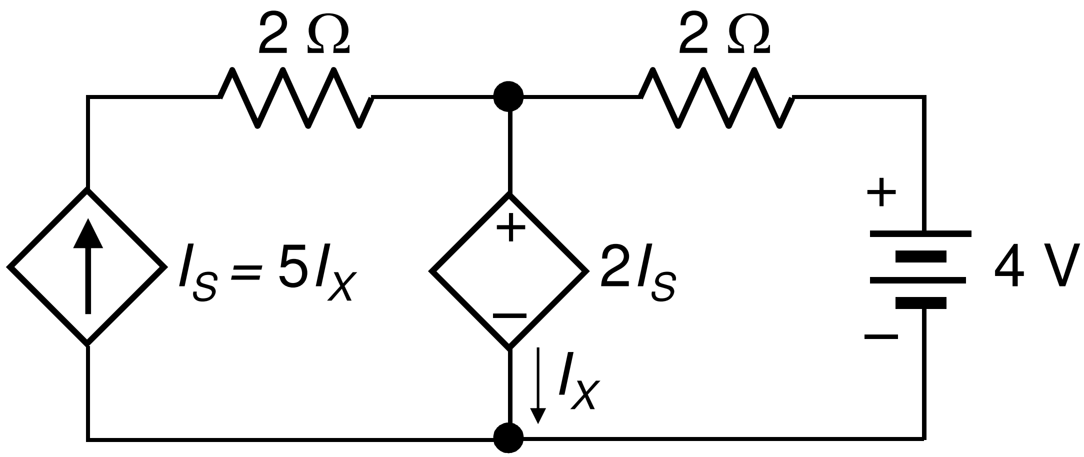


Figure P2.37

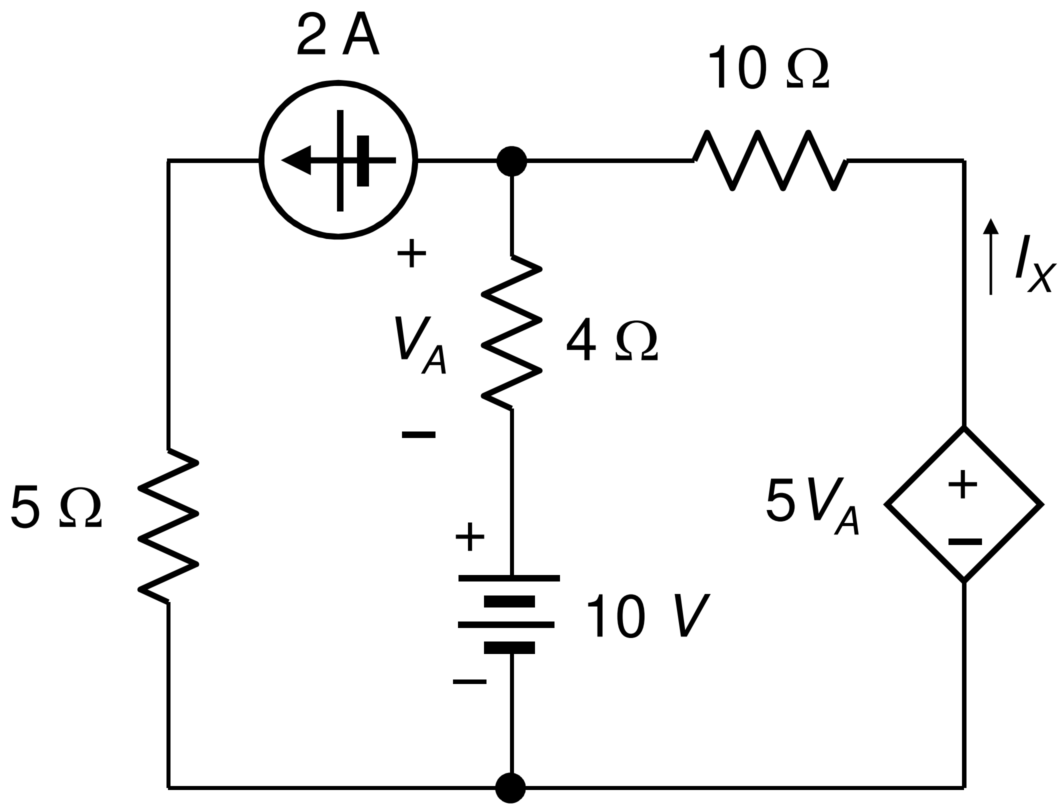
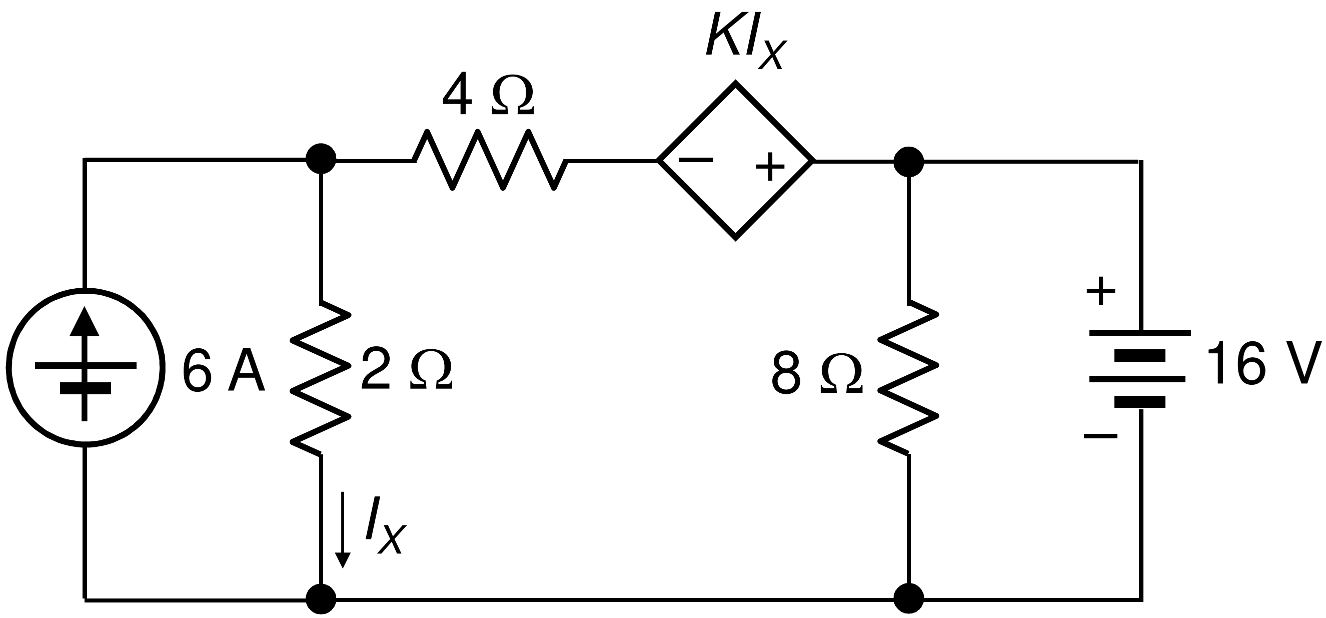


Figure P2.38



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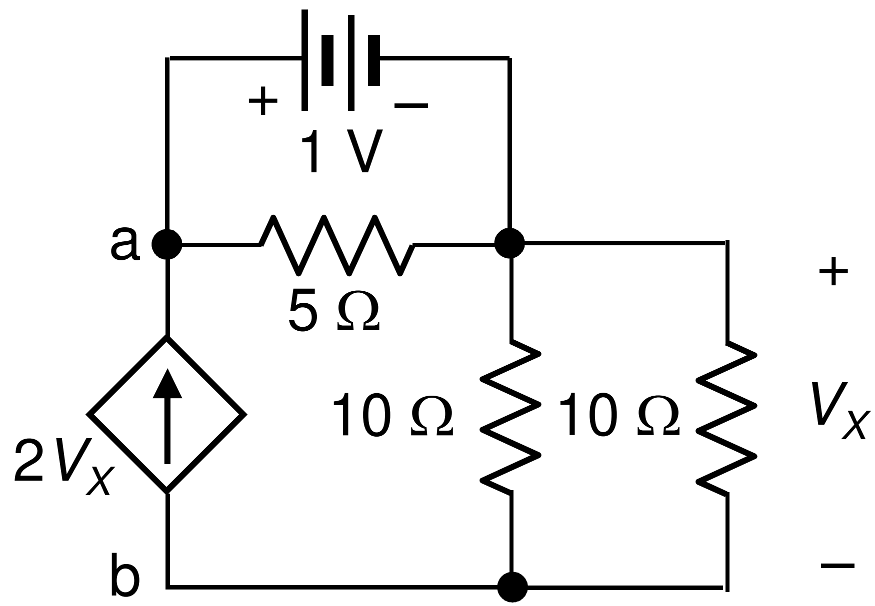


Figure P2.40

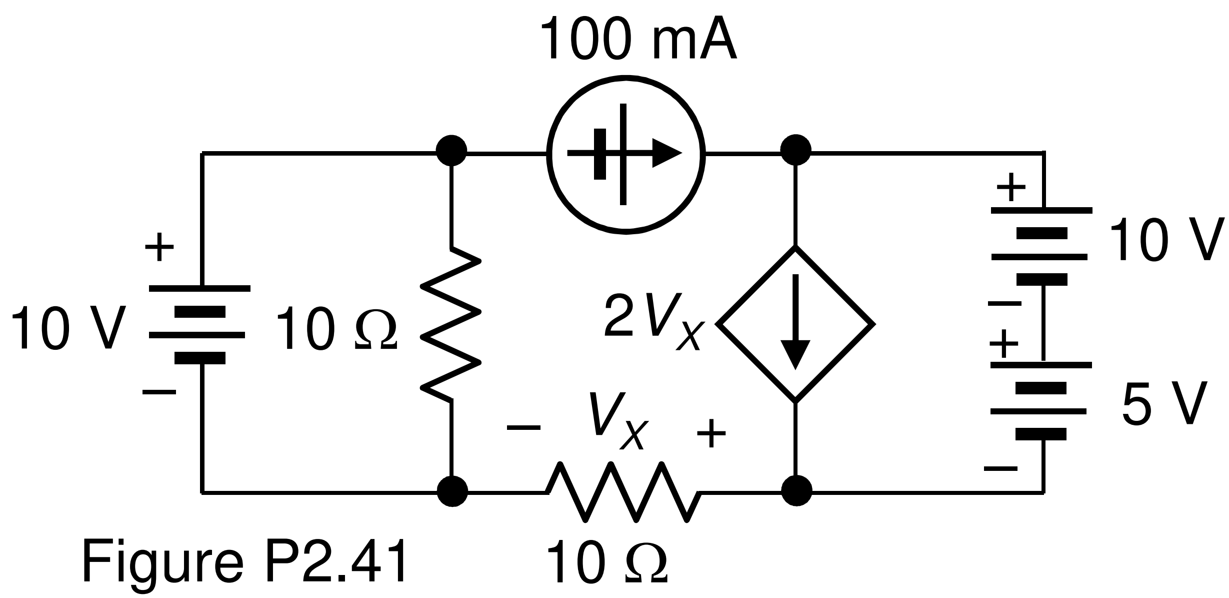


Figure P2.41

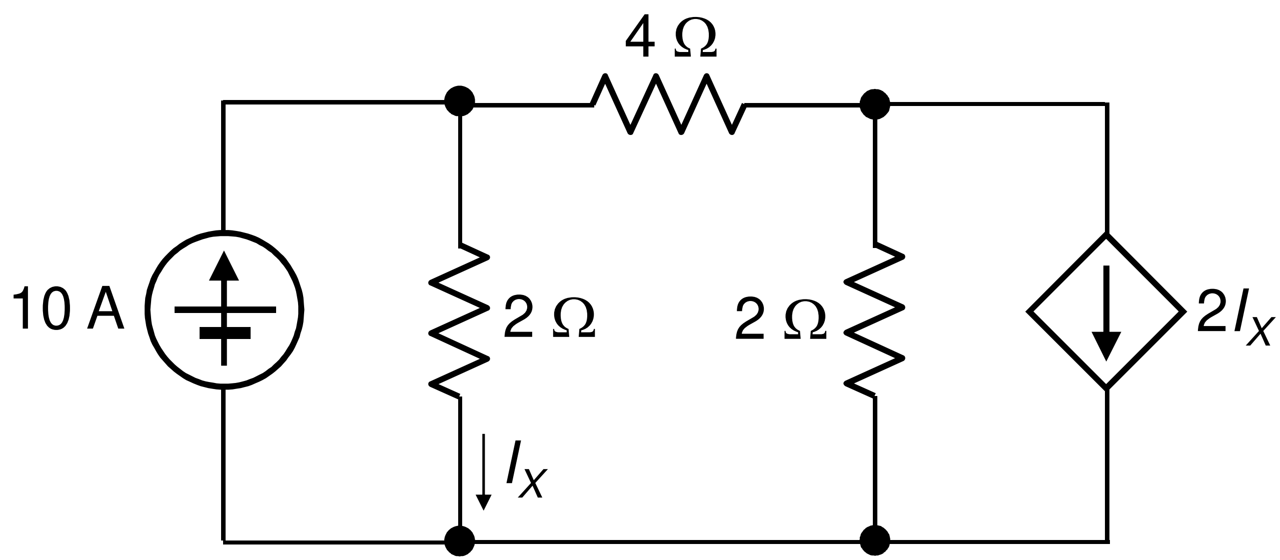


Figure P2.42

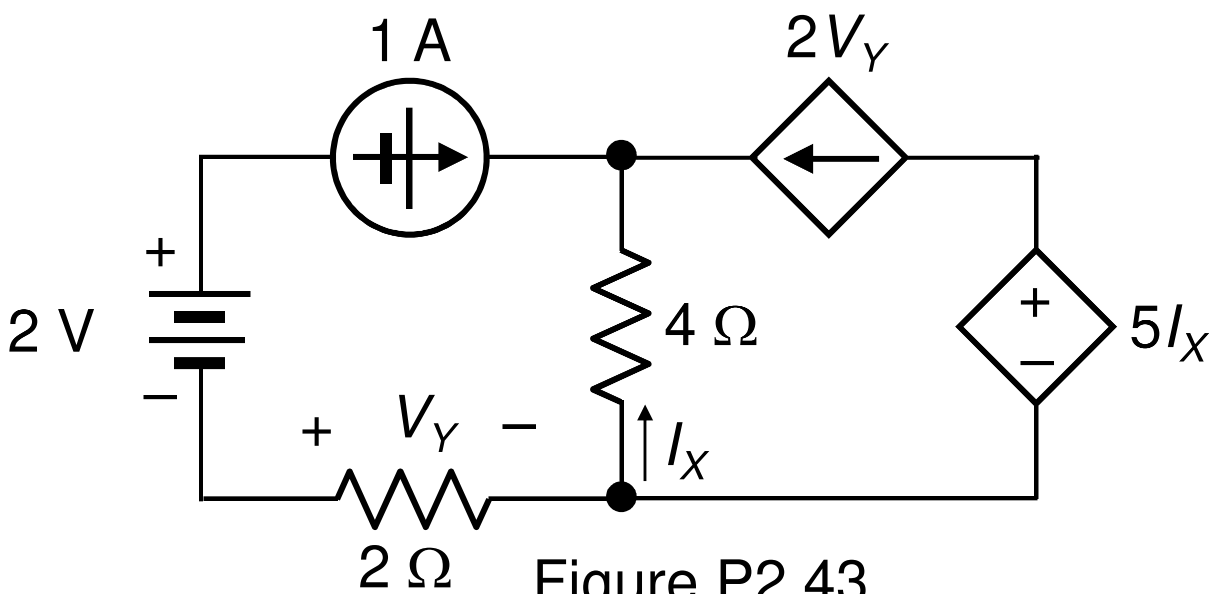


Figure P2.43

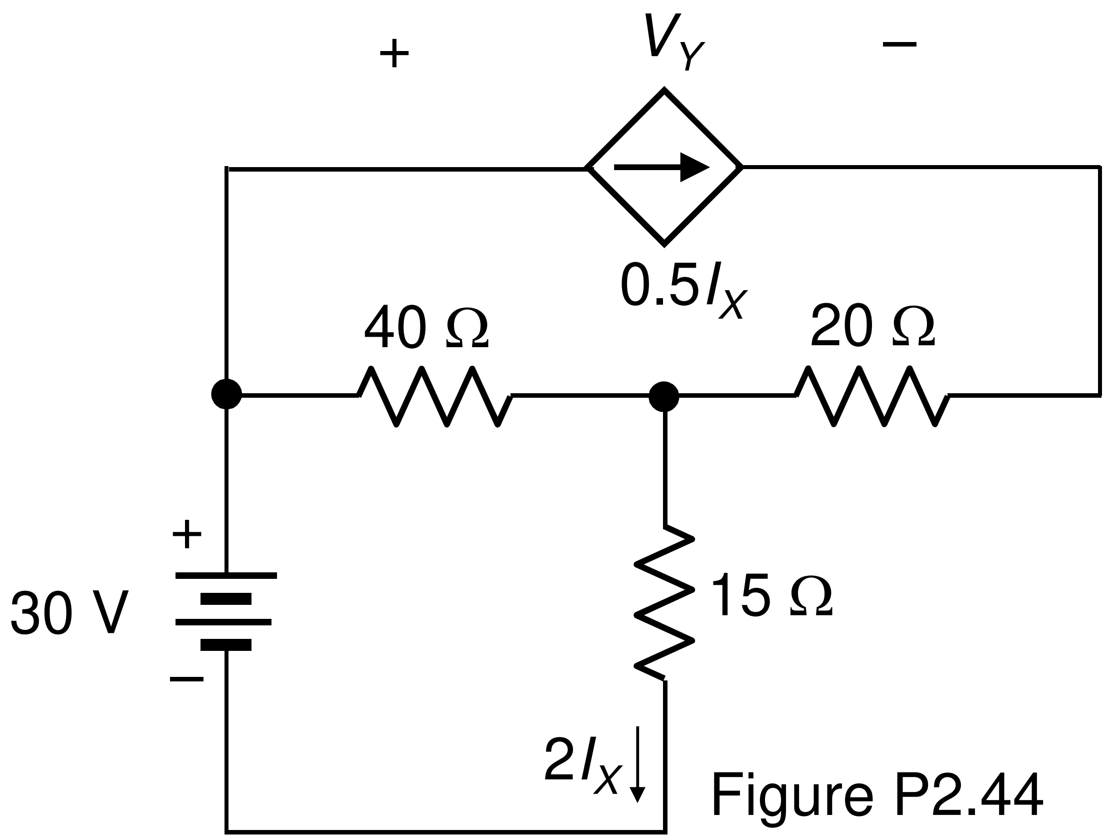


Figure P2.44

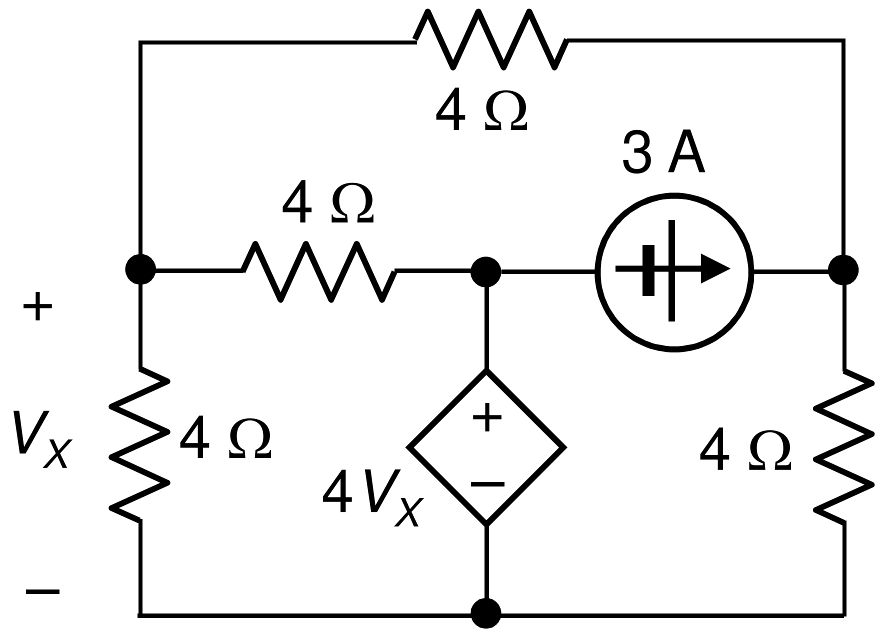


Figure P2.45

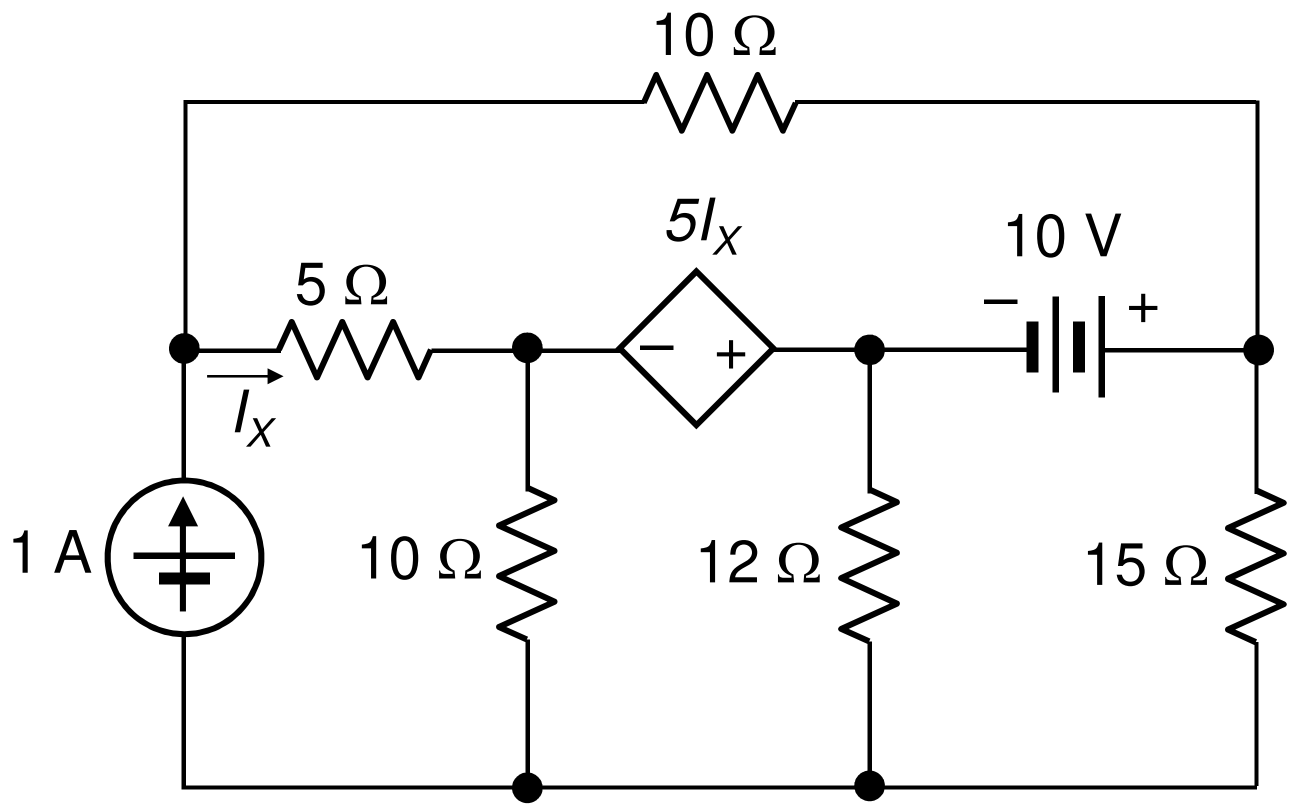
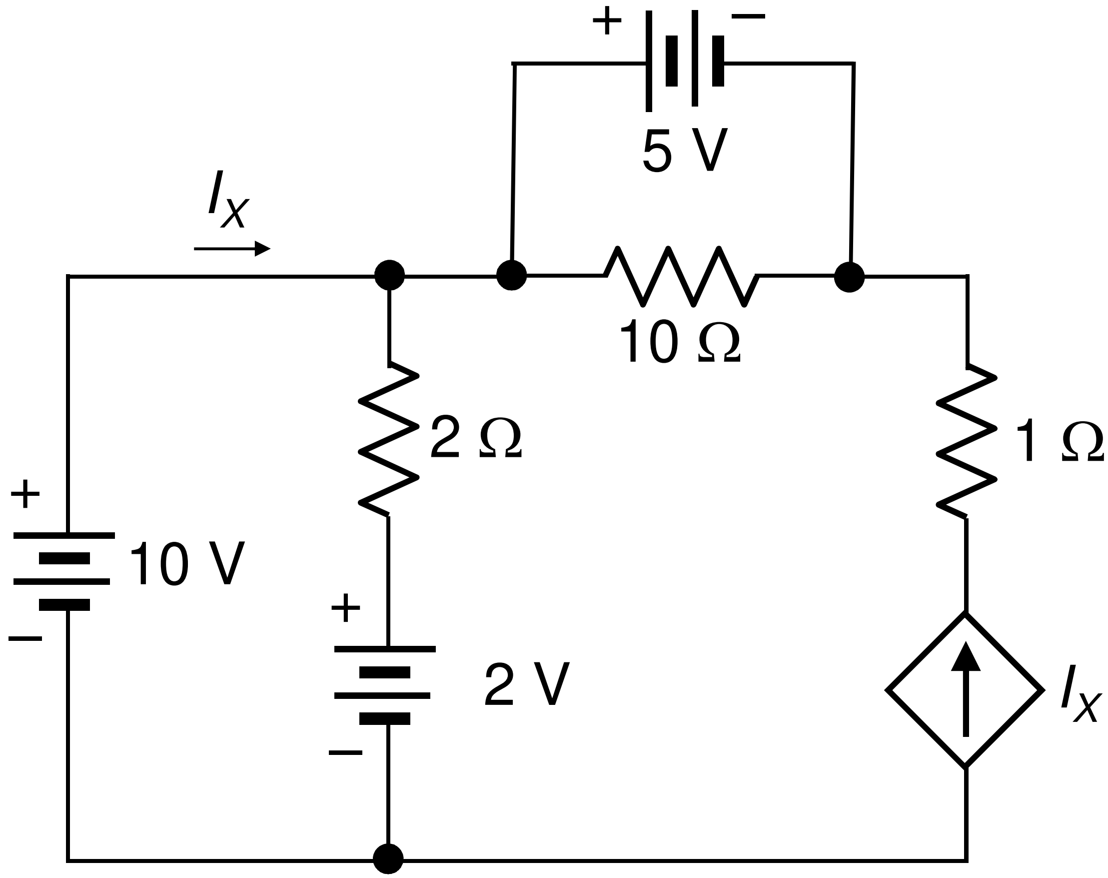


Figure P2.46



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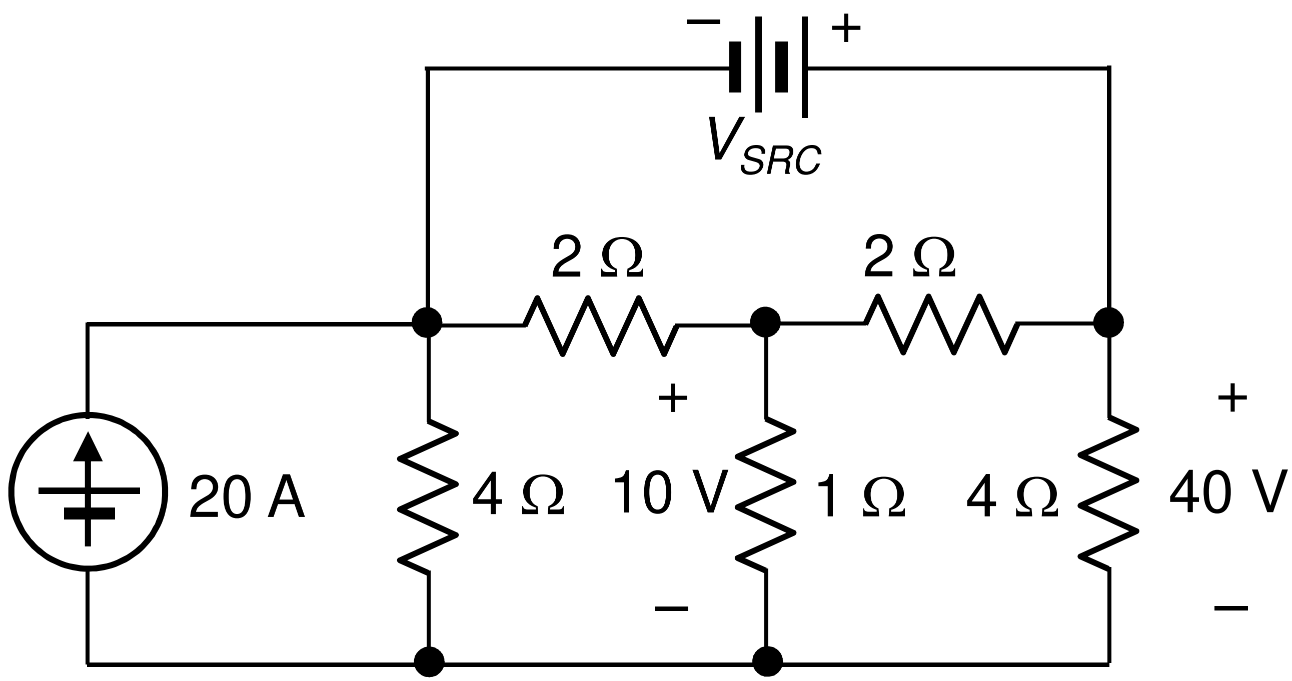

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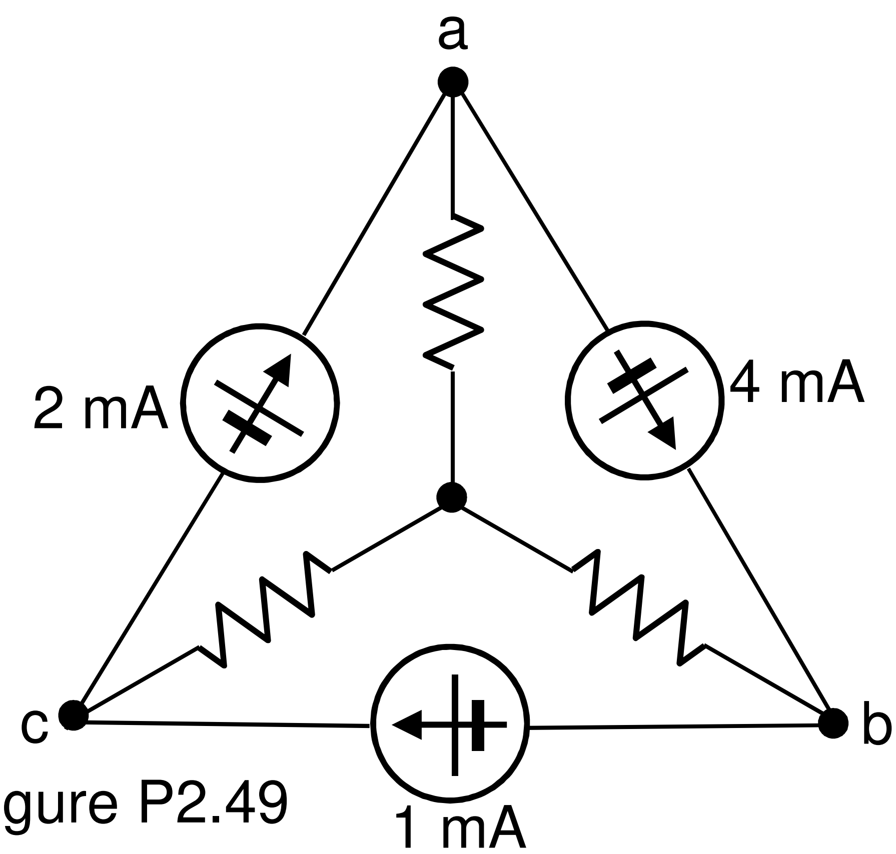


Figure P2.49

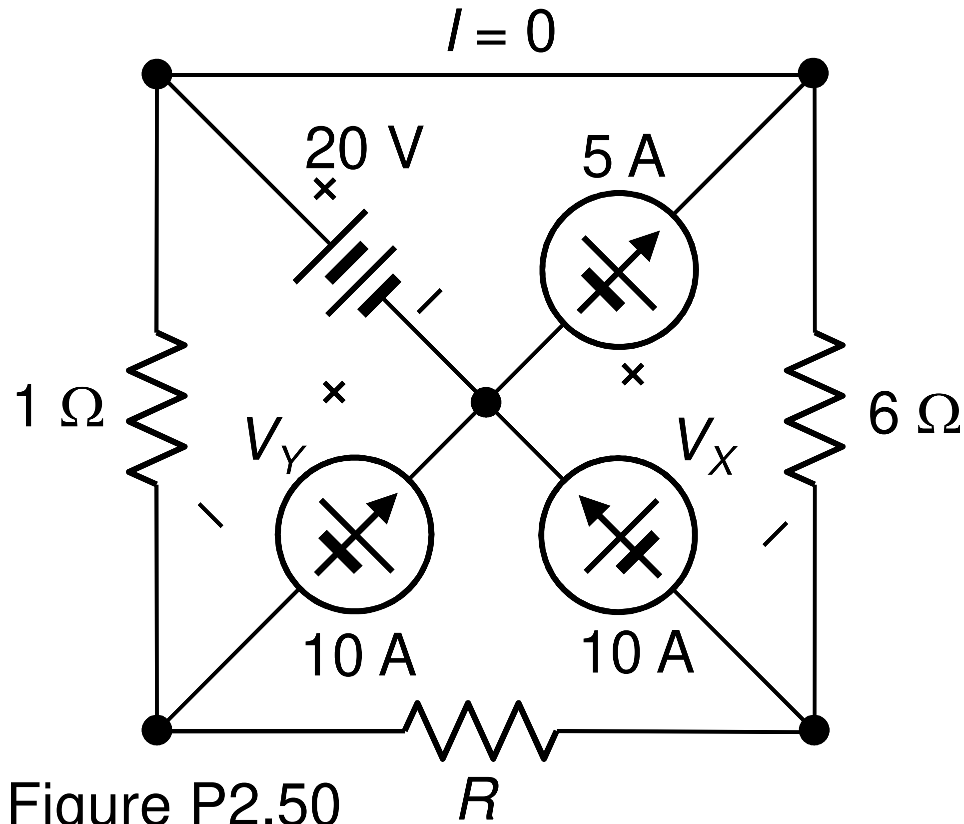


Figure P2.50

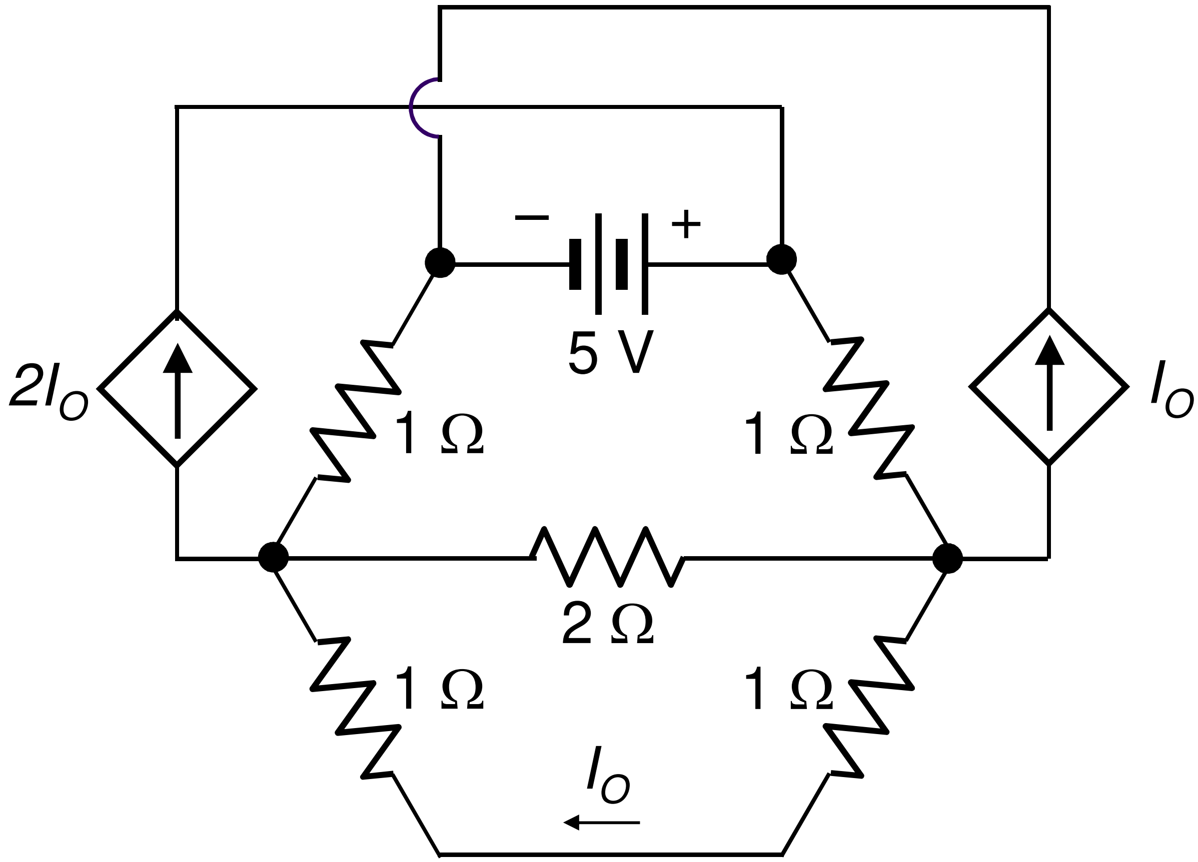


Figure P2.51

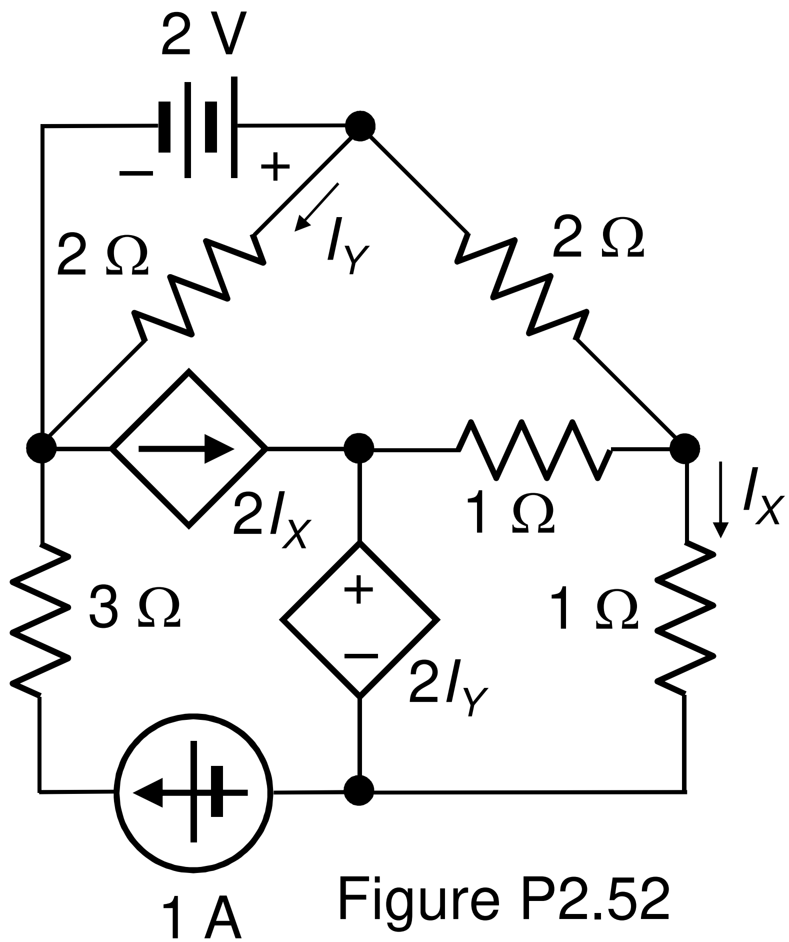
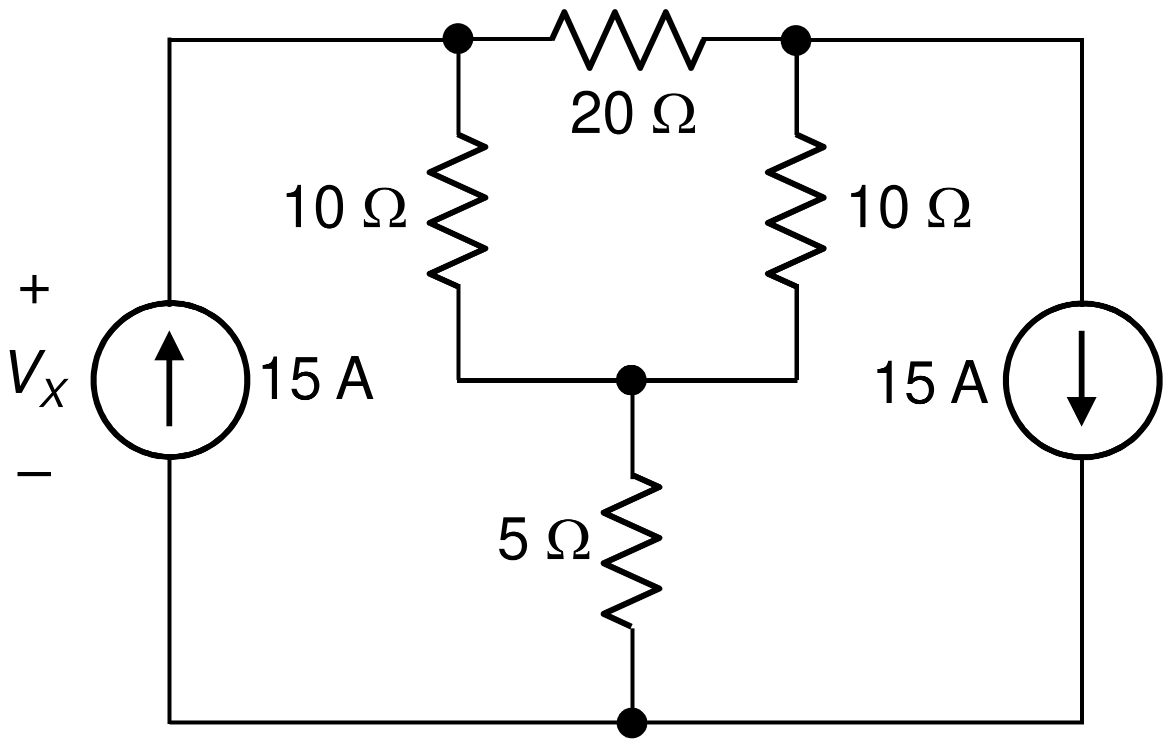


Figure P2.52



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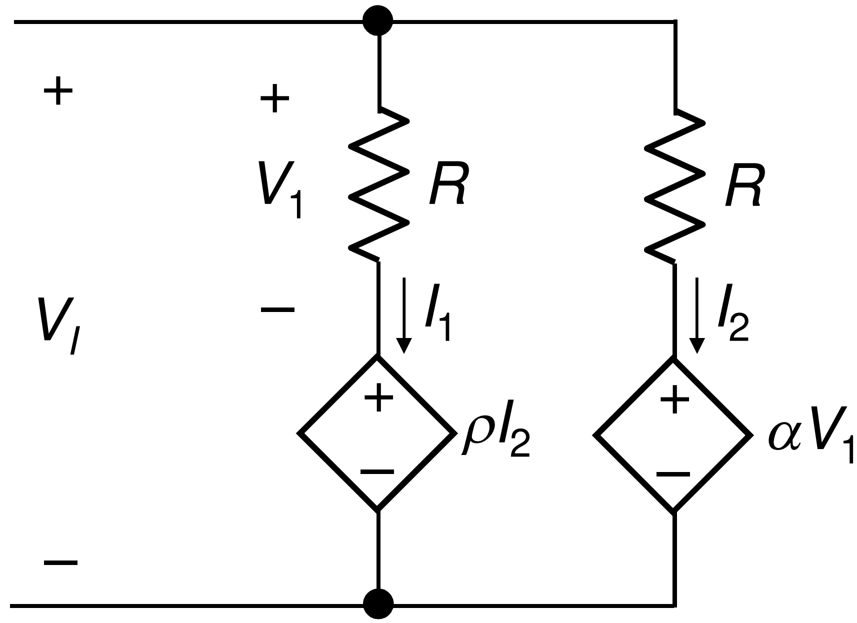

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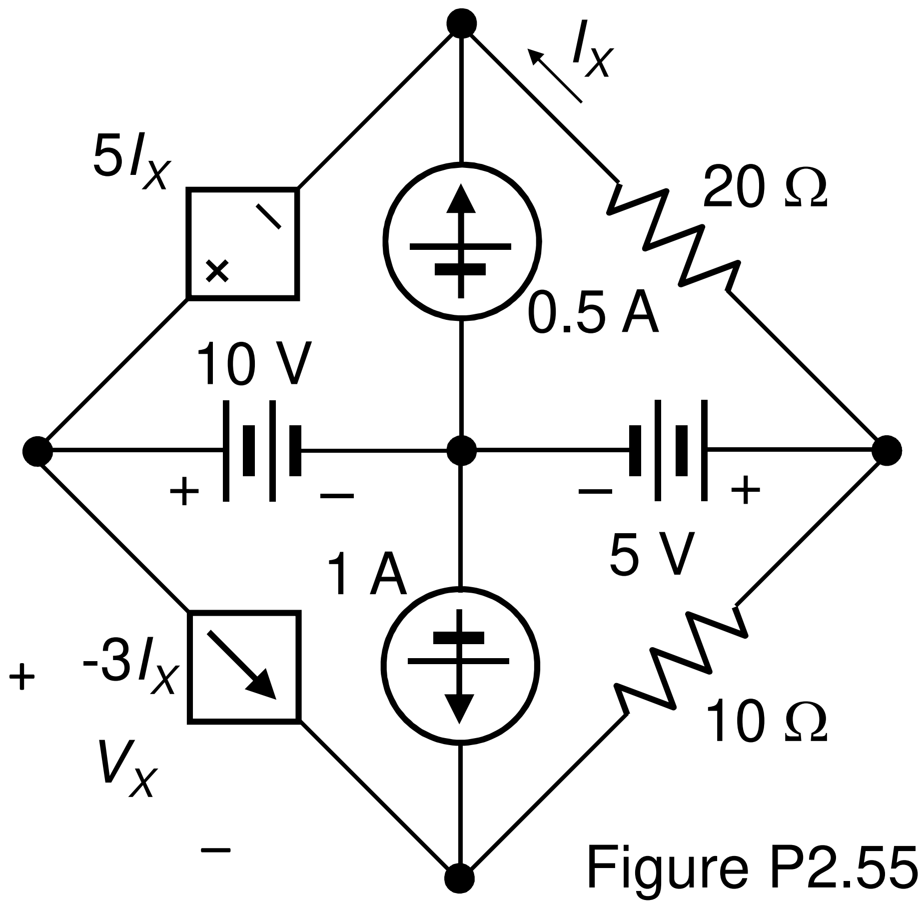

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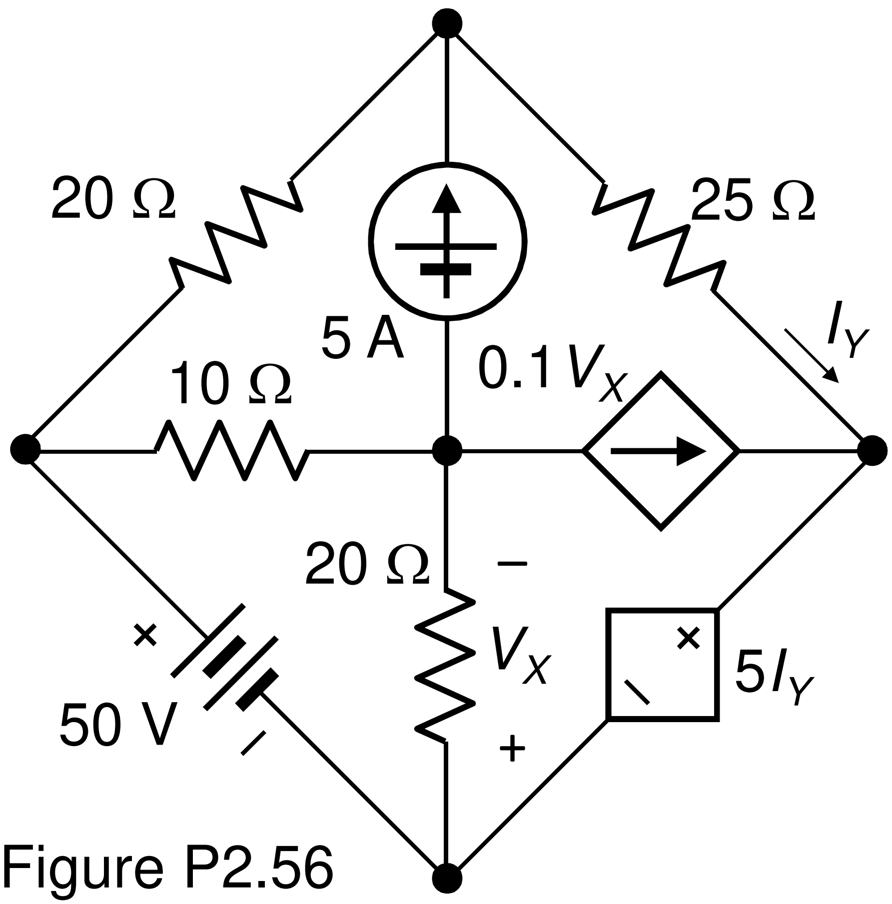


Figure P2.56

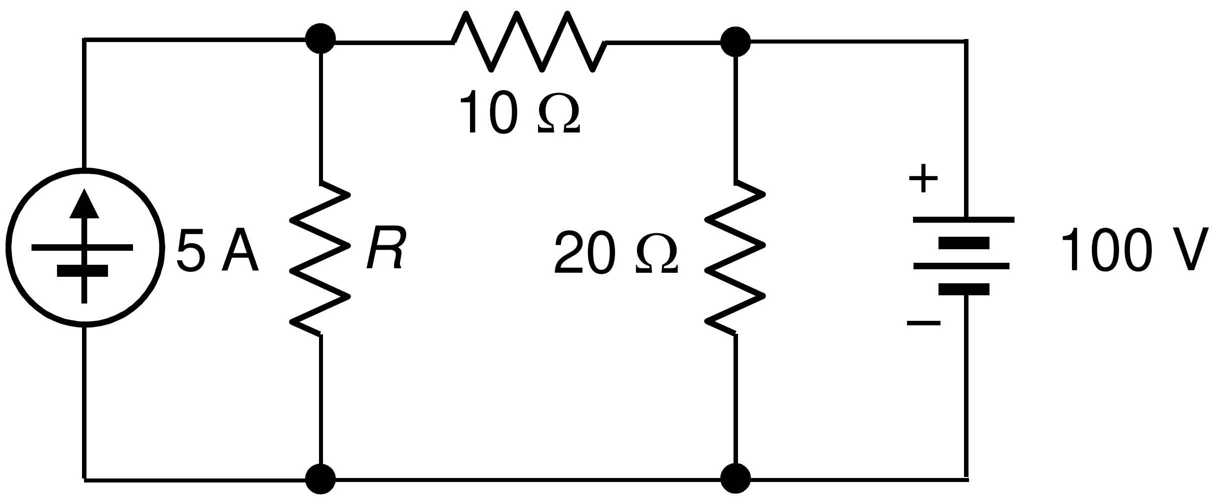


Figure P2.57

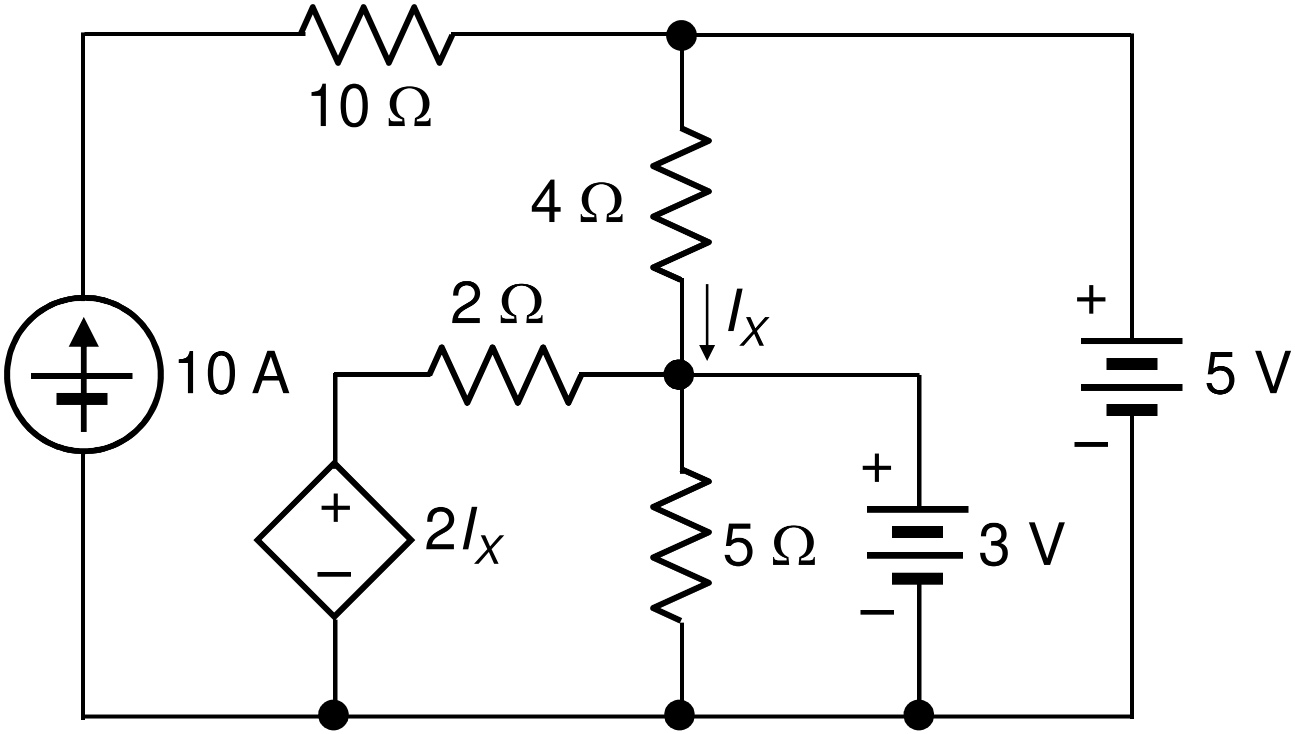


Figure P2.58

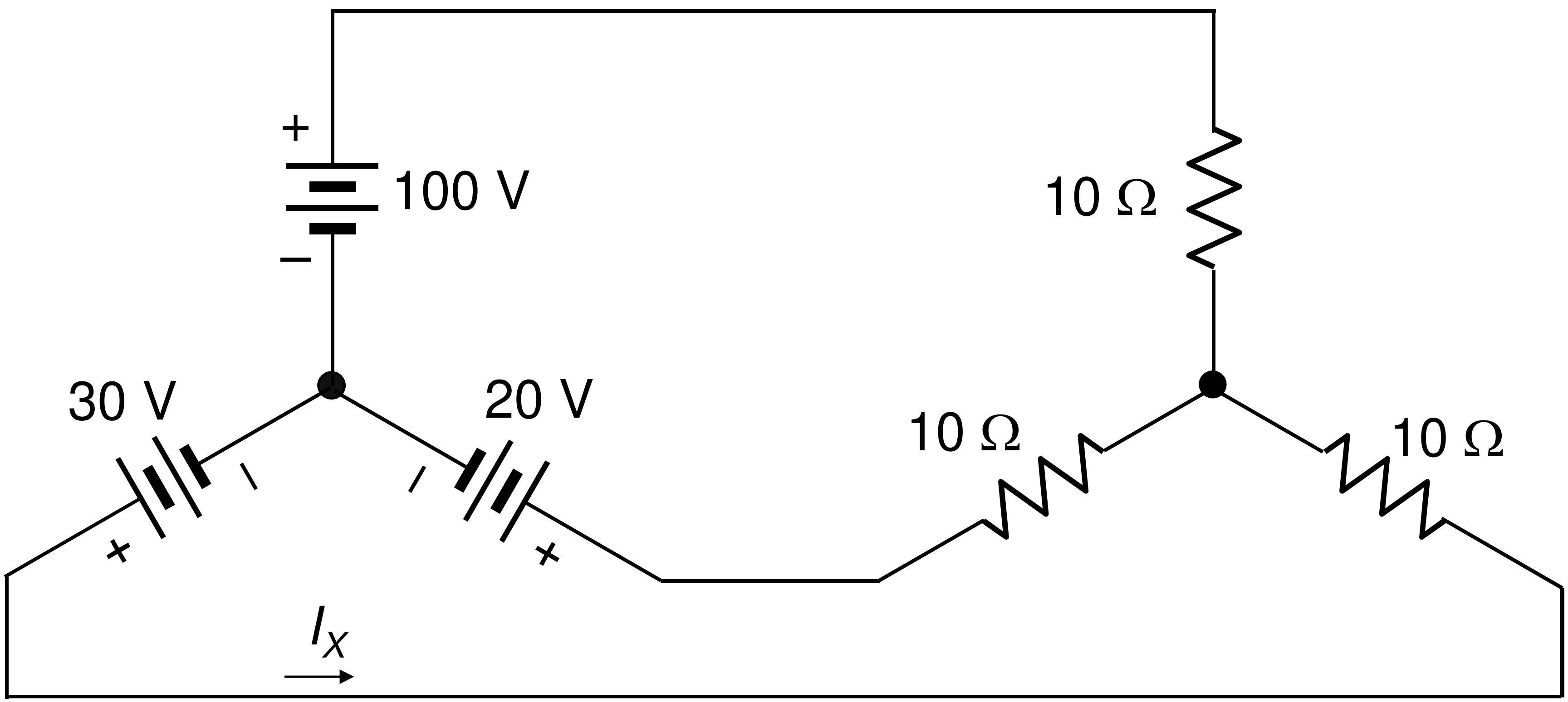


Figure P2.59

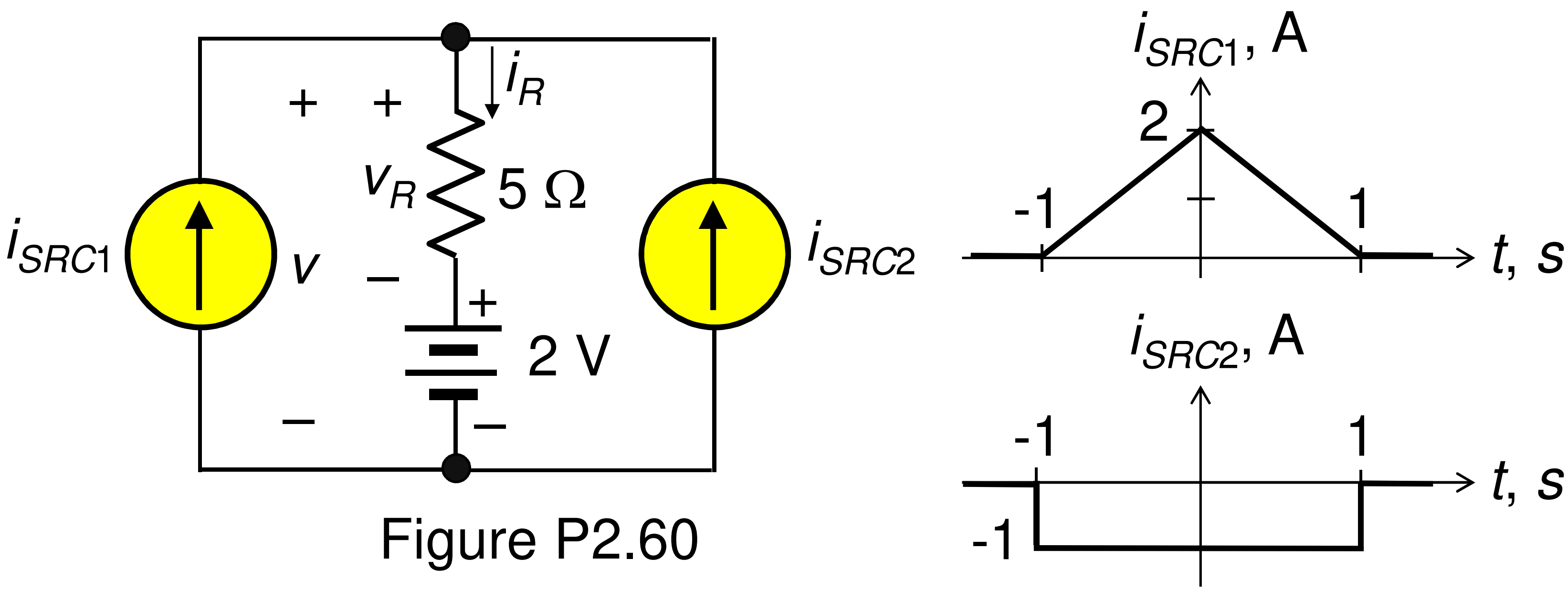


Figure P2.60

Not dc sources

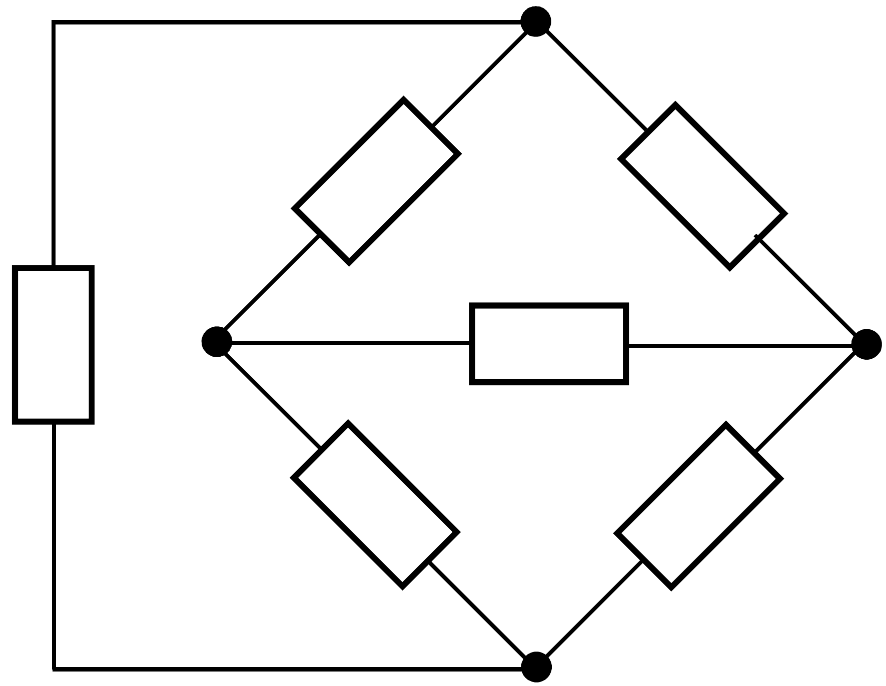
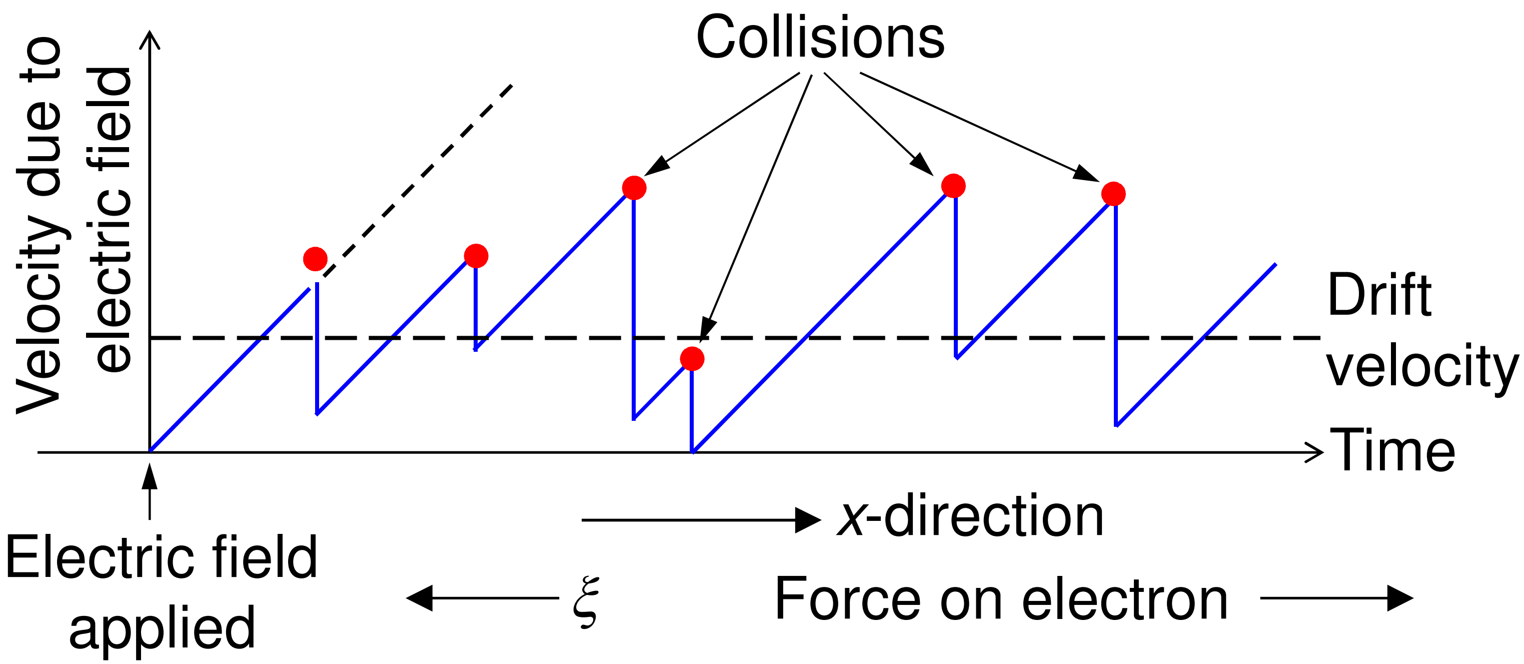
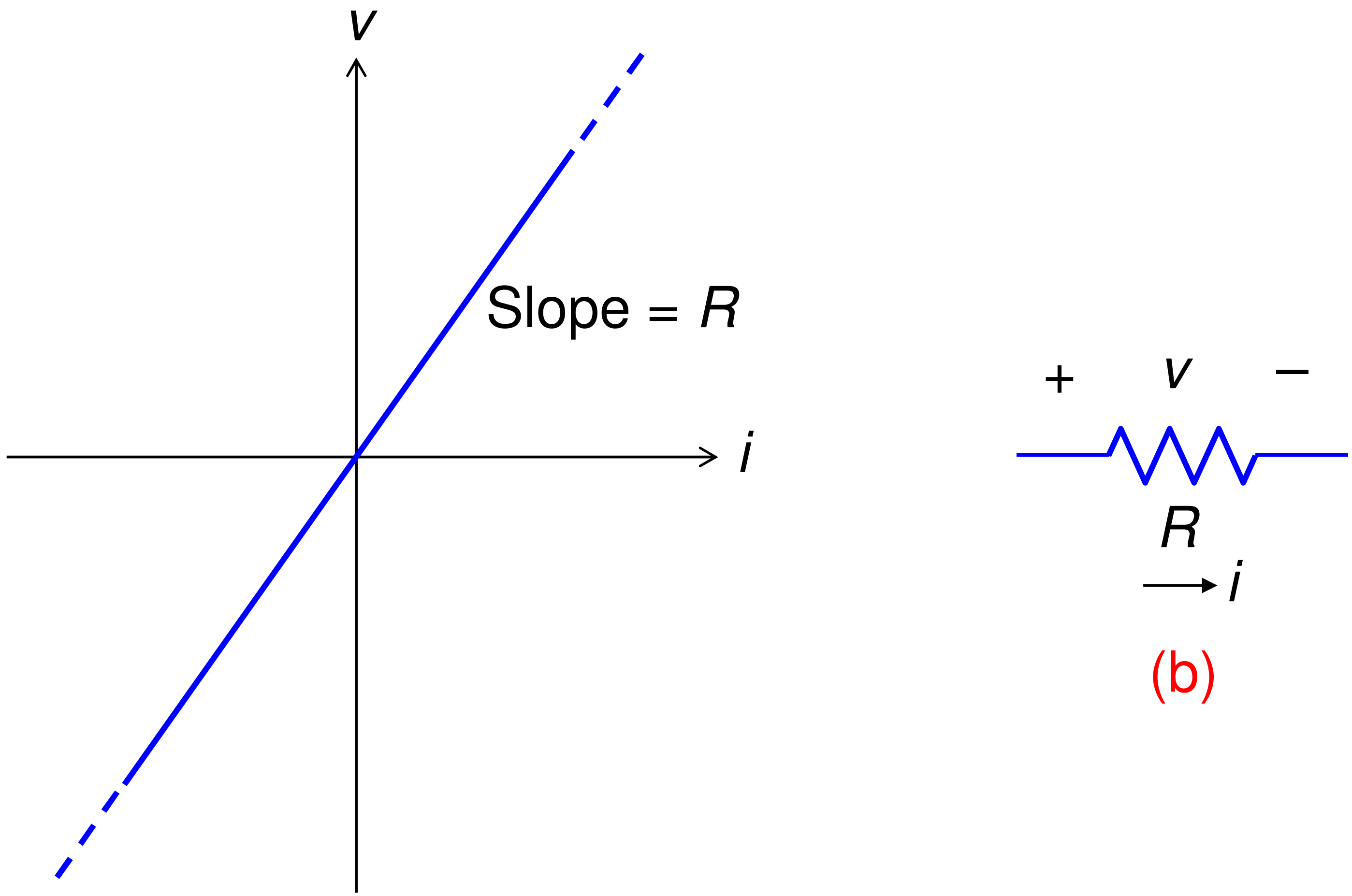


Figure P2.62



Collisions
Velocity due to electric field
Drift velocity
Time
Electric field applied
x-direction
ξ
Force on electron

Figure 2.1



(a)

Figure 2.2

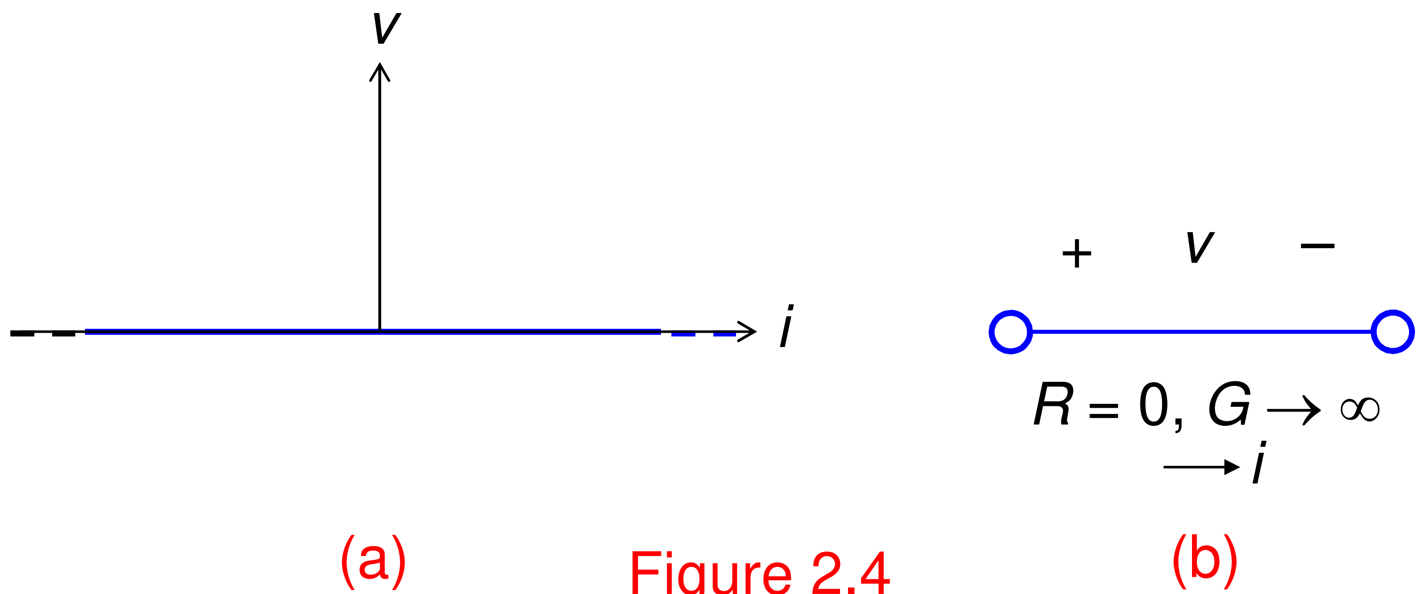
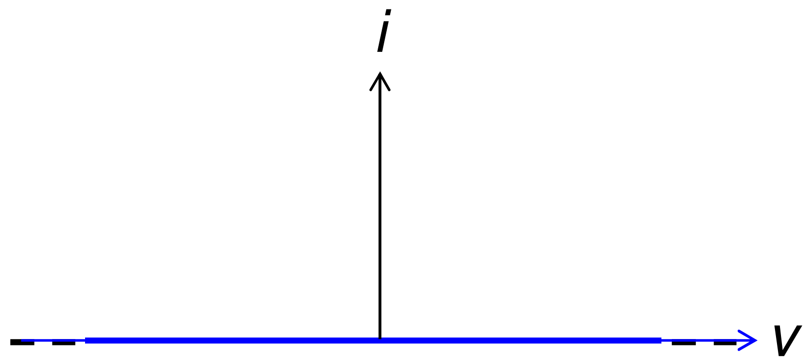
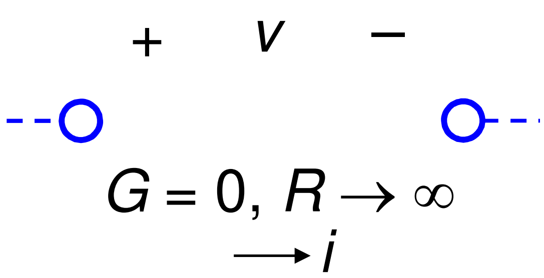


Figure 2.4



(a)



(b)

Figure 2.5

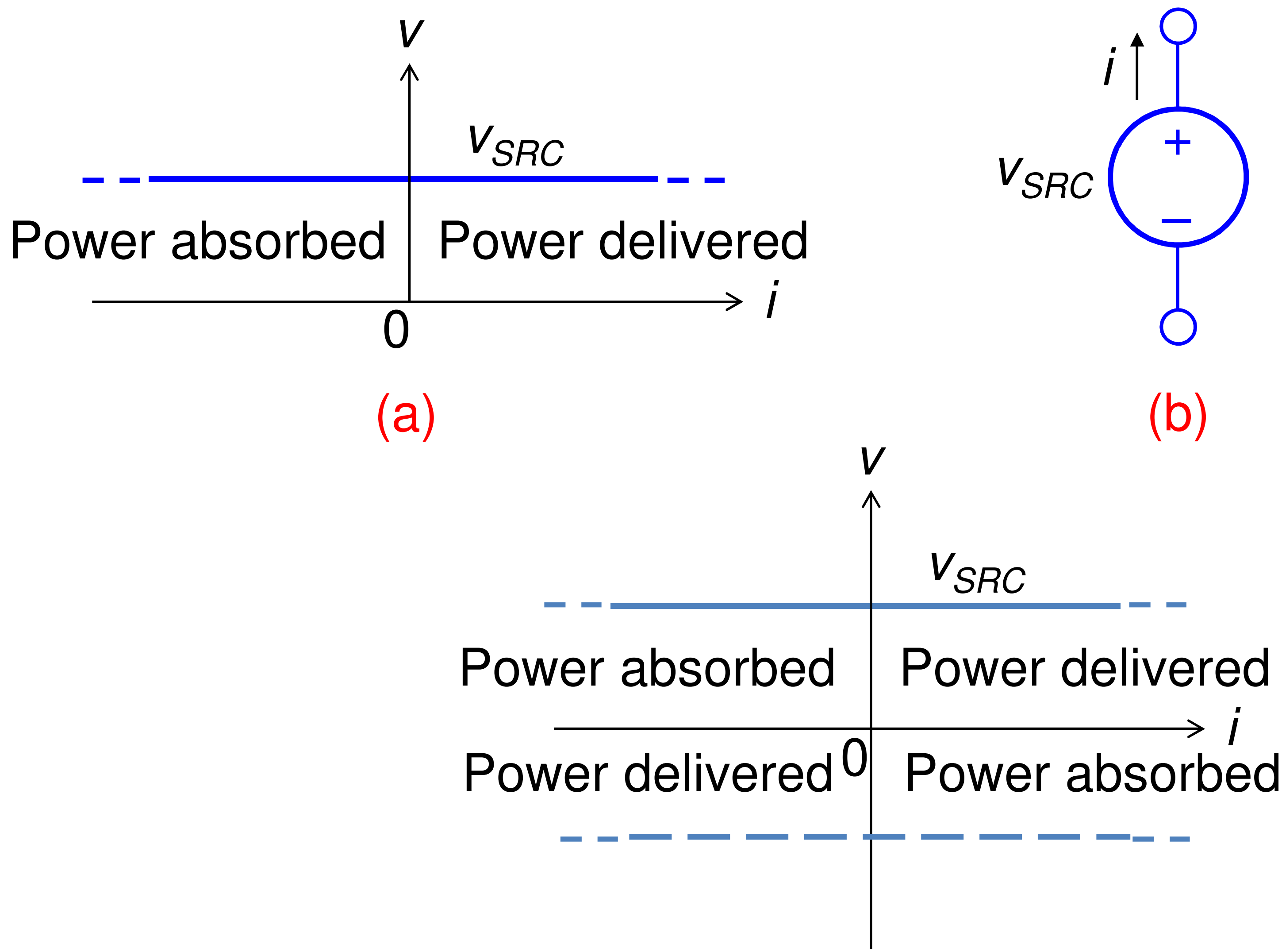
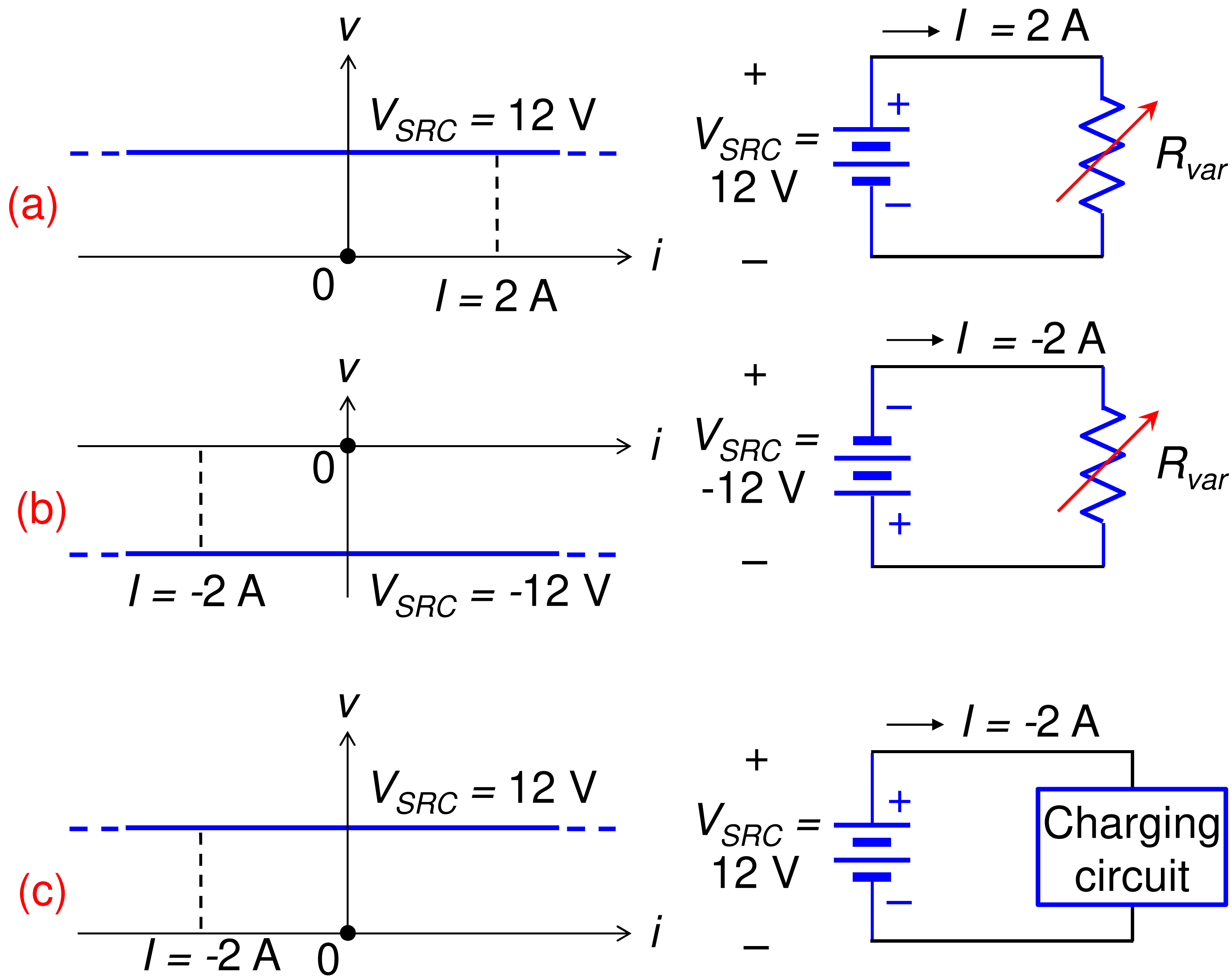

v
v_SRC
Power absorbed
Power delivered
i
0
(a)
i
v_SRC
+
−
(b)
v
v_SRC
Power absorbed
Power delivered
i
Power delivered
0
Power absorbed

Figure 2.7 (c)



v
V_{SRC} = 12 V
(a)
0
I = 2 A
i
I = 2 A
+
V_{SRC} = 12 V
−
R_{var}
v
i
0
(b)
I = -2 A
V_{SRC} = -12 V
I = -2 A
+
V_{SRC} = -12 V
−
R_{var}
v
V_{SRC} = 12 V
(c)
i
I = -2 A
0
I = -2 A
+
V_{SRC} = 12 V
−
Charging circuit

Figure 2.8

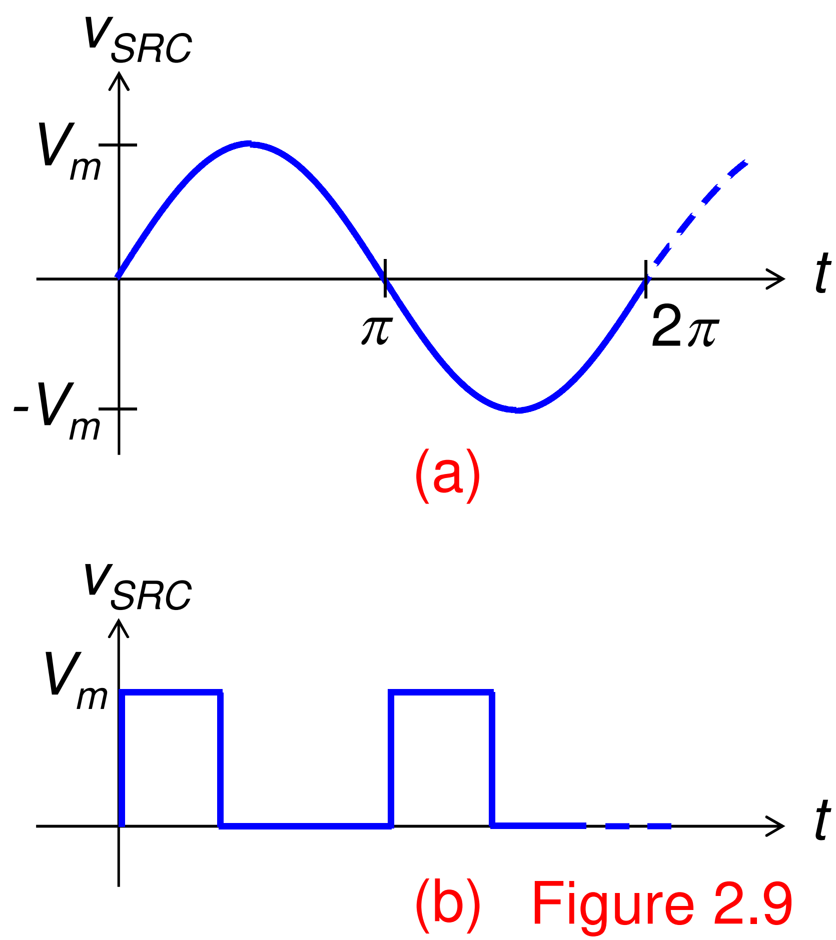


Figure 2.9

t, s	0.5	1.6	3.7	4.7
sin$t$, V	4.8	10	-5.3	-10

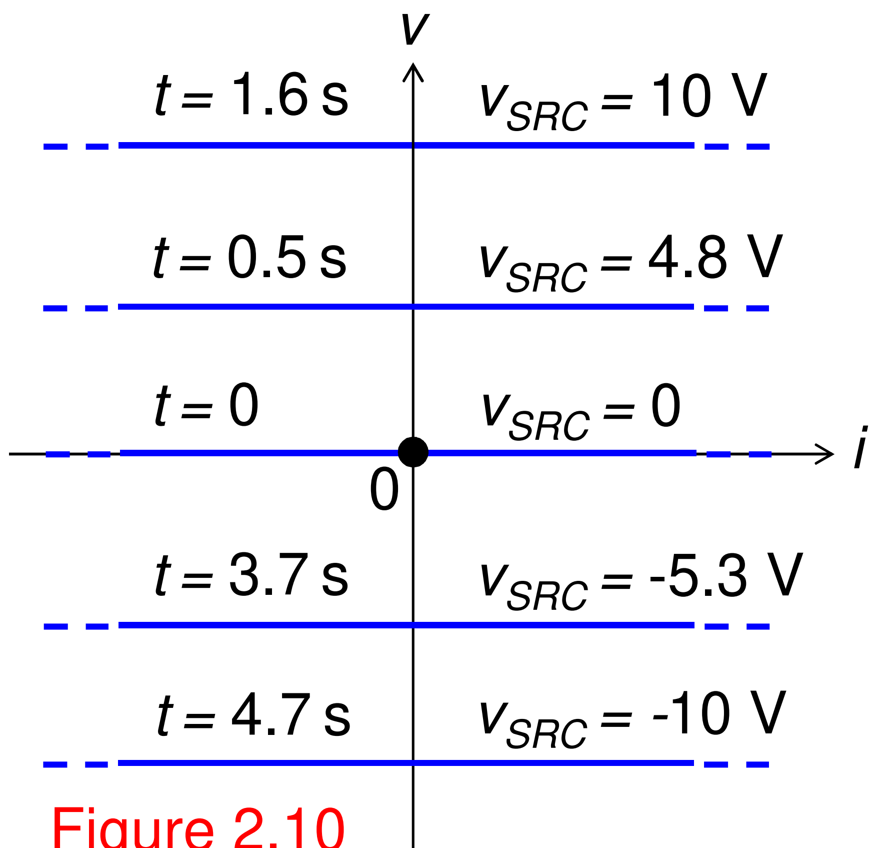
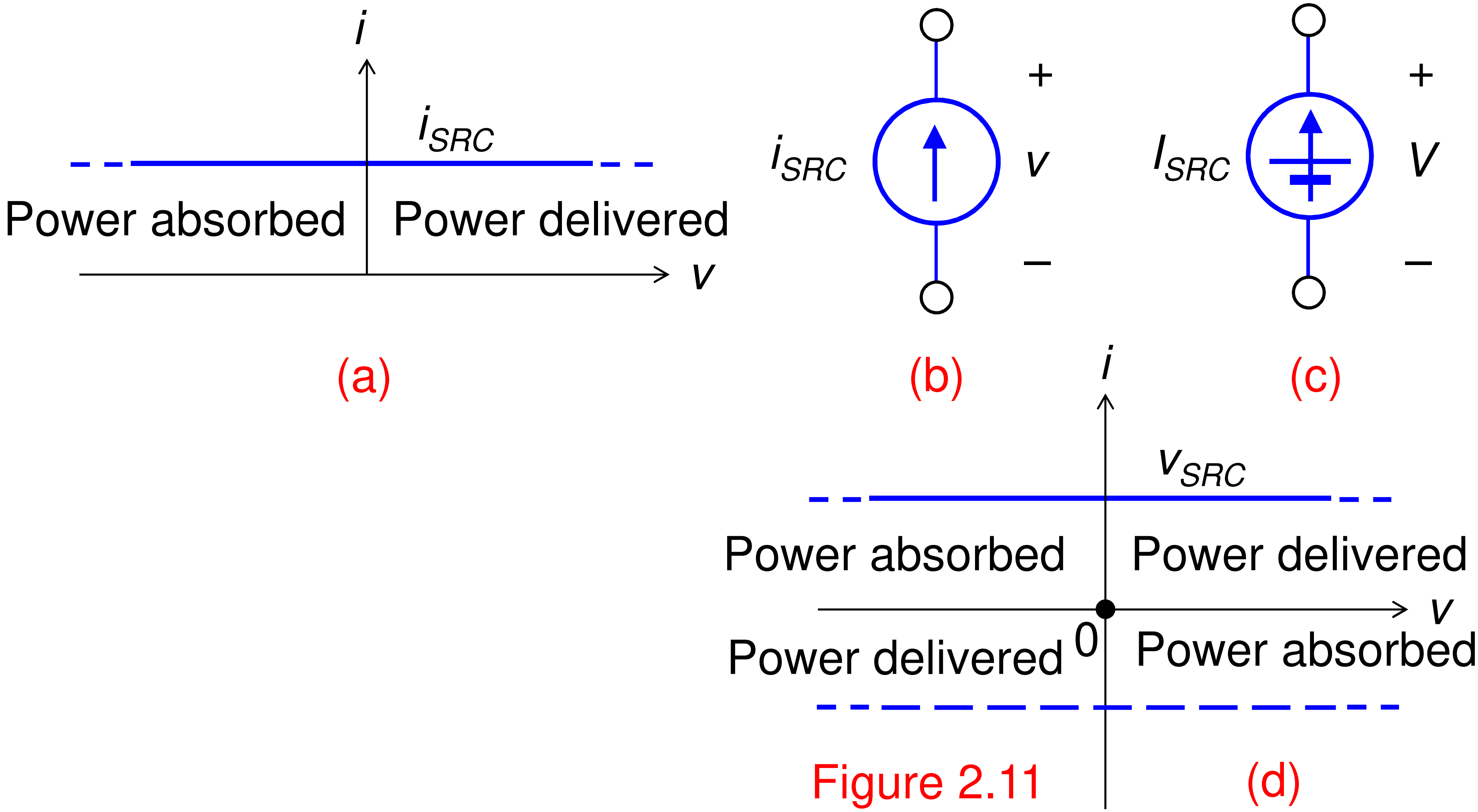


Figure 2.10



i
iSRC
Power absorbed
Power delivered
v
(a)
iSRC
+
v
–
(b)
ISRC
+
V
–
(c)
i
vSRC
Power absorbed
Power delivered
v
0
Power delivered
Power absorbed
(d)

Figure 2.11

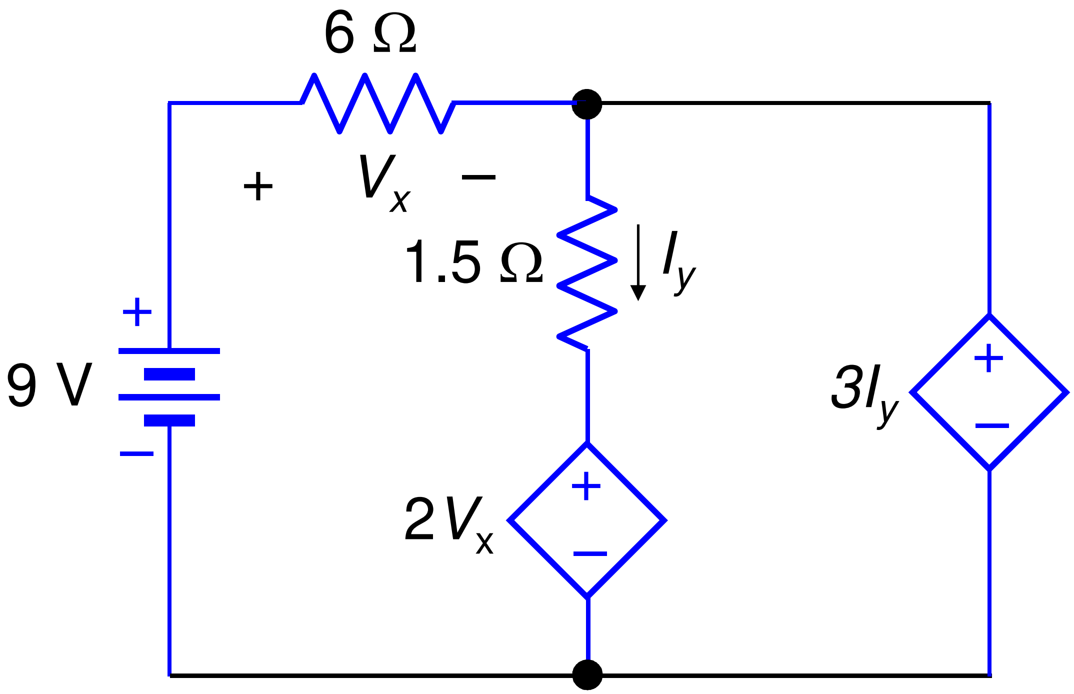


Figure 2.13

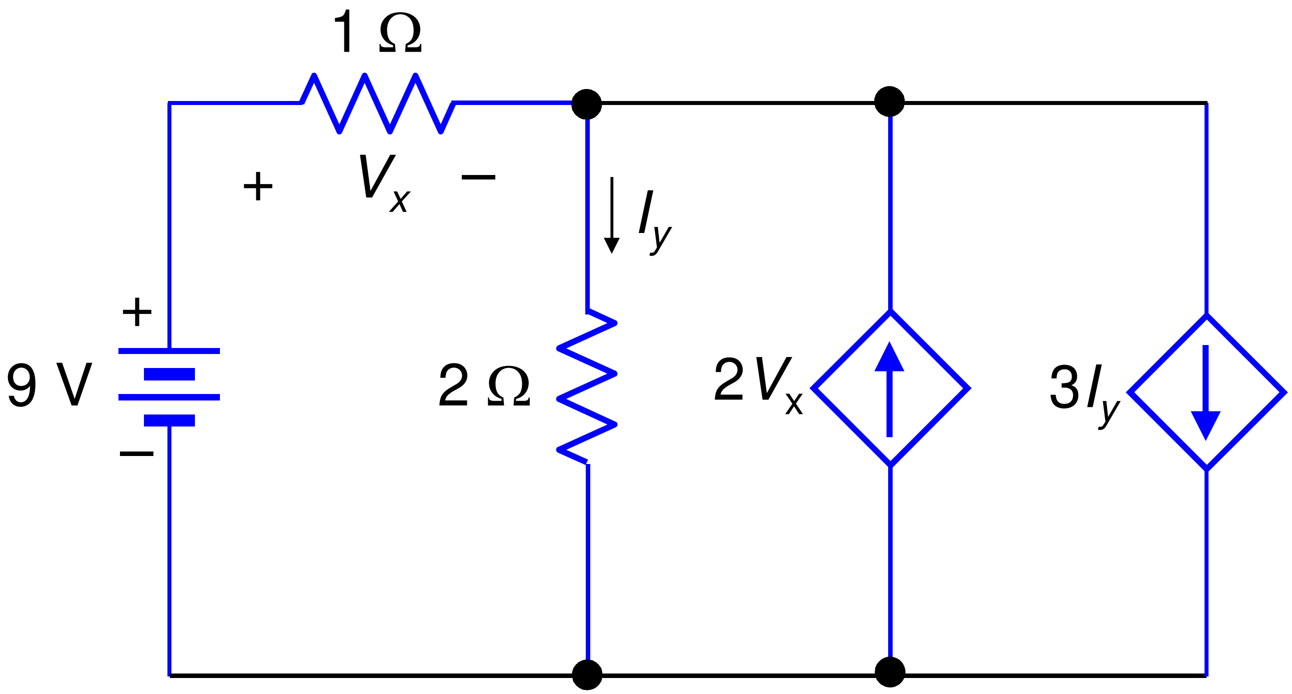


Figure 2.14

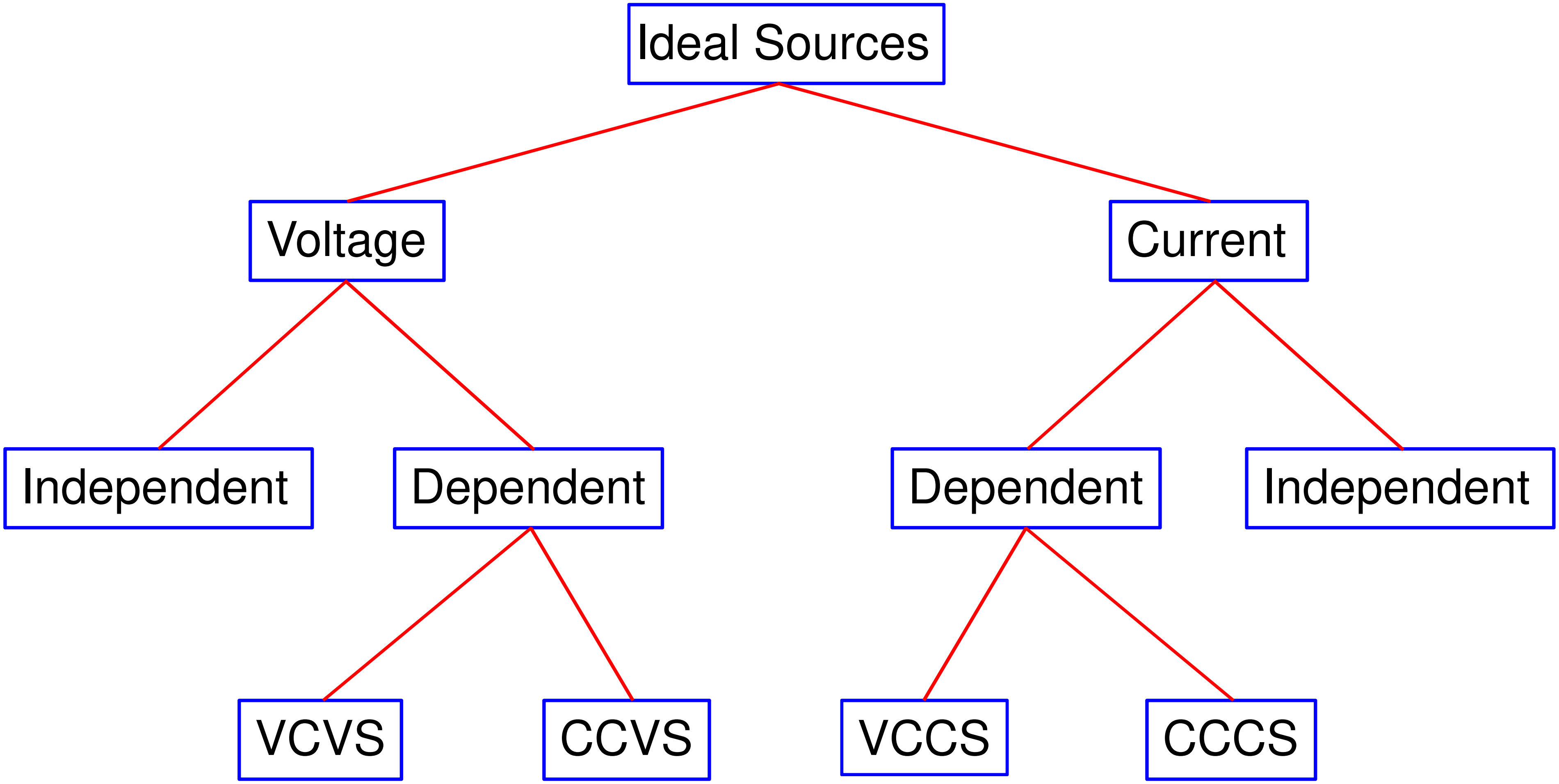

Ideal Sources
Voltage
Current
Independent
Dependent
Dependent
Independent
VCVS
CCVS
VCCS
CCCS

Figure 2.15

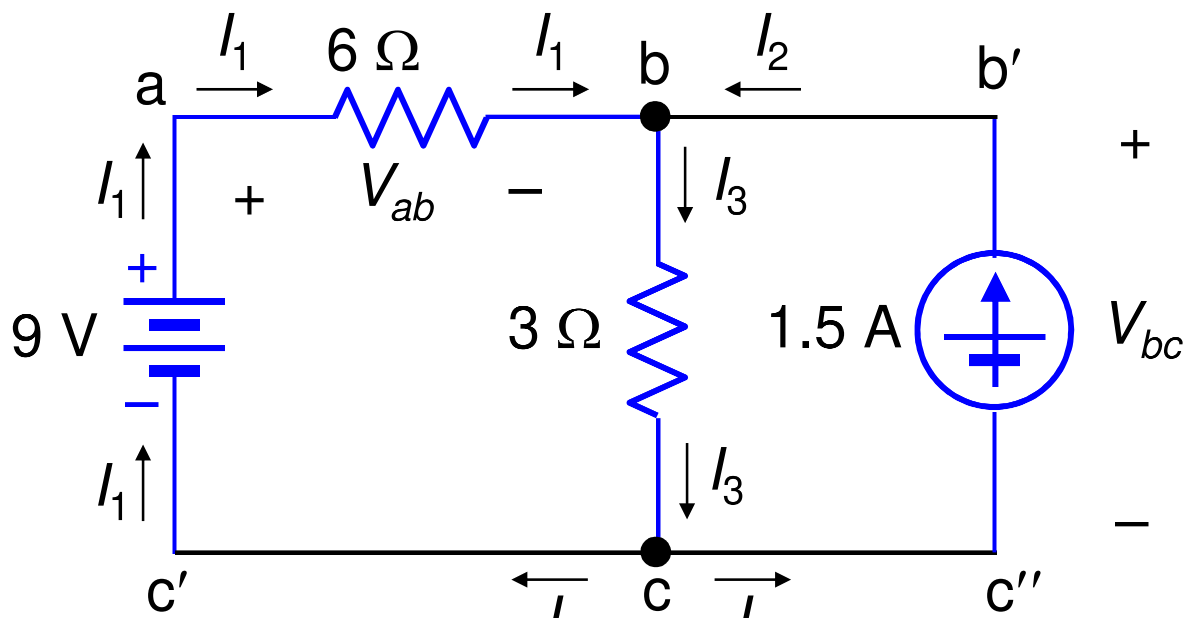
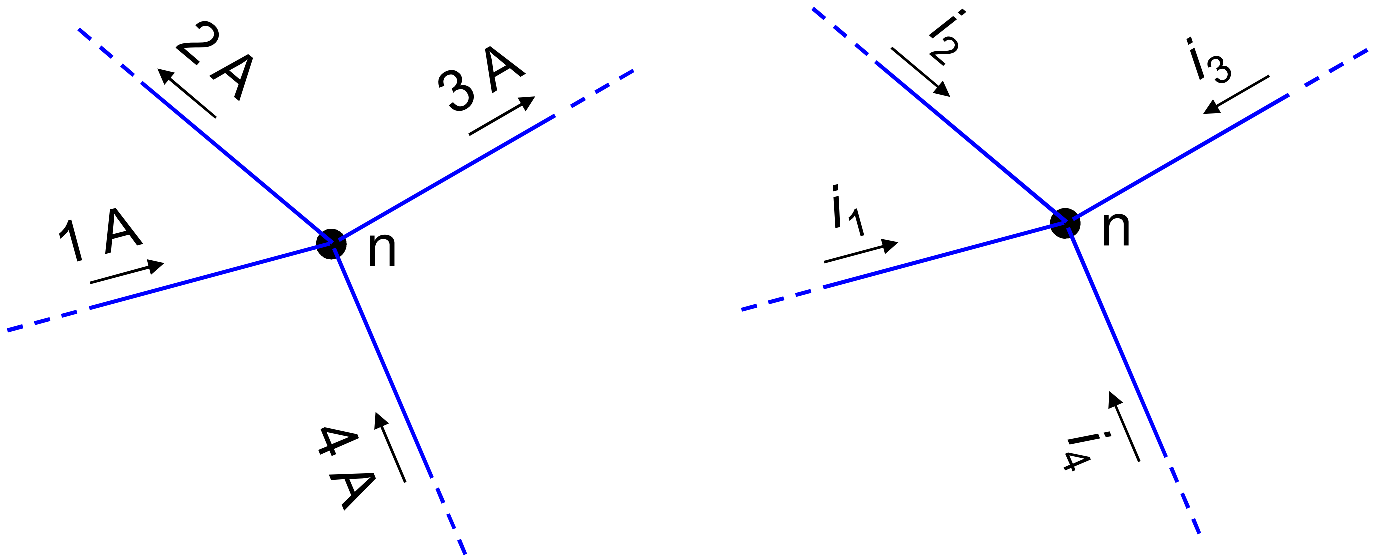
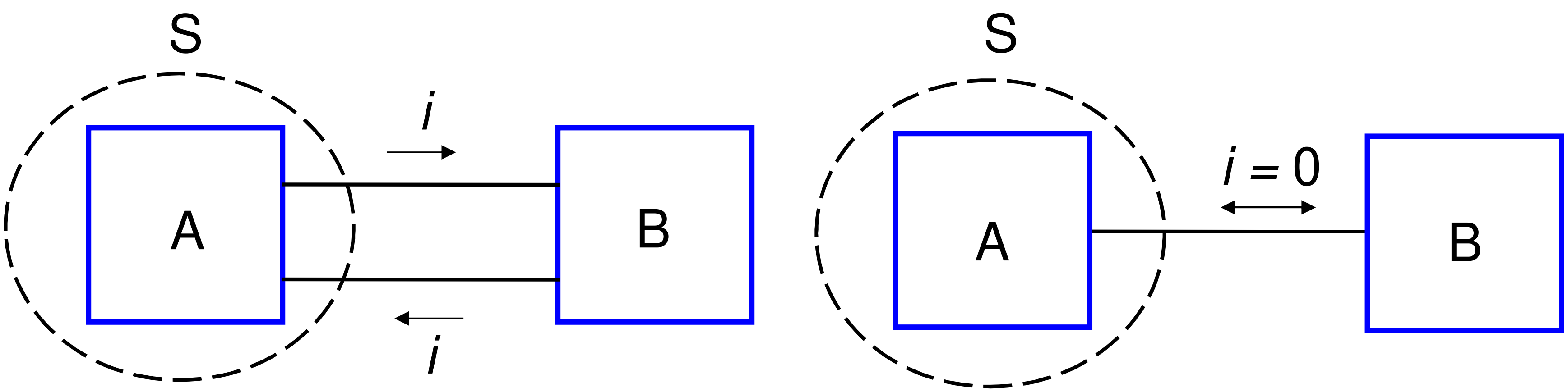


Figure 2.16



(a) Figure 2.18 (b)



(a) Figure 2.19 (b)

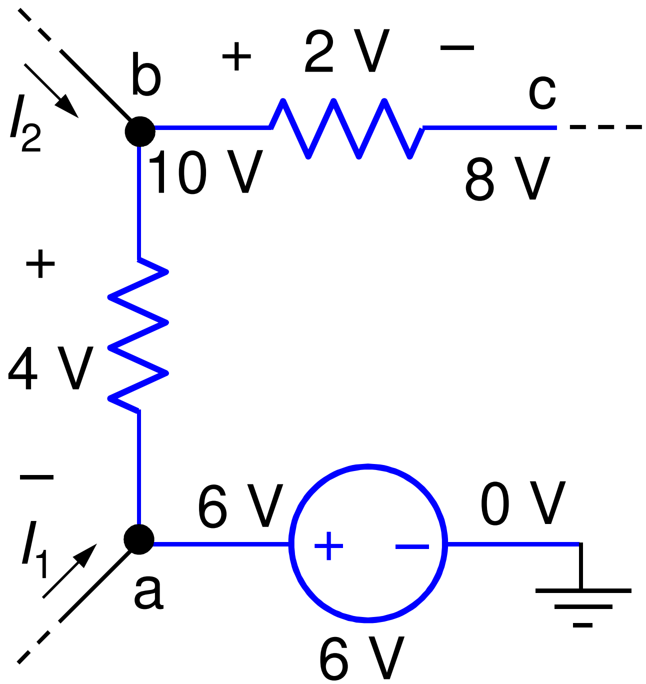


Figure 2.20

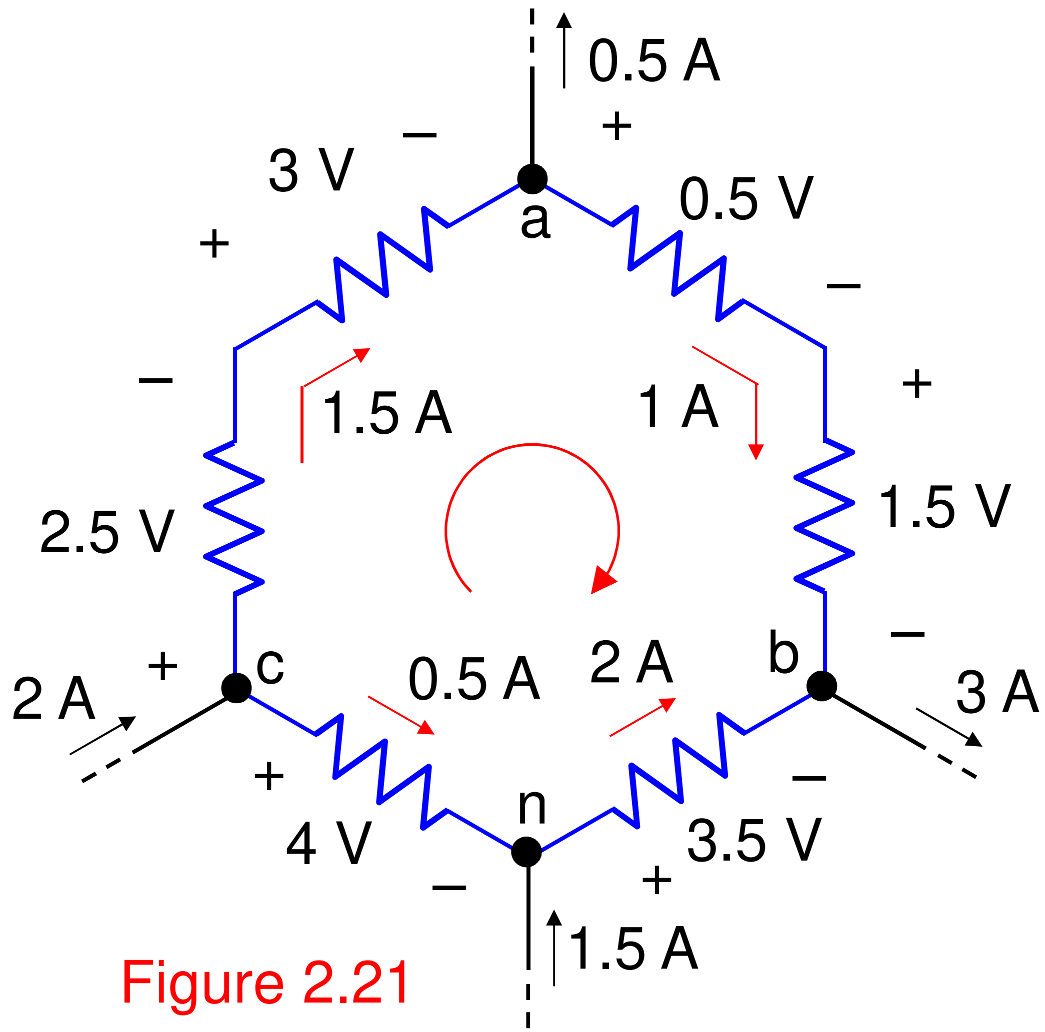


Figure 2.21

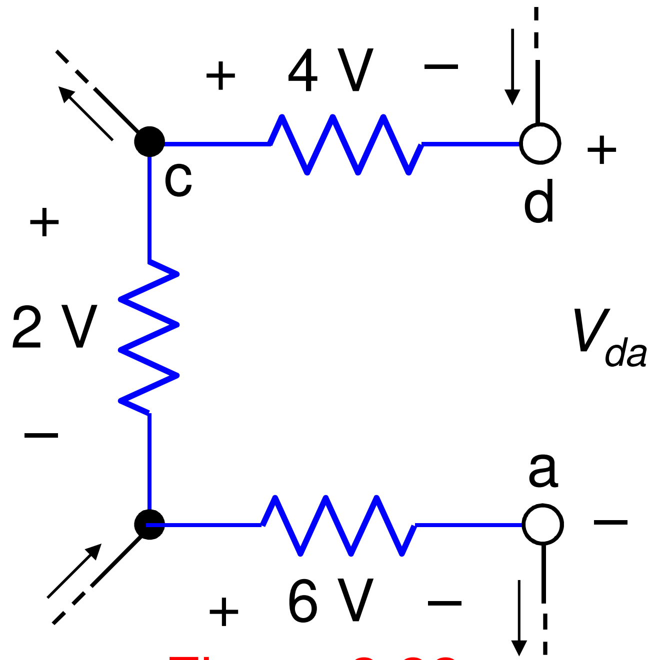


Figure 2.22

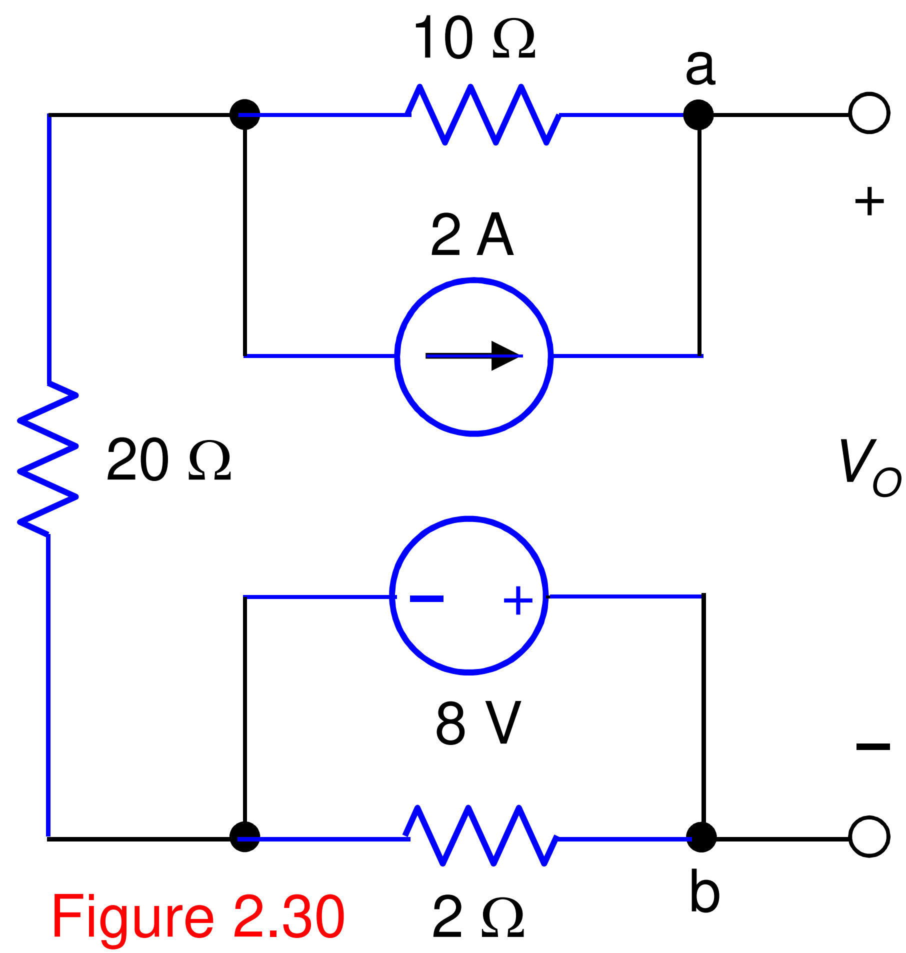


Figure 2.30

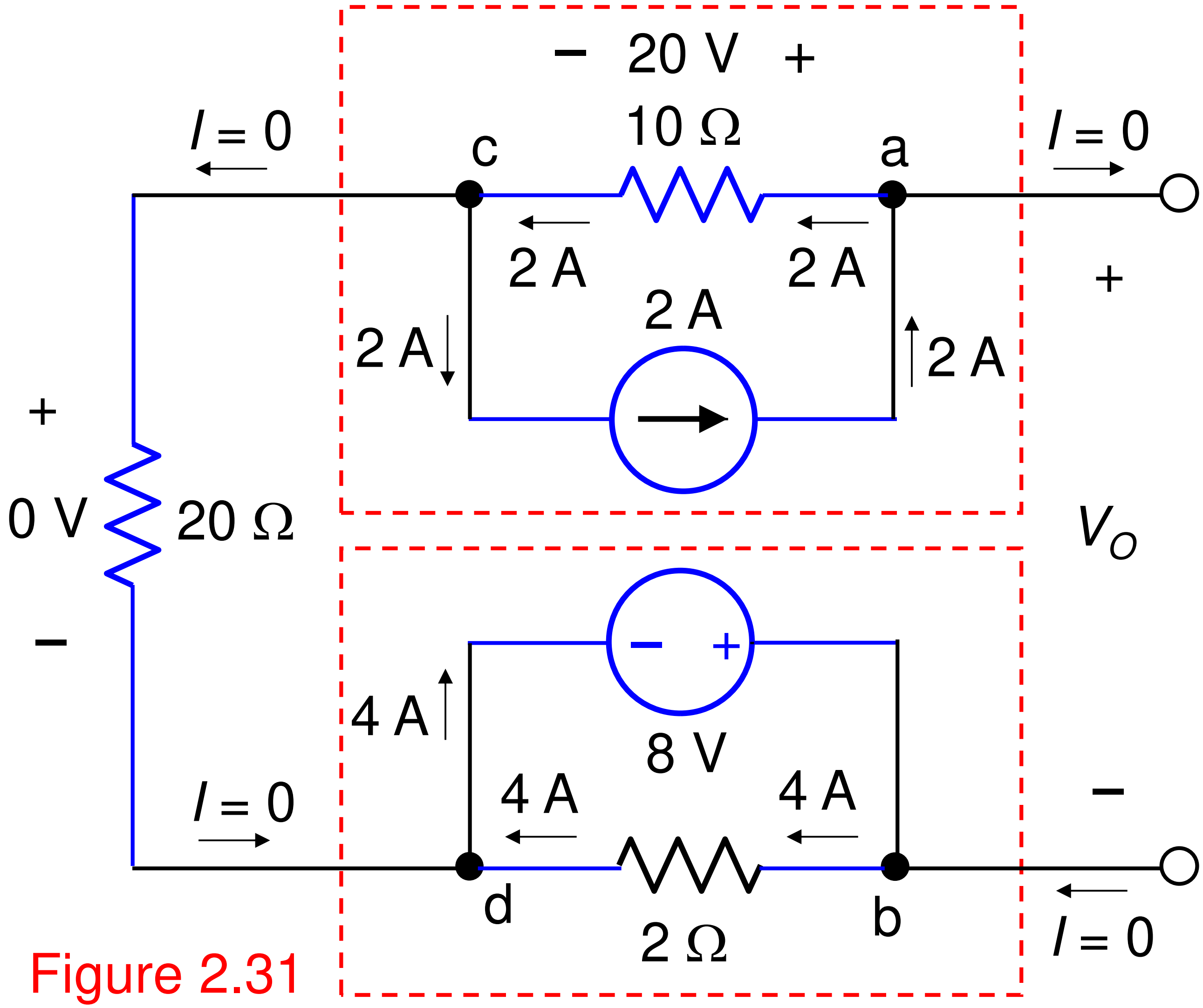


Figure 2.31

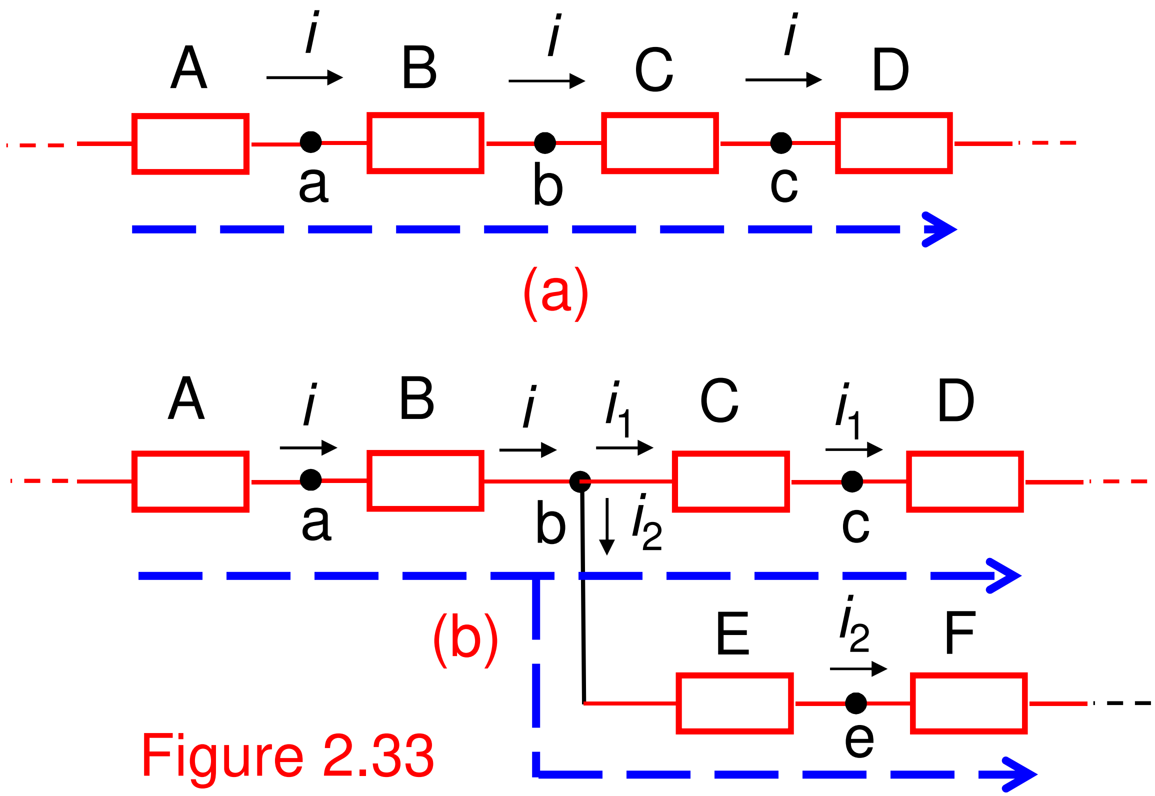


Figure 2.33

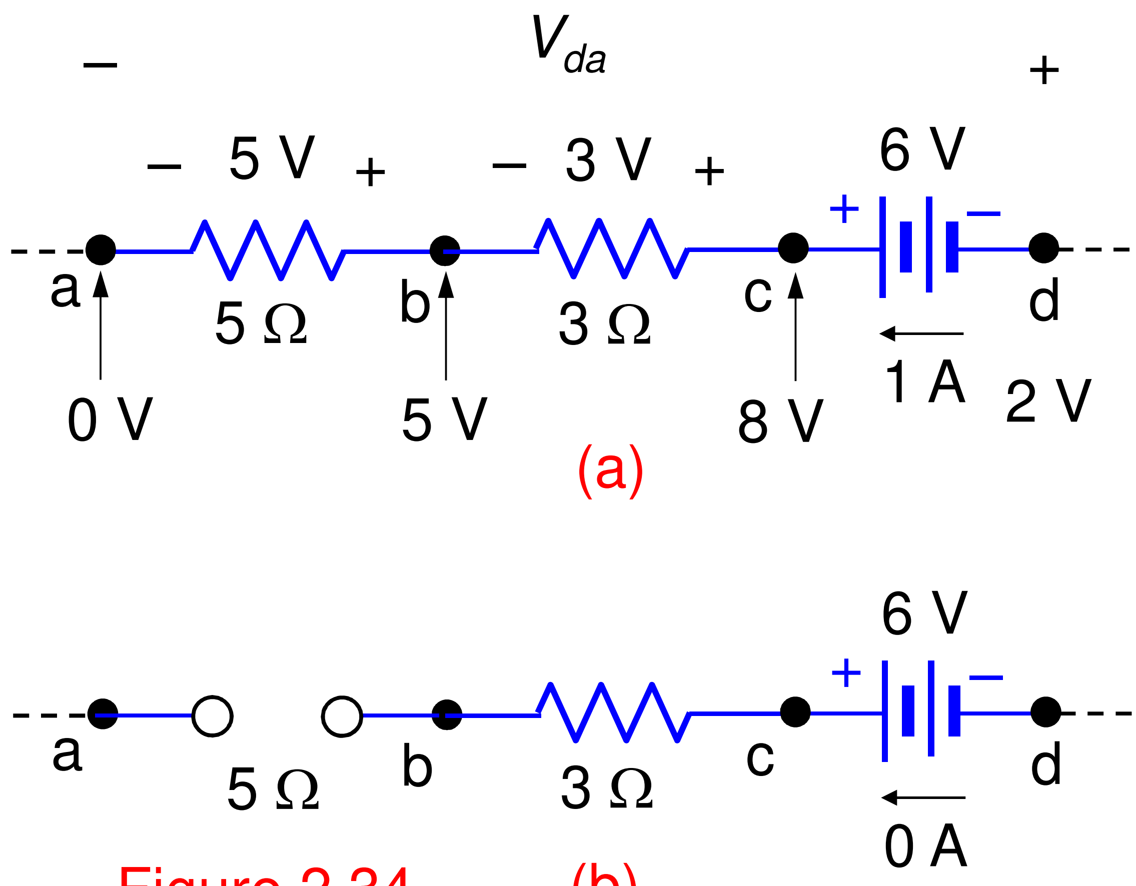


Figure 2.34

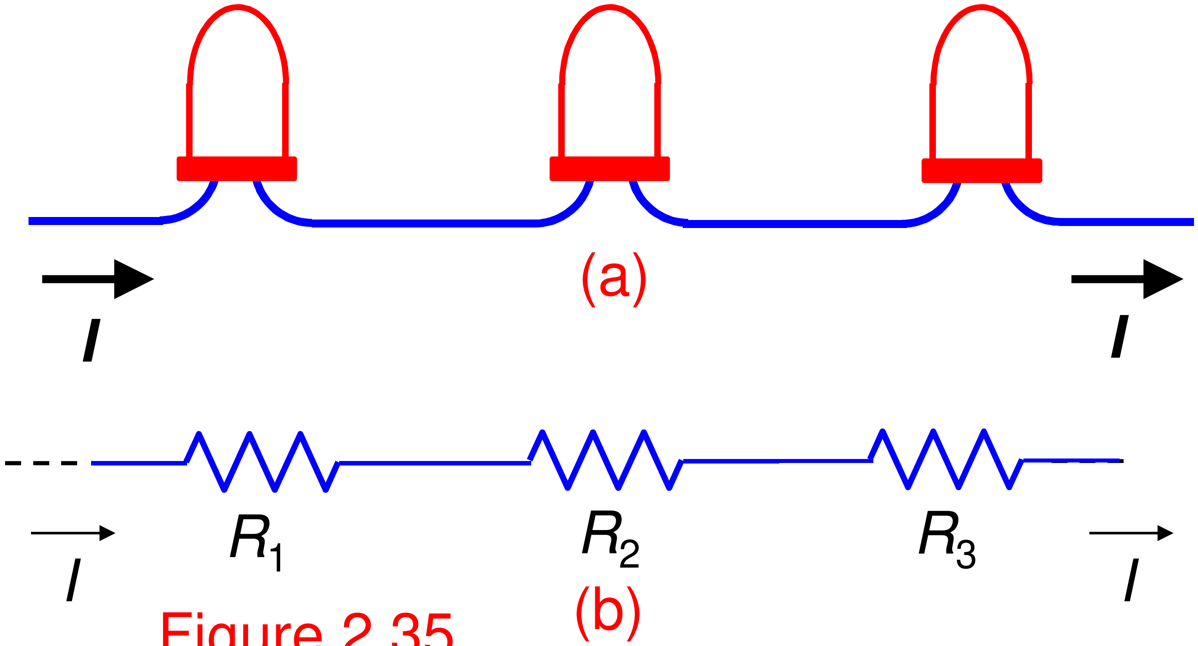
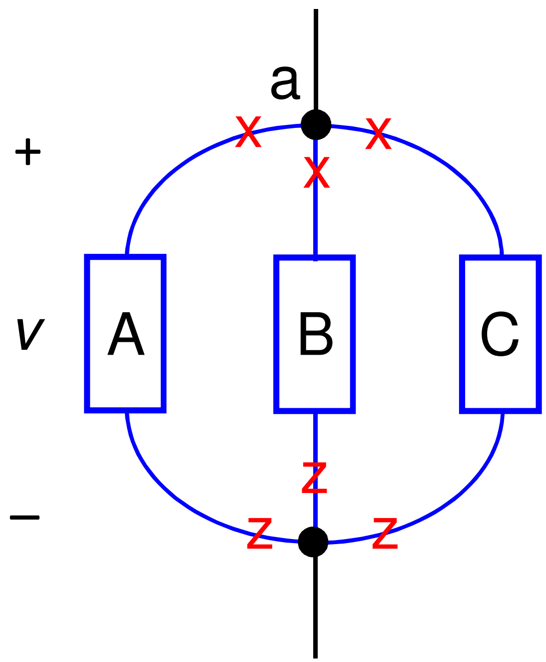
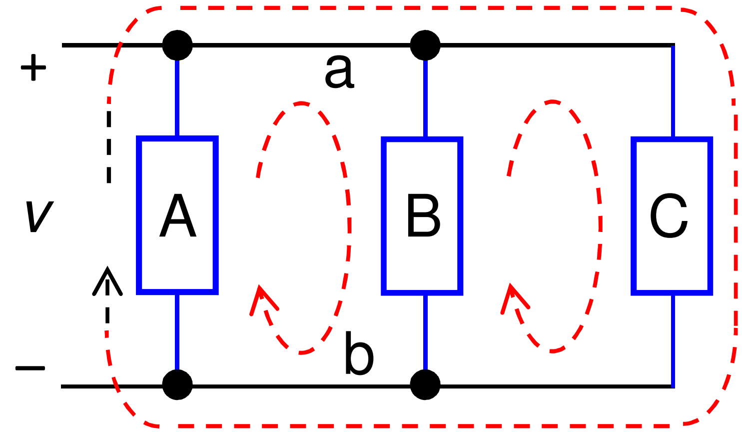


Figure 2.35



(a)



(b)

Figure 2.36

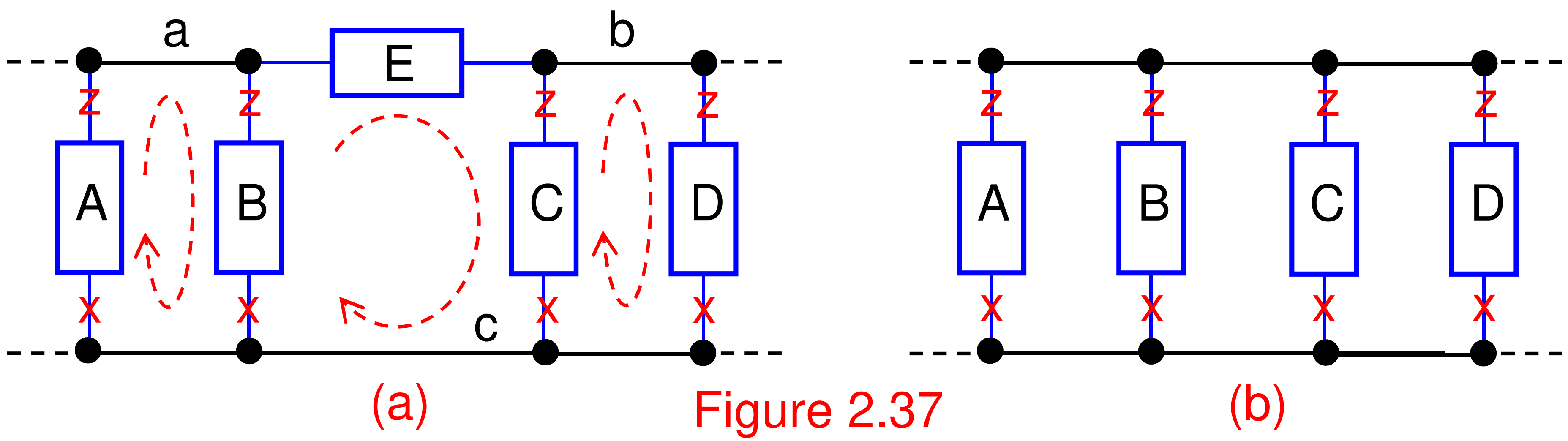


Figure 2.37

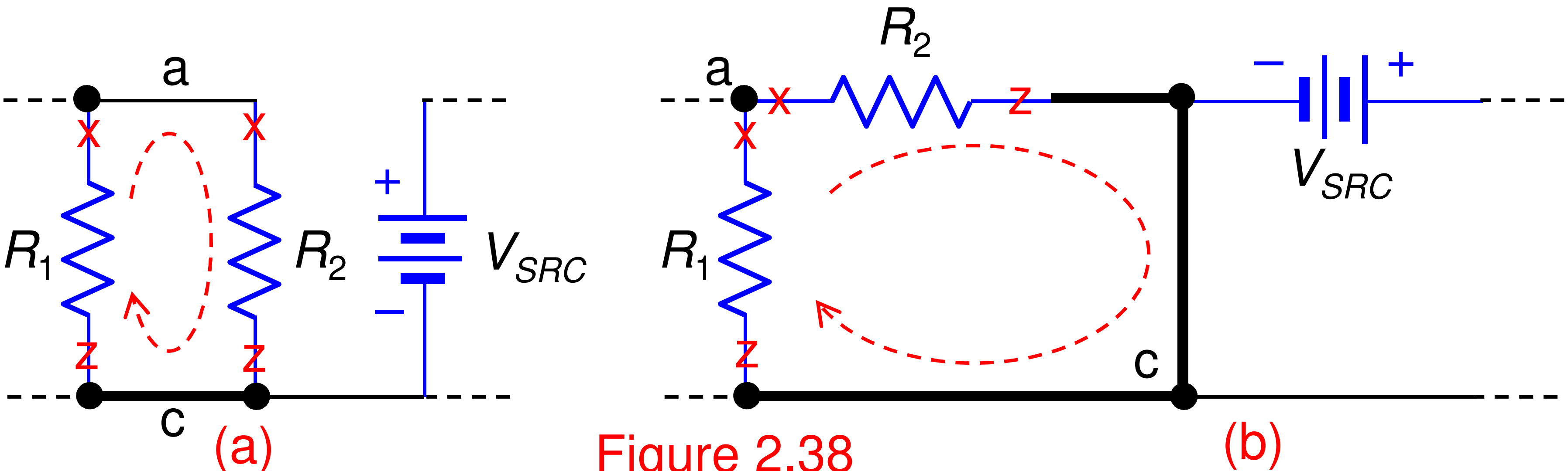


Figure 2.38

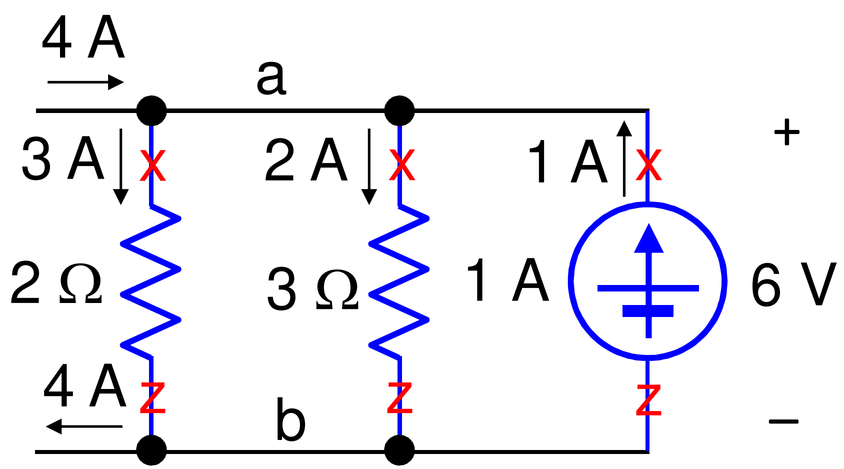


Figure 2.39

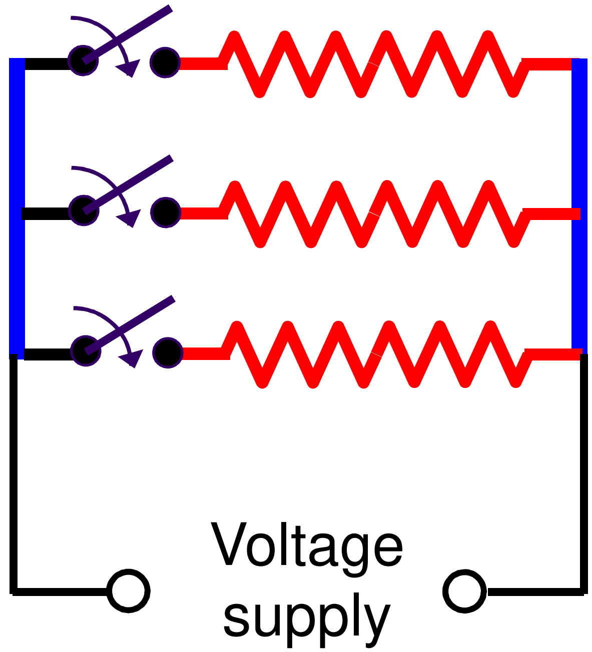


Figure 2.40

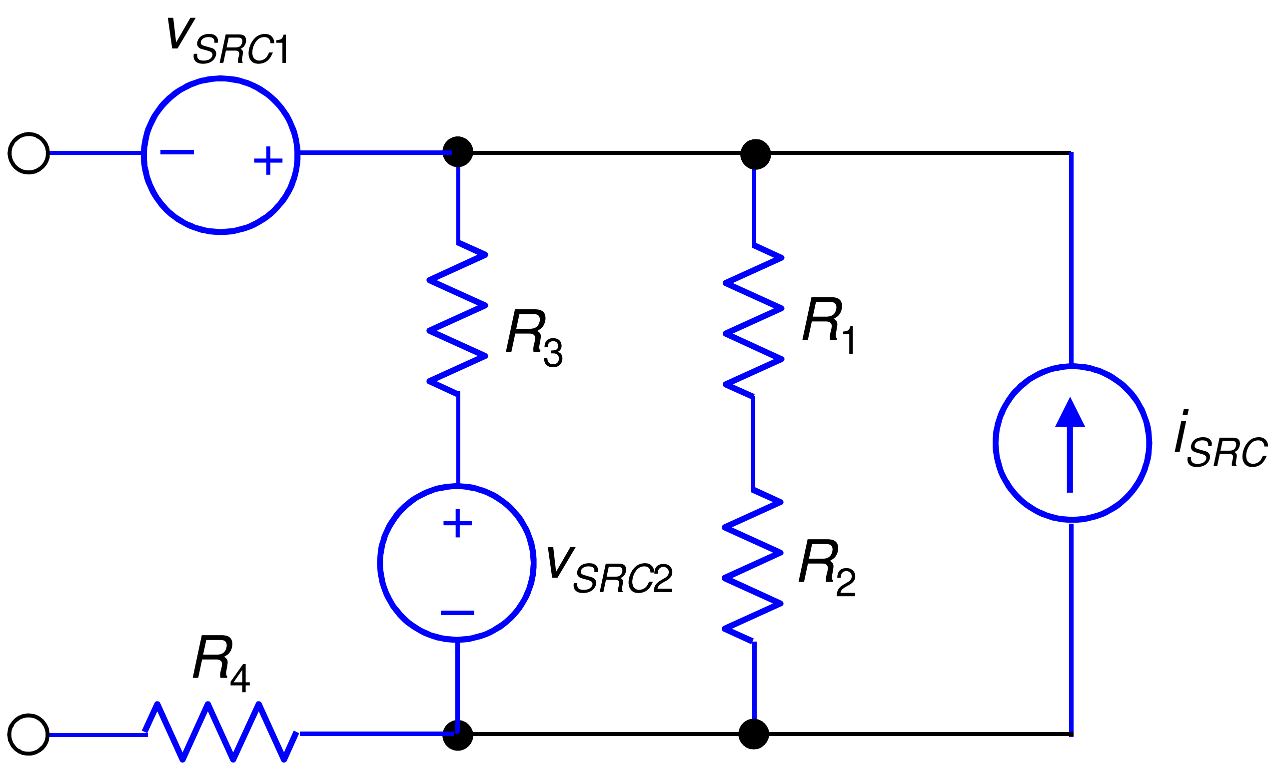
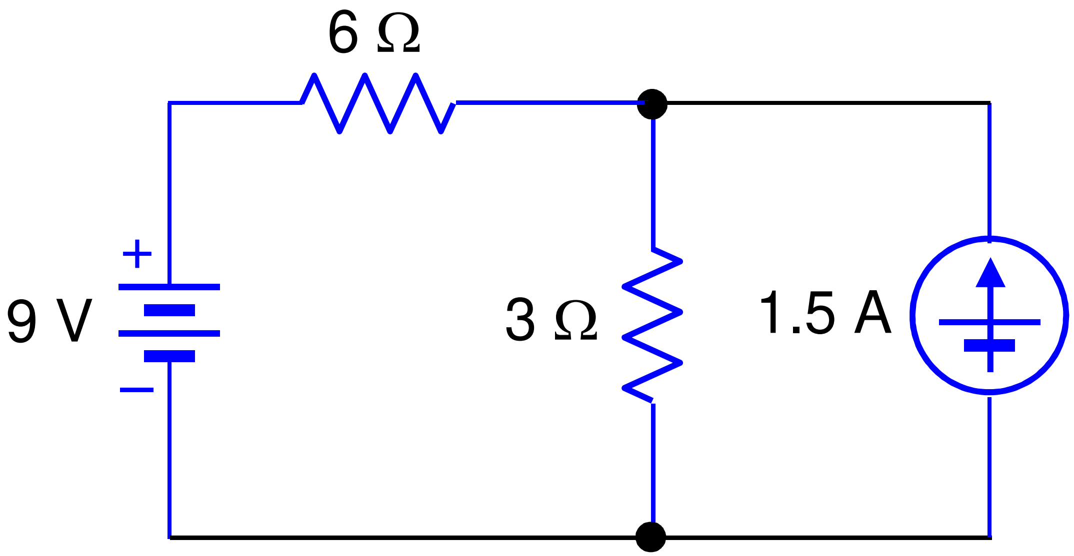
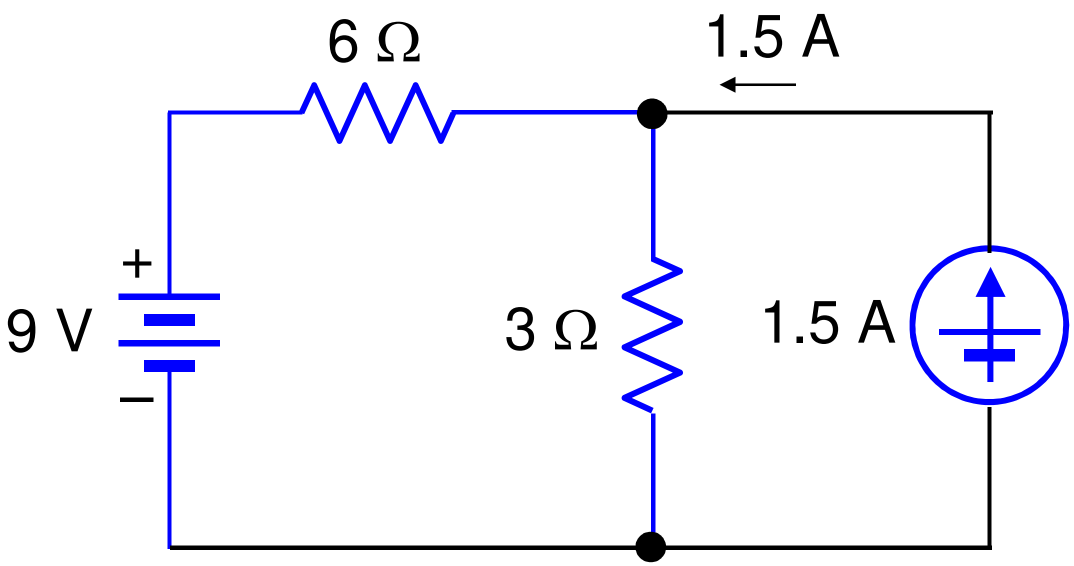


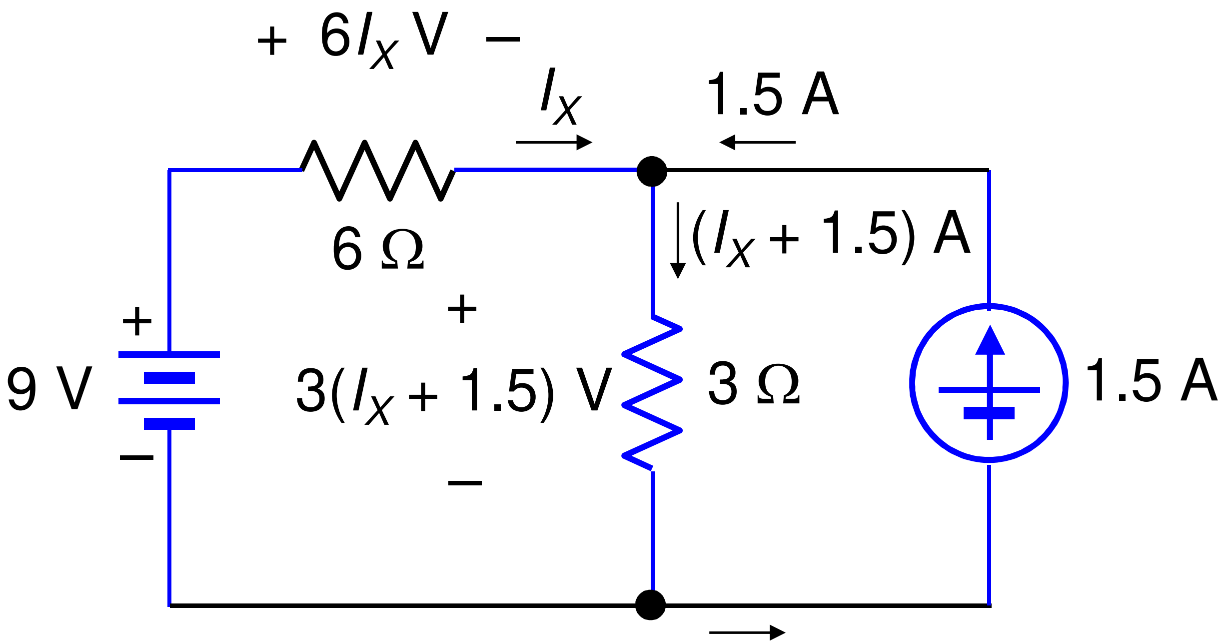
Figure 2.41



(a)



(b)



(c)

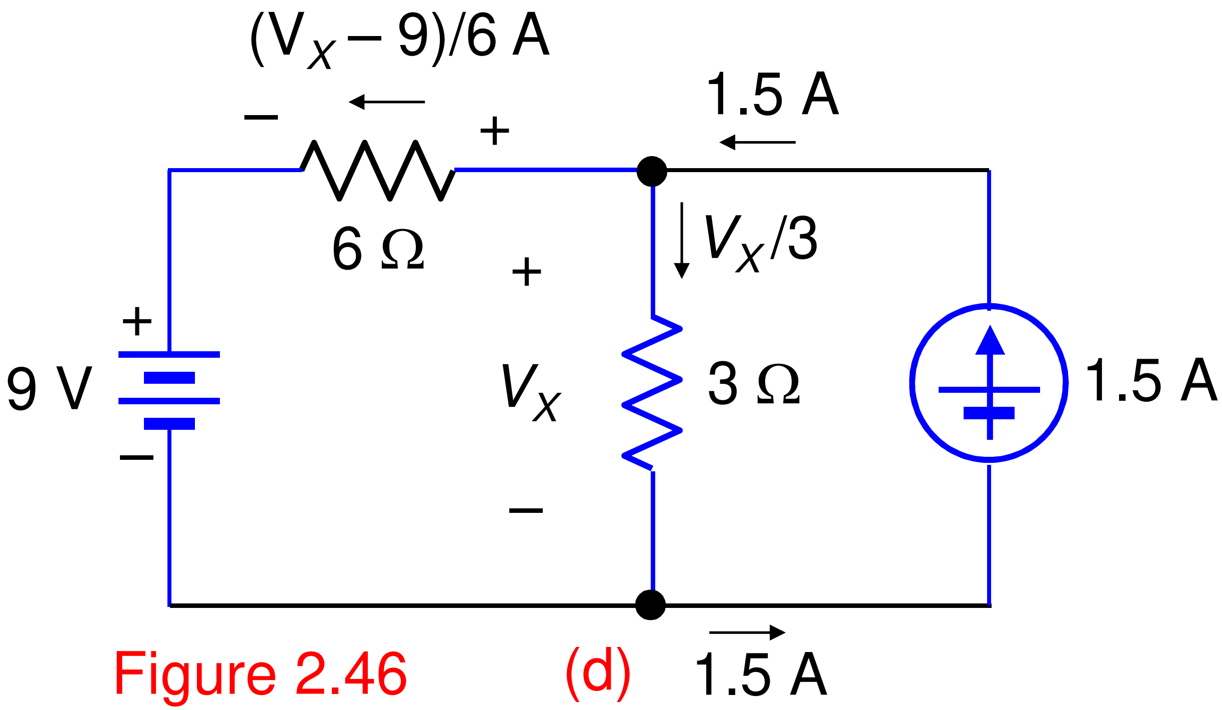
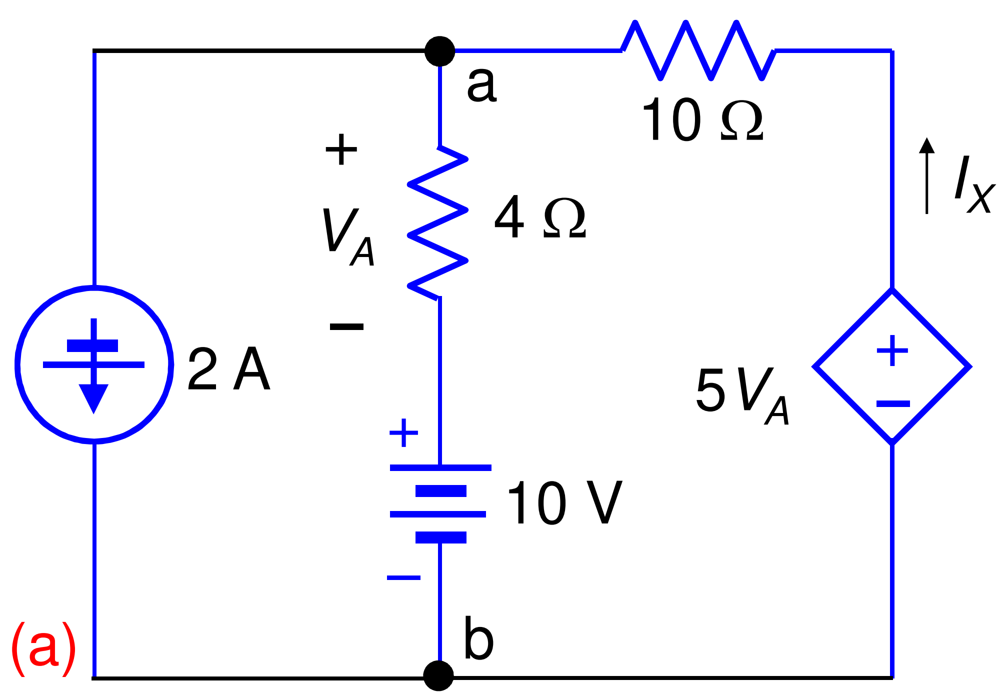
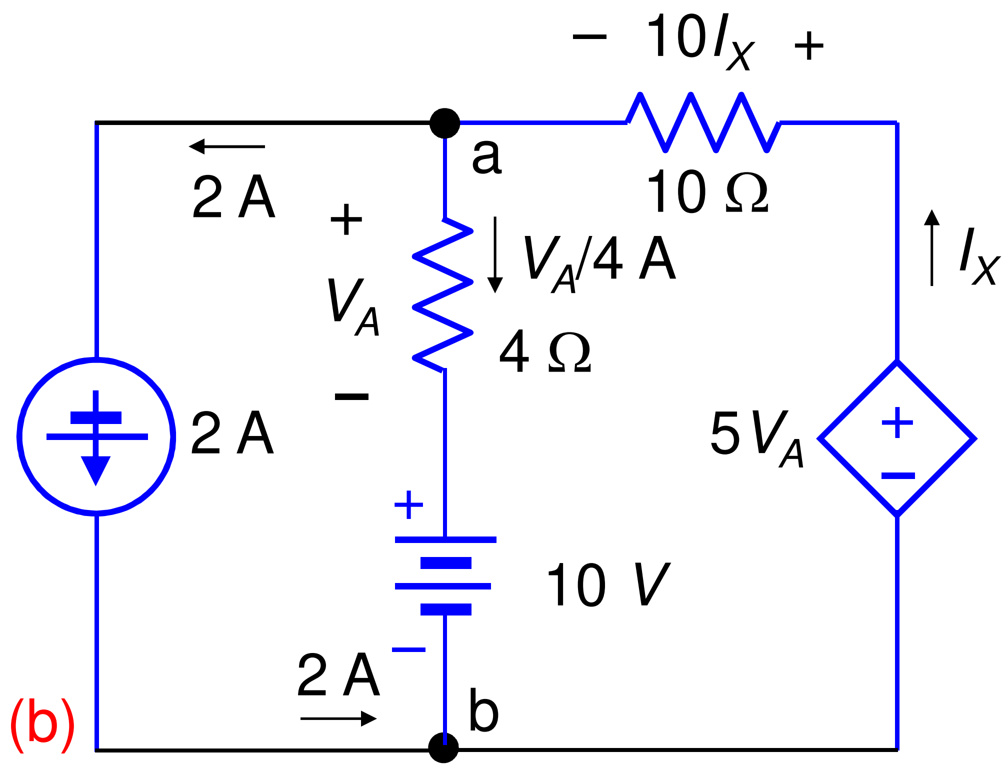


Figure 2.46 (d)


a
10 Ω
+
V_A
4 Ω
I_X
−
2 A
+
5 V_A
+
−
10 V
−
b
(a)



$-$ $10I_X$ $+$
a
$10\ \Omega$
I_X
2 A
$+$
V_A
$-$
$V_A/4$ A
$4\ \Omega$
2 A
$5V_A$
$+$
$-$
$+$
$-$
10 V
2 A
b
(b)

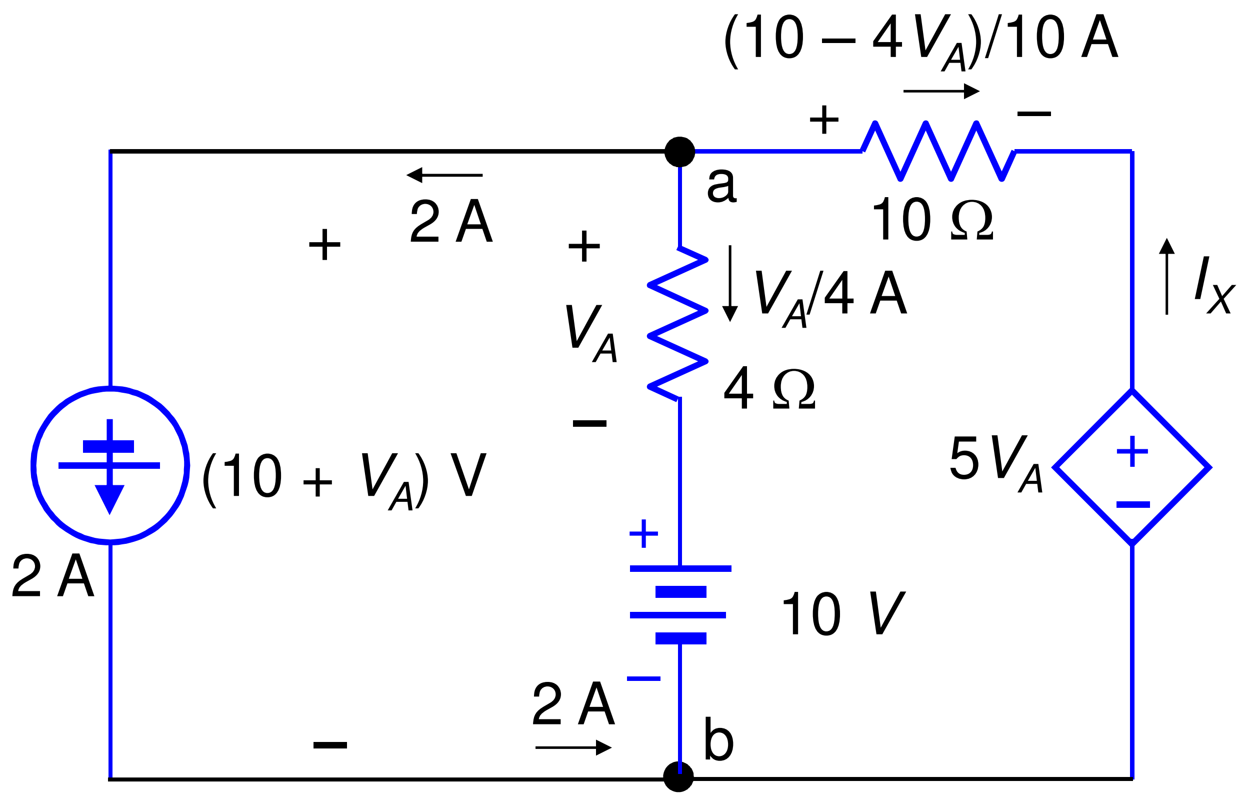
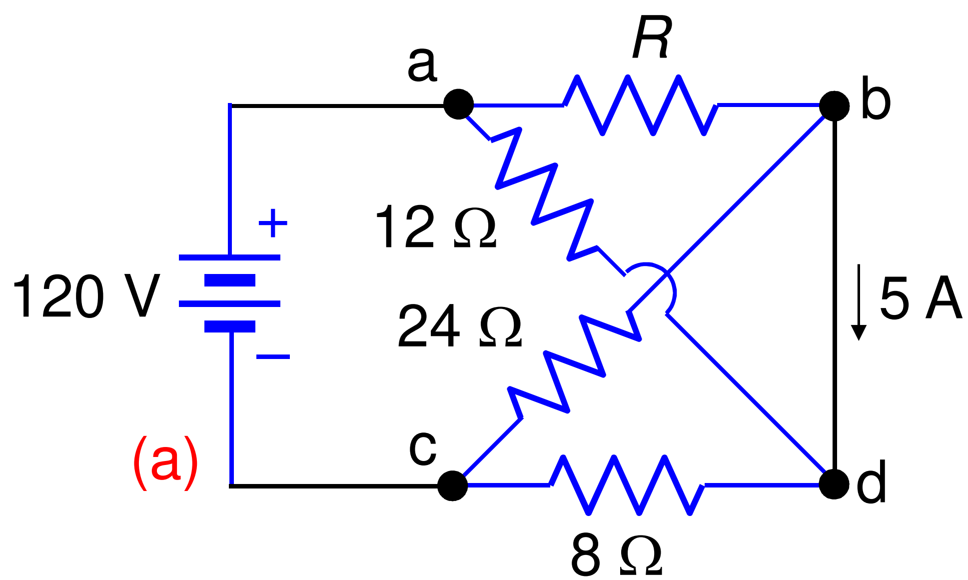
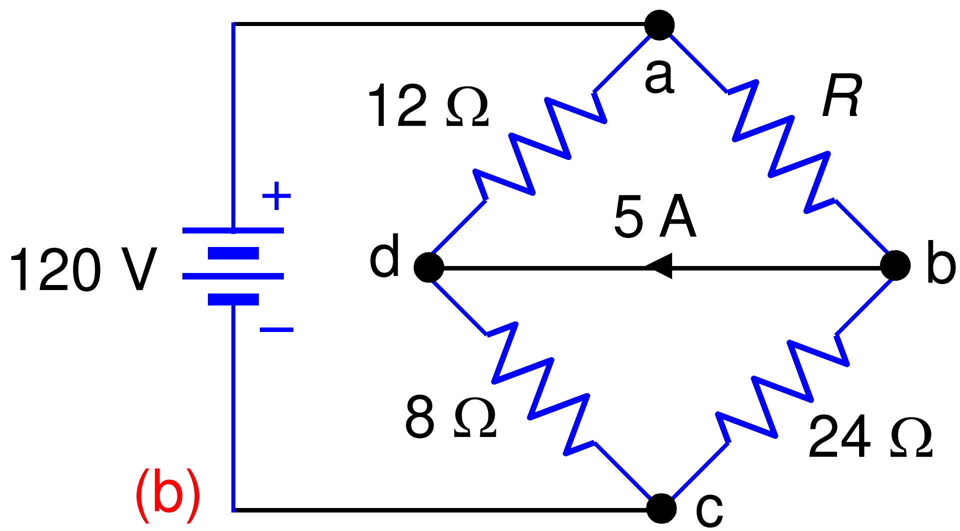


Figure 2.48 (c)



2p4


120 V
+
−
12 Ω
a
R
5 A
d
b
8 Ω
24 Ω
c
(b)

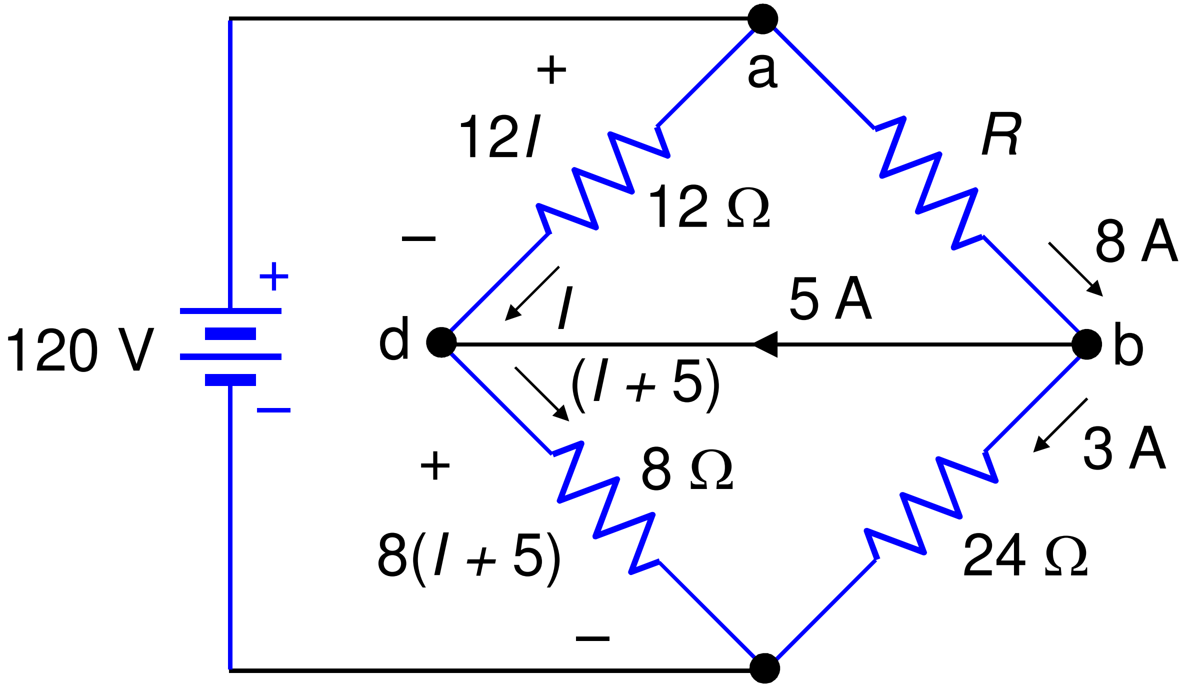


Figure 2.50 (c)

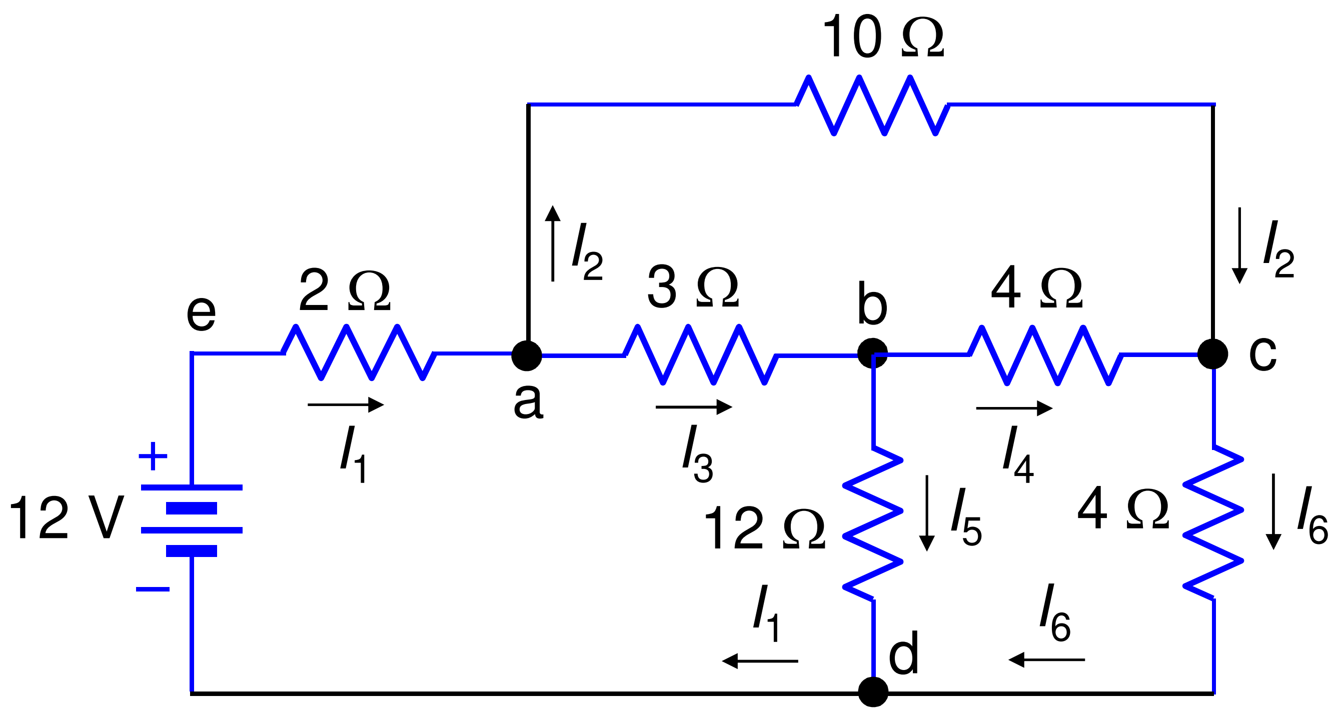


Figure 2.29