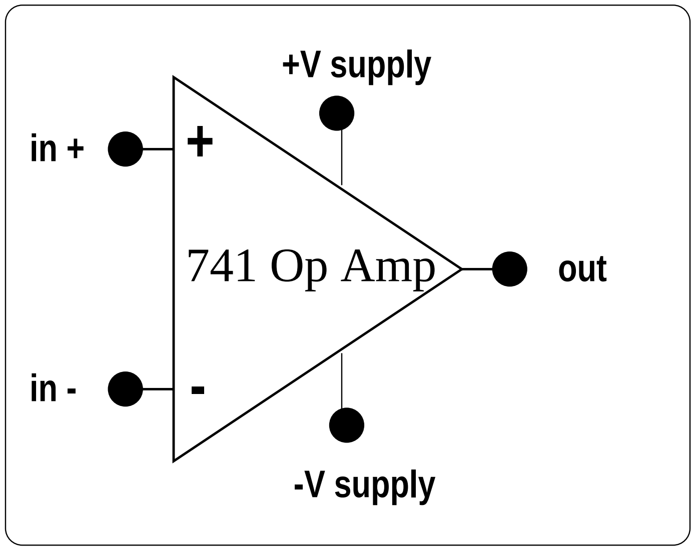
Op Amps (Operational Amplifiers) - A Self Guided Tour

An Op Amp can be looked at as a very simple or a very complicated device. When you first start using these useful little circuits, it is helpful to consider the simple case and explore the limitations of the simple case experimentally. In this lab, we will try to state a simple rule, verify it experimentally, and then test some of the limitations of the rule. We'll then apply what we learned to a few applications.

Ideal Op Amp



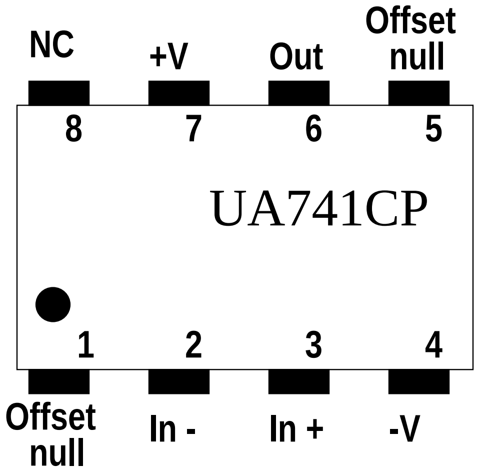
Rule 1:

- If you arrange a circuit so that there is a connection between the out pin and the 'in -' pin, the Op Amp will try to adjust its output to make the voltage at the 'in -' pin the same as the 'in +' pin.

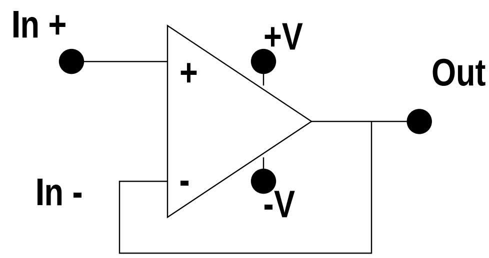
Demonstrate Rule 1:

Hook up your Op Amp using the following Pin Diagram for the chip, to make the following circuit:

Chip



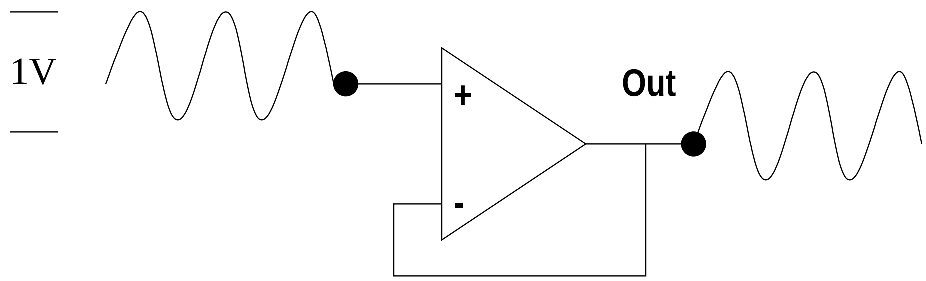
Circuit



Set +V = 12 V
and -V = -12 V
with a power supply

Note: Please check your connections before you power up. You can fry an Op Amp pretty quick if you set it up wrong. This can manifest itself as a very hot chip.

Hook up a 1V peak-to-peak sine wave at about 1 kHz to In + and observe Out. Describe what you see. By our simple rule, if In + changes in voltage, Out will try to do what it must to keep the voltage difference between In + and In - zero.
In other words, Out should be like In+.



Now, lets explore the limitations of the simple rule:

> Vary the frequency from DC (0 Hz) to the highest limit of the function generator. What did you see? (Don’t forget to use DC coupling on the scope at low frequency.)

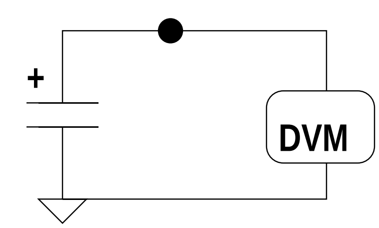
> Increase the amplitude of the input to the maximum value of the function generator. What did you see?

Rule 2:

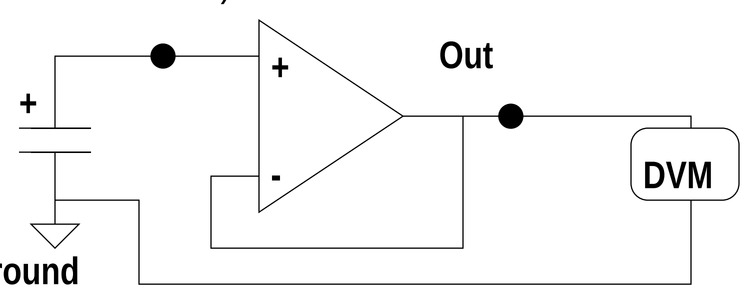
- The inputs draw no current. This implies that the input impedance is infinite. (In other words, it’s like there’s this huge resistor at the input.)

Demonstrate this:

Charge up a big capacitor (>1 micro Farad) to +5 V or so and measure the voltage across the capacitor with a DVM. It should change with time as the capacitor discharges through the resistance (input impedance) of the DVM. Now do the same thing by hooking the charged capacitor to In + and Ground. Does the voltage decay at the same rate when you look at the voltage on Out? Explain. (p.s. You used something like this when you measured the photoelectric effect!)



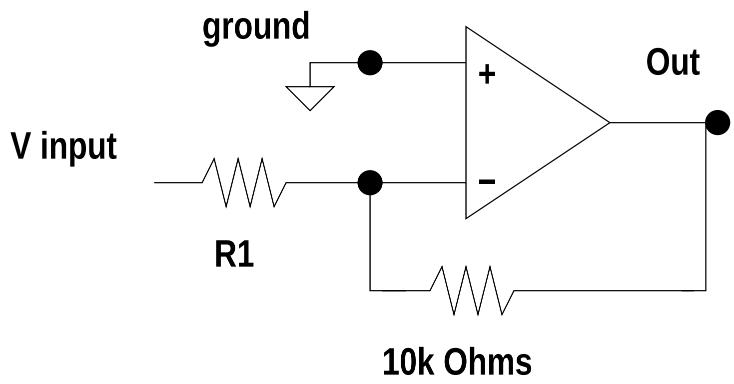
Compare to



(Note: a + on a capacitor means that lead of the capacitor is at the higher voltage)

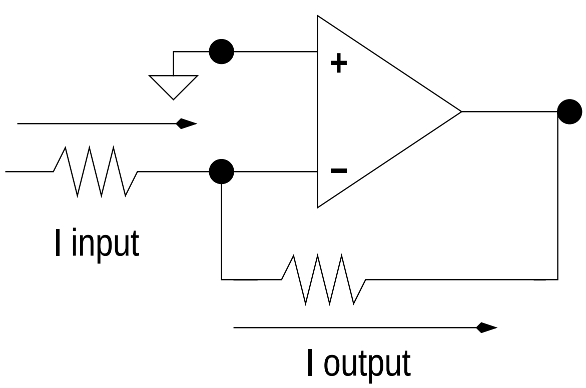
Practical Application: Inverting Amplifier

Remember, you still need to keep the Op Amp hooked up to +/− 12 V.



According to our rules, In− looks like ground to V input, and since no current can flow into or out of In−, Out has to remove that current. When Out does that, there is a voltage generated between In− and Out.

I input = I output (or else current would flow into In−)



or V input / R1 = I output

So

| Voutput | = | Vinput * 10k Ohm / R1 |

And since In− is at ground potential, if Vinput is positive, Voutput is negative.

Demonstrate this:

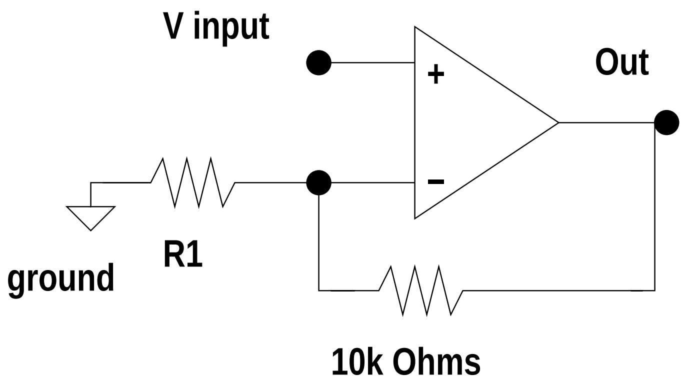
For R1 = 100, 1k, 10k, and 100k Ohms, both compute and measure the gain for this amplifier by comparing Vout / Vinput to 10k Ohms/R1. You may need to vary the input voltage to see the gain correctly (probably need it to be smaller).

For R1 = 1k, look at In+ and In− with an oscilloscope probe. You should see a small signal on one of the inputs (which?). You see this signal since the gain of an Op Amp is not infinite. What is the ratio of Out to this small signal?

To impress you that an Op Amp is a pretty good amplifier, replace the 10k Ohm with a 1M Ohm resistor and let R1 be 100 Ohms. Now, let your input signal be 0.5mV (advice: Take a large signal and attenuate it. Those dB numbers on an attenuator are useful: 20 dB = 20 log10 (In/Out) so In/Out = 10, so 40dB is a factor of 100=In/Out) What is your output signal? What do you think about Op Amps as amplifiers now?

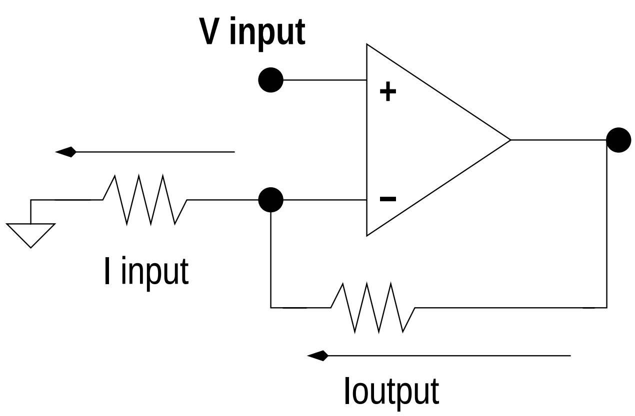
Practical Application: Non−Inverting Amplifier

Remember, you still need to keep the Op Amp hooked up to +/− 12 V.



According to our rules, In− looks like V input, and since no current can flow into or out of In−, Out has to supply the current that wants to flow through R1. When out does that, a voltage is generated between In− and out.

I input = I output (or else current would flow into In−)



or V input / R1 = I output

So

Voutput = V input + V input * 10,000 / R1

Since In− is at a voltage of ~V input

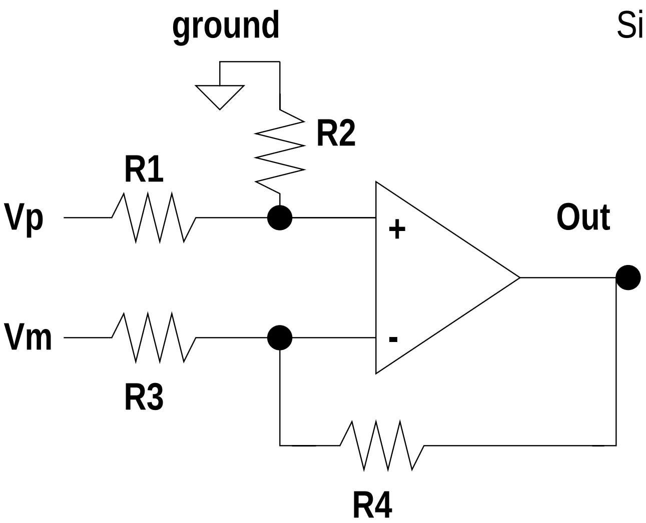
Demonstrate this:

For R1 = 100, 1k, 10k, and 100k Ohms, both compute and measure the gain for this amplifier by comparing Vout / Vinput to 10k Ohms/R1. You may need to vary the input voltage to see the gain correctly (probably need it to be smaller).

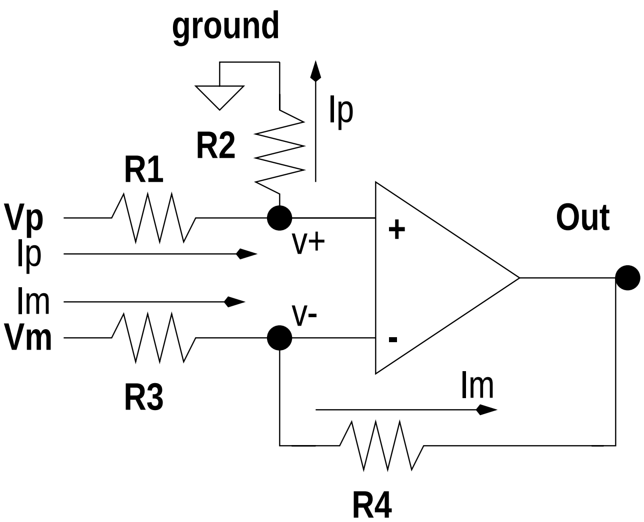
Can the gain of this circuit ever be less than 1? How come? How about the inverting amplifier?

Practical Aplication: Difference Amplifier

Remember, you still need to keep the Op Amp hooked up to +/- 12 V.



Since In+ can neither source nor sink current, the current through R1 is the same as the current through R2. This sets the voltage of In+. Out then will supply current to make In- the same as In+.



Referring to the figure at the lower left

$v+ = Vp - R1*Ip$ $v- = Out + R4*Im$

$v- = Vm - R3*Im$ $v+ = v-$

$Vp = R1*Ip + R2*Ip$ $Ip = Vp/(R1+R2)$

$Im = (Vm-Out)/ (R3+R4)$ So,

$Vp-R1*Vp/(R1+R2) =$

$Out + R4(Vm-Out)/(R3+R4)$

or,

$Vp(1 - R1/(R1+R2)) - Vm(R4/(R3+R4)) =$

$Out(1 - R4/(R3+R4))$

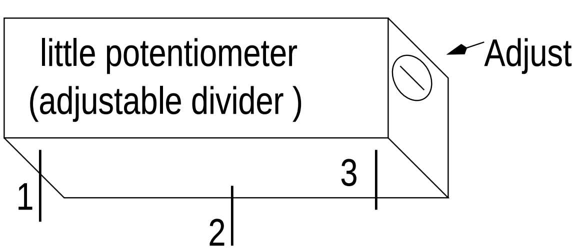
Re-arranging now: $Vp(R2/(R1+R2)) - Vm(R4/(R3+R4)) = Out(R3/(R3+R4))$

And if R2=R4 and R1=R3, this gets really simple (R3 + R4 = R1 + R2),

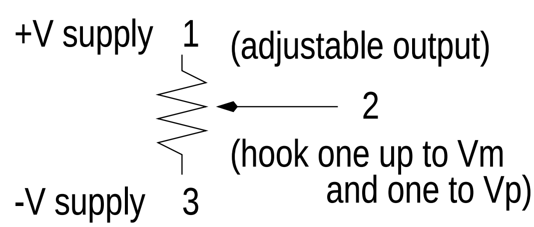
$(Vp - Vm)R4 = (Out)R3$ or finally **$R4/R3 = Out / (Vp-Vm)$**

Demonstrate this:

Chose R1 and R3 = 1k Ohm and R2, R4 to give you a gain of Out/(Vp - Vm) = 10. Sketch your circuit and describe its performance. You can make different voltages using little potentiometers. These little plastic boxes have a screw and 3 leads.



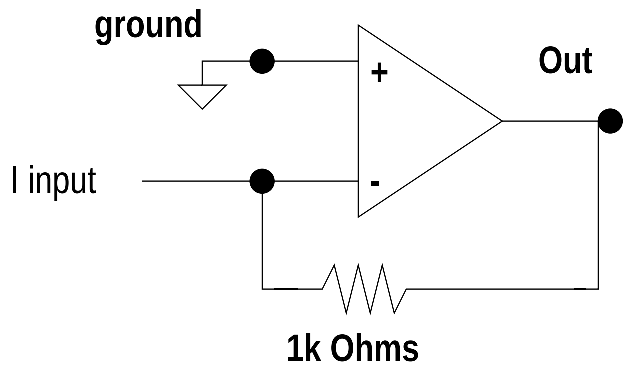
Hook Up:



Don't be discouraged if things don't work quite right, this circuit is REALLY sensitive to the EXACT values of the resistors you choose. A good choice, for future reference, is to use resistors matched to 0.01%! Usually too, you make this thing have a gain of 1 and use those precision resistors everywhere.

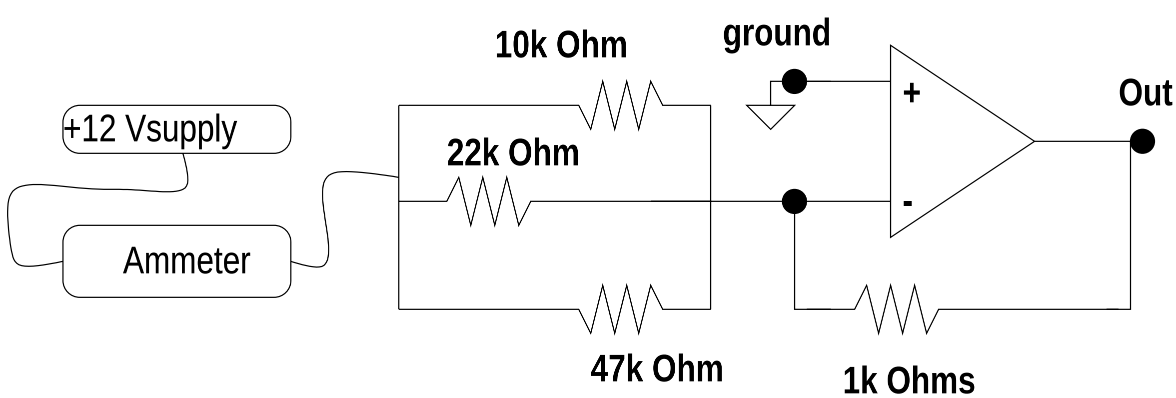
Practical Application: Current to Voltage Converter (Summer)

Remember, you still need to keep the Op Amp hooked up to +/- 12 V.



This should look very familiar, we've just replaced R1 and Vinput of the Inverting Amplifier with I input. The net effect of this is Out = (1k Ohm)(I input). Turns out that you can use this to your advantage if you want to add currents or voltages.

Demonstrate this:



You are sending 3 currents into In-. Arrange it so you can put in the resistors one at a time. Record current and Out (volts) after each. Does the data make sense? As a check, compute the parallel resistance of the 3 resistors you used. Now treat this parallel resistance as part of an inverting amplifier and compute your output voltage. Does your result agree with what you measured?