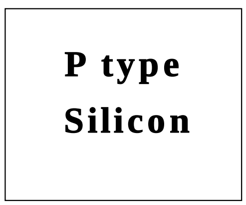
Gamma Ray Physics with Solid State Detectors

In this lab you will explore how relatively high energy gamma rays interact with matter. To do this, you will use a high resolution particle detector.

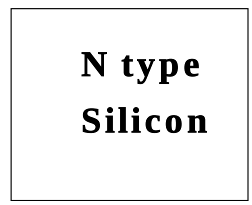
The detector you will use is a big piece of doped semiconductor. Sort of a giant diode. In this application, you reverse bias the diode. (Forward bias means you get a current.) By reversing the bias across the detector, the only charge you collect, to first order, is the charge created when a charged particle passes into the detector and ionizes some of the detector material.

Simplified view of a semiconductor:

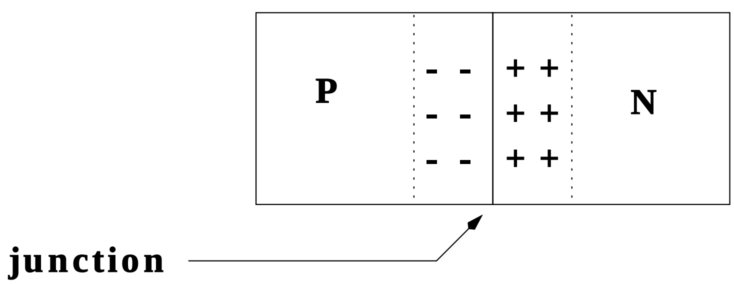
This type of silicon has positive conduction charges "built in"



This type of silicon has negative conduction charges "built in"

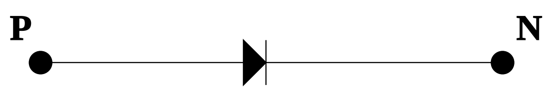


If you put them together



Some of the - charge moves into the P type, and some of the + charge moves into the N type. This happens until there is enough potential difference at the junction of the 2 types of silicon to stop the flow.

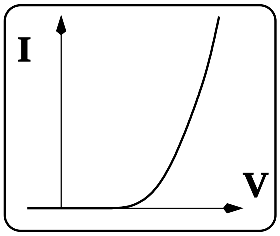
Now, if you place a potenital difference across this combination, you can change the potential difference across the gap. Symbolically, the combination looks like this:

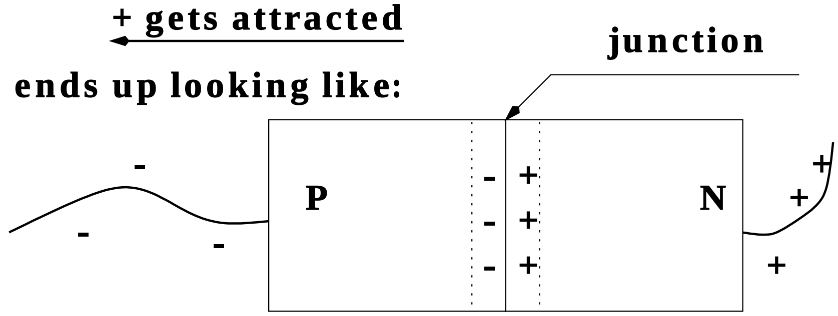


And you can probably guess which way to hook up a battery in order to get current to flow.

If you place a potential difference across the junction this way:

The P-N junction ends up looking like:

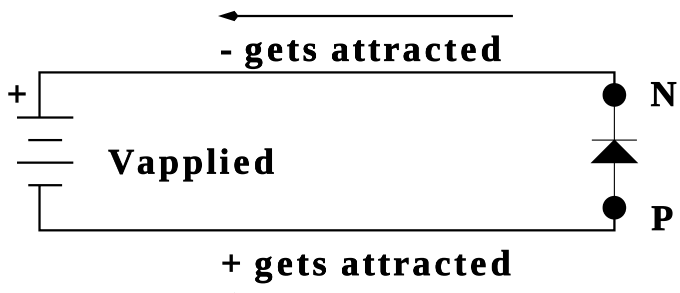




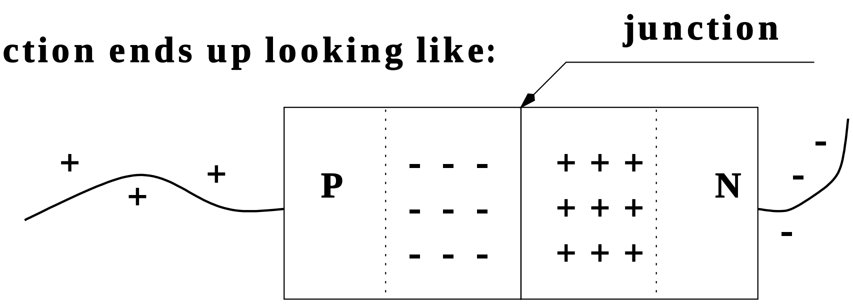
The gap in the center gets smaller

If the voltage is big enough, the gap gets small enough so that charge flows freely. For the diodes you've used in lab before, this is about 0.6 Volts.

If you place a potential difference across the junction this way:



The P-N junction ends up looking like:



The gap in the center gets bigger
It is even more difficult to get a current flowing this way!

The gap between the 2 regions is called the "depletion zone". There is no free charge in the depletion zone to make a current with, so no current flows in this configuration.

In this lab, we bias our "diode" so that the depletion zone is huge! When a charged particle passes through the depletion zone, it creates an ionization trail. This ionization looks like free charge, and a current is produced where normally there is very little.

Photon interactions at a glance

Photoelectric effect

This process dominates at lower energies (a few 10’s of KeV) and is characterized via a linear relatioship between the ejected electron on the incoming photon: KEmax = E photon - Work Function. There can also be a secondary energy associated with removing an electron from an atom if the electron is ejected from an inner shell. An outer shell electron fills the empty space and a characteristic x-ray is ejected from an atom.

Compton Scattering

This is a process where the incoming photon changes frequency as it scatters off of an electron. The change in wavelength is related to the angle of the ejected photon. This process tends to dominate from a few tens of keV to a few MeV.   Wavelength difference = (h/mc)(1-cos(photon angle)). A more useful formulation for this experiment is

(of incident photon)

$$\text{Energy of scattered photon} = \frac{E}{1 + (E /mc^2)(1-\cos(\text{angle of scattered photon}))}$$

This is interesting when one considers the extreme cases. When the angle of the scattered photon is 180 degrees, the energy of this backscatterd photon is $E/(1+2E/mc^2)$, and the enegy of the forward scattered electron is just the difference between the original photon energy and this backscattered value.

Pair production

This process dominates above a few MeV and is a reaction between the incoming photon and the nucleus where an electron and a positron are created. You can prove to yourself that the nucleus is needed in order to balance energy AND momentum.

⋆ Setting up the detector

Make sure there is at least 1/3 tank of liquid N2 left in the big tank. Connect hoses so that there is a feed from the liquid output of the N2 tank to the dewar, and 2 hoses for venting non-liquid N2 to the outside. Fill dewar with N2 until it bubbles through the seals around the neck. (Probably this has been done already by your lab instructor since it takes a few hours for the detector to cool down.)

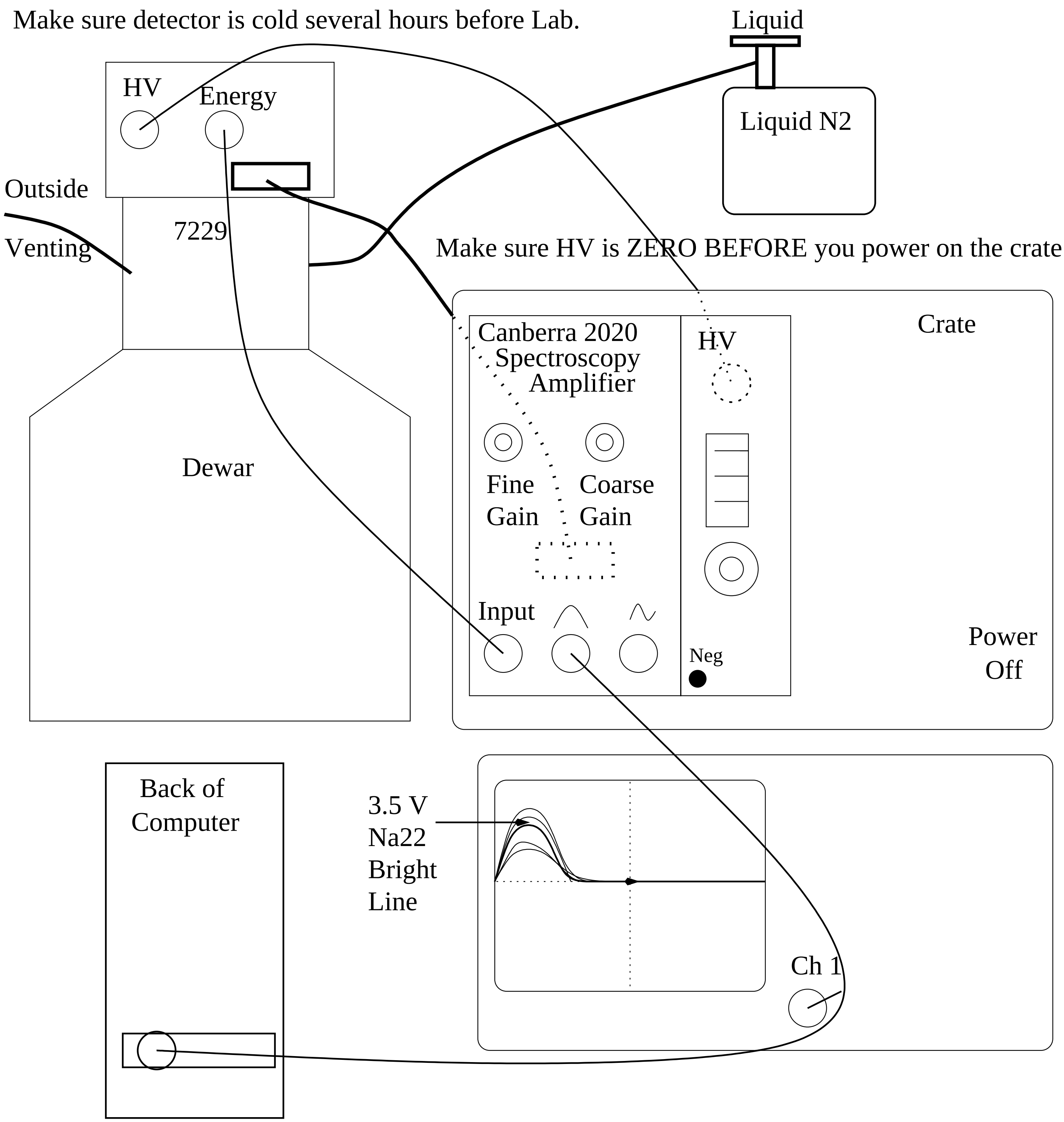
Make sure power is off on the NIM bin. That's the crate that houses the Canberra 2020 Spectroscopy amplifier and the High Voltage (HV) module. Be especially sure that the HV is turned all the way to ZERO and is shut off (you can seriously damage the sensitive pre-amplifier on the detector if you power up the HV abruptly)

Make the connections shown in the diagram. Have your instructor check your wiring. As a guide, a rough gain of 35 for the 2020 is a good place to start.

Make sure the dial on the HV is set to zero and that the HV is shut off. Power on the Crate (switch on lower right hand side (RHS)). Make sure the NEG light is lit on the HV module. If not, shut off the crate and call your instructor before doing anything else. If ok, turn on the HV module and slowly increase the HV to -2500V. Check both the knob and the indicator. Do not use a DVM! You don't need to be exact, a lower voltage means a decrease in the size of the depletion zone, and a higher voltage isn't too bad unless things start to break down (at which point you may have a disaster...).

You should see a few pulses on the scope if you've turned it on. You are now ready to begin the calibration procedure.

Detector Diagram



⋆ Calibrating the detector

With the detector properly set up, obtain an Na22 source from your lab instructor. This source has 2 well defined photon energies that will allow us to calibrate the detector. Place the source on the plastic cover protecting the fragile window of the solid state detector. Look at the output of the Canberra 2020 on a scope. Adjust the gain of the 2020 spectroscopy amplifier until the bright line you see coming from the source is about 3.5V in height. Here's the idea. You are going to use the signals coming from the solid state detector to determine how much energy was deposited in the detector. This signal is fed into a Multi Channel Analyzer (MCA) that converts a pulse height into a digital number. Your job is to take the known aspects of the Na22 source and calibrate the digital response.

If you were going to perform this calibration by hand, you would note that the maximum input voltage to the MCA in the lab is about 10 V. You would also note that we will not use any sources in this lab that have a prominent gamma energy of more than 1.4 MeV. So, if there are 2048 channels available in the MCA to cover the 10 V input range, we can compute the channel we expect the 511 keV annihiliation line from Na22 to end up in. Since we set this bright line up to be a signal of 3.5 V:

$$channel = 2048 \frac{3.5V}{10V} = about\ 750\ counts$$

and our other, fainter(tough to see), higher peak would be at around:

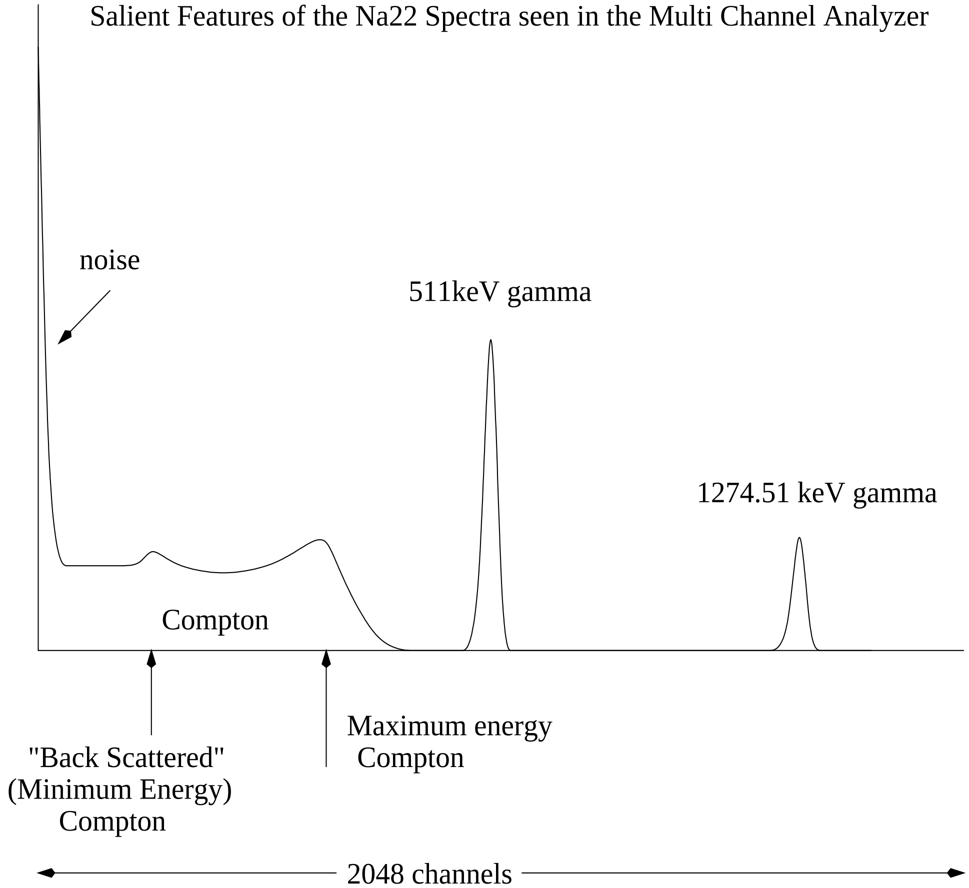
$$1274.51\ keV \frac{750\ counts}{511\ keV} = about\ 1900\ counts$$

and our maximum allowed energy of 1400 keV:

$$1400\ keV \frac{750\ counts}{511\ keV} = about\ 2050\ counts$$

Once you established this signal, fire up the PC that contains the MCA software. If the computer was completely off, turn it on, and if the windowing doesn't start, type "win" and hit return at the c: prompt. Double click on the MCA icon. Make sure the output of the Canberra 2020 is plugged into the BNC input of the MCA card (located at the back of the computer). Set the MCA display so that 2048 channels takes up the whole screen, and in the *Acquire* menu, choose *Start*. You can control the height of the maximum screen value with the up and down keys. After a few minutes, you should see a spectrum similar to the one shown on the next page. If you don't, you can try adjusting the gain of your signal, or if you are worried something really bad might be happening, call your instructor.

Salient Features of the Na22 Spectra seen in the Multi Channel Analyzer



After acquiring enough data to clearly see the 511 keV and 1274.51 keV peak (remember, you can determine the center of a peak with an accuracy of about half the width at half the maximum divided by the square root of the number of events), choose *Stop* in the *Acquire* menu. Then copy this data into the buffer (also in the *Acquire* menu) without saving it. Now, in the *Calculate* menu, choose the *Peak Search* option. If you are lucky, the 511 keV and 1274.51 keV peaks will be highlighted. if not, highlight them yourself by clicking and holding down the left and right mouse buttons at a point to the left of the peak, then moving the cursor to a point to the right of the peak and releasing the buttons. Click the mouse at the top of this peak and choose *Peak Info* from the *Calculate* menu. Clear any old calibration by choosing *Calibrate* from the *Calculate* menu and selecting *Destroy Calibration* as an option. Now choose *Calibrate* from the *Calculate* menu and enter the energy you expect this peak to sit at (in keV). Now choose the other peak and repeat (if not already highlighted). (There is a nice feature that moves you from peak to peak automatically with just a mouse click.) Your MCA should be calibrated. From the info on your peaks, estimate the accuracy of your calibration.

⋆ Identifying Unknown Sources

To check your calibration, ask your instructor to remove the Na-22 source and place Unknown Source #1 on the plastic cover of the detector. Clear your MCA and acquire enough data to get a good spectrum. Be patient and wait a few minutes! Repeat your peak search (do not re-calibrate!). What is Unknown Source #1, and how close did you get the peak(s) to match the one in the MCA's memory (you can scan likely suspects by clicking on the Lib arrow icons at the right of the screen near the Peak arrow icons). Does your estimate for the accuracy of the calibration account for any differences. Repeat for Unknown Source #2.

With Unknown Source #2 still in place, note the location and heights of the narrow peaks and the Compton maxima in your spectrum. Now put a 1cm thick piece of aluminum on top of the source and acquire a new spectrum. What changed (if anything)? Is there a special relationship between the Compton maxima and the narrow peak just above? What is it? (quantitatively too please) Remove the aluminum and replace it with a thin sheet of lead. (This is provided for you, already wrapped in tape.) What do you think the extra peak is? Can you prove it?