# Problem Wk.8.4.2: Amplifiers with offsets

Consider the following op-amp circuit, which can serve as an inverting or as a non-inverting amplifier (see Section 6.6.2 of the Course Notes) depending on the choice of inputs. The circuit has two input voltages V_1 and V_2 and produces an output voltage V_O. We want to derive an algebraic expression that relates the output voltage to the input voltages. We will be making the *ideal op-amp* assumption here. **All voltages are expressed relative to ground**.
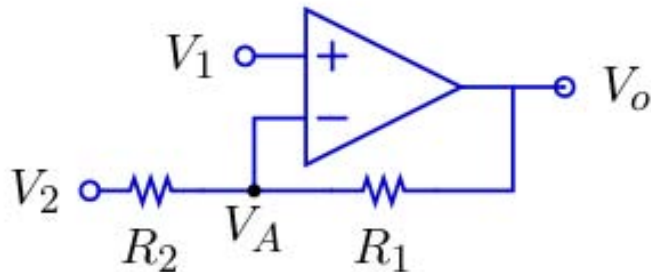
You will be asked to enter algebraic expressions for voltages in the problems below. For each one, enter an expression the way you would type it into Python (you can leave out * for multiplication if you prefer). Use the variable names exactly as specified in the question.

Make sure that you include parens so that your expression is unambiguous, A+B/C+D can be read to mean (A)+(B/C)+D, which might not be what you meant.

Note that the name of the output voltage is V_O (not V_0), that is, Vee followed by Oh (letter O) - not by a zero.

Non-Inverting Amplifier

1. Write an expression for the intermediate voltage VA in terms of V_1, V_2, R_1 and R_2, assuming this is an ideal op-amp. (This is a very simple answer).
   VA = $\boxed{\text{V_1}}$

2. If V_2 = 0, write an expression for the output voltage, V_O, that has the form

   ```
   V_O = K * V_1
   ```

   where K is in terms of R_1 and/or R_2, assuming this is an ideal op-amp. Enter the expression for K here:
   K = $\boxed{1 + \frac{R_1}{R_2}}$
   Compare this to the non-inverting amplifier in section 6.6.2 of the course notes.

3. Now, letting V_2 be an arbitrary value, write an expressing for the output voltage, V_O, in the form

   ```
   (V_O - V) = K * (V_1 - V)
   ```

   where V and K are in terms of V_1, V_2, R_1 and/or R_2, assuming this is an ideal op-amp. Enter expressions for V and K here:
   V = $\boxed{\text{V_2}}$
   K = $\boxed{1 + \frac{R_1}{R_2}}$

4. So, assuming that V_2 is 5V and that V_1 is in the range 0V to 10V, how does V_O behave?

A real op-amp can never produce voltage values that are outside of the range of voltages from its power supplies. So, if we have +10V an 0V provided to the op-amp, the output voltages can never be less than 0 or greater than 10. If some combination of inputs would have produced values outside of this range, the actual output would only reach the closest limit voltage (0V, 10V).

Keeping this in mind, indicate the output voltage **(rounded to an integer)** for each of the combinations of inputs below (assume R_2 = 10,000 Ω).

V_1	V_2	R_1	V_O
10	5	100	10
7	5	100	7
5	5	100	5
3	5	100	3
0	5	100	0
10	5	10,000	10
7	5	10,000	9
5	5	10,000	5
3	5	10,000	1
0	5	10,000	0

Inverting amplifier

Consider the circuit again (this is the same circuit as above):
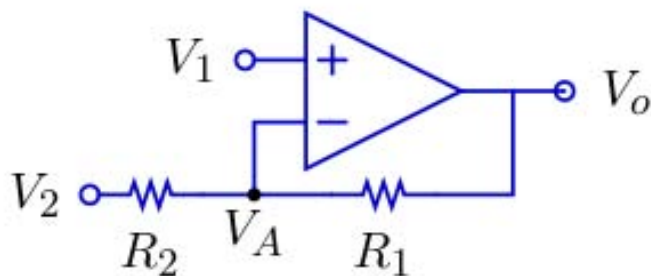
1. If V_1 = 0, write an expression for the output voltage, V_O, that has the form

   `V_O = K * V_2`

   where K is in terms of R_1 and/or R_2, assuming this is an ideal op-amp. Enter the expression for K here:

   K = [$-\frac{R_1}{R_2}$]

   Compare this to the inverting amplifier in section 6.6.2 of the course notes.

2. Now, letting V_1 be an arbitrary value, write an expressing for the output voltage, V_O, in the form

   `(V_O - V) = K * (V_2 - V)`

   where V and K are in terms of V_1, V_2, R_1 and/or R_2, assuming this is an ideal op-amp. Enter expressions for V and K here:

V = [V_1]

K = [$-\dfrac{R_1}{R_2}$]

3. So, assuming that V_1 is 5V and that V_1 is in the range 0V to 10V, how does V_O behave?

A real op-amp can never produce voltage values that are outside of the range of voltages from its power supplies. So, if we have +10V an 0V provided to the op-amp, the output voltages can never be less than 0 or greater than 10. If some combination of inputs would have produced values outside of this range, the actual output would only reach the closest limit voltage (0V, 10V).

Keeping this in mind, indicate the output voltage **(rounded to one decimal place)** for each of the combinations of inputs below (assume R_2 = 10,000 Ω).

V_1	V_2	R_1	V_O
5	10	5000	2.5
5	7	5000	4
5	5	5000	5
5	3	5000	6
5	0	5000	7.5
5	10	20,000	0
5	7	20,000	1
5	5	20,000	5
5	3	20,000	9
5	0	20,000	10

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