1. **Op-Amp Rules**

Here is an equivalent circuit of an op-amp (where we are assuming that $V_{SS} = -V_{DD}$) for reference:

(a) What are the currents flowing into the positive and negative terminals of the op-amp (i.e., what are $I^+$ and $I^-$)? Based on this answer, what are some of the advantages of using an op-amp in your circuit designs?

(b) Suppose we add a resistor of value $R_L$ between $u_{out}$ and ground. What is the value of $v_{out}$? Does your answer depend on $R_L$? In other words, how does $R_L$ affect $Av_C$? What are the implications of this with respect to using op-amps in circuit design?

For the rest of the problem, consider the following op-amp circuit in negative feedback:

(c) Assuming that this is an ideal op-amp, what is $v_{out}$?

(d) Draw the equivalent circuit for this op-amp and calculate $v_{out}$ in terms of $A$, $v_{in}$, and $R_L$ for the circuit in negative feedback. Does $v_{out}$ depend on $R_L$? What is $v_{out}$ in the limit as $A \rightarrow \infty$?
2. Modular Circuit Buffer

Let’s try designing circuits that perform a set of mathematical operations using op-amps. While voltage dividers on their own cannot be combined without altering their behavior, op-amps can preserve their behavior when combined and thus are a perfect tool for modular circuit design. We would like to implement the block diagram shown below:

\[
\begin{align*}
V_{\text{in}} & \quad \frac{1}{2} \quad \frac{1}{3} \quad V_x \quad V_y \\
\end{align*}
\]

In other words, create a circuit with two outputs \(V_x\) and \(V_y\), where \(V_x = \frac{1}{2}V_{\text{in}}\) and \(V_y = \frac{1}{3}V_x = \frac{1}{6}V_{\text{in}}\).

(a) Draw two voltage dividers, one for each operation (the \(1/2\) and \(1/3\) scalings). What relationships hold for the resistor values for the \(1/2\) divider, and for the resistor values for the \(1/3\) divider?

(b) If you combine the voltage dividers, made in part (a), as shown by the block diagram (output of the \(1/2\) voltage divider becomes the source for the \(1/3\) voltage divider circuit), do they behave as we hope (meaning \(6V_{\text{in}} = 3V_x = V_y\))?

HINT: The following circuit and formula may be handy:

\[
V_{\text{out}} = \left( \frac{1}{2 + \frac{R_x}{2R_y}} \right) V_{\text{in}}
\]

(c) Perhaps we could use an op-amp (in negative-feedback) to achieve our desired behavior. Modify the implementation you tried in part (b) using a negative feedback op-amp in order to achieve the desired \(V_x, V_y\) relations \(V_x = (1/2)V_{\text{in}}\) and \(V_y = (1/3)V_x = (1/6)V_{\text{in}}\).

HINT: Place the op-amp in between the dividers such that the \(V_i\) node is an input into the op-amp, while the source of the 2nd divider is the output of the op-amp!