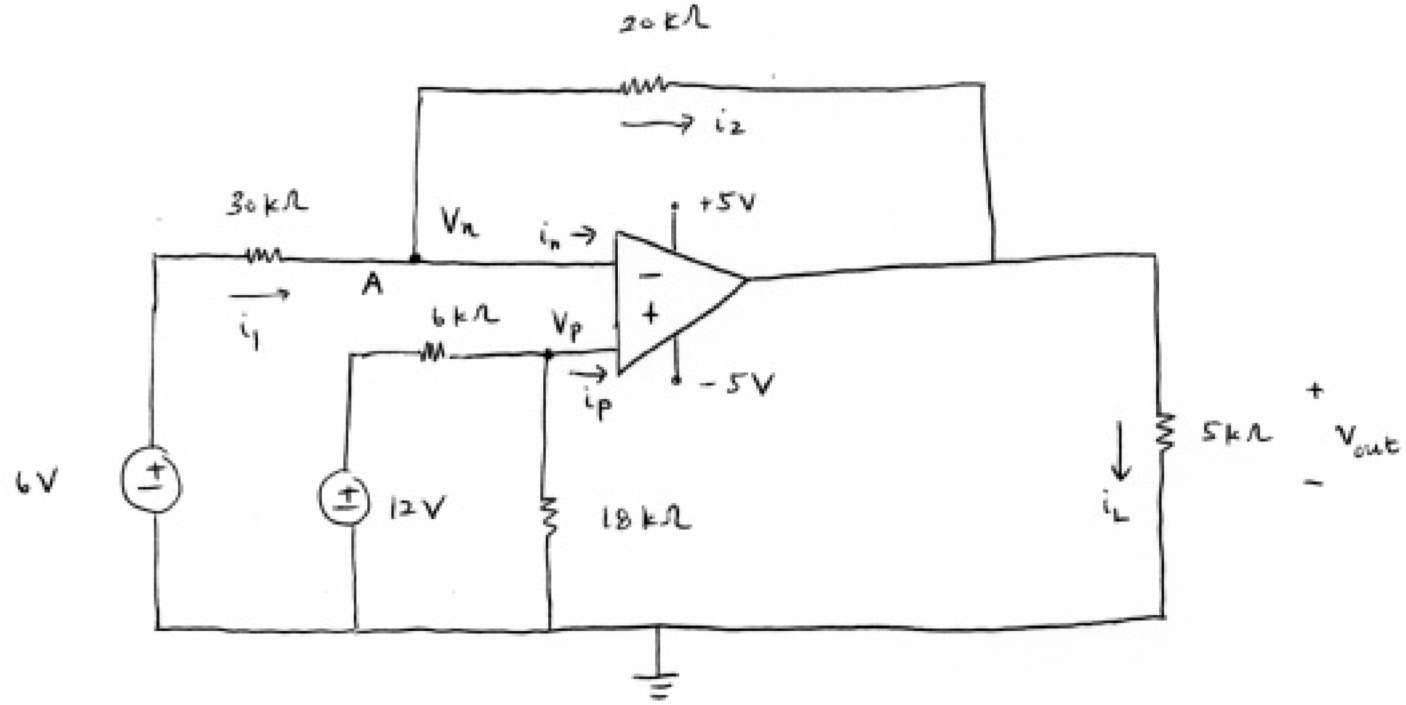
5.2 Find i_L in the circuit.



• Since $i_p = 0$, by a voltage divider

$$V_p = \frac{18\ (1000)}{18{,}000 + 6000}\ (12\text{ V}) = 9\text{ V}$$

From the golden rules, $V_p = V_n = 9$ V.

• Apply node-voltage analysis at node A:

$i_n = 0$.

$$-i_1 + i_2 = 0$$

$$-\frac{(6-9)}{30{,}000} + \frac{(9 - V_{out})}{20{,}000} = 0$$

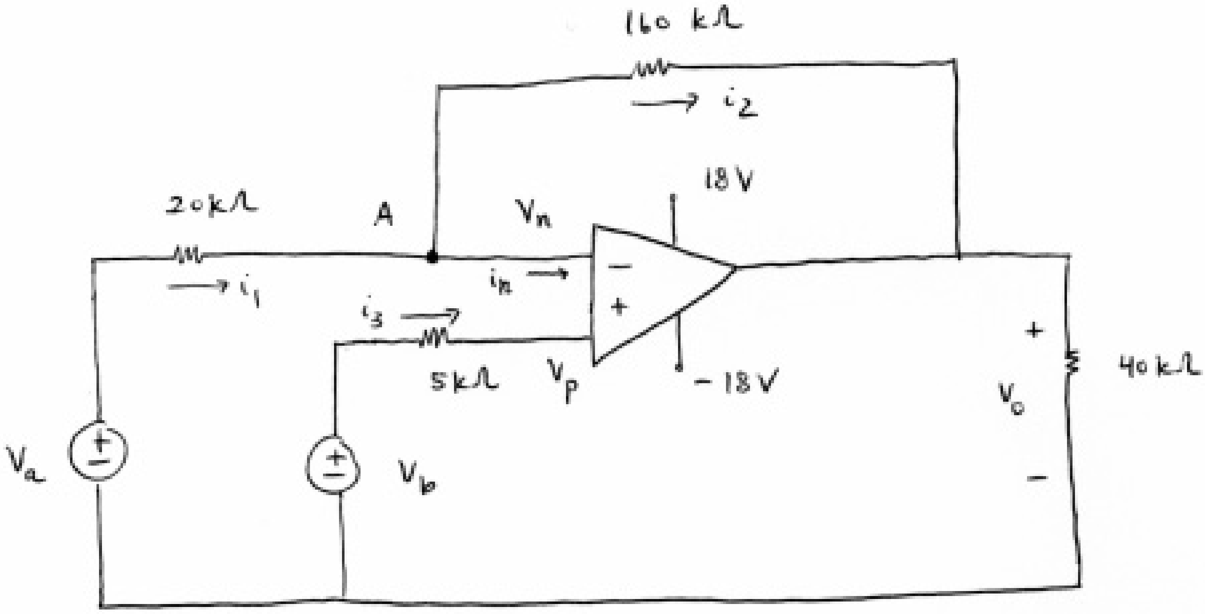
$$\Rightarrow \quad V_{out} = 11\text{ V}$$

(a) Because $+V_{cc} = 5$ V, op amp output saturated at 5 V.

$$i_L = \frac{5\text{V}}{5000\ \Omega} = 1\text{ mA} = \boxed{1000\ \mu A}$$

(b) Since $-15\text{V} \le V_{out} \le 15$ V, $V_{out} = 11$ V $\Rightarrow i_L = \frac{11\text{ V}}{5000\ \Omega} = \boxed{2200\ \mu A}$

5.3



Find v_o :

Node-voltage analysis at node A:

$$i_n = 0$$

$$-i_1 + i_2 = 0$$

$$\Rightarrow \quad \frac{V_a - V_n}{20{,}000} = \frac{V_n - V_o}{160{,}000} \qquad \text{eqn (1)}$$

Note that $\quad i_3 = 0$

$$\Rightarrow \quad V_p = V_b$$

Also, $\quad V_p = V_n = V_b$.

From eqn (1),

$$\frac{V_a - (V_b)}{20{,}000} = \frac{(V_b) - V_o}{160{,}000}$$

$$\Rightarrow \quad \boxed{V_o = 9\,V_b - 8\,V_a}$$

5.3 Now substitute in given values of V_b and V_a

(a) $V_o = 9(0) - 8(1.5\text{ V})$

$\boxed{V_o = -12\text{ V}}$

(b) $V_o = -24\text{ V}$

But $-V_{cc} = -18\text{ V}$ so output of op amp saturates at -18 V.

$\boxed{V_o = -18\text{ V}}$

(c) $\boxed{V_o = 10\text{ V}}$

(d) $\boxed{V_o = -14\text{ V}}$

(e) $V_o = 24\text{ V}$. But $+V_{cc} = 18\text{ V}$, so output of op amp saturates at 18 V.

$\boxed{V_o = 18\text{ V}}$

(f) $V_b = 4.5\text{ V}$. Specify range of V_a such that op amp does <u>NOT</u> saturate.

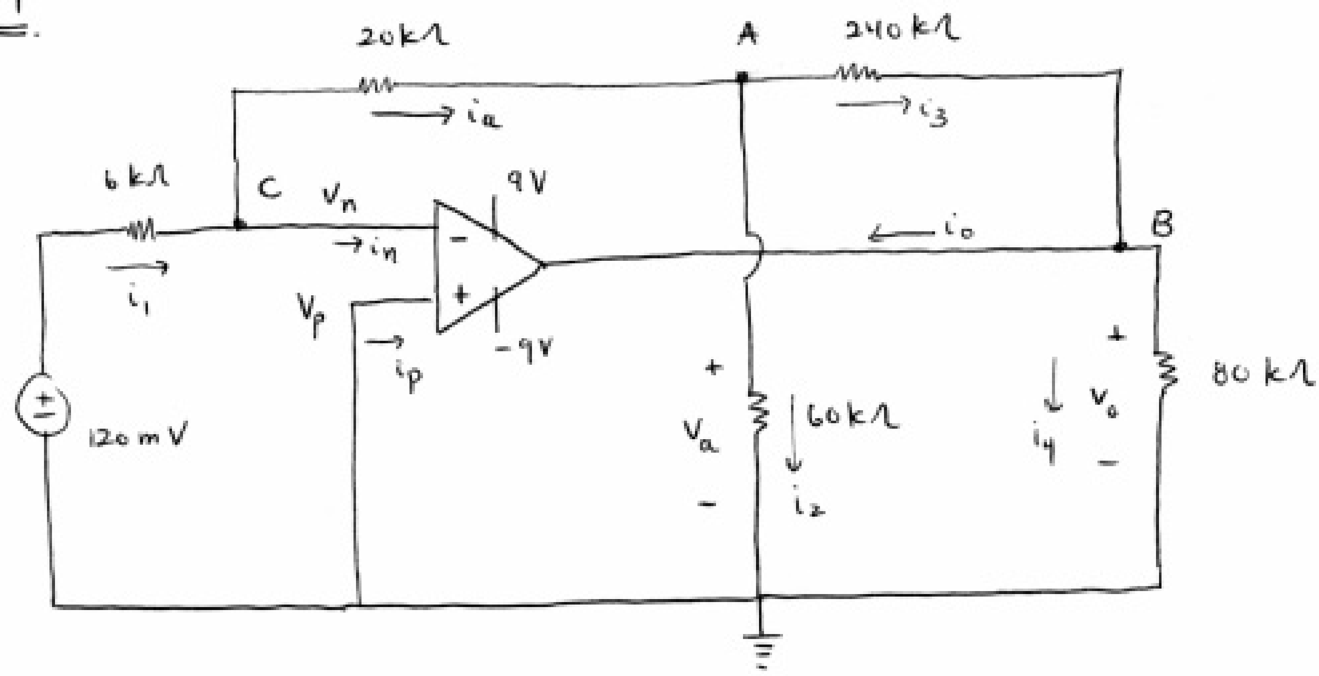
$$\Rightarrow \quad -18 \le V_o \le 18$$

$$-18 \le (9V_b - 8V_a) \le 18$$

$$\vdots$$

$$\Rightarrow \quad \boxed{2.81\text{ V} \le V_a \le 7.31\text{ V}}$$

5.4.



(a) Find V_a

• Node-voltage analysis at node C:

$$i_n = 0$$
$$-i_1 + i_a = 0$$
$$\Rightarrow \quad i_a = i_1$$
$$\frac{V_n - V_A}{20{,}000} = \frac{0.120 - V_n}{6000}.$$

Note that $\quad V_p = 0$

$$V_n = V_p = 0.$$

$$\Rightarrow \quad \frac{-V_A}{20{,}000} = \frac{0.120}{6000}$$

$$V_A = -0.4\text{ V}$$
$$\boxed{V_a = -0.4\text{ V}}$$

(b) Find V_o:

• Node-voltage analysis at node A: $\quad -i_a + i_2 + i_3 = 0$

$$\Rightarrow \quad -\frac{(\cancel{V_n}^{\,0} - V_A)}{20{,}000} + \frac{V_A}{60{,}000} + \frac{V_A - V_B}{240{,}000} = 0$$

$$\boxed{V_B = -6.8\text{ V}} \Rightarrow V_o = V_B = \underline{-6.8\text{ V}} \,//$$

5.4

(c) Find i_a.

$$i_a = \frac{V_n - V_A}{20{,}000} = \frac{0.4}{20{,}000} = \boxed{20\,\mu A}$$

(d) Find i_o

KCL at node B:

$$i_o - i_3 + i_4 = 0$$

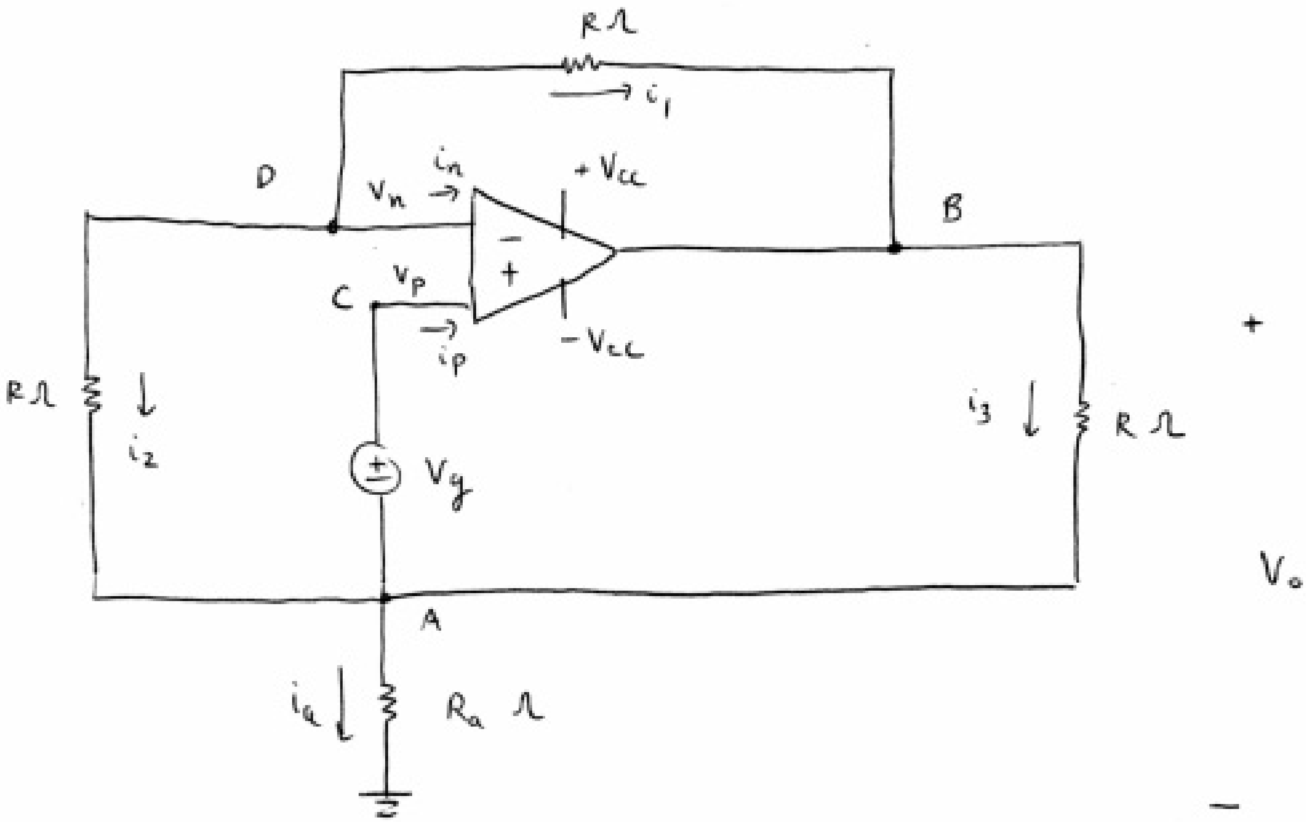
$$i_o = i_3 - i_4$$

$$= \frac{V_A - V_B}{240{,}000} - \frac{V_B}{80{,}000}$$

$$= \frac{V_a - V_o}{240{,}000} - \frac{V_o}{80{,}000}$$

$$\boxed{i_o = 111.7\ \mu A}$$

5.15 ⓐ Show that $i_a = \frac{3v_g}{R}$ when op amp operates in linear region.



Node-voltage analysis at node D. :

$$i_n = 0$$

$$i_2 + i_1 = 0$$

$$\frac{V_n - V_A}{R} + \frac{V_n - V_B}{R} = 0 \qquad \text{eqn ①.}$$

Note :

$$V_c = V_p$$

$$V_c = ?$$

$$V_c - V_A = V_g$$

$$V_c = V_A + V_g = V_p = V_n$$

⇒ eqn ① becomes: $\frac{(V_A + V_g) - V_A}{R} + \frac{(V_A + V_g) - V_B}{R} = 0$

5.15 (a)

$$\Rightarrow \quad \frac{V_g}{R} + \frac{V_A - V_B + V_g}{R} = 0$$

$$2 v_g = V_B - V_A$$

- Node-voltage analysis at node A:

$$-i_2 - i_3 + i_a = 0$$

$$i_a = i_2 + i_3$$

$$= \frac{V_n - V_A}{R} + \frac{V_B - V_A}{R}$$

$$= \frac{(V_A + V_g) - V_A}{R} + \frac{2V_g}{R}$$

$$\boxed{i_a = \frac{3V_g}{R}} \quad ✓$$

(b) Show saturation occurs when

$$R_a = \frac{R(\pm V_{cc} - 2v_g)}{3v_g}$$

Saturation does NOT occur when

$$-V_{cc} \leq V_o \leq V_{cc}$$

$$-V_{cc} \leq i_3 R + i_a R_a \leq V_{cc}$$

$$-V_{cc} - i_3 R \leq i_a R_a \leq V_{cc} - i_3 R$$

$$-V_{cc} - \left(\frac{2v_g}{R}\right) R \leq \left(\frac{3v_g}{R}\right) R_a \leq V_{cc} - \left(\frac{2v_g}{R}\right) R$$

$$\boxed{\frac{R(-V_{cc} - 2v_g)}{3v_g} \leq R_a \leq \frac{R(V_{cc} - 2v_g)}{3v_g}}$$

So, R_a is bounded by $\dfrac{R(\pm V_{cc} - 2v_g)}{3v_g}$. //

Solution

For an inverting amplifier the magnitude of gain is

$|G| = (R_f) / (R_s)$

For the nominal values of the resistors this ratio equals
100.0 / 2.4 = 41.67

The lowest gain is
$(R_{f,\ lowest}) / (R_{s,\ highest}) = (100.0 - 10.0) / (2.4 + 0.24) = 90.0 / 2.64 = 34.09$

The highest gain is
$(R_{f,\ highest}) / (R_{s,\ lowest}) = (100.0 + 10.0) / (2.4 - 0.24) = 110.0 / 2.16 = 50.93$

For a non-inverting amplifier,

$G = 1 + (R_f) / (R_s)$

Nominal value = 1+ 100.0 / 2.4 = 1+ 41.67 = 42.67

The lowest gain is
$1 + (R_{f,\ lowest}) / (R_{s,\ highest}) = 1 + (100.0 - 10.0) / (2.4 + 0.24) = 35.09$

The highest gain is
$1 + (R_{f,\ highest}) / (R_{s,\ lowest}) = 1 + (100.0 + 10.0) / (2.4 - 0.24) = 51.93$

Comment.
Students familiar with propagation of errors may apply their knowledge and arrive at essentially the same values in a more elegant way.

The maximal amplitude of the output signal, which is not clipped, is 20 V peak-to-peak or 10 V peak. The AC waveform has the amplitude 100 mV peak.

After amplification, the peak value of the AC signal is
$AC * |G|$
Even for the maximal gain it equals
$AC * |G|$ = 100 mV * 50.93 = 5.093 V.
This signal is not clipped.

The equation for maximal DC offset at which the output signal is not clipped is:

$(AC + DC_{max}) * |G| = 10\ V$

DC max = $\{ 10\ V / |G| \} - AC$

Substitution gives:

For nominal gain,
DC max = 140.0 mV

For minimal gain,
DC max = 193.3 mV

For maximal gain,
DC max = 96.3 mV

Since the clipping of waveforms occurs at +10 V and –10 V (same magnitude despite different signs), the largest negative DC offset at which the clipping does not occur equals to –DC max found above, that is

For nominal gain,
–140.0 mV

For minimal gain,
–193.3 mV

For maximal gain,
–96.3 mV