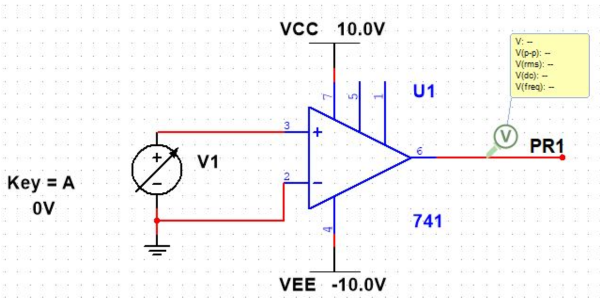
Op Amp Model

The huge gain of the op amp presents some interesting characteristics. Consider this: if the op amp had infinite gain, any non-zero input would produce an infinite output, because infinity times anything other than zero is infinity. Try this in Multisim:



The input signal is a DC_INTERACTIVE_VOLTAGE. Set it to a Maximum value of 0.1 V and a Minimum value of -0.1 V, and set the increment to 0.5%. Run the simulator, and see if you can get anything other than some maximum value (around 9 V) and a similar minimum value (around -9V).

Apparently, it's basically impossible to get anything out of this circuit other than its saturation values -- completely maxed out in either the positive or negative direction. A quick calculation will help you see why.

1. The gain of the 741 op amp is typically 200,000. If the input voltage to the circuit above is +0.05 V, what is the calculated output? 10000 V. However, the amplifier is only powered by a +10 V source, so it can't produce a voltage that high. In fact, since this is not a "rail to rail" op amp, it can't even get to +10 V out. So try as it might to produce 10,000 V, it's stuck at around 9 V.
2. If the input voltage to the circuit above is -0.005 V, what is the calculated output? -1000 V. Again, due to its limitations, it's stuck at around -9 V.
3. If the maximum output voltage is +8 V, what is the biggest input signal that can be amplified by this op amp? 40 μV. Using your digital multimeter (DMM), can you accurately measure just a few microvolts? No If you saw a measurement as small as 50 μV, you would probably record it as 0 V.

The pessimists in the group are probably saying "What's the use of an amplifier that can't be used to amplify any signal bigger than zero volts?" and the optimists are saying "I dunno -- there must be some way to make lemon juice out of this."

It turns out that this feature of the op amp helps us develop a really simple model to help us analyze any amplifier circuit. Based upon this interesting feature of the op amp and what we know about its input impedance, here are the *just two* parts of the op amp model:

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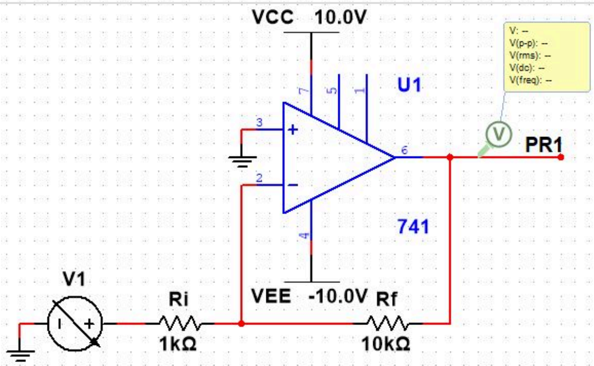
- ***No current flows into or out of the inputs*** of an op amp, because we consider the input impedances to be infinite.
- ***Virtual Short between inputs***: The voltage difference between the input pins will be so small when the op amp is acting as an amplifier that it can be considered as zero. (It's not a true short, because no current flows into or out of the inputs.)

That's it! That's all you need to know to analyze any operational amplifier circuit!

When we build op amp circuits, we add other components, like resistors, to the circuit, typically to introduce Negative Feedback. Any component that goes ***from the output to the inverting input*** introduces negative feedback, which reduces the overall gain of the amplifier. Here's a circuit with two resistors, one as feedback (R_f) and one at the input (R_i). This second resistor is sometimes the input impedance for the op amp, but sometimes it isn't, so we don't call it r_{in}. It's just a part of what's called the ***feedback network***. Again, you may want to build this circuit in Multisim to verify that it does what we expect it to do, based on our newly-acquired model.



4. Using the model, what voltage is the inverting input, pin 2, at? [0] V
5. If V_1 = +0.5 V, use Ohm's law to predict how much current, in milliamps, flows through R_i. [0.5] mA
6. Using the model, how much of this current flows into the inverting input? [0] mA
7. The current flowing through R_f must be flowing toward a negative voltage. According to Ohm's law, what must that voltage be? [-5] V (Consider the op amp as a "black box" that does whatever it takes to keep the voltage difference between its inputs at zero.)
8. Given that the answer to the previous question is V_{out} for this circuit, what is the gain of this amplifier? [-10]

We can now relate what we know back to the values of the resistors.

$$A_v = \frac{V_{out}}{V_{in}} = \frac{-IR_f}{IR_i} = -\frac{R_f}{R_i}$$

In this case, $A_v = -\frac{R_f}{R_i} = -\frac{10\ k\Omega}{1\ k\Omega} = -10$

9. Based upon this, what output would be expected if the input signal was -250 mV? [2.5] V (Try it and see!)
10. What would be the expected output if the input was +0.2 V? [-2] V (Again try it!)
11. If the output was +7.4 V, what must the input have been? [-0.74] V (Do it! Do it!)
12. If the input was -3.0 V, what will the output be? [maximum pos…] (It still can't jump over a tall building or stop a speeding train.)
13. If the input was a sine wave with an amplitude of 300 $mV_{p\text{-}p}$ at a frequency of 1 kHz, describe the expected output:

- Expected amplitude: [3] $V_{p\text{-}p}$
- Expected phase relationship: [180 degrees out of phase -- inv…]
- Expected frequency: [1] kHz (You can replace the DC supply with a function generator, and view the input and output using an oscilloscope to verify these answers.)

In the next lesson, we'll revisit this amplifier and develop the standard characteristics expected for some other standard op amp circuit configurations.