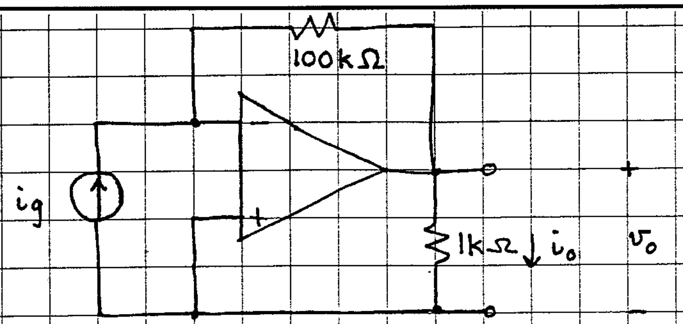
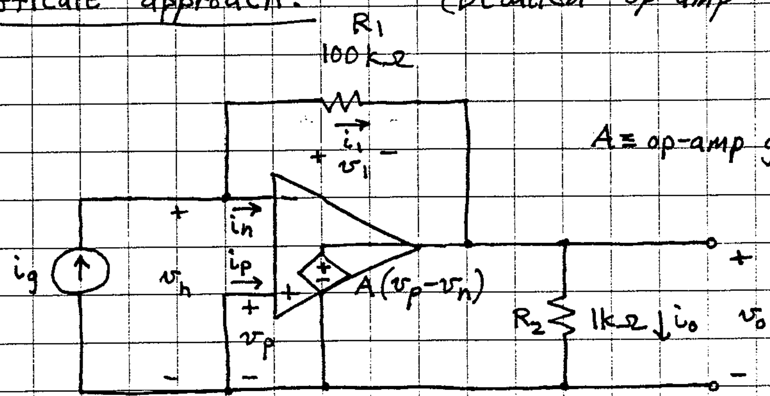
ex:



Difficult approach: (Detailed op-amp model)



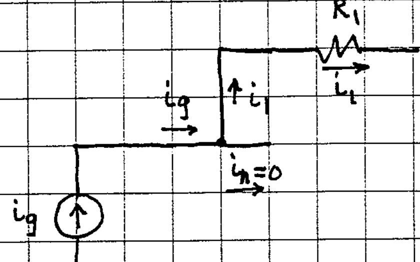
$A \equiv$ op-amp gain $\gtrsim 10^5$

Assume $i_n = i_p = 0$. Good assumption even if not linear mode, (i.e. negative feedback).

Use Kirchhoff's and Ohm's laws.

Sum of V drops around left loop avoided in this case because of i_g source. (In other situations, we would use this loop.)

Sum of currents out of node at − input of op amp:

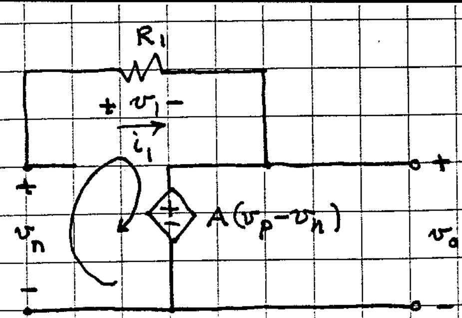


$-i_g + i_1 = 0A$ since $i_n = 0$

$\therefore\ i_1 = i_g$

Sum of V-drops around loop including feedback R and dependent V source:

ex: (cont)



$$v_n - v_1 - A(v_p - v_n) = 0V$$

but $v_1 = i_1 R_1$ by Ohm's law

$v_o = A(v_p - v_n)$ (useful later on)

$v_p = 0$ since + input connected to bottom rail by wire

Making these substitutions gives:

$$v_n - i_1 R_1 - A(-v_n) = 0V$$

From before, $i_1 = i_g$. Thus, we may solve for v_n:

$$v_n - i_g R_1 + A v_n = 0V$$

or $v_n(1+A) = i_g R_1$ or $v_n = \dfrac{i_g R_1}{1+A}$ Note: $V_o = -i_g R_1 \dfrac{A}{1+A} \approx -i_g R_1$

We observe that $i_g R_1 = v_1$ will be on the order of a few volts, typically. When divided by $1+A$, we have $v_n \approx 0V$.

Thus, $\underline{v_n \approx v_p}$. This is <u>always true in linear mode</u>.

An easier way to solve the problem is to leave out the dependent voltage source and, instead, determine what value of v_o will cause $v_n = v_p$.

Now for the easier approach.

ex: (cont)

Easier approach: (Simplified Op-Amp model)

Assume $i_n = i_p = 0A$ as always

Assume $v_n = v_p$ (Linear mode)

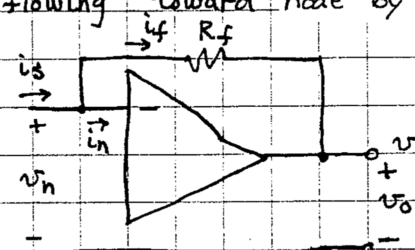
Apply Kirchhoff's and Ohm's laws and follow specific steps:

1) Determine v_p: Here $v_p = 0V$, since is v across wire.

2) Set $v_n = v_p$: $v_n = v_p = 0V$ here.

3) Calculate current, call it i_s, flowing toward node by − input of op-amp.

Here, $i_s = -i_g$



4) Use V-drop across feedback resistor, R_f, and Ohm's law to calculate i_f:

Here, $i_f = \dfrac{v_n - v_o}{R_f}$ (V drop across R_f is $v_n - v_o$ from V drops around loop sum to zero.)

5) Since $i_n = 0$, $i_f = i_s$.

6) Solve for v_o in terms of input signal:

Here, $i_f = i_s \Rightarrow \dfrac{\overset{0V}{\overset{\parallel}{v_n}} - v_o}{R_f = R_1} = i_g$

$\therefore \; v_o = -i_g R_1$

This is very close to answer $v_o = -i_g R_1 \dfrac{A}{1+A}$ from difficult approach.

ex: (cont)

7) v_0 is unaffected by "load" resistor R_2.

Note: This curious result occurs because we assume an ideal dependent source in the op-amp. A more detailed model would include a resistor, R_o, in series with the dependent V source in the op-amp. Typically, $R_o \approx 10\,\Omega$. If the load resistor is much larger than R_o, we may safely ignore R_o.

Here, $i_o = \dfrac{v_o}{R_2}$.

Now we can answer the problem at hand:

$$v_o = -i_g R_1 \quad \text{and} \quad i_o = \frac{v_o}{R_2} \quad \Rightarrow \quad i_o = -i_g \frac{R_1}{R_2}$$

$$\therefore \quad \frac{i_o}{i_g} = -\frac{R_1}{R_2} = -\frac{100\,k\Omega}{1\,k\Omega} = -100$$