

SOLUTIONS MANUAL

ESSENTIALS OF ELECTRICAL AND COMPUTER ENGINEERING

DAVID V. KERNS, JR. • J. DAVID IRWIN



Upper Saddle River, New Jersey 07458

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CHAPTER 1 H.W. SOLUTIONS

$$1.1 \quad F = k \frac{q_1 q_2}{d^2} \Rightarrow q_1 = \frac{F d^2}{k q_2} = \frac{(3 \times 10^{-3})(10^{-3} \text{ m})^2}{(8.99 \times 10^9)(1.6 \times 10^{-6})} = 2.09 \times 10^{-13} \text{ C.}$$

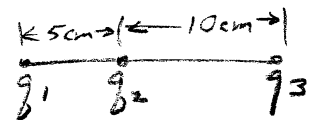
$$1.2 \quad F = k \frac{q_1 q_2}{d^2} = (8.99 \times 10^9) \frac{(6.5 \times 10^{-12} \text{ C})^2}{(4 \times 10^{-6})^2} = 2.37 \times 10^{-2} \text{ N}$$

$$1.3 \quad F = k \frac{q_1 q_2}{d^2} = (8.99 \times 10^9) \frac{(0.03 \times 10^{-6})^2}{(10^{-2})^2} = 8.09 \times 10^{-2} \text{ N. — Repulsive}$$

$$1.4 \quad F = k \frac{q_1 q_2}{d^2} = (8.99 \times 10^9) \frac{(1.6 \times 10^{-19})^2}{[(5.3 \times 10^{-9})(10^{-2})]^2} = 8.19 \times 10^{-8} \text{ N}$$

1.5 To solve problems of this type, first use the "like or unlike" charge rule to determine the direction of the force; then use Eq 1.1 to determine the magnitude

a) $q_1 = -2 \text{ mC}; q_2 = 4 \text{ mC}; q_3 = 10 \text{ mC}$



$$F_{q_1} = k \frac{q_1 q_2}{d_{12}^2} + k \frac{q_1 q_3}{d_{13}^2} \quad \text{where} \quad d_{12} = 5 \text{ cm} = 0.05 \text{ m}$$

Both q_2 & q_3 attract q_1 to the right.

$$F_{q_1} = (8.99 \times 10^9)(2 \times 10^{-3}) \left[\frac{4 \times 10^{-3}}{(0.05)^2} + \frac{10 \times 10^{-3}}{(0.15)^2} \right]$$

$$F_{q_1} = 1.28 \times 10^7 \text{ N}$$

• The force on q_2 caused by q_1 is to the left; The force on q_2 caused by q_3 is also to the left. Therefore total force is the sum, and directed to the left

$$F_{q_2} = k \frac{q_2 q_1}{d_{12}^2} + k \frac{q_2 q_3}{d_{23}^2} \quad \text{where} \quad d_{12} = 0.05 \text{ m}$$

$$d_{23} = 0.10 \text{ m}$$

$$F_{q_2} = (8.99 \times 10^9) \left[\frac{(4 \text{ mC})(2 \text{ mC})}{0.05^2} + \frac{(4 \text{ mC})(10 \text{ mC})}{0.10^2} \right]$$

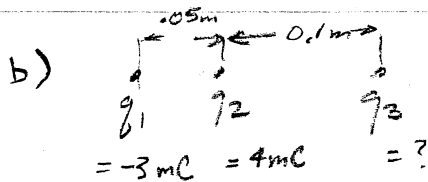
$$F_{q_2} = (8.99 \times 10^9) [3.2 \times 10^{-3} + 4.0 \times 10^{-3}] = 6.47 \times 10^7 \text{ N}$$

• The force on q_3 caused by q_1 is to the left; the force on q_3 caused by q_2 is to the right. Therefore if we let the right be defined as the "+" direction:

$$F_{q_3} = -k \frac{q_3 q_1}{d_{13}^2} + k \frac{q_3 q_2}{d_{23}^2}$$

$$= (8.99 \times 10^9) \left[\frac{(10 \text{ mC})(2 \text{ mC})}{0.15^2} + \frac{(10 \text{ mC})(4 \text{ mC})}{0.10^2} \right]$$

$$= (8.99 \times 10^9) [8.89 \times 10^{-4} + 4 \times 10^{-3}] = 4.40 \times 10^7 \text{ N}$$



Assume the right is "+" direction

$$F_{q_2}(\text{from } q_1) = -k \frac{q_2 q_1}{d_{12}^2} = -(8.99 \times 10^9) \frac{(4\text{mC})(3\text{mC})}{(0.05)^2} = -4.315 \times 10^7 \text{ N}$$

For the total force on q_2 to be zero, q_3 must create an equal and opposite force on q_2 . Since q_2 is "+", q_3 must be "-" to create attractive force to the right.

$$F_{q_2}(\text{from } q_3) = 4.315 \times 10^7 \text{ N} = k \frac{(4\text{mC})(q_3)}{(0.1)^2}$$

$$q_3 = - \frac{(4.315 \times 10^7)(0.1)^2}{k (4\text{mC})} = -1.2 \times 10^{-2} \text{ C}$$

1.6 insulators: glass, rubber, ceramics, plastic, wood (dry)
conductors: iron, gold, salt water, silver, brass, copper

1.7 a) wet aluminum b) salt water c) copper

1.8 $i = \frac{\Delta q}{\Delta t} = \frac{(8.2 \times 10^{21})(1.6 \times 10^{-19})}{10} = 131 \text{ A}$

1.9 $\Delta q = i \Delta t = (120)(6) = 720 \text{ C}$
electrons = $\frac{720 \text{ C}}{1.6 \times 10^{-19} \text{ C/e}} = 4.5 \times 10^{21} \text{ electrons}$

1.10 $i = \frac{\Delta q}{\Delta t} = \frac{(3 \times 10^{19})(1.6 \times 10^{-19})}{5} = 0.96 \text{ A}$

1.11 $3\text{A} - 1\text{A} = 2\text{A}$ (away from the node)

1.12 $I_H = \frac{I_T}{2} = \frac{6.5}{2} = 3.25 \text{ A}$

1.13 $i = 0.2 \text{ A} = \frac{\Delta q}{\Delta t} \Rightarrow \text{If } \Delta t = 1 \text{ s}, \Delta q = 0.2 \text{ C}$
electrons = $\frac{\Delta q}{q} = \frac{0.2 \text{ C}}{1.6 \times 10^{-19}} = 1.25 \times 10^{18} \text{ electrons}$

1.14 a) $150 \cdot 10^3 \text{ A}$ b) $2 - 20 \text{ A}$ c) 10^4 A d) 10^{-8} A

1.15 $V = \frac{dW}{dq} = \frac{\Delta W}{\Delta q} = \frac{3}{0.25} = 12 \text{ V}$

1.16 a) $I = 0.5 \text{ A}$ # electrons/sec = $\frac{0.5}{1.6 \times 10^{-19}} = 3.125 \times 10^{18} \text{ e/sec}$

sec in half hour = $60 \times 30 = 1800$

\therefore # electrons in half-hour = $(1800)(3.125 \times 10^{18}) = 5.625 \times 10^{21}$

b) $P = VI = 12(0.5) = 6 \text{ W}$

c) $E = P \Delta t = \left[6 \frac{\text{Joules}}{\text{sec}} \right] [1800 \text{ sec}] = 1.08 \times 10^4 \text{ J}$

1.17 $W = Vq = (25 \times 10^3)(1.6 \times 10^{-19}) = 4 \times 10^{-15} \text{ J}$

1.18 $W = Vq = (1)(1.6 \times 10^{-19}) = 1.6 \times 10^{-19} \text{ J}$

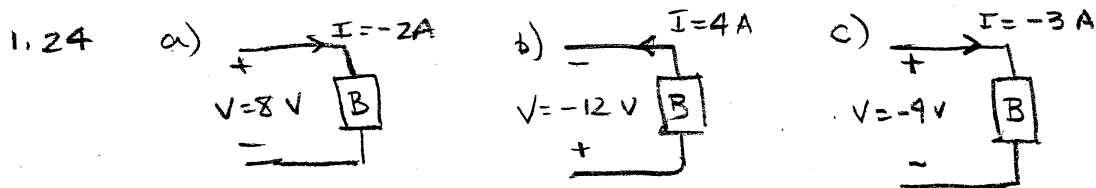
1.19 $\Delta W = V \Delta q$
 $\Delta q = i \Delta t = (150)(1) = 150 \text{ C}$
 $\Delta W = 12(150) = 1800 \text{ J}$

1.20 1) dc 2) dc 3) ac 4) dc 5) ac 6) dc

1.21 1) 10^{14} Hz 2) 10^7 Hz 3) 10^{21} Hz

1.22 a) 10^8 Hz b) 10^{16} Hz c) 10^{19} Hz

1.23 a) $V = -15 \text{ V}$; $I = 1 \text{ A}$
 b) $V = 2 \text{ V}$; $I = 2 \text{ A}$
 c) $V = 1 \text{ V}$; $I = -1 \text{ A}$



1.25

a) $P = VI = (3)(2) = 6 \text{ W}$ absorbing power
 (+ current enters + node)
 b) $P = (-10)(3) = -30 \text{ W}$ -absorbing power
 (+ current enters + node)
 c) $P = VI = (6)(4) = 24 \text{ W}$ -supplying power
 (+ current exits + node)

1.26 a) A absorbing ; + current enters + node
 B supplying ; + current exits + node
 $P = VI = (3)(6) = 18 \text{ W}$ (constant)

$E = P \cdot t = 18 \cdot t$ $t = \# \text{ secs/hr} = 60 \cdot 60 = 3600$
 $E = (18)(3600) = 64,800 \text{ J}$

b) A supplying ; + current exits + node
 B absorbing ; + current enters + node
 $P = VI = (6)(7) = 42 \text{ W}$
 $E = P \cdot t = (42)(3600) = 151,200 \text{ J}$

1.27 a) $V_o = V_i \mu = (4.3)(25) = 107.5 \text{ V}$

b) $V_o = V_i \mu = (30)(25) = 750 \text{ V}$

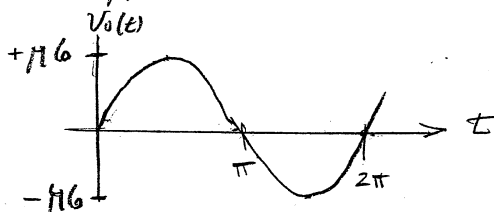
1.28 $I_o = \beta I_i \Rightarrow I_i = \frac{I_o}{\beta} = \frac{2 \text{ mA}}{30} = 66.7 \mu\text{A}$

1.29 $V_o = \mu V_i = (10^3)(3 \times 10^{-4}) = 0.30 \text{ V}$

1.30 $V_o = \mu V_i = (48)(-3) = -144$

1.31 $\mu = \frac{V_o}{V_i} = \frac{30}{6} = 5$

1.32 $V_o = \mu V_i = \mu 6 \sin t$



1.33 a) $I_o = I_R = g V_i = (10^{-3})(6) = 6 \text{ mA}$

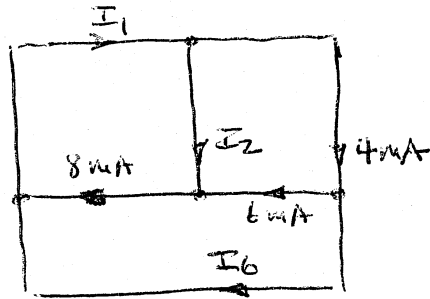
b) $I_o = I_R = g V_i = (10^{-3})(-9) = -9 \text{ mA}$

1.34 a) $I_o = I_R = \beta I_i = (25)(1 \text{ mA}) = 25 \text{ mA}$

b) $I_o = I_R = \beta I_i = (25)(-6 \text{ mA}) = -150 \text{ mA} = -0.150 \text{ A}$

2.1 $10 = I_1 + 4 \Rightarrow I_1 = 6 \text{ mA}$

2.2

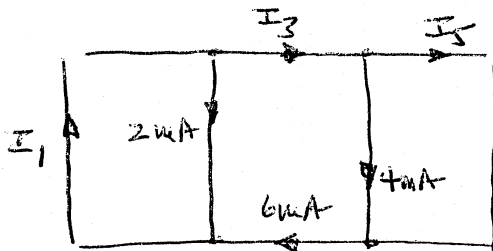


$$4 = 6 + I_6 \Rightarrow I_6 = -2 \text{ mA}$$

$$I_2 + 6 = 8 \Rightarrow I_2 = 2 \text{ mA}$$

$$I_1 = I_2 + 4 \Rightarrow I_1 = 6 \text{ mA}$$

2.3

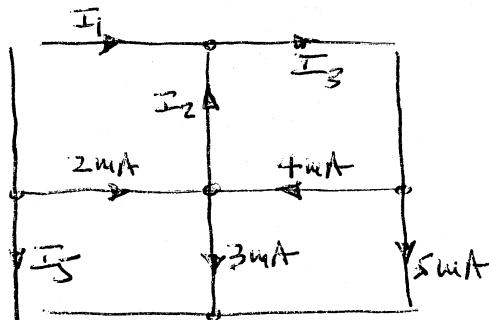


$$I_3 = 6 \text{ mA}$$

$$6 = I_1 + 2 \Rightarrow I_1 = 4 \text{ mA}$$

$$I_5 + 4 = 6 \Rightarrow I_5 = 2 \text{ mA}$$

2.4



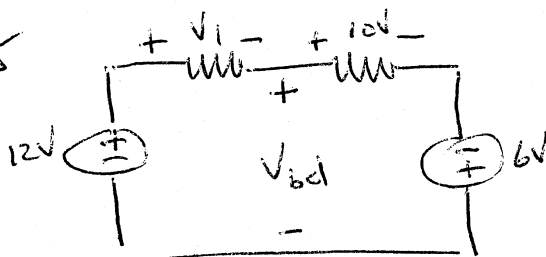
$$I_3 = 4 + 5 \Rightarrow I_3 = 9 \text{ mA}$$

$$-I_2 + 2 + 4 \cdot 3 = 0 \Rightarrow I_2 = 3 \text{ mA}$$

$$I_5 + 3 + 5 = 0 \Rightarrow I_5 = -8 \text{ mA}$$

$$-I_1 - 2 + 8 = 0 \Rightarrow I_1 = 6 \text{ mA}$$

2.5



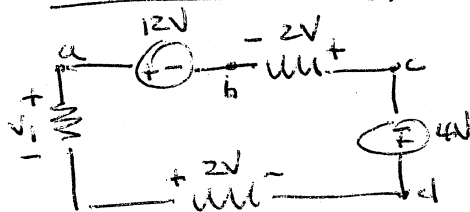
$$-12 + V_1 + 10 - 6 = 0$$

$$V_1 = 8 \text{ V}$$

$$-V_{bd} + 10 - 6 = 0$$

$$V_{bd} = 4 \text{ V}$$

2.6



$$V_{bc} = -2 \text{ V}$$

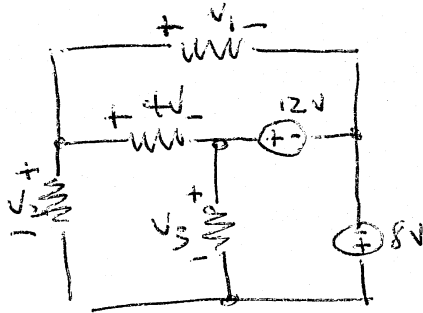
$$-V_{da} + 4 + 2 - 12 = 0$$

$$V_{da} = -6 \text{ V}$$

$$-V_1 + 12 - 2 - 4 - 2 = 0$$

$$V_1 = 4 \text{ V}$$

2.7

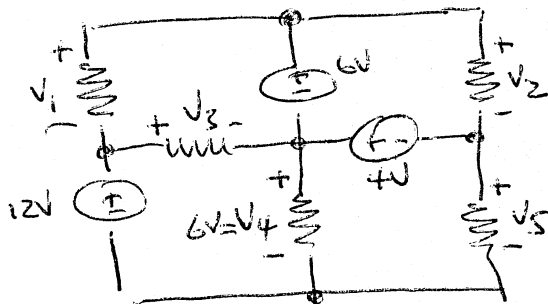


$$V_1 - 12 - 4 = 0 \Rightarrow V_1 = 16V$$

$$-V_3 + 12 - 8 = 0 \Rightarrow V_3 = 4V$$

$$-V_2 + 4 + V_3 = 0 \Rightarrow V_2 = 8V$$

2.8



$$-6 + V_2 - 4 = 0 \Rightarrow V_2 = 10V$$

$$-6 + 4 + V_5 = 0 \Rightarrow V_5 = 2V$$

$$-12 + V_3 + 6 = 0 \Rightarrow V_3 = 6V$$

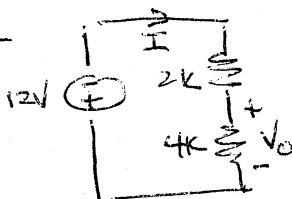
$$-V_1 + 6 - V_3 = 0 \Rightarrow V_1 = 0V$$

2.9 $I = 6/3k = 2mA$

2.10 $R = 12/2k = 6k\Omega$

2.11 $V_5^2/2k = 8/k \Rightarrow V_5^2 = (2 \times 10^3)(8 \times 10^3) = 16 ; V_5 = \pm 4V$

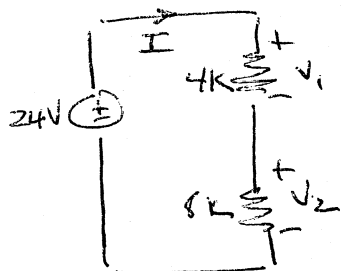
2.12



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

$$V_0 = \left(\frac{2}{k}\right)(4k) = -8V$$

2.13

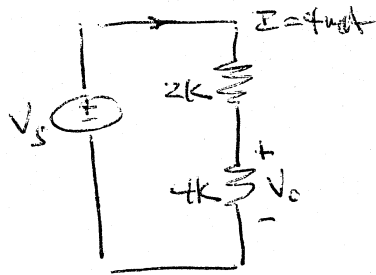


$$I = \frac{24}{4k + 8k} = 2mA$$

$$V_1 = 4kI = 8V$$

$$V_2 = 8kI = 16V$$

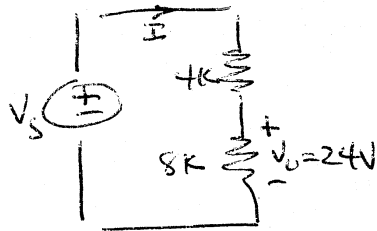
2.14



$$V_o = (4k) \left(\frac{4}{k} \right) = 16V$$

$$V_s = \frac{4}{k} (2k + 4k) = 24V$$

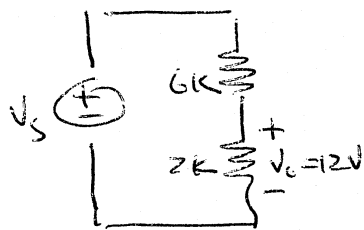
2.15



$$I = \frac{24}{8k} = 3mA$$

$$V_s = \frac{3}{k} (4k + 8k) = 36V$$

2.16

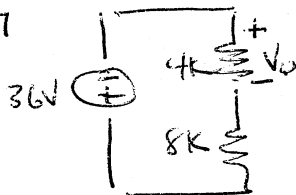


Voltage Div.

$$V_o = \frac{V_s (2k)}{6k + 2k} = 12$$

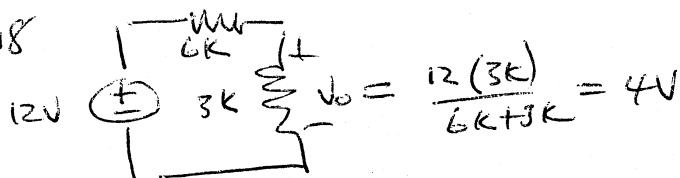
$$V_s = 48V$$

2.17



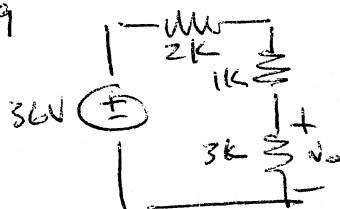
$$V_o = \frac{-36 (4k)}{4k + 8k} = -12V$$

2.18



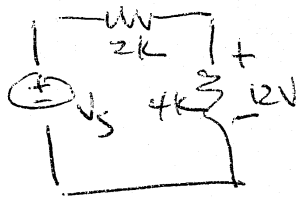
$$V_o = \frac{12 (3k)}{6k + 3k} = 4V$$

2.19



$$V_o = \frac{36 (3k)}{2k + 1k + 3k} = 18V$$

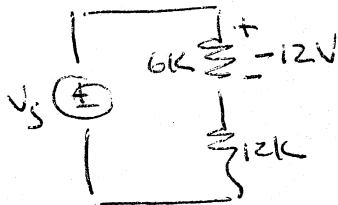
2.20



$$12 = \frac{V_S(4k)}{4k+2k}$$

$$V_S = 18V$$

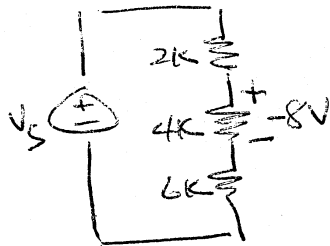
2.21



$$-12 = \frac{V_S(6k)}{6k+12k}$$

$$V_S = -36V$$

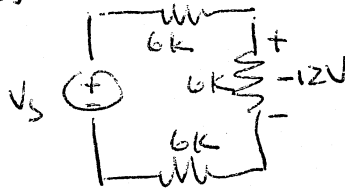
2.22



$$-8V = \frac{V_S(4k)}{2k+4k+6k}$$

$$V_S = -24V$$

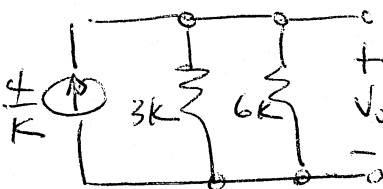
2.23



$$-12 = \frac{V_S(6k)}{(3)(6k)}$$

$$V_S = -36V$$

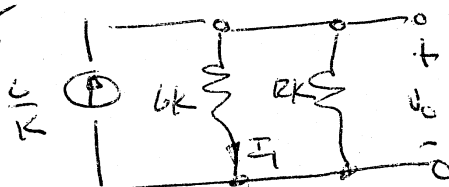
2.24



$$\frac{V_0}{3k} + \frac{V_0}{6k} = \frac{4}{K}$$

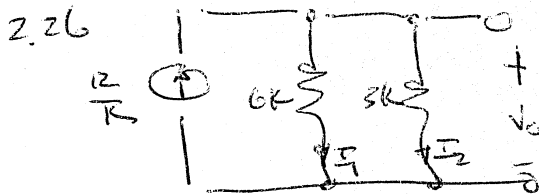
$$V_0 = 8V$$

2.25



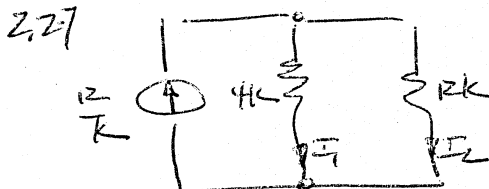
$$\frac{V_0}{6k} + \frac{V_0}{12k} = \frac{6}{K} \Rightarrow V_0 = 24V$$

$$I_1 = \frac{24}{6k} = 4\mu A$$



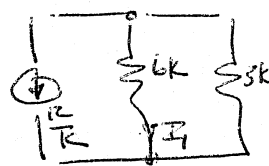
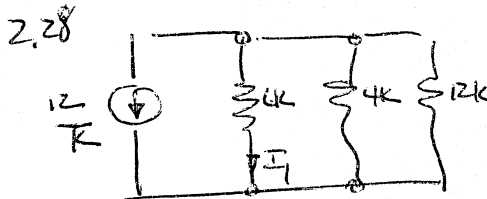
$$\frac{V_0}{6k} + \frac{V_0}{3k} = \frac{12}{k} \Rightarrow V_0 = 24V$$

$$I_1 = \frac{24}{6k} = 4mA \quad I_2 = \frac{24}{3k} = 8mA$$

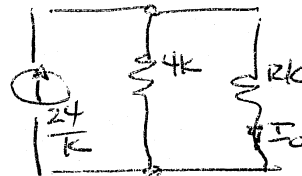
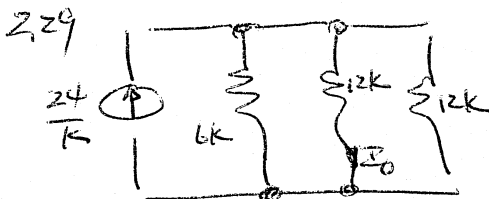


$$I_1 = \frac{12}{k} \left(\frac{2k}{4k+2k} \right) = 9mA$$

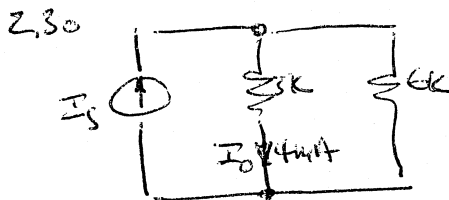
$$I_2 = \frac{12}{k} \left(\frac{4k}{4k+2k} \right) = 3mA$$



$$I_1 = \frac{-12V(3k)}{3k+6k} = -4mA$$

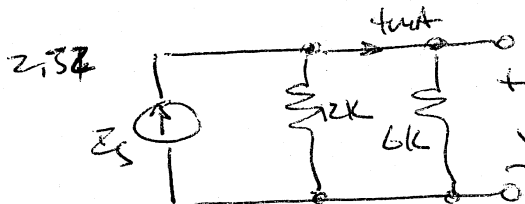


$$I_0 = \frac{24}{k} \left(\frac{4k}{4k+12k} \right) = 6mA$$

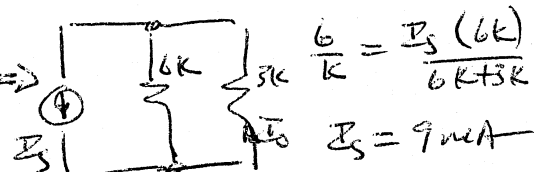
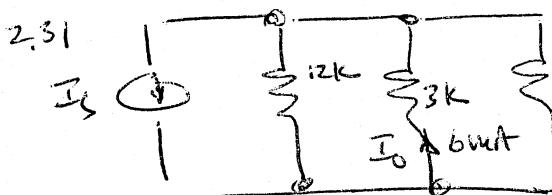


$$\frac{4}{k} = \frac{I_s(6k)}{3k+6k}$$

$$I_s = 6mA$$



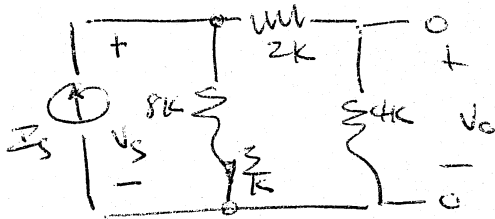
$$V_0 = \left(\frac{4}{k} \right) (6k) = 24V$$



$$\frac{6}{k} = \frac{I_s(6k)}{6k+3k}$$

$$I_s = 9mA$$

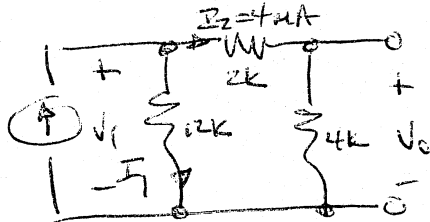
2.33



$$V_s = \left(\frac{3}{k}\right)(8k) = 24V$$

$$V_o = \frac{24(4k)}{2k+4k} = 16V$$

2.34

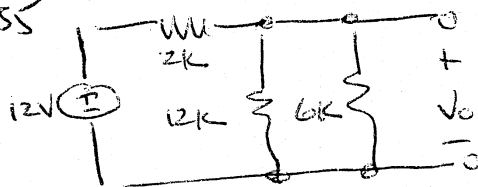


$$V_o = I_2(4k) = 16V$$

$$V_1 = I_2(2k+4k) = 24V$$

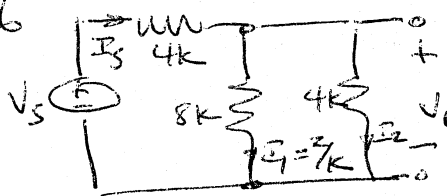
$$I_1 = \frac{24}{12k} = 2mA$$

2.55



$$\Rightarrow V_o = \frac{12(4k)}{2k+4k} = 8V$$

2.36



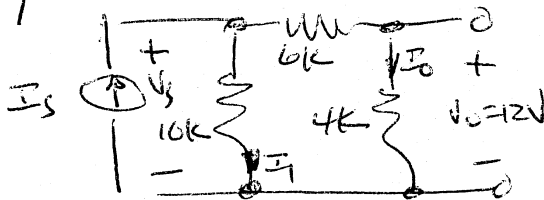
$$V_1 = 8k I_1 = 16V$$

$$I_2 = \frac{V_1}{4k} = 4mA$$

$$I_s = I_1 + I_2 = 6mA$$

$$V_s = 4k I_s + V_1 = 40V$$

2.37



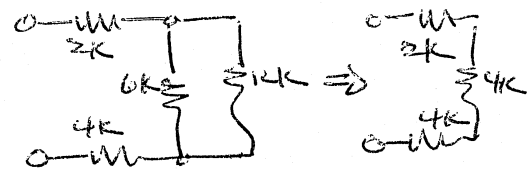
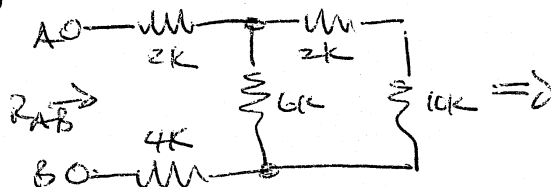
$$I_0 = \frac{12}{4k} = 3mA$$

$$V_s = I_0(4k+6k) = 30V$$

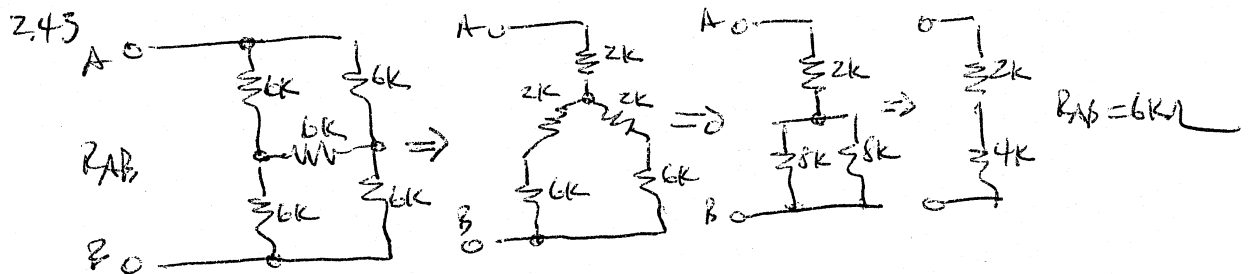
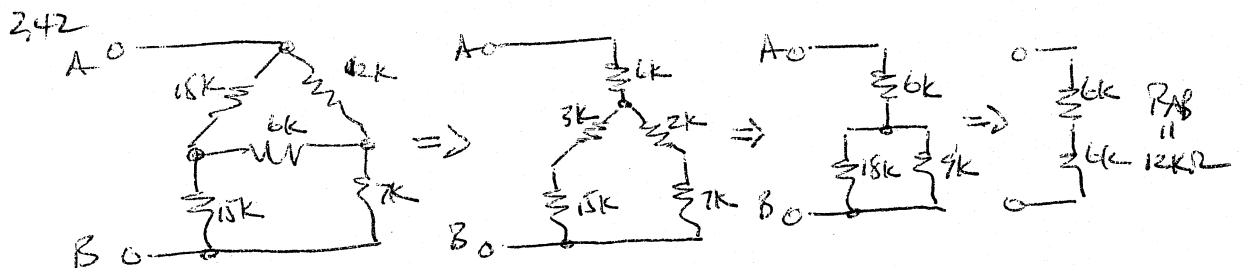
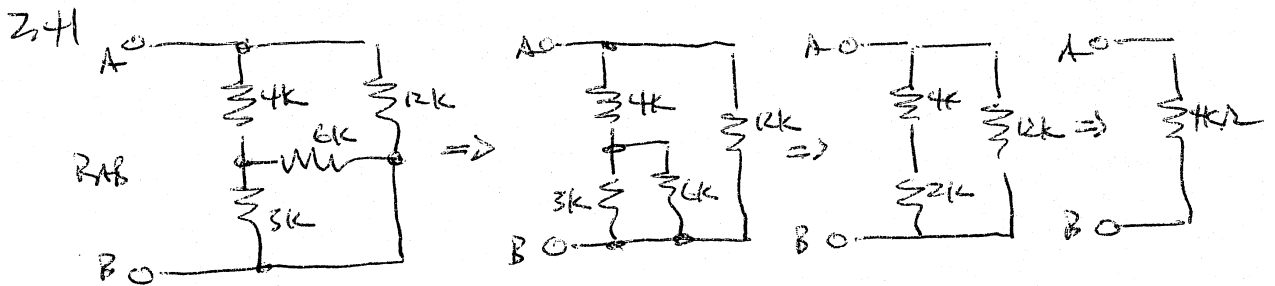
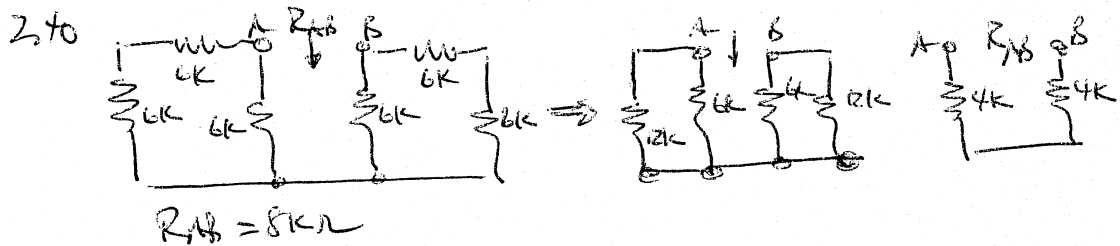
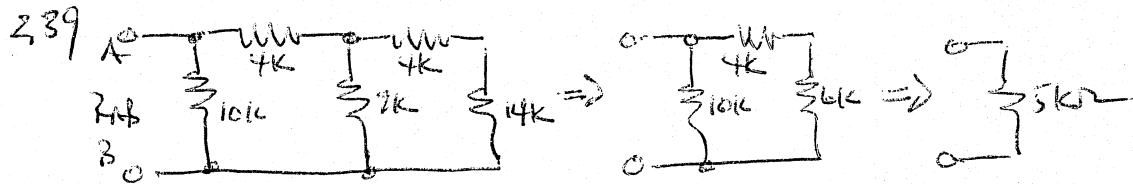
$$I_1 = \frac{V_s}{10k} = 3mA$$

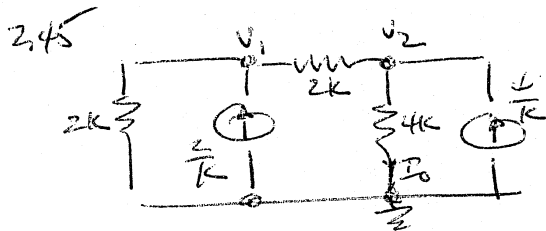
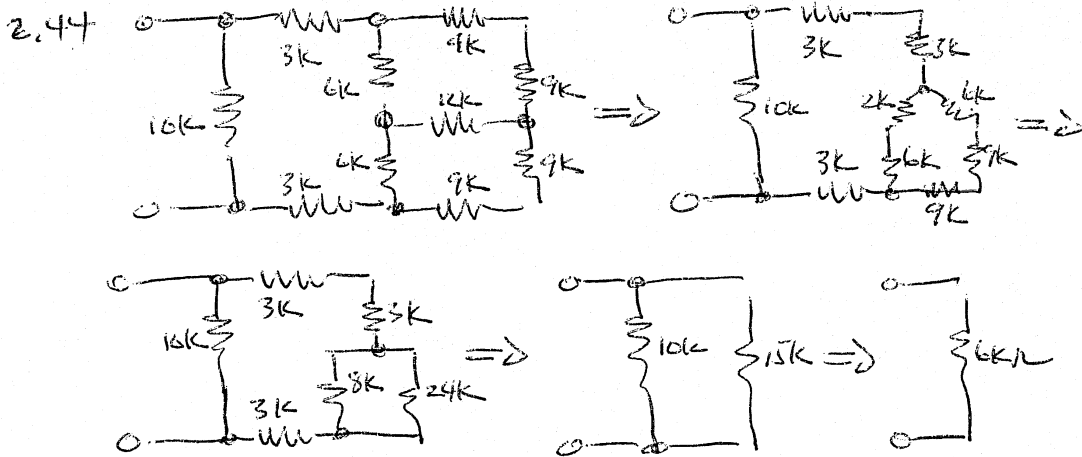
$$I_s = I_1 + I_0 = 6mA$$

2.58



$$R_{AB} = 10k\Omega$$





$$V_1\left(\frac{1}{2k} + \frac{1}{2k}\right) - V_2\left(\frac{1}{2k}\right) = \frac{2}{k}$$

$$-V_1\left(\frac{1}{2k}\right) + V_2\left(\frac{1}{2k} + \frac{1}{4k}\right) = \frac{4}{k}$$

$$V_1 - \frac{1}{2} V_2 = 2$$

$$-\frac{1}{2}v_1 + \frac{3}{4}v_2 = 4$$

$$\begin{pmatrix} 1 & -1/2 \\ -1/2 & 3/4 \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} = \begin{pmatrix} 2 \\ 4 \end{pmatrix}$$

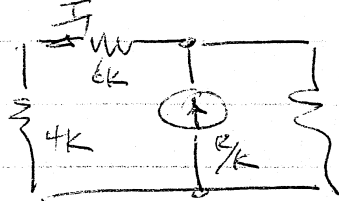
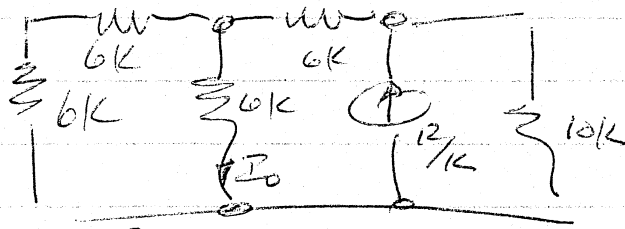
$$\Delta = (1)(\frac{3}{4}) - (-\frac{1}{2})(-\frac{1}{2}) = \frac{3}{4} - \frac{1}{4} = \frac{1}{2}$$

$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = 2 \begin{pmatrix} 3/4 & 1/2 \\ 1/2 & 1 \end{pmatrix} \begin{bmatrix} 2 \\ 4 \end{bmatrix}$$

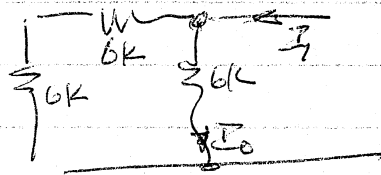
$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} 2(\frac{6}{4} + 2) \\ 2(1 + 4) \end{bmatrix} = \begin{bmatrix} 2(3\frac{1}{2}) \\ 2(5) \end{bmatrix} = \begin{bmatrix} 7 \\ 10 \end{bmatrix}$$

$$I_0 = \frac{10}{4k} = 2.5 \text{ mA}$$

2.46

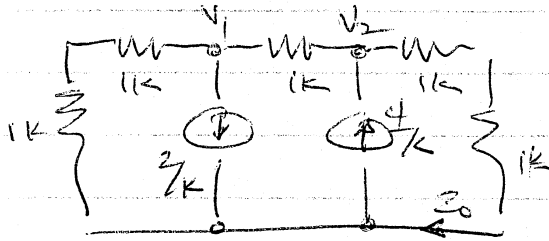


$$I_1 = \frac{12k}{2} = 6k$$



$$I_0 = \frac{I_1(12k)}{18k} = \frac{(6)(12k)}{18k} = \frac{4}{k} A$$

2.47



$$V_1 \left(\frac{1}{k} + \frac{1}{2k} + \frac{4}{k} \right) - V_2 \left(\frac{1}{k} \right) = -\frac{2}{k}$$

$$-V_1 \left(\frac{1}{k} \right) + V_2 \left(\frac{1}{k} + \frac{1}{2k} \right) = \frac{4}{k}$$

$$V_1 \left(\frac{3}{2} \right) - V_2 = -2$$

$$-V_1 + V_2 \left(\frac{3}{2} \right) = 4$$

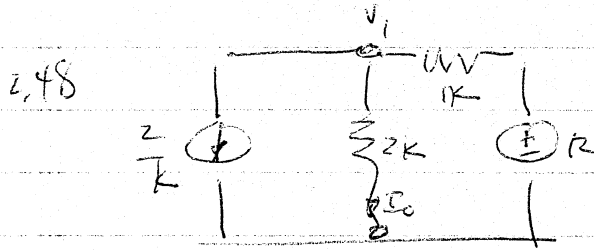
$$V_1 = \frac{4}{5} \left[-3 + 4 \right] = \frac{4}{5}$$

$$V_2 = \frac{4}{5} \left[-2 + 6 \right] = \frac{16}{5}$$

$$\Delta = \frac{9}{4} - (-1)(-1) = \frac{9}{4} - \frac{1}{4} = \frac{8}{4}$$

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \frac{4}{5} \begin{bmatrix} 3/2 & 1 \\ 1 & 3/2 \end{bmatrix} \begin{bmatrix} -2 \\ 4 \end{bmatrix}$$

$$\frac{2}{5} \begin{bmatrix} 10 & 12 \\ 5 & 16 \end{bmatrix}$$



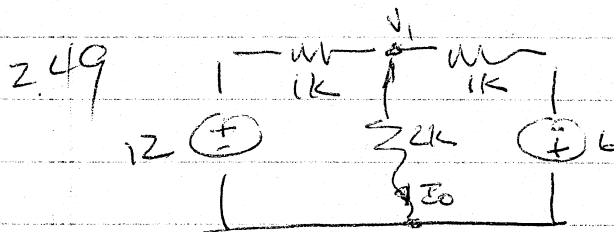
$$2 + \frac{V_1}{2k} + \frac{V_1 - 12}{1k} = 0$$

$$2 + \frac{V_1}{2} + \frac{V_1}{1} - 12 = 0$$

$$\frac{3}{2}V_1 = 10$$

$$V_1 = \frac{20}{3}V$$

$$I_0 = \frac{V_1}{2k} = \frac{10}{3k}A$$



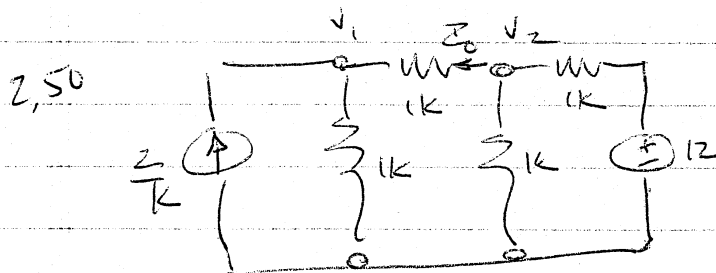
$$\frac{V_1 - 12}{1k} + \frac{V_1}{2k} + \frac{V_1 + 6}{1k} = 0$$

$$V_1 - 12 + \frac{V_1}{2} + V_1 + 6 = 0$$

$$\frac{5}{2}V_1 = 6$$

$$V_1 = \frac{12}{5}V$$

$$I_0 = \frac{V_1}{2k} = \frac{6}{5k}A$$



$$2V_1 - V_2 = 2$$

$$2\left(\frac{18}{5}\right) - V_2 = 2$$

$$\frac{36}{5} - 2 = V_2$$

$$\frac{36 - 10}{5} = V_2$$

$$\frac{26}{5}V = V_2$$

$$V_1\left(\frac{1}{k} + \frac{1}{k}\right) - V_2\left(\frac{1}{k}\right) = \frac{2}{k}$$

$$-V_1\left(\frac{1}{k}\right) + V_2\left(\frac{1}{k} + \frac{1}{k} + \frac{1}{k}\right) = \frac{12}{k}$$

$$2V_1 - V_2 = 2$$

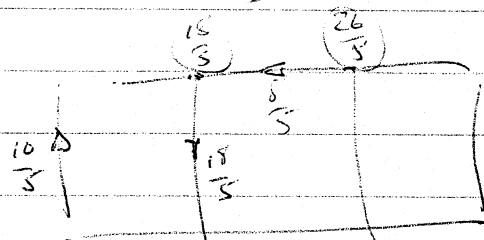
$$-V_1 + 3V_2 = 12$$

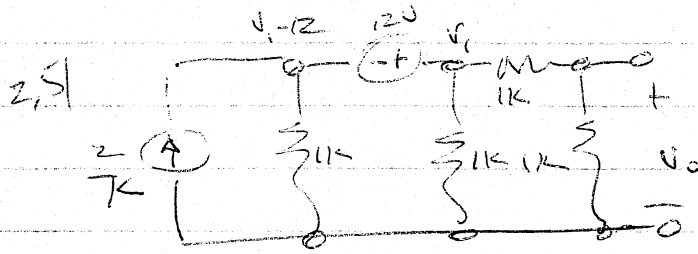
$$2V_1 - 2 = V_2$$

$$-V_1 + 3(2V_1 - 2) = 12$$

$$5V_1 - 6 = 12$$

$$V_1 = \frac{18}{5}V$$





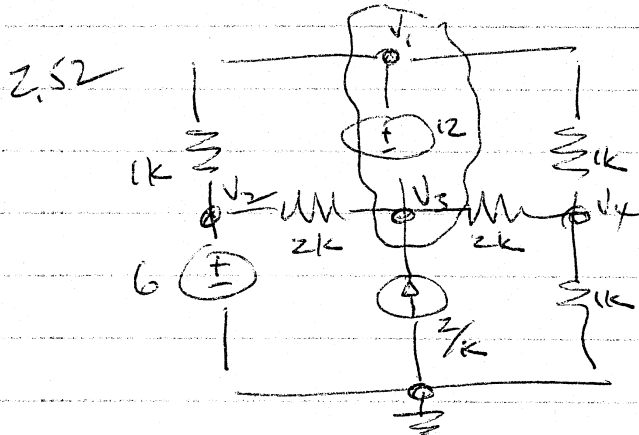
$$\frac{V_i - 12}{1k} + \frac{V_i}{1k} + \frac{V_i}{2k} = \frac{2}{k}$$

$$V_i + V_i + \frac{V_i}{2} = 14$$

$$\frac{5}{2}V_i = 14$$

$$V_i = \frac{28}{5}V$$

$$V_o = \frac{1}{2}V_i = \frac{14}{5}V$$



$$\frac{V_i - 6}{k} + \frac{V_3 - 6}{2k} + \frac{V_i - V_4}{1k} + \frac{V_3 - V_4}{2k} = \frac{2}{k}$$

$$V_i - V_3 = 12 \quad V_2 = 6$$

$$\frac{V_4 - V_i}{k} + \frac{V_4 - V_3}{2k} + \frac{V_4}{k} = 0$$

$$V_i - 6 + \frac{V_3}{2} - 3 + V_i - V_4 + \frac{V_3}{2} - \frac{V_4}{2} = 2$$

$$V_4 - V_i + \frac{V_4}{2} - \frac{V_3}{2} + V_4 = 0$$

$$V_i = V_3 + 12$$

$$V_3 + 12 + \frac{V_3}{2} - 3 + V_3 + 12 - V_4 + \frac{V_3}{2} - \frac{V_4}{2} = 2$$

$$V_4 - V_3 - 12 + \frac{V_4}{2} - \frac{V_3}{2} + V_4 = 0$$

$$3V_3 - \frac{3}{2}V_4 = -13$$

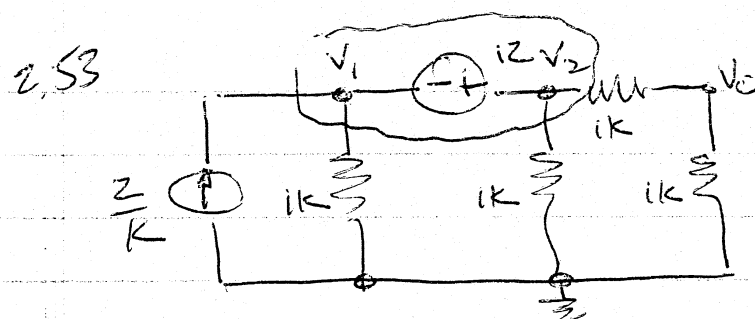
$$-\frac{3}{2}V_3 + \frac{5}{2}V_4 = 12$$

$$\Delta = (3)(\frac{5}{2}) - (\frac{-3}{2})(\frac{-3}{2}) = \frac{15}{2} - \frac{9}{4} = \frac{21}{4}$$

$$\begin{bmatrix} V_3 \\ V_4 \end{bmatrix} = \frac{4}{21} \begin{bmatrix} \frac{5}{2} & \frac{3}{2} \\ \frac{3}{2} & 3 \end{bmatrix} \begin{bmatrix} -13 \\ 12 \end{bmatrix}$$

$$V_3 = \frac{4}{21} \left(\frac{-65}{2} + \frac{36}{2} \right) = \left(\frac{4}{21} \right) \left(\frac{-29}{2} \right) = -\frac{58}{21}V$$

$$V_4 = \frac{4}{21} \left(\frac{-39}{2} + \frac{72}{2} \right) = \left(\frac{4}{21} \right) \left(\frac{33}{2} \right) = +\frac{66}{21}V$$



$$V_2 - V_1 = 12$$

$$-\frac{2}{1K} + \frac{V_1}{1K} + \frac{V_2}{1K} + \frac{V_2 - V_0}{1K} = 0$$

$$\frac{V_0 - V_2}{1K} + \frac{V_0}{1K} = 0$$

$$-V_1 + V_2 = 12$$

$$V_1 + 2V_2 - V_0 = 2$$

$$-V_2 + 2V_0 = 0$$

$$\begin{bmatrix} -1 & 1 & 0 \\ 1 & 2 & -1 \\ 0 & -1 & 2 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_0 \end{bmatrix} = \begin{bmatrix} 12 \\ 2 \\ 0 \end{bmatrix}$$