Departamento de Física do IST
DFA em Segurança e Protecção Radiológica

INTERACÇÃO DE PARTÍCULAS CARREGADAS COM A MATÉRIA E DETECTORES DE IONIZAÇÃO
O DETECTOR DE GEIGER-MÜLLER: Operação e aplicações

Estudam-se características do detector – seu princípio de detecção e modo de operação, tipo de partículas que detecta, taxa de contagem que suporta, eficiência na detecção dos diferentes tipos de partículas, bem como aplicações sobre medidas de radioactividade do meio ambiente.

Este Módulo divide-se nos seguintes temas:

- Estudo da curva de resposta do detector em função da tensão aplicada e escolha da zona de operação, usando uma fonte de ^{204}Tl de 0.5 μCi.

- Estudo da correcção à taxa de contagem do detector devido ao seu tempo morto (uso das fontes *meia-lua* de ^{204}Tl de 5 μCi cada).

- Estudo da eficiência do detector a radiações β produzidas por uma fonte de ^{204}Tl. A actividade da fonte de ^{204}Tl era de 0.5 ± 0.1 μCi em 1/4/08 e considere um erro de 10% para o tempo. As medições devem ser efectuadas com a chapa metálica de $\phi = 7.25 \pm 0.05$ mm, que define uma eficiência geométrica mais precisa para a radiação β.

- Estudo da eficiência do detector a radiações γ produzidas por uma fonte de ^{137}Cs. A actividade da fonte de ^{137}Cs era de 5 ± 1 μCi em 1/5/94 (use a fonte sem a pinta verde – janela fina e considere um erro de 10% para o tempo). As medições devem ser efectuadas com uma chapa de alumínio (a absorção de γs na chapa de Al é de 10%).

- Estudo da retrodifusão de partículas β, oriundas de uma fonte simétrica de ^{204}Tl, causada por materiais de diferentes números atómicos.

NOTA:
$\star$ Use todas as fontes com a janela fina virada "para cima" na prateleira do meio (n° 3).
$\star$ Faça sempre 2 aquisições de 60 s. No caso do estudo da retrodifusão faça duas aquisições de 120 s e, depois verificar a sua compatibilidade, **some** esses resultados.

Segue-se o Guia detalhado do Módulo.

1.1 Discussion

In the study of radioactivity there are usually three parameters associated with an unknown source that are necessary to know. These are: 1) What kinds of particles is the source emitting, 2) What are the energies of these particles, and 3) How many particles per unit time is the source emitting. In this experiment, the Geiger-Mueller counter (called GM) will be used to help answer the third question. In subsequent experiments, the other two questions will be studied in great detail.

The GM tube is one of a variety of radiation detectors that take advantage of the fact that charged particles lose energy in a gas by creating electron-ion pairs. In air for example, an alpha particle will ionize from 50,000 to 100.000 molecules per cm of its path. The Geiger tube is simply a metal cylinder that is filled with some kind of counting gas. A thin window at one end of the cylinder allows the radiation to enter the counting region. The ion-pairs that are produced by the radiation are swept out and collected by an electric field that is maintained between a thin wire on the axis of the tube (anode) and the metal cylinder (cathode). The electric field between these two electrodes is high enough that the ions produced by the initial radiation are accelerated and produce secondary ions. This phenomena is called an avalanche.

In this experiment βs and γs will be measured with one of these end-window Geiger tubes. In order to detect gammas with these detectors a two step process must occur. The gamma must first make a photoelectric or Compton interaction in the gas. The recoil electrons from these interactions then produce the ion-pairs that cause the avalanche. In the experiment, it will be seen that the GM tube is quite efficient for detecting beta particles and the voltage gradient across the tube will be such that any of these ionizing particles that enter the sensitive region will cause an avalanche. The output pulse is usually greater than one volt. The GM tube does not differentiate between kinds of particles or energies: it simply gives an output pulse when any ionizing particle triggers this avalanche. These output pulses are then recorded in a scaler which acts as an electronic adding machine.

2. DETERMINING THE OPERATING PLATEAU FOR THE GEIGER TUBE

2.1 Experimental Procedure

Figure 1 shows a typical voltage plateau curve for a GM tube. At low voltages there is no output. As the voltage is increased, a few counts will be recorded at the "starting voltage." As the voltage is further increased, the counting rate will change rapidly until the "knee" or threshold of the plateau is reached. From this point on, the counting rate is fairly constant for approximately 200 volts. This is called the plateau region. Shortly after the plateau region, the tube breaks down and goes into a continuous discharge. The operating voltage for the measurements in this experiment will be 25% of the plateau above the knee or threshold. Halogen quenched Geiger tubes, such as the Model PK-2 used in this experiment, are NOT harmed by a continuous discharge. Lower the voltage to the plateau level, and the GM tube will again operate normally.
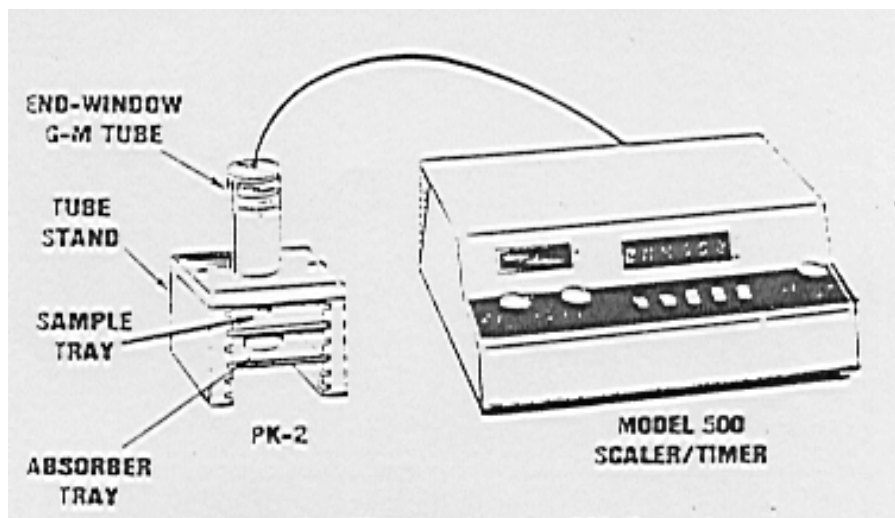
Figure 2. Electronics for GM Counting

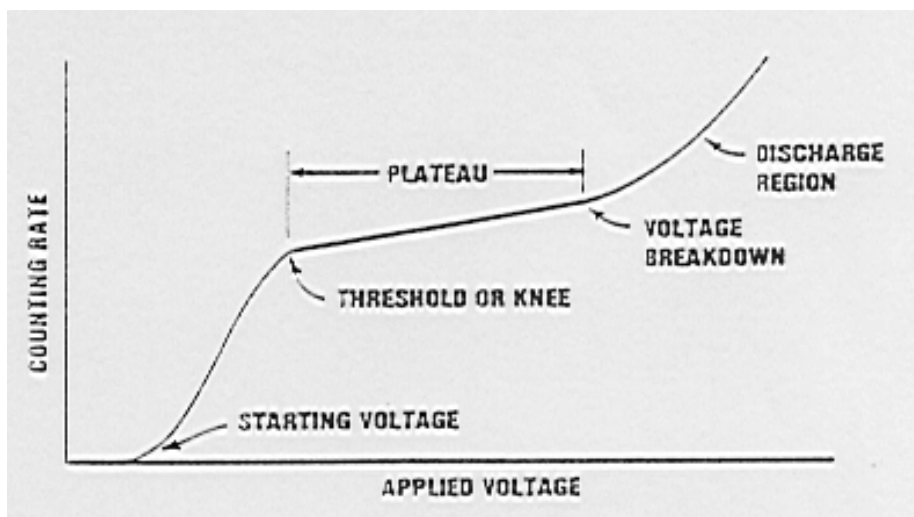1. Set up the electronics as shown in Figure 2

Figure 1. Typical Geiger-Mueller Characteristic Curve.

2. Place the ^{204}Tl beta source on the second shelf of the GM stand. Set the timer on "manual" so that the voltage on the tube can be slowly raised and the student can observe all of the features of figure 1. Slowly raise the voltage until the starting voltage is reached. Record this value. Continue to increase the voltage until the counting rate levels off. This is the knee of the plateau. Record this value.

Continue increasing the voltage until the voltage breakdown region is reached. Record this value. This concludes the visual inspection of the curve.

3. Now we will take data so that the plateau curve can be plotted and the operating voltage for the GM tube established. Go back to the value of the starting voltage and take 60 sec. counts in 50V increments until the breakdown point is reached. Fill in Table 1.

Table 1 Data for Constructing a Plateau Curve

Run No	Voltage	Counts	Time (sec)	Counting Rate (Cts/s)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

2.2 Data Analysis

Plot a curve of counting rate versus voltage and determine the position of the knee and the voltage breakdown region. Record the operating point which is 25% of the plateau starting from the knee.

The plateau region rises with a gentle slope. Calculate the value of the slope. It should be slightly less than 10%.

3. RESOLVING TIME CORRECTIONS

3.1 Discussion

In the earlier discussion it was mentioned that the Beta particle enters the GM tube through the window and loses its energy by creating electron-ion pairs. The electrons that are produced in the resulting avalanche are accelerated to the anode and collected in a short period of time. The positive ions, however, are more massive and make their way slowly to the cylindrical cathode. If their average transient time is called Δt_1 the GM tube is busy, so to speak, during Δt_1. If another ionizing particle enters the GM tube during Δt_1 it will not be counted. This time Δt_1 is called the "dead time" of the tube. In this experiment the resolving time of the GM tube will be determined and the correction factor which can account for these lost events will be shown.

3.2 Experimental Procedure

1. Set the GM counter at its operating voltage. Obtain the split source from the instructor. This source is designed such that each half of the source can be counted separately without too many losses, but

when both parts are counted at the same time, substantial losses occur. Count the first half of the source on shelf one for 60 sec. Calculate the counting rate and call this rate R_a. Repeat the exact measurement for the second half of the source and call this rate R_b. Now count both halves together for 60 sec and call this rate R_{a+b}.

3.3 Data Analysis

Calculate the resolving time of the GM tube which is given by:

$$T_R = \frac{R_a + R_b - R_{a+b}}{2R_a R_b} \qquad (1)$$

The true counting rate R_1 can be calculated from the observed counting rate (R_2) by the following:

$$R_1 = \frac{R_2}{1 - R_2 T_R} \, counts/\sec \qquad (2)$$

Note: Because of the solid state electronics used in the circuitry of modern instrumentation such as the scaler, the resolving time of these instruments is normally one microsecond or less. Therefore, only the resolving time of the GM tube affects the true count rate.

For the rest of the data taken in the experiment with the GM tube, eq. (2) should be used to correct the resulting counting rate. Also, the radioactive sources should be moved away and a 60 sec background taken. This background rate should be subtracted from all measurements.

4. STUDY OF THE EFFICIENCY OF A GM COUNTER FOR GAMMAS AND BETAS

4.1 Experimental Procedure

1. Set up the GM system (Fig. 2) as we did in section 2. (Note: A GM radiation survey meter may also be used for this experiment). Adjust the voltage of the GM tube to its operating value.

2. Place the l μCi ^{137}Cs source on the second shelf and count for 1 minute. Record this value in Table 2 as Beta and Gamma (trial 1) and record the average cts/min.

3. Place a 1/8 inch piece of aluminum on shelf between the source and the detector number 1. This thickness of aluminum is greater than the range of the 514 keV beta from ^{137}Cs but will not appreciably attenuate the 662 keV gammas from the source (See the decay scheme fig.3). Make two independent 60 second measurements with this beta shield in place. Record the average in Table 2 as gamma only.

Table 2 GM Relative Efficiency Data

Radiation	Cts/Min (Trial 1)	Cts/Min (Trial 2)	Cts/Min (Av)
Beta and Gamma			
Gamma Only			
Beta Only			

4.2 Data Analysis

Subtract the *Gammas only* from the *Beta and Gamma* count to get the actual number of Betas and record. Since the GM tube is nearly 100% efficient for betas, this number represents the number of betas that impinge on the window of the GM tube. How does this number compare to the theoretical number that you calculate from the ^{137}Cs source activity and the geometry?

Relative Efficiency of GM Tube for Gammas: This number is calculated by taking the ratio of gammas counted to the theoretical number that impinge on the face of the tube. From this experiment the student should gain some familiarity with beta absorbers and GM efficiencies. The portable GM counter or survey meter is one of the basic instruments used in Health Physics monitoring.
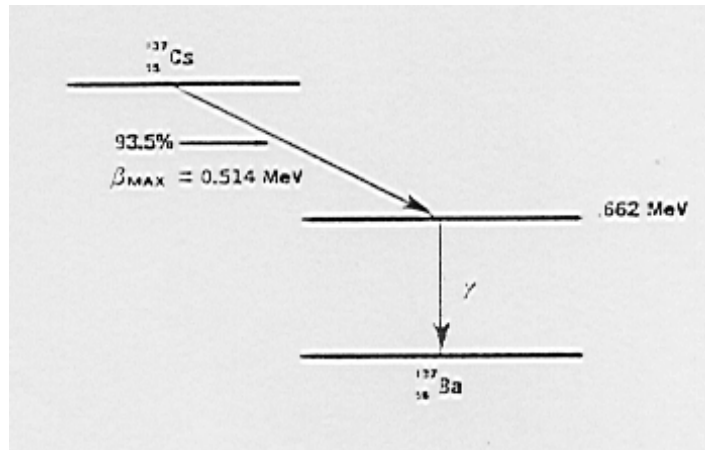

Figure 3. Decay scheme for ^{137}Cs (simplified).

5. BETA BACKSCATTERING AS A FUNCTION OF ATOMIC NUMBER

5.1 Beta Radiation

The processes by which β particles lose energy in absorbers are similar to those for alphas. However, an additional process must be considered in dealing with β absorption. This is the process whereby electromagnetic radiation, called *bremsstrahlung,* is produced.

A β particle has a very small mass and one-half the value of the charge on an α particle. So, for a given energy, a β particle will have a much greater velocity than a α particle. As a result of these and other factors, the β particle has a lower specific ionization which means that the penetration in any absorber will be much greater than that of an α particle.

A 1 MeV β particle will travel about 10 feet in air. In order to penetrate the dead layer of skin, a β particle must have an energy of about 70 keV. Beta radiation is considered a slight external hazard.

The thickness and choice of material for shielding from beta radiation depends upon: (1) stopping the most energetic βs*,* and (2) bremsstrahlung.

The shielding thickness which is necessary to stop β particles at a given energy will decrease with increasing density. For example, about 0.1 inch of aluminum (ρ = 2.7 g/cm^3) will stop 1.5 MeV beta, whereas only about 0.024 inches of lead (ρ = 11.3 g/cm^3) is needed for the same purpose.

However, the production of bremsstrahlung increases with increasing atomic number of absorber. A β source with E_{max} = 1 MeV will lose about 3% of its energy as bremsstrahlung when lead (Z = 82) is the absorber. If aluminum (Z = 13) is the absorber, the fraction is about ? %. Therefore, low-Z absorbers such as aluminum, plastics or even glass are effective β shields.

When you are trying to measure a beta-emitting source, the environmental surroundings are important. For example, let's assume that at a reactor site some beta activity has spilled on a steel pipe. The measurement that was made with a portable GM counter would have to be corrected for beta backscattering for Iron. This experiment is designed to give the student an overview of this backscattering phenomena and how it can affect the observed counting rate from the source.

5.2 Experimental Procedure

1. Use the same GM electronics (fig. 1) that was employed in the last experiments.

2. Place the ^{204}Tl source (see fig.4 for its decay scheme) on the third shelf of the GM assembly. Count for 60 seconds and record in Table 2 as NONE.

3. Place the aluminum backscattering sheet from the backscatter kit (see Table 3) in contact with the source to enhance backscattering. Count for 60 seconds and record in Table 3. Repeat for the other materials in the kit and fill in the rest of the Table.
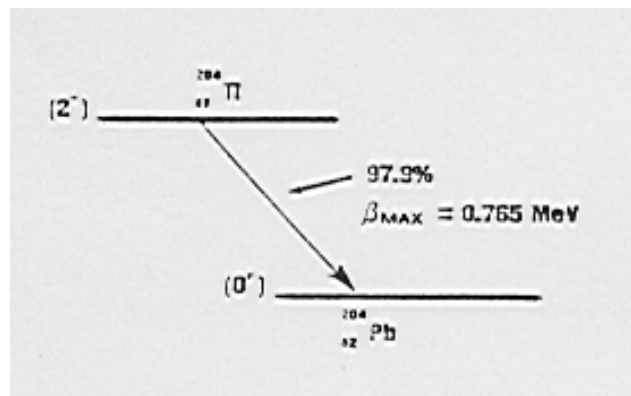

Figure 4 Beta decay scheme for ^{204}Tl.

Table 3 Data for Beta Backscattering Analysis

Run No	Backscattering Material	Atomic Number	Cts/Min (Gross)	Backscattering Factor
1	None			
2	Aluminum			
3	Iron			
4	Copper			
5	Cadmium			
6	Molybdenum			
7	Tungsten			
8	Lead			

5.3 Data Analysis

From the known activity of the ^{204}Tl source and the fact that the GM counter is almost 100% efficient for a pure beta source, calculate the counts/minute that you would expect for the geometrical set up being used. How does your answer compare to the measurement made with no backscatter?

The Backscattering Factor (BF) is defined be the ratio of counts/minute with a scatterer, divided the counts/minute without a scattering medium. Calculate this value for each of the measurements and fill in Table 3. Calculate the percent backscattering from your data and plot this value (y axis) as a function of the atomic number of the backscattering material. Figure 5 shows a plot of some typical experimental data.
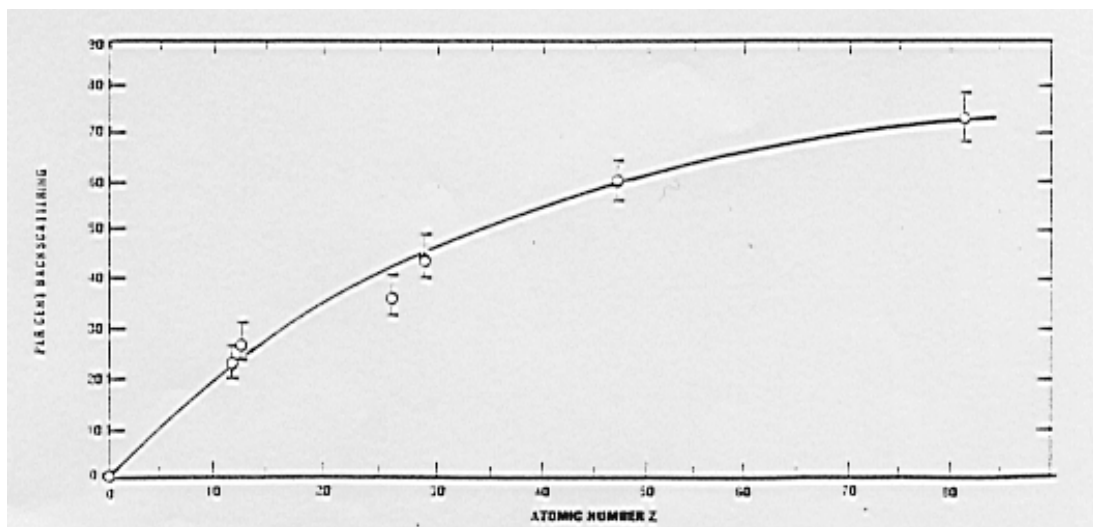

Figure 5. Percent beta backscattering as a function at the atomic number of the backscateting material.

6. THE INVERSE SQUARE LAW

6.1 Discussion

Most radioactive sources are isotropic in nature. This means that gammas (for a gamma source) are given off equally in all directions. There are some sources, however, where there is a correlation of one gamma relative to the other that is not isotropic. This angular correlation allow to predict some properties of the nuclear states that are involved in the decay of these isotopes. In the case of an isotropic source, it is a well known fact that the intensity of the source falls off as $1/R^2$. In this experiment, this $1/R^2$ relationship for a ^{137}Cs source will be verified.

6.2 Experimental Procedure

1. Set the voltage of the GM counter at its operating value. Determine the background counting rate.

2. For this experiment, use a ^{137}Cs source. The betas from the source must be attenuated out, since air absorption of the betas will modify the results. This can be done by placing a thin piece (1/16") of almost any material between the source and the window. Place the ^{137}Cs source 1 cm from the window and count for a long enough period of time to get good statistics. Record this uncorrected counting rate in Table 4.

Table 4 Data for $1/R^2$ Determination

Run No.	Distance (cm)	Counting Rate uncorrected	Background Rate	Counting Rate Correction for Background and Resolving Time
1	1			
2	2			
3	3			
4	4			
5	5			
6	6			
7	7			
8	8			

3. Move the source to the 2 cm position and count for a period of time long enough to get reasonable statistics. Record the uncorrected counting rate in Table 4. Continue for the other distances in the table. It should be obvious that the counting time will have to be increased for the longer distances to get good statistics.

6.3 Data Analysis

On linear graph paper, plot the corrected intensity vs distance. From the 3 cm data point, obtain the constant K as follows:

$$I=K/R^2 \tag{3}$$

On the same curve, plot eq. (3) with the other values of R. Use the value of K that was found above. What we have done is normalize the data to the 3cm measurement. How do the two curves compare?

7. STATISTICAL VARIATION OF DATA

7.1 Discussion

There is no way to predict when a person will have an automobile accident that does $1000 worth of damage to the car. However, if a very large number of drivers are considered it is possible for an insurance company to predict with reasonable accuracy, how many accidents, costing $1000 will occur this year. Insurance companies use large computers to store mounds of statistical data so they can accurately predict these probabilities from random events.

The radioactive decay of a nucleus is also a random event. There is no way to determine when a particular nucleus will decay. However the half-life can accurately be determined. If two identical counts are taken in sequence on a long lived radioisotope, the counts will almost always differ. If a large number of these individual counts are taken, the average count N can be determined. From this data, a predictable deviation of each count from this average can be calculated. The standard deviation is:

$$\sigma = \sqrt{N}$$

For this experiment, 35 independent measurements will be taken on the long lived isotope ^{137}Cs ($T_{1/2}$ = 30y) and with this data the predictable behavior of the measurements will be shown.

7.2 Experimental Procedure

1. 1.Set the operating voltage of the GM counter to its recommended value. Place the ^{137}Cs source at a distance such that 2000 counts can be obtained in 0.5 min.

2. Take 35 sequential 0.5 minute counts and record these uncorrected events (N) in a Table similar to Table 5.

Table 5 Counting Statistics Data Table

Run No	N	$N - \overline{N}$	$\dfrac{N - \overline{N}}{\sigma}$	$\dfrac{N - \overline{N}}{\sigma}$ (rounded)

7.3 Data Analysis

Calculate the average of these 35 counts N. Tabulate $N - \overline{N}$ in the table. Note, the number $N - \overline{N}$ can be positive or negative. If you will add up all of the $N - \overline{N}$ in the table, the answer

should be zero. If it is not, a mistake has been made. Calculate σ which is $\sqrt{N}$. This is called the standard deviation. Sixty-eight (68) percent of the observed data should lie within the range. In the above case, 24 of these measurements should fall within this range. Does the data fit?

Calculate $(N - \overline{N})/\sigma$ and tabulate it in the data table. Now round off the value for each entry to the nearest 0.5. For example, if $(N - \overline{N})/\sigma = +1.11$, the rounded off figure would be +1, etc. Plot the frequency of rounded off events versus σ and a normal distribution curve should be seen.

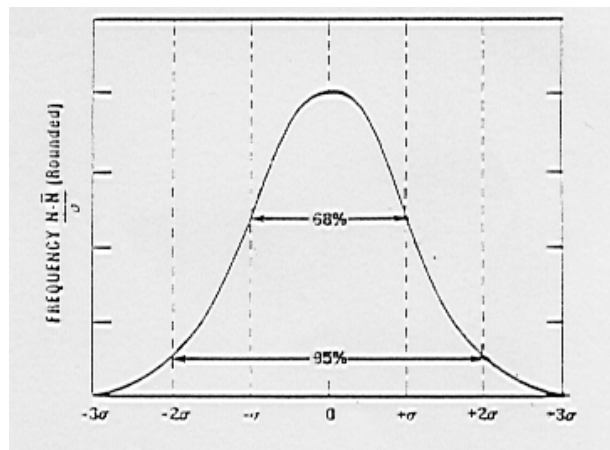Figure 6 shows a normal distribution curve that should be similar to your calculations.

Figure 6. Typical Gaussian. Generated from an
Extensive Set of Data.