By Golden Rules of Op-amps
(1) \( V_n = V_p \) & (2) \( I_n = I_p = 0 \)

with reference to the above circuit,

\[ I_p = 0 \Rightarrow V_p = 320 \text{ mV} \]

But since \( V_n = V_p \), \( V_n = 320 \text{ mV} \)

But \( V_o = V_n \) (from circuit diagram)

\[ V_o = 320 \text{ mV} \]

\( V_o \rightarrow \) voltage across the 16k resistor

\( V_o \rightarrow \) power delivered to the 16k resistor

\[ P_{16k} = \frac{V_o^2}{R_L} \quad (\text{where } R_L = 16k) \]

\[ = \frac{(0.32)^2}{16k} \]
\[ P_{16k} = 6.4 \text{ uW} \]

b) \text{ckt redrawn with op-amp removed from the ckt}

\[ V_{16k} = \left( \frac{16k}{16k+48k} \right) (0.32) = 0.08 \text{ V} \]

(Voltage Divider)

\[ P_{16k} = \frac{(0.08)^2}{16k} \]

\[ P_{16k} = 0.4 \text{ uW} \]

c) \text{Ratio} = \frac{P_{16k}^a}{P_{16k}^b} = \frac{6.4 \text{ uW}}{0.4 \text{ uW}} \]

\[ \text{Ratio} = 16 \]
Yes, it does. Some of them are:

1) It enables the source to control 16 times as much power delivered to the load resistor—as found in part (c). Thus, it aids in Power Amplification.

2) Irrespective of the source resistance (in this case 48k + the internal resistance of 320mV source), the o/p voltage is always equal to the input. Thus, it's a VOLTAGE FOLLOWER (o/p voltage = i/p voltage) ckt.

3) It serves as a buffer amplifier between the i/p voltage ckt and the o/p ckt to which the voltage is delivered. Thus, it prevents the loading of i/p ckt by the o/p ckt.

4) It also allows the load resistor voltage (and its current) to be set without drawing any current from i/p. This is called current amplification function of the ckt.
By golden rules, \( V_n = V_p \)

\[ V_n = i_b R_b \]

Applying KCL at node \( n \),

\[ -i_a + \frac{V_n - 0}{3k} + \frac{V_n - V_o}{R_f} = 0 \]

\[ -i_a + \frac{i_b R_b}{3k} + \frac{i_b R_b - V_o}{R_f} = 0 \]
\[ (-ia)(3k)(Rf) + (ibRb)Rf + (ibRb)(3k) = (V_o)3k \]  \(-1\)

Since, \( V_o = 2000 (ib - ia) \) (Given)

\[ (V_o)3k = 3k(2000)ib - 3k(2000)ia \]  \(-2\)

Comparing eqns 1 & 2

\[ R_f = 2000 = 2k \Omega \]

and \( (3k)(2000) = R_bR_f + R_b3k \)

\[ R_b = \frac{(3k)(2000)}{5k} \]

\[ R_b = 1200 \Omega \]

Problem 5.30
Using ideal model for op-amps, resistance seem by voltage source $V_b = R_a + R_b$

$$R_a + R_b = 220k$$ (from given)

Now by Golden rules, $I_p = 0$

$$V_p = \left( \frac{R_b}{R_a + R_b} \right) V_b$$ (from ckt, using voltage divider)

Since $V_m = V_p$ (also by Golden Rules)

$$V_m = \left( \frac{R_b}{R_a + R_b} \right) V_b$$

Applying KCL at node $n$, using node-voltage method, we get

$$\frac{V_m - V_a}{4.7k} + \frac{V_m - V_o}{R_f} = 0$$

$$V_m \left( \frac{1}{4.7k} + \frac{1}{R_f} \right) - \frac{V_a}{4.7k} = \frac{V_o}{R_f}$$

$$V_o = \left( \frac{R_b}{R_a + R_b} \right) \cdot R_f \cdot \frac{(R_f + 4.7k)}{(4.7k)R_f} \cdot V_b - \frac{V_a}{4.7k} \cdot R_f$$
Now since \( v_0 = 10v_b-10v_a \) as given,

\[
\frac{R_f}{4.7k} = 10
\]

\[
R_f = 47k
\]

Also, \( \left( \frac{R_b}{R_a+R_b} \right) R_f \left( \frac{R_f + 4.7k}{4.7k(R_f)} \right) = 10 \)

Putting \( R_a+R_b = 220k \), and \( R_f = 47k \) in there, we get

\[
v_0 = \left( \frac{R_b}{220k} \right) 47k \left( \frac{4.7k+4.7k}{4.7k(4.7k)} \right)
\]

\[
R_b = 200k
\]

and \( R_a = 20k \) (since \( R_a+R_b = 220k \))

4. Problem 5.34
By golden rules,

\[ I_{n1} = I_{p1} = I_{n2} = I_{p2} = 0 \]

(where the subscripts \(1\) and \(2\) refer to the respective opamps in the ckt)

Applying KCL at node \(n_2\),

\[ \frac{V_{n2}}{27K} + \frac{V_{n2} - V_0}{3K} = 0 \quad (\text{since } I_{n2} = 0) \]

\[ V_{n2} = \frac{9}{10} V_0 \]

Again by golden rules,

\[ V_{p2} = V_{n2} \quad \text{and} \quad V_{p1} = V_{n1} \]

\[ V_{p2} = \frac{9}{10} V_0 \quad \text{and} \quad V_{n1} = 0 \quad (\text{since } V_{p1} = 0) \]

Now applying KCL at node \(n_1\),

\[ \frac{0 - 1.1}{3K} + \frac{0 - V_{p2}}{18K} + \frac{0 - V_0}{24K} = 0 \]

\[ \frac{-1.1}{3} - \left( \frac{9}{10} \right) \frac{V_0}{18} - \frac{V_0}{24} = 0 \]

\[ -\frac{1.1}{3} = V_0 \left( \frac{1}{20} + \frac{1}{24} \right) = \frac{(V_0)11}{120} \]

\[ V_0 = \left( \frac{-1.1}{3} \right) \left( \frac{120}{11} \right) \]

\[ V_0 = -4 \text{ V} \]
Now applying KCL at node 0,

\[ i_0 + \frac{V_0 - 0}{4.5K} + \frac{V_0 - V_{n1}}{24K} + \frac{V_0 - V_{n2}}{3K} = 0 \]

\[ i_0 + \frac{V_0}{4.5K} + \frac{V_0}{24K} + \frac{V_0}{30K} = 0 \]

\[ (i_0)(10^3) = -4 \left( \frac{1}{4.5} + \frac{1}{24} + \frac{1}{30} \right) \]

\[ i_0 = 1.188 \text{ mA} \]

Problem 5.40

We draw a new circuit equivalent to the one given, but one which takes into account the non-idealities of the op-amp.
Applying KCL at node n,
\[
\frac{V_n - V_g}{8k} + \frac{V_n - V_p}{400k} + \frac{V_n - V_o}{320k} = 0
\]

\[V_p = 0\]

\[V_n \left( \frac{1}{8k} + \frac{1}{400k} + \frac{1}{320k} \right) - \frac{V_o}{320k} = \frac{V_g}{8k}\]

\[41.85 V_n - V_o = 40 V_g\]  \[\text{--- (1)}\]

Applying KCL at node 0, and putting \(V_p = 0\):
\[
\frac{V_o - 500,000 (1-V_n)}{2k} + \frac{V_o - V_n}{320k} = 0
\]

\[80 \times 10^6 V_n + 161 V_o = 0\]  \[\text{--- (2)}\]

Solving eqns (1) and (2) we get
\[ V_v = -39.997 V_g \]

\[ \frac{V_v}{V_g} = -39.997 \]

(b) Again, from eqns 1 & 2 derived in part (a),

\[ V_n = 8.05 \times 10^{-5} V_g \]

Since \( V_g = 50 mV \),

\[ V_n = 4.02 \mu V \]

(c) Resistance seen by source \( V_g \), is the ratio \( V_g / i_g \), where \( i_g \) is the current drawn from that source \( V_g \).

Now, in our case, it's the current \( i_g \) flowing through 8K resistor.

\[ i_g = \frac{V_g - V_n}{8K} \]

\[ = \frac{V_g - 8.05 \times 10^{-5} V_g}{8K} \quad \text{(from @ & @b)} \]

\[ R_g = \frac{V_g}{i_g} = \frac{V_g}{V_g - 8.05 \times 10^{-5} V_g} \quad \text{(8K)} \]

\[ R_g = 8000.64 \Omega \]
For an ideal inverting amplifier,

\[ \text{Gain} = \frac{V_o}{V_g} = -\frac{R_F}{R_{in}} \]

In this case,

\[ \text{Gain} = -320k = -40 \]

\[ \frac{8k}{8k} \]

By Golden rules, \( V_n = V_p \)

Since \( V_p = 0 \), \( V_n = 0 \)

And \( i_g = \frac{V_g - V_n}{8k} = \frac{V_g - 0}{8k} = \frac{V_g}{8k} \)

\[ R_g = \frac{V_g}{i_g} = 8k \]

\[ R_g = 8k \]
Comments:

Comparing the results from part (d), with results from other parts, we find that they are very close. We conclude from this that for very high /op/ resistance, very low /op/ resistance and very high open-loop gain, the ideal op-amp model yields very accurate results. Thus we can safely assume our op-amp to be ideal under the above-mentioned conditions, and simplify our analysis, while still getting close to accurate results.

lab-related problem - By A. Gango

@ RL = 8 ohm

Vcc = 10 V

for LM380, max V0ppk = (Vcc-4) = 10 - 4 = 6 V

max o/p short-ckt current for LM380

I(oc)(380) = 1.3 A

(Isc_max)(RL) = (1.3)(8) = 10.4 V
Thus if \((V_o)_{ppk}\) exceeds 10.4 V, current clipping will occur.

But voltage clipping will occur when \((V_o)_{ppk}\) exceeds \(\frac{6}{2} = 3 V\).

Thus current clipping will not occur.

* Max \((V_o)_{pk} = \frac{6}{2} = 3 V\)

Max power delivered to the load when olp is not clipped, will be

\[
(P_L)_{max} = \frac{(V_o)_{pk}(max)}{2R_L}
\]

\[
= \frac{(3)^2}{2(8)}
\]

\[
(P_L)_{max} = 0.5625 W
\]

\(R_L = 8 \Omega, \ V_{cc} = 10 V\)

* Now, for \(V_{cc} = 22 V\)

\(\text{max } (V_o)_{ppk} = 22 - 4 = 18 V\)

\(\text{max } (V_o)_{pk} = 9 V\)

Since \(9 V < 10.4 V\), current clipping will not occur.

* Also \((P_L)_{max} = \frac{(9)^2}{2(8)}\)

\[
(P_L)_{max} = 5.0625 W
\]

\(R_L = 8 \Omega, \ V_{cc} = 22 V\)
When two 8Ω speakers are connected in parallel,
\[ R_L = 8 \Omega / 2 = 4 \Omega \]

For \( V_{cc} = 10 \text{V} \)

\[ (I_{sc, max}) R_L = (1.3) 4 = 5.2 \text{V} \]

Since \( 5.2 \text{V} > 3 \text{V} \), current clipping will not occur.

and \( (P_L)_{max} = \frac{(3)^2}{2(4)} = 1.125 \text{W} \)

\[ R_L = 4 \Omega, V_{cc} = 10 \text{V} \]

For \( V_{cc} = 22 \text{V} \), since \( 5.2 \text{V} < 9 \text{V} \), current clipping will occur.

and unlike the \( R_L = 8 \Omega \) case,

\[ (V_{pk})_{max} = 5.2 \text{V} \]

\[ (P_L)_{max} = \frac{(5.2)^2}{2(4)} = 3.38 \text{W} \]

\[ R_L = 4 \Omega, V_{cc} = 22 \text{V} \]

The combination of \( R_L = 8 \Omega \) and \( V_{cc} = 22 \text{V} \), gives the max power to load, which is 5.0625 W.
⇒ Since max power delivered = 5.0625 W and package dissipation limit (from specs) is 8.3 W, the power limits are not exceeded.

⇒ When Vcc = 10 V, connecting two speakers gives more power (1.125 W against 0.5625 W), but when Vcc = 22 V, the power decreases with two speakers (3.38 W against 5.0625 W) because of current clipping.

(b) for LM741

\[(I_{sc})_{max} = 25 \text{ mA}\]
\[R_L = 8 \Omega\]
\[\therefore (I_{sc})_{max} \cdot R_L = (25 \text{ mA}) \cdot (8 \Omega) = 200 \text{ mV} = 0.2 \text{ V}\]

Now \(|V_{cd}| = 12 \text{ V} \Rightarrow |V_{cc} - 2| = 10 \text{ V} \).

Since \(0.2 < 10 \text{ V}\), current clipping will occur and
\[\quad (V_{opk})_{max} = 0.2 \text{ V}\]

New max power delivered to o/p
\[\frac{(P_L)_{max}}{2} = \frac{(V_{opk})_{max}}{2R_L} \]
\[
(\text{P}_L)_{\text{max}} = \frac{(0.2)^2}{2(8)} = 0.0025 \text{ W}
\]

\[(\text{P}_L)_{\text{max}} = 2.5 \text{ mW}\]

\[V_{\text{cc}} = 12 \text{ V}, R_L = 8 \Omega\]

Compared to LM380, the power delivered to OLP is very very small. Thus LM741 is not useful for audio power amplification purposes, as against LM380.