Problem 1(a)

From Golden Rule #2, no current flows into or out of terminal V+. Then we know the voltage drop across R2 is zero. In turn, we know V+ = 0.

From Golden Rule #1, V- = V+ = 0.

\[ \text{KCL @ V-}: -I_{IN} + 0 + \frac{(V_{out} - 0)}{R_1} = 0 \]

Then, we know: \( V_{out} = R_1 I_{IN} \)

Problem 1(b):
No. When R2 is a short circuit, V+ = 0. By Golden Rule #1, V- = V+ = 0. The KCL equation at V- is still the same. Therefore, the answer does not change.
**Problem 1(c):**

Considering the non-ideality, we can redraw the circuit:

1. From the amplifier: \( V_{out} = A(\Delta V) = A(V_p - V_n) \).

2. KCL @ Vx: 
   \[-I_{IN} + \frac{(0-V_n)}{R_2+R_{in}} + \frac{V_{out}-V_n}{R_1} = 0 \]

3. From voltage division, \( \Delta V = V_p - V_n = V_n \cdot \frac{-R_{in}}{R_{in}+R_2} \)

Solving the above system:

\[
V_x = \frac{-I_{IN}}{\frac{AR_{in}}{R_1(R_2+R_{in})} + \frac{1}{R_1} + \frac{1}{R_2+R_{in}}} = \frac{-I_{IN}(R_2+R_{in})R_1}{AR_1+R_1+(R_2+R_{in})}
\]

\[
V_{out} = A \cdot \Delta V = A \cdot -V_n \frac{R_{in}}{R_{in} + R_2} = \frac{AI_{IN}R_1R_{in}}{AR_{in} + R_1 + (R_2 + R_{in})}
\]
Problem 1(d)

Conceptually, to reduce the effect of Rin on Vout, we should try to reduce the current flowing through Rin. Therefore, we should have as **LARGE** R2 as possible.

Mathematically:

From 1(c):

\[ V_{out} = \frac{A_{I_{IN}} R_1 R_{in}}{A R_{in} - R_1 - (R_2 + R_{in})} \]

The effect of Rin on Vout =

\[ \frac{\partial V_{out}}{\partial R_{in}} = \frac{-A_{I_{IN}} R_1 \{R_1 + R_2\}}{[A R_{in} - R_1 - (R_2 + R_{in})]^2} \]

\[ = \frac{O(R_2)}{O(R_2^2)} \]

(Big O notation, the numerator has R2 in the first order, and the denominator has R2 in the second order.

Therefore, when R2 -- > infinity, \[ \frac{\partial V_{out}}{\partial R_{in}} = 0 \] (changes of Rin has no effect on Vout)

Therefore, we should have as **LARGE** R2 as possible.
Problem 2(a)

1) KCL @ Vb: \[ \frac{V_{in} - V_b}{1k} + \frac{V_d - V_b}{1k} + 0 = 0 \]

2) KCL @ Vc: \[ 0 + \frac{0 - V_b}{1k} + \frac{V_{out} - V_b}{1k} = 0 \]

3) KCL @ Vout: \[ \frac{V_d - V_{out}}{40} + \frac{V_b - V_{out}}{1k} = 0 \]

Three unknowns: Vb, Vd, and Vout; three equations.

After solving for the system, we get \[ V_{out} = -50V_{in} \]
Problem 2(b)

1) KCL @ Vb: \[ \frac{V_{in} - V_b}{1k} + \frac{V_d - V_b}{1k} + 0 = 0 \]

2) KCL @ Vc: \[ 0 + \frac{0 - V_b}{1k} + \frac{V_{out} - V_b}{1k} = 0 \]

3) KCL @ Vout: \[ \frac{V_d - V_{out}}{40} + \frac{V_b - V_{out}}{1k} + \frac{0 - V_{out}}{R_L} = 0 \]

Three unknowns: Vb, Vd, and Vout; three equations.

After solving for the system, we get \( V_{out} = V_{in} \cdot \frac{-50}{1 + \left( \frac{2000}{R_L} \right)} \)

Then, \( I_L = \frac{V_{out}}{R_L} = V_{in} \cdot \frac{-50}{R_L + 2000} \)
**Problem 3(a)**
We want to be able to change the gain without changing the internal design of the op-amp. In addition, negative feedback provides stable gain as well.

**Problem 3(b)**
Amp*100 = 15V. Amp, max = 0.15V. The maximum amplitude without clipping is 0.15V.

**Problem 3(c)**
When clipping occurs, a pure sinusoidal wave is no longer sinusoidal. The distorted wave now contains waves of some high frequencies (since such clipped waves can be modeled as a combination of numerous sinusoids of multiple frequencies. Because of these additional frequencies, the sound is no longer the same.

**Problem 3(d)**
dB = 20 log (Gain) = 20 log (100) = 40 dB.
0) Label all the nodes as shown above.

1) From Golden Rule #1, \( V_c = V_b \).

2) KCL @ \( V_b \):
\[
\frac{V_{in} - V_b}{(1-a)R} + 0 + \frac{0 - V_b}{aR} = 0
\]

3) KCL @ \( V_c \):
\[
\frac{V_{in} - V_b}{R} + 0 + \frac{V_{out} - V_b}{R} = 0
\]

From the two KCL equations, We can solve for \( V_{out} \).

\( V_b = aV_{in} \)

\( V_{out} = (2a - 1)V_{in} \)

\[
\frac{V_{out}}{V_{in}} = 2a - 1
\]