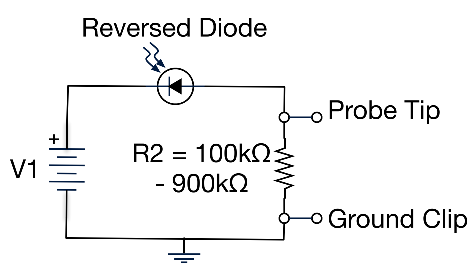
Exercise #2: Detecting Photons ("reverse bias")

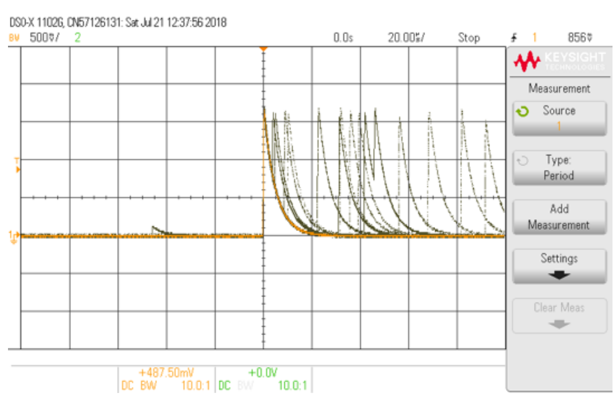
LEDs, as their name suggests, are intended to be used as light-*emitting* devices. However, the semiconductor physics that governs their behavior also allows them to be used as light *detectors*.

When the voltage on the Cathode is more positive than the voltage on the Anode, the diode is said to be in *Reverse Bias*. For typical reverse-bias voltages, very little current flows through the device (*essentially* zero current). Even when the reverse bias is small (nowhere near *breakdown*), LEDs can be used as photodiodes (essentially tiny solar cells) to detect light near their own wavelength, but under those operating conditions the response of the LED is typically linearly proportional to the intensity of the incident light, and the LED will not be capable of detecting ***single*** photons of light.

When the reverse bias voltage is *large enough*, the diode will start to conduct on its own (even in the dark) – this process is called *breakdown*. For many diodes, the onset of breakdown happens for voltages of order 1000V, and the effect can be **EXPLOSIVE!** However, for the particular LEDs that we will use, the breakdown voltage is only around 25V and (critically) the capacitance of the junction is so little that the amount of energy stored will not cause explosive damage, and so they (usually) survive. That is, if you ***carefully approach*** an operating point *near* breakdown, you can detect ***single*** photons of light, exploiting the fact that the system is unstable enough that the input of even a solitary photon can (sometimes) result in momentary pulse of current flowing through the reverse-biased LED. A single photon can give rise to cascading "breakdown" avalanche; by then passing this current pulse through a large resistor, a measurable voltage signal is produced, read by an oscilloscope.

Many of the single-photon detectors used for cutting-edge projects, such as the Photomultiplier Tubes (PMTs), Silicon Photomultipliers (SiPMs), superconducting bolometers, and specially optimized avalanche photodiodes (APDs) can be rather expensive, can (**like the Geiger tube**) require dangerous high voltages, and can also be easily damaged. Fortunately, a few intrepid physicists found out that there are a handful of inexpensive LEDs that can survive the same kind of *avalanche breakdown* required of ***single***-photon detectors. These LEDs are *not* designed for this purpose, so they make *rather poor* single-photon detectors, but they are useful for the didactic exercises that follow. In this experiment, one of these special LEDs is reverse biased and as the bias voltage is increased, the LED becomes a (***low efficiency***) avalanche photodiode.





Procedure:

1. Begin with your voltage source V1 adjusted so that it is near 0Vdc.
2. Noting that the LED **should now be in reverse bias**, construct the circuit above (**R2** >> **R1**).

3. Use an oscilloscope probe to monitor the voltage *across the resistor*.

a. Make sure that both your oscilloscope probe and oscilloscope channel are set to the ×10 setting. (Triple check!!!).

b. Start with the oscilloscope vertical scale on 100mV/div and horizontal scale on 10µs/div.

c. Trigger on the active channel and set the trigger level to ≈100mV.

d. When I was being mentored by Prof. Jonathan Newport, I was able to try these labs using a model AND113R LED, which starts to act like an avalanche photodiode at ≈ 26 ± 2V of reverse bias. What I ordered for our lab is a similar model, the AND114R, so I'm guessing that the breakdown voltage. is likely to be similar. Approach this value slowly until you start to see pulses. Make small adjustments to convince yourself that you are not merely in the "self-ionization" limit, but that the pulses you observe are very likely being triggered by photons coming from outside the device. We *claim* that these pulses represent ***single*** photons of light striking your detector! (It is only much later that you will be in position to experimentally determine whether or not these pulses each correspond to *single* photons.) For now, what can you do to confirm that this circuit is indeed acting as a photodetector? — **RECORD YOUR OPERATING VOLTAGE!** (I look forward to *learning* what voltage level worked for you!)

e. Adjust circuit and oscilloscope parameters and make observations, including:

- Reverse-bias voltage level
- Trigger level
- Current-limiting resistor values (keeping them between 100kΩ-900kΩ). Why does the pulse ***shape*** change with different resistors? Reminder: the LED has a *junction capacitance*. Describe the pulse shape, in words, in your notebook. How would you **quantify** the time constants?

f. Use *LabVIEW* to capture some of your data and include this, with analysis, in your laboratory notebook. [Caution: whenever faced with a model predicting an exponential decay, it can be helpful to switch back and forth between a linear plot and a semi-log plot. *Each can provide important insights!* Also, please be reminded, as seen in your data using aluminum absorbers, that simple models typically have a limited range of validity, and that data outside that range can reasonably be excluded from any fit or application of that model, so long as you clearly communicate, to your audience, what you have done.]