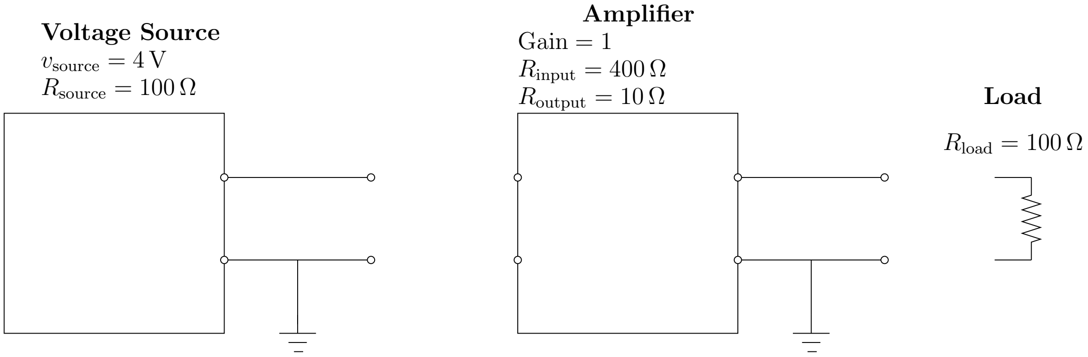
PHYS 235: Homework Problems

53. Consider a voltage source with an open-circuit output of 4 V, and an output impedance of 100 Ω, an amplifier with a gain of 1, input impedance $R_{\text{input}} = 400\,\Omega$ and an output impedance $R_{\text{output}} = 10\,\Omega$, and a 100 Ω resistive load.

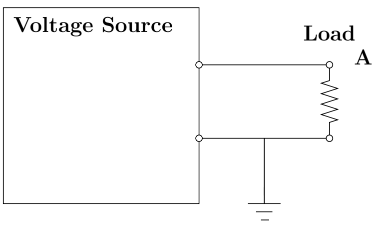


(a) When the load is connected directly to the source:

i. determine the voltage at point **A**,

ii. determine the current through the load, and

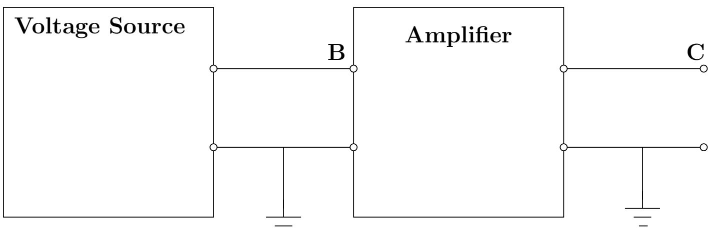
iii. determine the power dissipated in the load.



(b) When the amplifier is connected to the voltage source, but no load is attached:

i. determine the voltage at point **B** at the input to the amplifier, and

ii. determine the voltage at point **C** at the output of the amplifier.



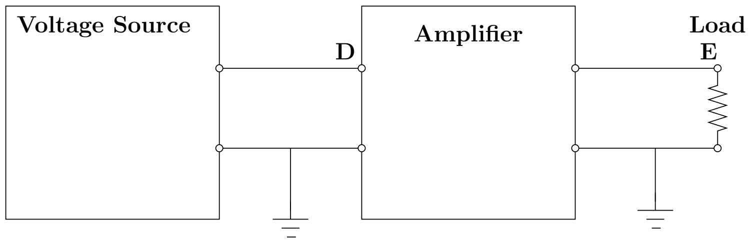
(c) When the amplifier is connected to the voltage source, and the load is connected across the output of the amplifier:

i. determine the voltage at point **D** at the input of the amplifier,

ii. determine the voltage at point **E**,

iii. determine the current through the load, and

iv. determine the power dissipated in the resistor.



(d) Repeat the previous calculations for the loaded amplifier, except this time assume the the amplifier has an input impedance $R_{\text{input}} = 10\,\text{k}\Omega$ and an output impedance $R_{\text{output}} = 1\,\Omega$.

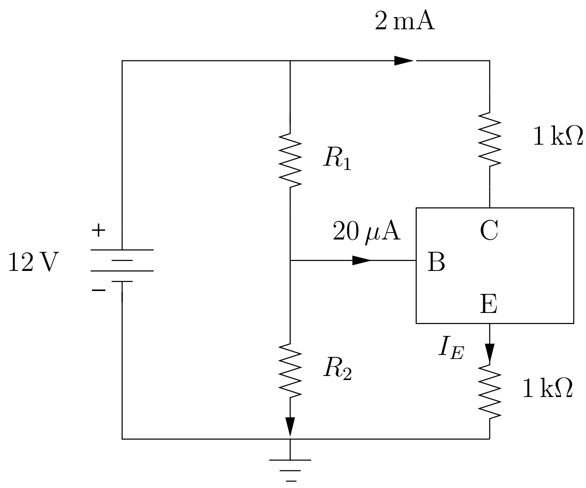
54. A “black box” with three terminals labeled E, B, and C is connected in the following illustrated circuit.

(a) Calculate I_E.

(b) Calculate V_C and V_E.

(c) If terminal B is 0.6 V more positive than terminal E, calculate the ratio of R_1 and R_2, assuming that I_d is very large compared to the $20\,\mu$A flowing in the B lead. (The “black box” is a silicon NPN transistor.)

(d) Calculate the approximate power dissapated in the “black box.”



55. (a) Write a simple formula that expresses the relationship between I_C, I_B, and I_C in a bipolar transistor.

(b) Write an expression for I_C as a function of I_B and α.

(c) Write an expression for I_C as a function of I_B and β.

(d) Write an expression for I_C as a function of I_E and α.

(e) Write an expression for I_C as a function of I_E and β.

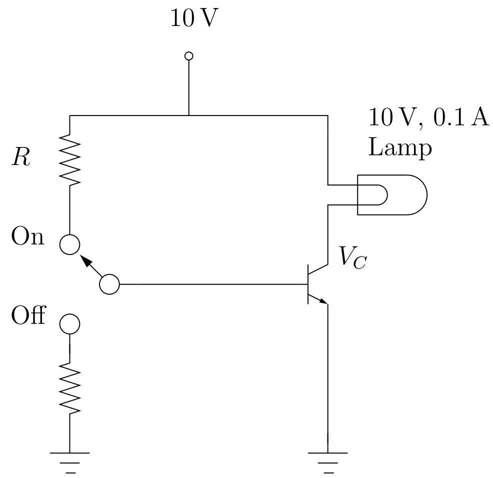
(f) Write an expression for I_B as a function of I_E and α.

(g) Write an expression for I_B as a function of I_E and β.

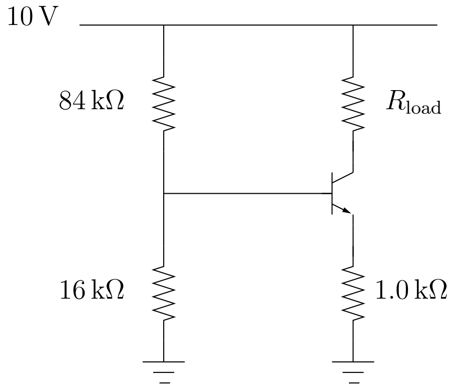
56. Fill in the blanks: The base voltage of an “on” silicon NPN transistor is always approximately ______ more ______ than the emitter.

57. Consider the illustrated circuit in which a mechanical switch is used to turn on a small control current that activates the transistor "switch" that enables a much larger current through the lamp. The manufacturer says that the lamp was desigend for 1 V, 0.1 A operation; for the purposes of this exercise consider the lamp as a simple resistor of with $R_{\text{lamp}} = 100\,\Omega$, and assume that $\beta = 100$ for this transistor. Fill in the following table giving the the base current I_B, the collector current I_C and the voltage at the collector V_C for the indicated values of R. For which resistor(s) will the lamp light be powered as it was designed to be?

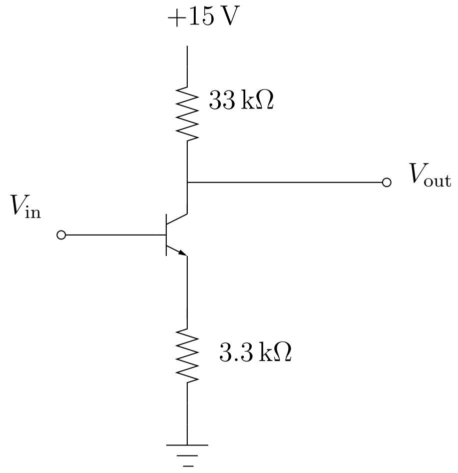
R	I_B	I_C	V_C
$100\,\text{k}\Omega$			
$10\,\text{k}\Omega$			
$1\,\text{k}\Omega$			



58. Calculate the current through the load resistor R_{load} in the illustrated circuit. (Use the "simplest" model of the transistor.) Does your result depend on the value of R_{load}?



59. Consider the simple common-emitter amplifier discussed in class. (This is also part of the amplifier that some of you built in the optional part of the Introduction to Transistors Lab.) Consider as the input the voltage $V_{\text{in}} = 1.59 + 0.33\cos(\omega t)$, i.e., a signal that oscillates between $1.59 - 0.33 = 1.26\,\text{V}$ and $1.59 + 0.33 = 1.92\,\text{V}$.

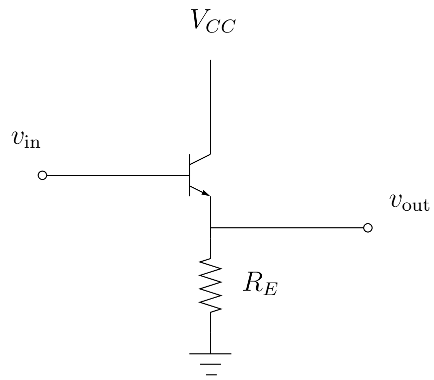


(a) Use the "simplest model" of transistors to calculate V_{out} when $V_{\text{in}} = 1.26\,\text{V}$.

(b) Use the "simplest model" of transistors to calculate V_{out} when $V_{\text{in}} = 1.92\,\text{V}$.

(c) Using the results you obtained in the previous parts of this problem determine the voltage gain for AC signals ($\Delta V_{\text{out}}/\Delta V_{\text{in}}$).

60. In class we showed that the input impedance of the simple voltage follower shown below is $(\beta + 1)R_E$. Show that the output impedance is given by $R_{\text{source}}/(\beta + 1)$, where R_{source} is the output impedance of the source that is providing v_{in}. Remember that the output impedance is $\Delta v_{\text{out}}/\Delta i_{\text{out}}$.



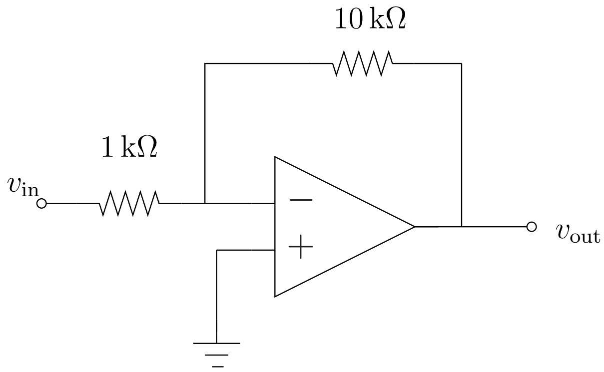
61. State the two rules for ideal op-amp behavior when the op-amp is hooked up with negative feedback.

62. For the illustrated amplifier, determine

(a) the voltage gain A_v,

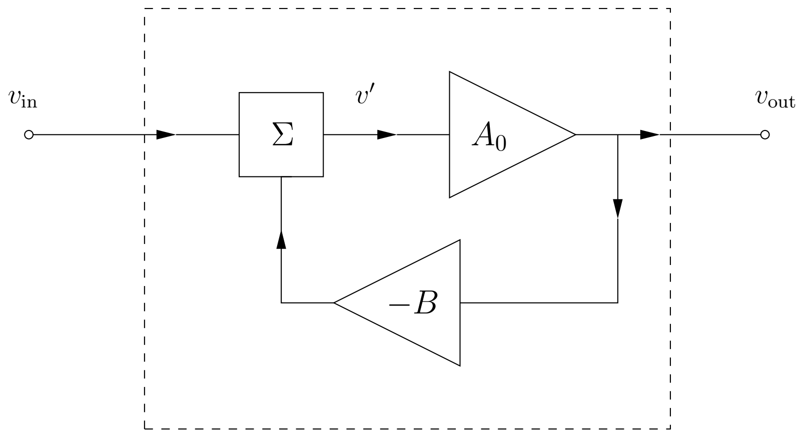
(b) the input impedance, and

(c) the qualitative effect on sinusoidal signals of adding a 1600 pF capacitor in parallel with the 10 kΩ resistor.



63. Why is an amplifier with a voltage gain of 1 (i.e., with $v_{out} = v_{in}$) of any use to anyone?

64. Consider the simple generalized negative feedback amplifier discussed in class.



(a) Derive the expression that gives the closed-loop gain A_v in terms of the open-loop gain A_0 and the percentage of the output B fed back into the summming amplifier.

(b) Show using specific numerical values in your formula that if $A_0 = 10^6$ and $B = 0.01$, then a 20% change in A_0 results in a 0.002% change in A_v.

(c) Prove that a fractional change in the open-loop gain $\Delta A_0/A_0$ results in an approximate fractional change in the closed-loop gain given by

$$\frac{\Delta A_v}{A_v} \simeq \frac{1}{(1 + A_0 B)} \frac{\Delta A_0}{A_0} \simeq \frac{1}{A_0 B} \frac{\Delta A_0}{A_0}.$$

65. (a) Explain why negative feedback will increase rather than decrease the input impedance of an amplifier.

(b) Explain why a large input impedance is usually desirable.

66. Design an amplifier with op-amps that takes four inputs v_A, v_B, v_C, and v_D, and produces an output $v_{\text{out}} = v_A + 2v_B + 4v_C + 8v_D$.

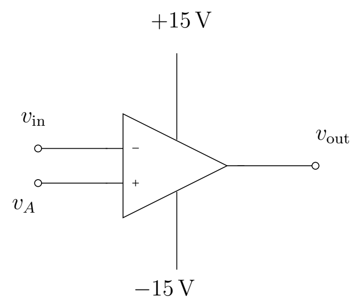
67. Design an op-amp amplifier that will give a constant current I_L through a load resistance, independent of the value R_L of the load resistance; the output current should be proportional to the input voltage. Choose component values that will give a current I_L of 1 mA for a 10 mV input. Explain why your circuit works. (Look back at the transistor current source for ideas.)

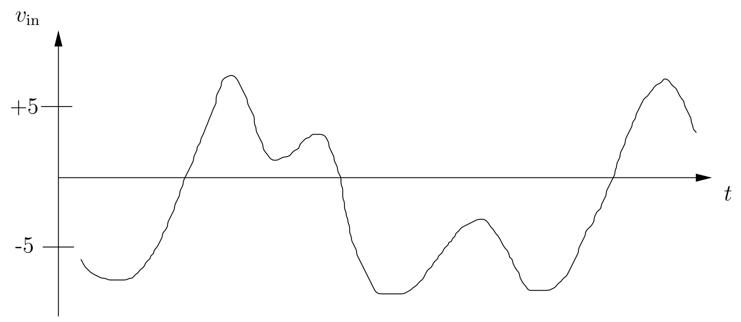
68. (a) Design a current-to-voltage converter to convert a 1 μA DC input current from a constant current source into a 2 V signal.

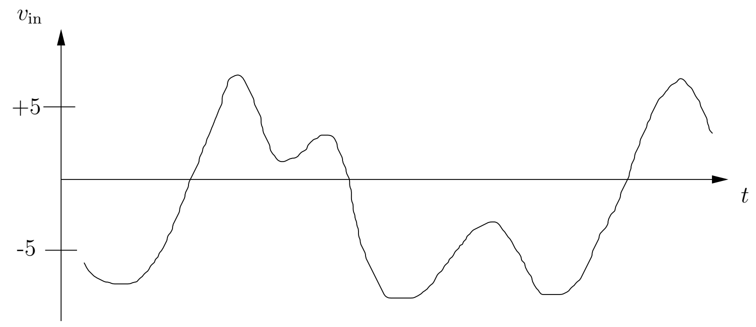
(b) Now consider an AC input current with an amplitude of 1 μA and a frequency of 100 HZ. There is also AC noise present at 10,000 Hz. Redesign your current-to-voltage converter so that your output voltage has an amplitude of 2 V, and the noise is significantly attenuated.

69. (a) Sketch the output v_{out} of the illustrated op-amp when $V_A = +5$ V.

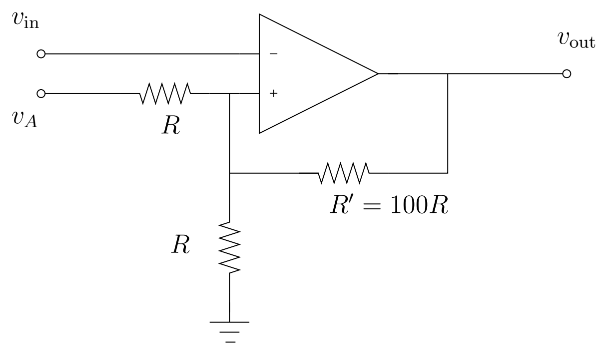
(b) Sketch the output v_{out} of the illustrated op-amp when $V_A = -5$ V.







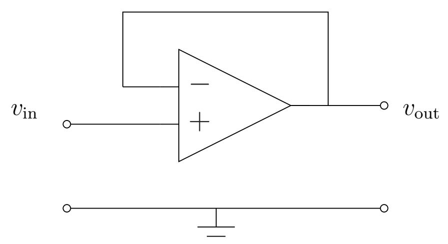
70. In lab you investigated the operation of a Schmitt trigger. Your trigger made transitions at reference voltages that were near 0 V. In the illustrated circuit the transitions have been shifted away from zero because of the voltage v_A. Determine the transition voltages for this more general Schmitt trigger. Express your answer in terms of v_A, R, and the saturation voltage of the op-amp V_{CC}. (You may assume that the negative saturation voltage is $V_{EE} = -V_{CC}$).



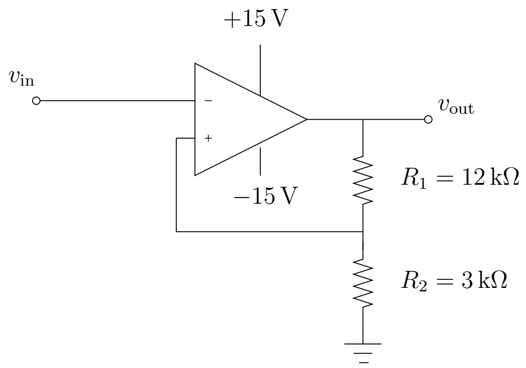
71. Ideal op-amps are assumed to have open-loop gains A_0 that are infinite, and this infinite open-loop gain leads to equal voltages at the inverting and non-inverting inputs (when the op-amp is placed in a circuit with negative feedback). The following circuit is a voltage follower, and for an ideal op-amp $v_{\text{out}} = v_{\text{in}}$. For this problem assume that the op-amp is **not** ideal, and A_0 is finite. (All other properties of the op-amp may be assumed to be ideal; for example, you may still assume that the inputs draw no current.)

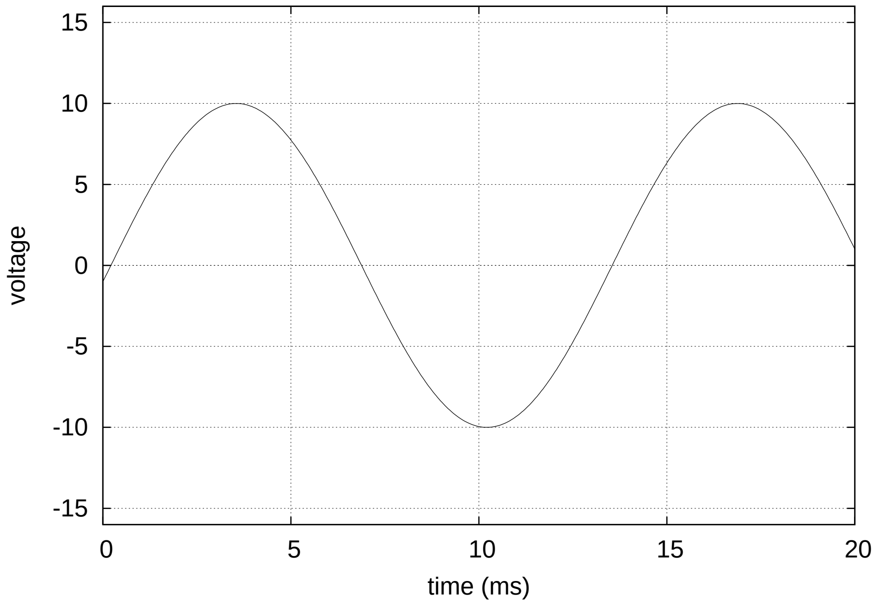
   (a) Determine v_{out} in terms of v_{in} and A_0. Show that you recover the ideal op-amp result in the limit $A_0 \to \infty$.

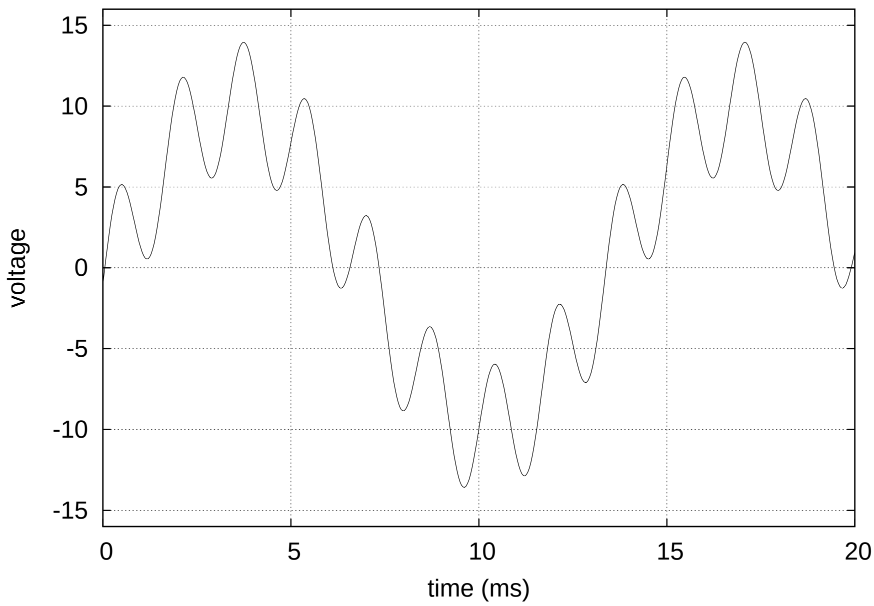
   (b) Determine the potential difference at the inputs, $v_2 - v_1$. Show that you recover the ideal op-amp result in the limit $A_0 \to \infty$.



72. Sketch the output v_{out} of the illustrated op-amp for the two illustrated inputs.

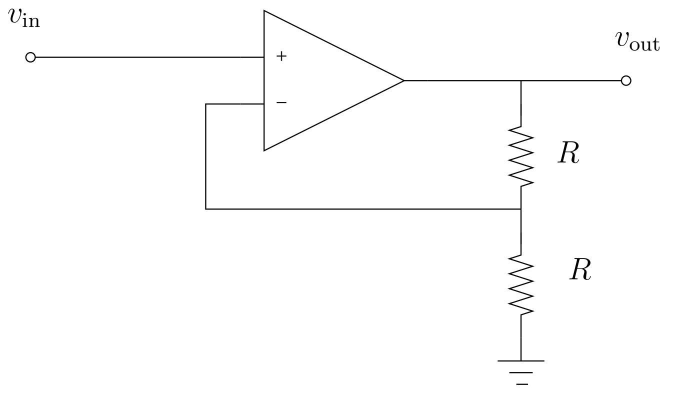




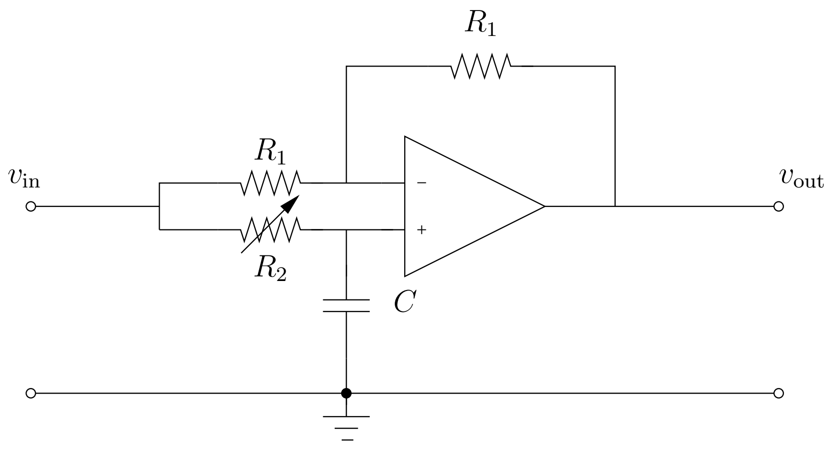


73. (a) Assume that the op-amp in the illustrated circuite is ideal and determine an expression for the gain of the illustrated circuit.

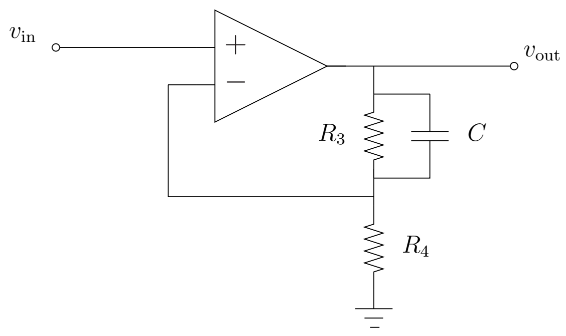
(b) Assume the that illustrated op-amp is **not** ideal in one respect: the open-loop gain A_0 is **not** infinite. Determine an expression for the gain of the circuit. (This result should reduce to your previous result in the limit $A_0 \to \infty$.)



74. What does the illustrated circuit do? (Consider a sinusoidal input v_{in}, and determine v_{out}.) There is a nice formula that gives the output as a general function of input frequency ω, R_2, and C, but it might be easier to start by calculating the output for the specific values $\omega = 2\pi \times 10^3\,\text{s}^{-1}$, $C = 10\,\text{nF}$, and $R_2 = 15.915\,\text{k}\Omega$.



75. The illustrated amplifier is a slight modification of a circuit that should be familiar to you.

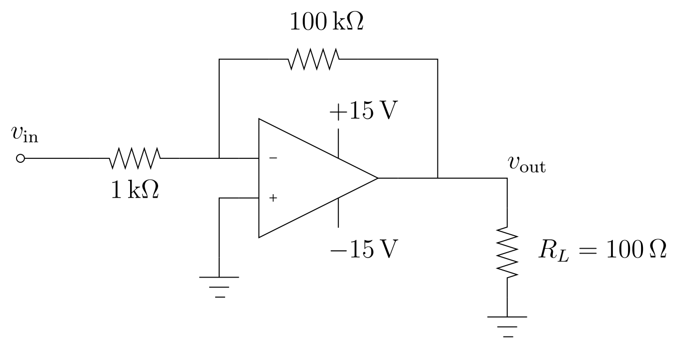


(a) What is the gain of the amplifier A_v for DC signals, i.e., when $\omega = 0$? (You should be able determine this from applications of derivations done previously in class and lab.)

(b) What is the gain of the amplifier A_v for sinusoidal AC signals when $\omega \to \infty$? (You should be able determine this from applications of derivations done previously in class and lab.)

(c) What is the gain of the amplifier A_v when $\omega = 1/(R_3C)$?

76. The output impedance of most op-amps is *extremely* low when negative feedback is used. When you tried to determine the output impedance in lab by decreasing the value of the load resistance R_L (the way you did with voltage dividers) you probably saw something go "wrong" with the sinusoidal signal output voltage v_{out} before the amplitude dropped to half of its open-circuit value. Typical inexpensive op-amp chips can supply a maximum current of approximately 25 mA, and if they are used in a way that calls for more current, the output wave is distorted. (One manifestation in lab was a flat-topped sine wave that looked like clipping.) Calculate the maximum amplitude sinusoidal input that will produce a non-distorted output across a load resistor $R_L = 100\,\Omega$ in the illustrated circuit. Repeat your calculation for $R_L = 1\,\text{k}\Omega$.



77. Make a qualitative sketch of v_1, v_2, and v_{out} vs. time for the illustrated circuit for the following two cases:

- $R_2 = 2R_1$, and
- $R_2 = R_1/2$.