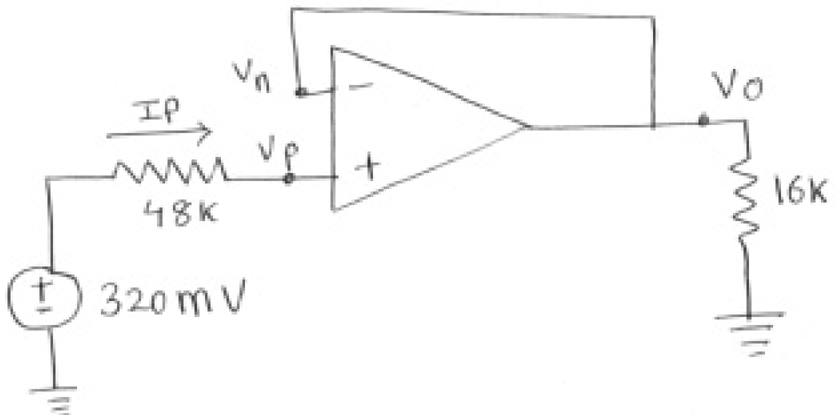
HOMEWORK #7 SOLUTIONS

1

5.20

(a)



By Golden Rules of Op-amps

(1) $V_n = V_p$ & (2) $I_n = I_p = 0$

$\therefore$ with reference to the above ckt,

$I_p = 0$ $\therefore$ $V_p = 320\,mV$

But since $V_n = V_p$, $V_n = 320\,mV$

But $V_o = V_n$ (from ckt diagram)

$\therefore$ $V_o = 320\,mV$

$V_o \rightarrow$ voltage across the 16K resistor

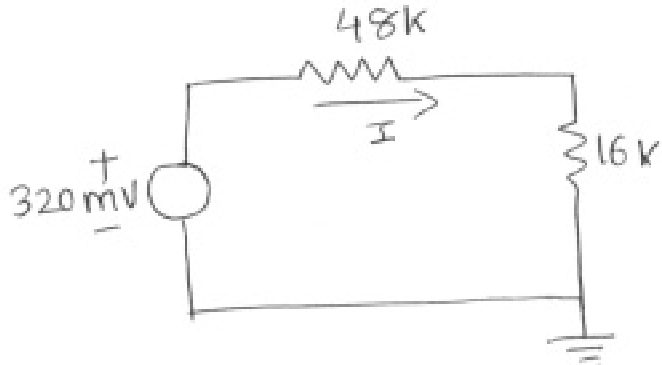
$\therefore$ power delivered to the 16K resistor

$$= P_{16K} = \frac{V_o^2}{R_L} \quad \text{(where } R_L = 16K\text{)}$$

$$= \frac{(0.32)^2}{16K}$$

$$\therefore \boxed{P_{16k} = 6.4\mu W}$$

(b) ckt redrawn with op-amp removed from the ckt



In this case,

$$V_{16K} = \left(\frac{16k}{16k+48k}\right)(0.32) = 0.08\ V$$

(Voltage Divider)

$$\therefore P_{16k} = \frac{(0.08)^2}{16k}$$

$$\therefore \boxed{P_{16K} = 0.4\mu W}$$

(c) $$\text{Ratio} = \frac{(P_{16K})_{(a)}}{(P_{16K})_{(b)}}$$

$$= \frac{6.4\ \mu W}{0.4\ \mu W}$$

$$\boxed{\text{Ratio} = 16}$$

(d) Yes it does. Some of them are:

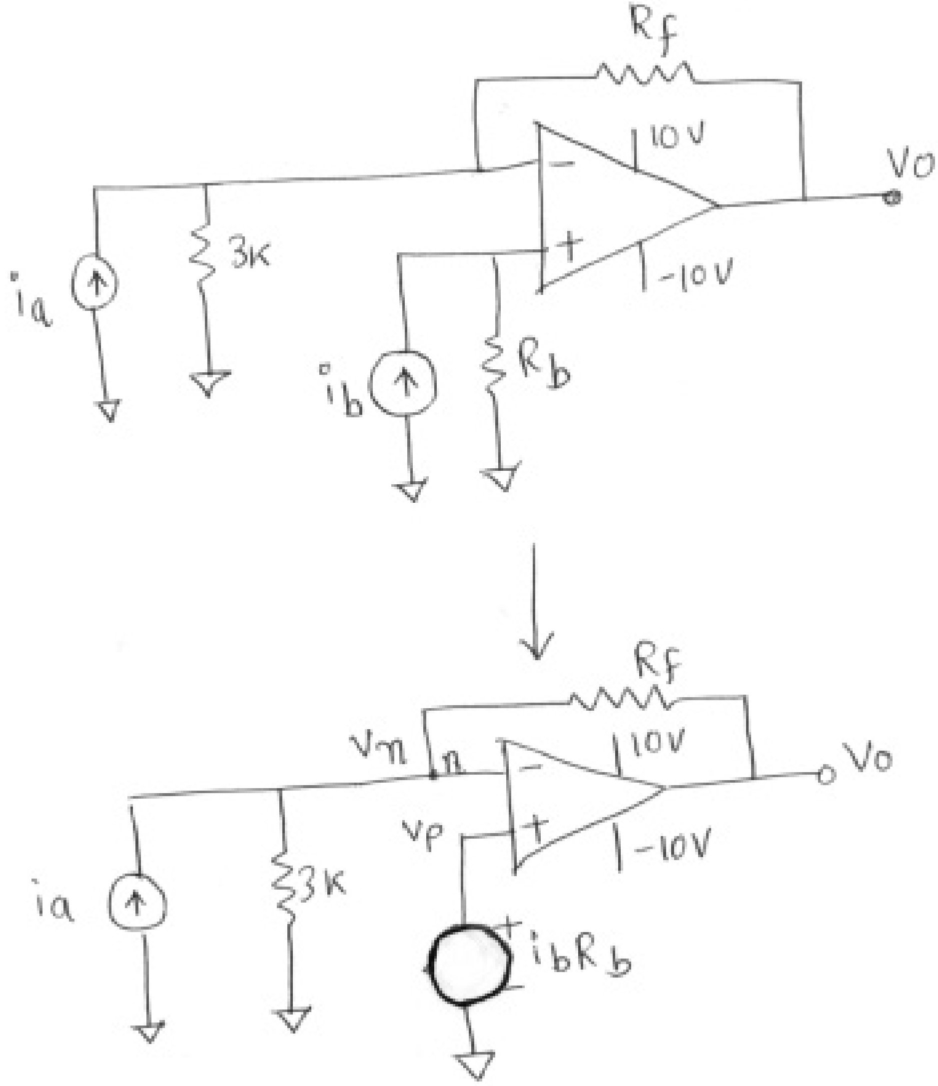
1) It enables the source to control 16 times as much power delivered to the load resistor — as found in part (c). Thus it aids in Power Amplification

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, its 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

$\boxed{2}$ $\boxed{\text{Problem 5.29}}$



By Golden rules, $V_n = V_p$

$\therefore V_n = i_b R_b$.

Applying KCL at node n,

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

$$\therefore -i_a + \frac{i_b R_b}{3k} + \frac{i_b R_b - V_o}{R_f} = 0$$

$\therefore (-i_a)(3K)(R_f) + (i_b R_b) R_f + (i_b R_b) 3K$

$= (V_o) 3K \qquad -①$

Since, $V_o = 2000 (i_b - i_a)$ (Given)

$(V_o) 3K = 3K(2000)\, i_b - 3K(2000)\, i_a \qquad -②$

Comparing eqns ① & ②

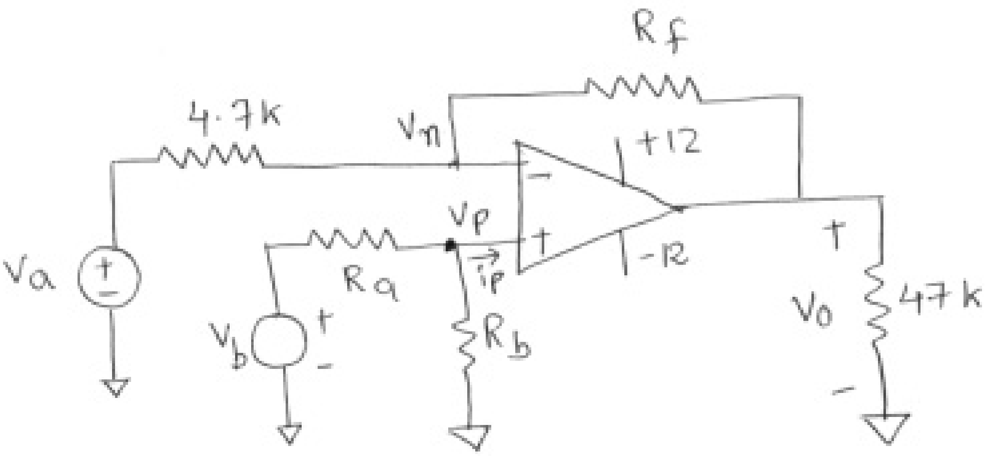
$$\boxed{R_f = 2000 = 2K\,\Omega}$$

and $(3K)(2000) = R_b R_f + R_b 3K$

$$\therefore R_b = \frac{(3K)(2000)}{5K}$$

$$\therefore \boxed{R_b = 1200\,\Omega}$$

3 Problem 5.30



Using ideal model for op-amps, resistance seen by voltage source V_b

$= R_a + R_b$

$\therefore \boxed{R_a + R_b = 220K}$ (from given)

Now by Golden rules,

$i_p = 0$

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

since $V_n = V_p$ (also by Golden Rules)

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

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

$$\frac{V_n - V_a}{4.7K} + \frac{V_n - V_o}{R_f} = 0$$

$$\therefore \quad V_n\left(\frac{1}{4.7K} + \frac{1}{R_f}\right) - \frac{V_a}{4.7K} = \frac{V_o}{R_f}$$

$$\therefore \quad V_o = \left(\frac{R_b}{R_a+R_b}\right) \cdot R_f \cdot \left(\frac{R_f + 4.7K}{(4.7K)R_f}\right) \cdot V_b$$

$$- \frac{V_a}{4.7K} \cdot R_f$$

Now since $v_o = 10v_b - 10v_a$ is given,

$$\therefore \frac{R_f}{4.7K} = 10$$

$$\therefore \boxed{R_f = 47k}$$

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

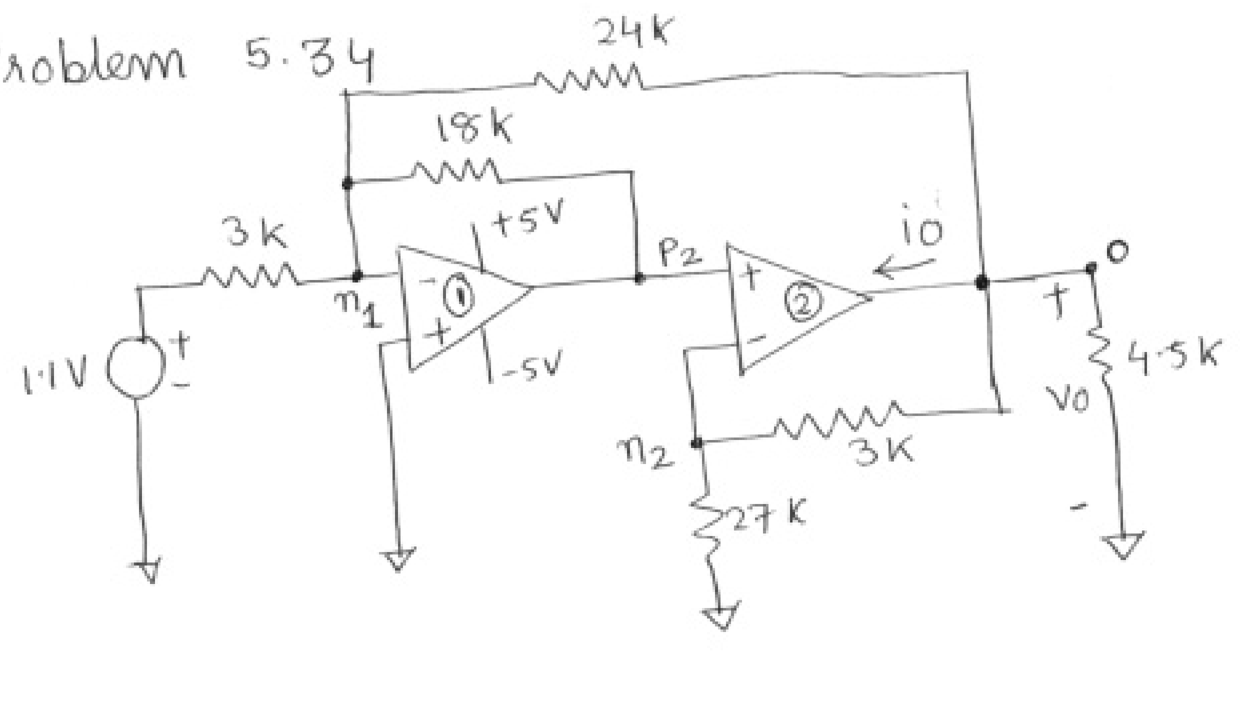
putting $R_a + R_b = 220k$, and $R_f = 47k$ in there, we get

$$v_0 = \left(\frac{R_b}{220K}\right) \cdot 47k \left(\frac{47k + 4.7k}{4.7k(47k)}\right)$$

$$\therefore \boxed{R_b = 200k}$$

and $\boxed{R_a = 20K}$ (Since $R_a + R_b = 220K$)

$\boxed{4}$ Problem 5.34



By Golden rules,

$$I_{n1} = I_{p1} = I_{n2} = I_{p2} = 0$$

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

Applying KCL at node n_2,

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

$$\therefore \boxed{V_{n2} = \frac{9}{10} V_0}$$

Again by Golden rules,

$V_{p2} = V_{n2}$ and $V_{p1} = V_{n1}$

$$\therefore \boxed{V_{p2} = \frac{9}{10} V_0} \quad \text{and} \quad \boxed{V_{n1} = 0} \quad (\text{since } V_{p1} = 0)$$

Now applying KCL at node n_1,

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

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

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

$$\therefore V_0 = \left(\frac{-1.1}{3}\right)\left(\frac{120}{11}\right)$$

$$\therefore \boxed{V_0 = -4\,V}$$

Now applying KCL at node o,

$$i_o + \frac{V_o - 0}{4.5K} + \frac{V_o - V_{n1}}{24K} + \frac{V_o - V_{n2}}{3K} = 0$$

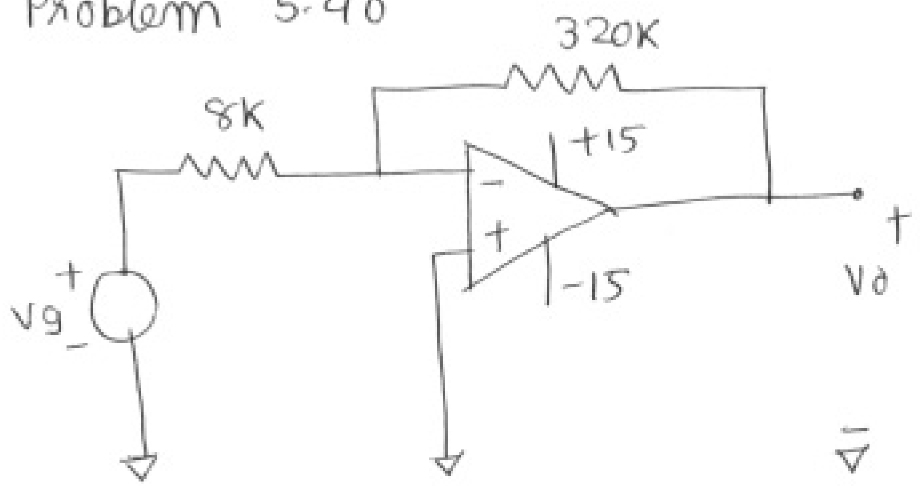
$$\therefore i_o + \frac{V_o}{4.5K} + \frac{V_o}{24K} + \frac{V_o}{30K} = 0$$

$$\left(\because V_{n2} = \frac{9}{10} V_o\right)$$

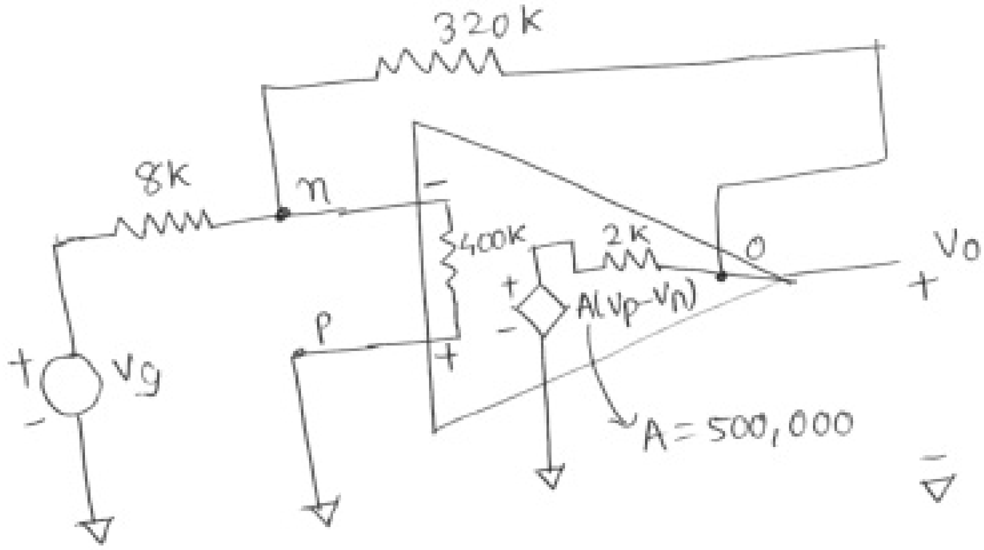
$$\therefore (i_o)(10^3) = +4\left(\frac{1}{4.5} + \frac{1}{24} + \frac{1}{30}\right)$$

$$\therefore \boxed{i_o = 1.188 \text{ mA}}$$

5 Problem 5.40



We draw a new ckt equivalent to the one given, but one which takes into account the non-idealities of the op-amp



ⓐ Applying KCL at node n.

$$\frac{V_n - V_g}{8K} + \frac{V_n - V_p}{400K} + \frac{V_n - V_o}{320K} = 0$$

$$V_p = 0$$

$$\therefore V_n\left(\frac{1}{8K} + \frac{1}{400K} + \frac{1}{320K}\right) - \frac{V_o}{320K} = \frac{V_g}{8K}$$

$$\therefore \boxed{41.8V_n - V_o = 40V_g} \quad -①$$

Applying KCL at node o, and putting $V_p = 0$;

$$\frac{V_o - 500{,}000(-V_n)}{2K} + \frac{V_o - V_n}{320K} = 0$$

$$\therefore \boxed{80\times10^6 V_n + 161 V_o = 0} \quad -②$$

solving eqns ① & ② we get

$$v_o = -39.997\, v_g$$

$$\therefore \boxed{\frac{v_o}{v_g} = -39.997}$$

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

$$v_n = 8.05 \times 10^{-5}\, v_g$$

since $v_g = 50\,mV$,

$$\boxed{v_n = 4.02\,\mu V}$$

(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, its the current i_g flowing through $8K$ resistor.

$$\therefore i_g = \frac{v_g - v_n}{8K}$$

$$= \frac{v_g - 8.05\times10^{-5}\, v_g}{8K} \quad \text{(from (a) \& (b))}$$

$$R_g = \frac{v_g}{i_g} = \frac{v_g}{v_g - 8.05\times10^{-5}\, v_g} \cdot (8K)$$

$$\boxed{R_g = 8000.644\,\Omega}$$

(d) For an ideal inverting amplifier,

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

$\therefore$ in this case,

$$\boxed{\text{Gain} = \frac{-320K}{8K} = -40}$$

By Golden rules, $V_n = V_p$

since $V_p = 0$, $\boxed{V_n = 0}$

and $$i_g = \frac{V_g - V_n}{8K} = \frac{V_g - 0}{8K} = \frac{V_g}{8K}$$

$$\therefore R_g = \frac{V_g}{i_g} = 8K$$

$$\boxed{R_g = 8K}$$

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 i/p resistance, very low o/p resistance and very high openloop 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!

6 Lab-related problem - By A. Gango

(a) $R_L = 8\,\Omega$

$V_{cc} = 10V$

for LM380, max $V_{o\,ppk} = (V_{cc} - 4) = 10 - 4$
$= 6V$

max o/p short ckt current for LM380

$= I_{(sc)(380)} = 1.3\,A$

$(I_{sc.max})(R_L) = (1.3)(8) = 10.4\,V$

Thus if $(V_o)_{ppk}$ exceeds 10.4V, current clipping will occur.

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

$10.4 > 3$

Thus current clipping <u>will not</u> occur.

* Max $(V_o)_{pk} = 6/2 = 3V$

$\therefore$ Max power delivered to the load when o/p is not clipped, will be

$$(P_L)_{max} = \frac{(V_o)_{pk(max)}^2}{2R_L}$$

$$= \frac{(3)^2}{2(8)}$$

$$\boxed{(P_L)_{max} = 0.5625\,W}$$ $R_L = 8\Omega,\ V_{cc} = 10V$

* Now for $V_{cc} = 22V$

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

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

since $9V < 10.4V$, current clipping <u>will not</u> occur.

* Also $(P_L)_{max} = (9)^2/2(8)$

$$\boxed{(P_L)_{max} = 5.0625\,W}$$ $R_L = 8\Omega,\ V_{cc} = 22V$

* When two 8Ω speakers are connected in parallel,

$$R_L = 8 \| 8 = 4\Omega$$

for $V_{CC} = 10V$

$(I_{sc,max}) \cdot R_L = (1.3) 4 = 5.2V$

since $5.2V > 3V$ current clipping will not occur.

and $\boxed{(P_L)_{max} = (3)^2 / 2(4) = 1.125W}$

$R_L = 4\Omega, V_{CC} = 10V$

for $V_{CC} = 22V$,

since $5.2V < 9V$, current clipping WILL occur.

and unlike the $R_L = 8\Omega$ case,

$(V_{pk})_{max} = 5.2V$

$\boxed{\therefore (P_L)_{max} = (5.2)^2 / 2(4) = 3.38W}$

$R_L = 4\Omega, V_{CC} = 22V$

$\Longrightarrow$ The combination of $R_L = 8\Omega$ and $V_{CC} = 22V$, gives the max power to load, which is 5.0625 W

$\Rightarrow$ Since max power delivered = 5.0625 W and package dissipation limit (from specs) is 8.3W, the power limits are not exceeded.

$\Rightarrow$ When $V_{cc} = 10$ V, connecting two speakers, gives more power (1.125W against 0.5625 W), but when $V_{cc} = 22$V, the power decreases with two speakers (3.38W against 5.0625W) because of current clipping.

(b) for LM 741

$(I_{sc})_{max} = 25$ mA

$R_L = 8\,\Omega$

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

Now $|V_{cc}| = 12$V $\therefore |V_{cc} - 2| = 10$V.

Since $0.2 < 10$V, current clipping will occur. and

$(V_{opk})_{max} = 0.2$ V

Now max power delivered to o/p

$$(P_L)_{max} = \frac{(V_{opk})^2_{max}}{2R_L}.$$

$$\therefore (P_L)_{max} = \frac{(0.2)^2}{2(8)} = 0.0025\,W$$

$$\therefore \boxed{(P_L)_{max} = 2.5\,mW}$$

$V_{CC} = 12V,\ R_L = 8\Omega$

Compared to LM380, the power delivered to o/p is very very small. Thus LM741 is not useful for audio power amplification purposes, as against LM 380 //