P 5.2 [a] Let the value of the voltage source be v_s:

$$\frac{v_n - v_s}{10{,}000} + \frac{v_n - v_o}{40{,}000} = 0.$$

But $v_n = v_p = 0$. Therefore,

$$v_o = -\frac{40{,}000}{10{,}000}v_s = -4v_s.$$

When $v_s = -6$ V, $v_o = -4(-6) = 24$ V; saturates at $v_o = 15$ V.
When $v_s = -3.5$ V, $v_o = -4(-3.5) = 14$ V.
When $v_s = -1.25$ V, $v_o = -4(-1.25) = 5$ V.
When $v_s = 1$ V, $v_o = -4(1) = -4$ V.
When $v_s = 2.4$ V, $v_o = -4(2.4) = -9.6$ V.
When $v_s = 5.4$ V, $v_o = -4(5.4) = -21.6$ V; saturates at $v_o = -15$ V.

[b] $-4v_s = 15 \qquad \text{so} \qquad v_s = \frac{15}{-4} = -3.75 \text{ V;}$

$-4v_s = -15 \qquad \text{so} \qquad v_s = \frac{-15}{-4} = 3.75 \text{ V.}$

The range of source voltages that avoids saturation is
$-3.75 \text{ V} \leq v_s \leq 3.75 \text{ V}$.

P 5.4 $\dfrac{v_b - v_a}{20} + \dfrac{v_b - v_o}{100} = 0, \qquad \text{therefore} \quad v_o = 6v_b - 5v_a.$

[a] $v_a = 4$ V, $\quad v_b = 0$ V, $\quad v_o = -16$ V (sat).

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

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

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

[e] If $v_b = 1.6$ V, $\quad v_o = 9.6 - 5v_a = \pm 16;$

$$\therefore \quad -1.25 \leq v_a \leq 5.12 \text{ V}.$$

P 5.5 [a] $i_a = \dfrac{240 \times 10^{-3}}{8000} = 30\,\mu\text{A}.$

[b] $\dfrac{0 - v_a}{60{,}000} = i_a \quad \text{so} \quad v_a = -60{,}000 i_a = -1.8 \text{ V}.$

[c] $\dfrac{v_a}{60{,}000} + \dfrac{v_a}{40{,}000} + \dfrac{v_a - v_o}{30{,}000} = 0;$

$$\therefore \quad v_o = 2.25 v_a = -4.05 \text{ V}.$$

[d] $i_o = \dfrac{-v_o}{20{,}000} + \dfrac{v_a - v_o}{30{,}000} = 277.5\,\mu\text{A}.$

P 5.6 $v_p = \dfrac{5000}{5000 + 10{,}000}(6) = 2 \text{ V} = v_n;$

$$\frac{v_n + 5}{3000} + \frac{v_n - v_o}{6000} = 0;$$

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

$$v_o = 16 \text{ V}.$$

$$i_L = \frac{v_o}{8000} = \frac{16}{8000} = 2000 \times 10^{-6};$$

$$i_L = 2 \text{ mA}.$$

P 5.7 Since the current into the inverting input terminal of an ideal op-amp is zero, the voltage across the 3.3 MΩ resistor, positive on the left, is $(3.3 \times 10^6)(2.5 \times 10^{-6})$ or 8.25 V. Therefore the voltmeter reads -8.25 V.

P 5.12 [a] This circuit is an example of an inverting summing amplifier.

[b] $v_o = -\frac{220}{33}v_{\rm a} - \frac{220}{22}v_{\rm b} - \frac{220}{80}v_{\rm c} = -8 + 15 - 11 = -4\ \text{V}.$

[c] $v_o = -19 - 10v_{\rm b} = \pm 6;$

$$\therefore\quad v_{\rm b} = -1.3\ \text{V} \quad \text{when} \quad v_o = -6\ \text{V};$$

$$v_{\rm b} = -2.5\ \text{V} \quad \text{when} \quad v_o = 6\ \text{V};$$

$$\therefore\quad -2.5\ \text{V} \le v_{\rm b} \le -1.3\ \text{V}.$$

P 5.17 [a] $\frac{8-4}{40{,}000} + \frac{8-9}{22{,}000} + \frac{8-13}{100{,}000} + \frac{8}{352{,}000} + \frac{8-v_0}{R_f} = 0;$

$$\frac{8-v_o}{R_f} = -2.7272\times 10^{-5} \quad \text{so} \quad R_f = \frac{8-v_o}{-2.727\times 10^{-5}}.$$

For $v_o = 15$ V, $R_f = 256.7\,\text{k}\Omega;$

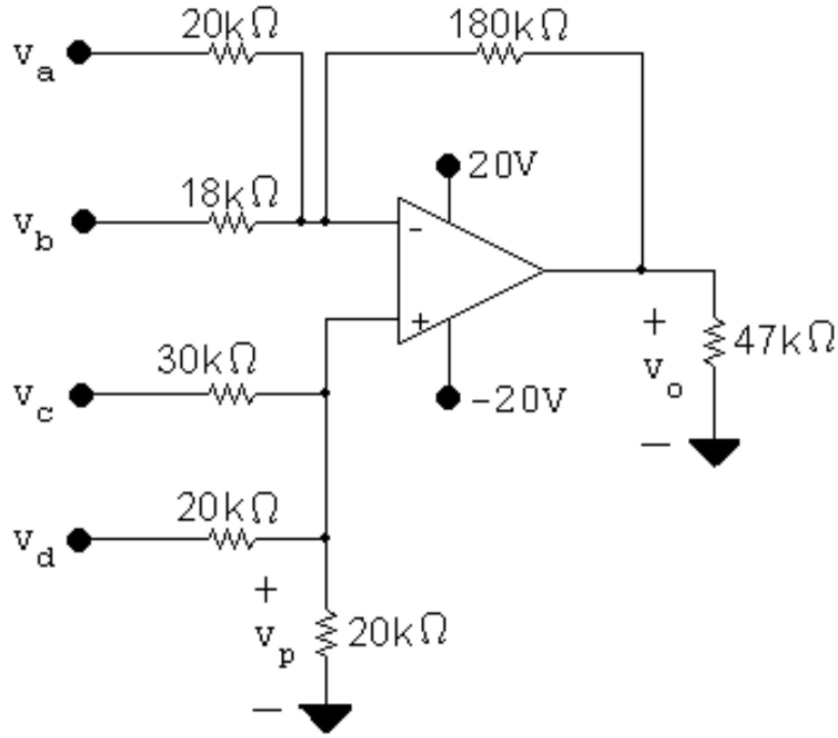
For $v_o = -15$ V, $R_f < 0$ so this solution is not possible.

[b] $i_o = -(i_f + i_{10\text{k}}) = -\left[\frac{15-8}{256.7\times 10^3} + \frac{15}{10{,}000}\right] = -1527\,\mu\ \text{A}.$

P 5.14 $v_o = -\left[\frac{R_f}{3000}(0.15) + \frac{R_f}{5000}(0.1) + \frac{R_f}{25{,}000}(0.25)\right];$

$$-6 = -8\times 10^{-5}R_f; \qquad R_f = 75\,\text{k}\Omega; \qquad \therefore\quad 0 \le R_f \le 75\,\text{k}\Omega.$$

P 5.31 [a]



$$\frac{v_p}{20{,}000} + \frac{v_p - v_c}{30{,}000} + \frac{v_p - v_d}{20{,}000} = 0;$$

$$\therefore \quad 8v_p = 2v_c + 3v_d = 8v_n.$$

$$\frac{v_n - v_a}{20{,}000} + \frac{v_n - v_b}{18{,}000} + \frac{v_n - v_o}{180{,}000} = 0;$$

$$\begin{aligned}
\therefore \quad v_o &= 20v_n - 9v_a - 10v_b \\
&= 20[(1/4)v_c + (3/8)v_d] - 9v_a - 10v_b \\
&= 20(0.75 + 1.5) - 9(1) - 10(2) = 16 \text{ V}.
\end{aligned}$$

[b] $v_o = 5v_c + 30 - 9 - 20 = 5v_c + 1;$

$$\pm 20 = 5v_c + 1;$$

$$\therefore \quad v_b = -4.2 \text{ V} \qquad \text{and} \qquad v_b = 3.8 \text{ V};$$

$$\therefore \quad -4.2 \text{ V} \le v_b \le 3.8 \text{ V}.$$