Van De Graaff Mid Lab Report

Benjamin Brandwin

1 Tuning the Proton Beam

The proton beam travels through a number of different stages which all help to tune the final beam and direct it towards the target. The first stage comes directly after the negative ion generator and consists of a series of glass and metal plates, each at a slightly higher potential then the next. The openings on the metal plates create a gentle focus and terminate at the start of a 3 stage Einzel Lens.

The Einzel Lens works by placing 3 successive plates along the sides of the beam path. The center plate is given a high voltage, while the outer plates are grounded. This creates electric field lines that curve into the center of the beam path and curve back down to the HV plate. The effect of this arrangement is to focus the beam along one of it's directions orthogonal to the beam path. Particles in the center of the path fly right through the lens unchanged, while particles on the outer edges are pulled to the center by the electric field. Three of these arrangements are placed together successively. The outer lenses focus in the X direction, while the center lens focuses in the Y direction. The net result of these three lenses placed closely together, is a net focusing effect in both the X and Y directions. These lenses, known as the ground station triplet, are then followed by a fixed and a variable steerer to further straighten the now focused beam. When the beam is directed properly, a pneumatically operated Faraday cup, placed in the beam path, should generate a negative voltage.

Once the beam has been properly focused, it will then travel through the Tandem Van De Graaff Accelerator. In the center of the Van De Graaff, a 20 micron thick copper sheet is used to strip the electrons from our H^- ions. The beam then travels through the mass and charge selector, which consists of a very large magnet to steer the beam 90° using the Lorentz Force. This selects both the charge that we want, as well as the mass. After the 90° turn, the beam is now directed into the target room. There it is directed down the 30° selection tube and further steered with another fixed and variable steerer. At the end of the tube is a metal frame followed by a metal collection cap. The current generated by the beam is measured on both the frame and the end cap. Once the voltage on the frame has reached zero, we can confidently say that the the beam is properly focused on the target.

2 Measuring the $1\mu\ Ci\ ^{22}Na$ decay

The measurement device for the decay rate consists of a number of different components. The first stage in the detection process consists of two Bicron NaI(Tl) crystals with photomultiplier tubes and bases. The NaI(TI) crystals are scintillators, which means that they emit photons in the presence of ionizing radiation. When a gamma ray is directed into the crystal it excites electrons into higher energy levels. Due the Tl impurities in the crystal, recombination is a likely occurrence, and as the electrons return to their ground states they emit photons. These photons then strike a photocathode 'window' in the front of the photomultiplier tube. Due to the photoelectric effect, the photocathode emits electrons when bombarded by photons. Inside the photomultiplier tubes there are a series of Dynodes. The final dynode (closest to the photocathode)is at a high negative voltage around -1100V to -1200V. A resistor network between the high negative final dynode and the grounded Anode at the end (furthest from the photocathode), places a higher voltage at each successive dynode. When electrons strike the first dynode, secondary emission causes additional electrons to be jarred loose. These electrons are now compelled to accelerate towards the next, higher potential dynode, and so on a so forth to the anode. This creates a cascading effect and overall amplification of the initial signal.

2.1 Coincidences

When a positron and electron come into contact the result is two gamma bursts that fire at 180° from each other, with an energy equal to approximately the energy of an electron; 0.511 MeV. Since we are only interested in the coincidences, the two photomultiplier tubes are placed facing each other, with the source in between. (I should mention here that during our first and only trial, the two tubes were placed at too great a distance from each other and as a result we are unable to currently produce an accurate ^{22}Na decay rate. Unfortunately, this crucial detail did not occur to us until after the lab period. Next time we are in the lab we will re-measure by placing the tubes closer to the center). The anodes of the two tubes are fed through channels one and two of a Tektronix TDS 2024B oscilloscope and then to a Phillips Scientific 710 Octal Discriminator. The discriminator is essentially a voltage comparator that will output a negative logic signal when the voltage is above (in magnitude) a user selected value. The scope allows us to adjust the triggering voltage to find the most likely occurrence voltages which then allows us to adjust the triggering voltage on the discriminator to only select the signals from decays that have deposited their full energies. The outputs from both discriminator channels are then fed into inputs A and B of a Lecroy 364 AL 4 fold Logic Gate. The Lecroy outputs a negative logic signal when A and B fire at the same time. The result of this full arrangement is the output a negative logic signal for only the coincidences which have deposited their full energy. This experiment orginally called for the use of an Ortec 871 Timer and Counter, however we have replaced this using more modern techniques. Instead of the Ortec 871, we have fed the output of the Lecroy into a gate and delay generator to convert the signal to a TTL positive logic signal. This is then fed into a counter circuit which I built and is further explained in the next section.

3 Improving Experimental Methods

Our goal before starting this experiment was to improve the experimental methods, both to improve the quality of the data collected, as well as decrease decrease our error. This was done by collecting data using an Arduino Mega 2560 micro-controller, as well as a SeeedStudio SD card shield, for storing our data. An external counter was developed using two SN74LS393 counters chained together to make a single 16 bit counter. This counter was assembled on a Radio Shack PCB board. LED indicators were attached to each output through 10Ω resistors for visual confirmation of the correct counting sequence. The outputs were also connected to a set of 8 pin female headers to provide a binary output of the count back to Arduino.

The assembled circuit board also contains two buttons. The button on the right(next to the green LED's) is a test button. When the external count is disabled, pressing this button will advance the count by one (often times more than one as there is no need for a de-bounce in the real measurement). The button on the left (next to the red LED's) is a save button. To save time in the code, and improve accuracy, it is beneficial to use a manual save button. Pressing this button closes the file being written to, thus saving the data along with a time stamp of the save.

Accuracy We can easily test the accuracy of the counter by applying an external counting pulse to the device (with attached code programmed) and watching the serial monitor on a computer. When a timestamp is placed before and after the data is written in the code, we can see that the data takes no longer than 1 ms to write, thus ensuring an accuracy of $\pm$ 1ms. So, for example, a 5kHz square wave would have a count accuracy of $\pm$ 5 counts. This maintains a 0.1% error for each measured value, and 0.2% error for final counts/second value. The provided Ortec 871 counter does have a much higher accuracy. It's 1Mhz crystal oscillator has $< \pm$ 2ppm/ °C and an inaccuracy of $< \pm$ 5ppm. However, this collection method is limited because the data must be collected manually. This means that we require a dwell period which must be long enough to read and record the count. This requires additional calculation of the starting point for each counting cycle. Collecting data with the micro-controller allows us to collect continuously, without any dwell period. We can therefore collect a much larger data set, with a constant known accuracy of $\pm$ .2% for a 1 s count interval. This accuracy can be greatly increased by increasing the time interval. However it is important to note that the time interval must allow us to consider a fairly constant decay rate in order to be accurate. Carbon 11 is known to have a half life of around 20 - 21 minutes. If we make a very rough estimation (linear estimation) of how many decays occur over the first 100 ms, we see it's around 0.05% to 0.1% of the remaining carbon. Since only a small fraction of the total carbon decays during this time interval, considering the decay rate to be fairly constant seems like a safe estimation. Increasing the time interval will cause the curve to look more like how it really is, an exponential, rather than linear, which is what we are using to calculate the infinitesimal change of rate per step.