E. K. A. ADVANCED PHYSICS LABORATORY

STATISTICS OF COUNTING WITH A GEIGER COUNTER

ARTIFICIAL RADIOACTIVITY

1. INTRODUCTION

The Geiger Müller (GM tube) detector for ionizing particles operates on the principle of gas multiplication of the initial small number of electrons freed by ionizing particles traversing it. Relativistic charged particles lose ~ 1300 eV of energy per cm in argon at NTP. Typical gas in a GM tube is Ar at 1/10 atm, resulting in 130 eV energy loss per cm. An electron ion pair is formed in average per ~ 25 eV of energy loss, resulting in ~ 10 free electron in the gas of the GM tube. The electric field in the tube accelerates the initial electrons which in turn collide with the gas atoms to produce more e-ion pairs. If the field is large enough the multiplication becomes regenerative, a self sustaining chain reaction and, helped by deexcitation UV photons, ionization of the gas spreads to the whole length of the GM tube. In the GM tube the field is large only around the central thin wire ($E \propto 1/r$) and this is the region where electron multiplication occurs. The negative electric charge of the electrons is collected by the anode, which remains surrounded by the positive charge of the ions, resulting in a decrease of the electric field and a termination of the multiplication mechanism. The GM tube becomes insensitive to particles until the positive charge has drifted significantly toward the cathode, which requires tens to hundreds of μs. The multiplication mechanism is further controlled by quenching components, alcohols or halogens. These components also prevent restart of the regenerative discharge by absorbing deexcitation UV photons and by positive charge transfer from the argon ions. The GM tube was the first single particle detector because of the large electric signal it produces; its limitations are the loss of information about the initial energy deposit and the fact that the detector does not respond to a second particle traversing it until the positive ion cloud is largely swept out. The GM tube is used in this experiment to study the statistics of counting and to perform measurements of "dead time" as well as to study artificial radioactivity induced by slow neutron capture by measuring the lifetimes of the short lived unstable isotopes produced.

2. EXPERIMENTAL SET UP

The experiment consists of a GM tube in a lead enclosure, a high voltage power supply (DO NOT EVER EXCEED 1200 VOLT!), a threshold circuit, which recognizes an electric pulse larger than about 2 volts from the GM tube, a digital counter with visual display, sometimes called a scaler, for visual indication that signals are detected at the tube output and additional counters which can be read by a computer, for data acquisition. One of this counters counts, modulo $2^{16} = 65536$, the pulses generated by the GM tube. The content of this counter is transferred to a register after a time interval T has elapsed; the value of T can be selected by a switch to be 1.28, 5.12 .. up to .. seconds. Whenever a transfer occurs, a status register, called flag, is set. Running the appropriate program, the computer is in a loop, continuously testing the flag. When the flag is found to be set the computer reads the count stored in the register and resets the flag. This somewhat contorted sequence of operations guarantees correctness of the counting rate even if the computer is performing data manipulations, as long as the status register is interrogated frequently enough. The time interval is defined to $\sim 10^{-8}$ seconds, the absolute accuracy is 0.01%. A second counter (also modulo 65536) counts a 100 Hz clock, its count being transferred to a register every time the GM tube outputs a pulse. The same pulse also sets a second flag which can be interrogated by the computer, to know when to read the register containing the time when a particle was detected; this flag must also be reset after reading the time. Both counting rates and time intervals can be obtained taking differences between consecutive reading of the appropriate counters. Note that in general the first reading of a sequence should be discarded, since you don't know when the register transfer took place. Also it is possible that a difference between successive readings of pulse counts or time intervals is negative; in such case the correct answer is obtained by adding 65536. All this operation are performed by a set of programs which can read count rates and time interval in several ways as shown on the computer screen whenever the menu is invoked by typing m or menu followed by the enter key.

3. GETTING STARTED

The first step is to insure proper operation of the apparatus. Turn on the computer and follow instruction. Slowly raise the high voltage to 950-990 volts and with a source below the GM tube observe the visual scaler counting. The next step is to insure that you are using the proper value of the high voltage. Chose the rate program on the computer (type RATE followed by the enter key), set the time interval to 1.28 seconds, enter the value in the computer. Every 1.28 second a new count has been read by the computer and the corresponding rate computed and displayed. Obtain the counting as a function of the counting voltage. Note the very rapid increase in counting rate with high voltage around 950 V, and the long plateau, about 200 V, during which the counting rate increases by a few % per 100 V. If you go too high in voltage, the counting rate increases rapidly since the GM tube begins to break down. Operation in this condition, even for very short times, damages the counter, reducing its life and its stability. It is better not to ever exceed 1200 V, even if you do not see any increase in counting rate. Plot your result. Once you have found the region where the counting rate is almost independent of high voltage, set the voltage no more than 80 V above the lower knee of the plateau. This should be your operating voltage for the rest of the experiment. Also you should take a good measurement of the ambient background count for later use. Finally the signal from the GM tube should be observed on an oscilloscope, with a source giving a fairly high counting rate, to visually verify the fact that the tube is "dead" for some time after detection of a particle and that full sensitivity is not acquired abruptly.

4. DEAD TIME MEASUREMENT

See Rainwater & Wu. As outlined in the introduction the GM tube is not sensitive to radiation after detection of a particle. The deadtime is determined by many factor as described in the reference above. It is among other things a function of the rate at which the counter is used. (The dead time of the digital counters is of the order of 10^{-8} seconds, that of the threshold discriminator about 10^{-7} seconds). You can measure the GM tube deadtime at different counting rates, although one good measurement is sufficient. Follow the procedure in the reference above using sources giving counting rates around 300-1000 Hz and make sure you obtain a result with a reasonably small error, say a few %. You might have to accumulate several long counting intervals. Do not forget the background rate in your calculation. The result of this measurement will be used later.

5. POISSON DISTRIBUTION AT SMALL COUNTING RATE

Chose a source giving a counting rate of $\sim 2-4$ counts/sec (labelled $20-40/10$ sec), set the time interval at 1.28 seconds and take 1000 measurement of the counting rate. You should use the program that writes a file of counts to disk. You chose part of the name of the file, for instance 2 decimal digits nn in the name FILECnn.DAT. Follow instructions on the computer. Compute the average rate from the 1000 measurements, plot the distribution of the measurements and the expected distribution. This can be done in the lab, with the computer which is connected to the experiment or on any other IBM PC compatible, if you copy the data file to a diskette.

6. GAUSSIAN DISTRIBUTION AT LARGE COUNTING RATE

Use now a sample giving a counting rate around 100-1000 counts and collect 1000 readings of the rate, each for 1.28 seconds. Histogram the data and compute average and rms spread of the collected readings. Compare with theory of counting. Remember the 1.28 second interval!

7. TIME INTERVAL DISTRIBUTION

Obtain the distribution of the time interval between counts for a) a counting rate of $\sim$ 1 Hz and b) an input counting rate of 10 Hz, prescaled to 1Hz (this can be done for instance by adding the time measurements in sets of 10). Write the data to FILETnn.DAT. Histogram the results and compare with expectation.

8. ARTIFICIAL RADIOACTIVITY BY NEUTRON IRRADIATION

With an appropriate understanding of the GM tube operation, we can use it to study artificial radioactivity induced in by slow neutron capture. This can result in two (or more) activities. Irradiating ^{116}In results in two activities with lifetimes: $\sim$ 14 s and about one hour. When the two lifetimes are very different, as for the case above, one can simplify the measurements, by using a short measurement period for the short lifetime, immediately after activation. Remembering that $e^{-10} \approx 4.5 \cdot 10^{-5}$, measuring the disintegration rate of the irradiated sample for longer than 3-5 minutes will not give more information about the short lifetime. Similarly we can avoid trouble from the short lived activity by waiting 5 minutes or so after irradiation, before beginning measurements of the long lived activity. If silver, (natural silver is approximately 50% ^{108}Ag and 50% ^{110}Ag) is irradiated with slow neutron its 109 and 111 isotopes are produced. Their lifetimes are about 2.4 m and 24 s. Having at your disposal a reasonable amount of computer power, it is interesting to try to extract both lifetimes from a single set of measurements by performing a “fit” to the data. Means on how to do so, together with the proper way for obtaining errors on the lifetime estimates are given in the appendix.

Do not forget however that one lifetime is short. This means high initial counting rate and therefore you must apply deadtime corrections. Also if you do not start counting your sample within seconds after irradiation, there is no short lived activity left to measure. Discuss the importance of background subtraction and deadtime correction for obtaining accurate results.