Ionising radiation II

Task objective: Gaining experience by determining the dead time using the two-beam method and its effect on the Geiger-Müller counter readings.

Measurement objective

1) Measure the dead time of the Geiger-Müller counter using method utilizing two radiation sources. Consider the background effect.

Task theoretical basis

The Geiger-Müller (GM) detector is an ionization chamber, hermetically sealed, filled with gas at a pressure usually below atmospheric pressure and operating in pulsed mode. The electrodes of this chamber are connected in an electrical circuit at a voltage of about 600 to 1000 V. When a quantum of ionizing radiation enters the gas, ionization occurs, whereupon electrons begin to move towards the anode and positive ions towards the cathode. Since the gas is diluted, or the voltage at the electrodes is high enough, the mean free path of each electron is long enough that it acquires enough kinetic energy in the electric field to knock out more electrons (and ions) when it strikes a gas atom. These secondary electrons then knock out more secondary electrons, and so on. This process of secondary ionization occurs in an avalanche-like fashion (up to 10^{10} secondary electrons are produced from one primary electron) – an electrical discharge is produced in the space between the electrodes. A relatively strong current pulse passes through the circuit and a relatively high voltage pulse is generated at the working resistor, which is led through a decoupling capacitor to be processed in the appropriate electronic unit (amplifier, counter, integrator) – thus the detection of the quantum of the respective ionizing radiation is realized by converting it into an electrical pulse. The resulting electrical pulses have the same size and shape, regardless of the type and energy of the detected quantum.

The discharge that occurs when a particle is detected in the space between the electrodes must be interrupted as soon as possible because no further particles can be registered during the discharge. Two circumstances are involved in the interruption of the discharge. The first is the voltage drop across the relatively high working resistance (on the order of MΩ), which reduces the voltage across the electrodes and limits the production of secondary electrons. However, in the ionized gas charge, recombination of ions and de-excitation of excited atoms occurs, with the emission of ultraviolet photons. The UV photons are able to ionize and photoeject additional electrons from the cathode, which tends to prolong the discharge. Therefore, an extinguishing agent (usually methyl alcohol vapour, bromine, etc.) is added to the gas charge, whose molecules absorb the UV photons and thus contribute to the rapid interruption of the discharge.

Detector dead time – During the duration of the avalanche discharge in the GM tube, the detector is insensitive to other incoming quanta. The time from the registration of one pulse until the detector is unable to register further pulses is called the detector dead time, denoted by τ and measured in microseconds. For GM detectors, the dead time is on the order of 10^{-4} seconds, i.e. $\tau \cong 100\ \mu s$ (which is quite a long dead time!), for scintillation detectors it is often shorter than 1 μs. The dead time causes that not all interacting quanta of radiation are detected, but there is some loss of detected pulses, and this loss due to dead time increases with the frequency (flux) of the quanta of radiation being measured. Instead of the actual average input (theoretical) frequency N [imp./s] of incoming radiation quanta, we measure the registered pulse frequency n [imp./s], with $n < N$.

There are two types of dead time (non-paralyzable and paralyzable) depending on the type of detector. The non-paralyzable dead time is characterized by the fact that during this dead time the detector does not detect the incoming particles, while these particles have no effect on its operation, and after the dead time the detector is immediately ready to detect the next pulse. Paralyzable dead time (also called cumulative dead time) is such that not only does the detector not detect any more particles during this dead time, but each such particle that flies into the detector during the dead time will again extend its insensitivity by the same amount of time – it "paralyzes" the detector's operation, the dead time "accumulates".

We can determine the dead time by the two-beam method. Suppose that in a unit of time N particles pass through a computer whose dead time is t_D, of which only n are registered. It is true that $n < N$, in other words after each registered particle the GM counter is insensitive for t_D. If we do not consider the overlap of the individual counting times, when n particles are registered, the GM counter is insensitive for $n \cdot t_D$, so the time the computer is able to register pulses is $1 - n \cdot t_D$. Thus, the ratio between the number of particles passed and registered per unit time is

$$\frac{N}{n} = \frac{1}{1 - n \cdot t_D} \tag{1}$$

The real particle count, which pass through GM counter in unit of time can be expressed:

$$N = \frac{n}{1 - n \cdot t_D} \tag{2}$$

The principle of the two-emitter method is to compare the number of pulses registered from two identical emitters, first measuring the number of pulses registered from each emitter separately, then from both simultaneously. It is necessary that both emitters have approximately the same parameters. If N_1 and N_2 are the number of particles that hit the computer from emitters 1 and 2, the number of particles that hit the computer from both emitters simultaneously will be

$$N_{12} = N_1 + N_2 \tag{3}$$

If the number of pulses registered from the first emitter is n_1 and from the second emitter n_2, then by substituting relation 3 into relation 2

$$\frac{n_{12}}{1 - n_{12} \cdot t_D} = \frac{n_1}{1 - n_1 \cdot t_D} + \frac{n_2}{1 - n_2 \cdot t_D} \tag{4}$$

By expressing t_D from this equation and neglecting t_D^2 (a very small number), we get the relationship for calculating the dead time

$$t_D = \frac{n_1 + n_2 - n_{12}}{2 \cdot n_1 \cdot n_2} \tag{5}$$

If the background cannot be neglected in relation to the measured abundances, its value must be subtracted from the measured abundances. For a background value of n_P, we then calculate t_D as:

$$t_D = \frac{n_1 + n_2 - n_{12} - n_P}{2 \cdot (n_1 - n_P) \cdot (n_2 - n_P)} \quad (6)$$

Measurement procedure

1) Measure the background value several times n_P.

2) Measure several times the frequency of pulses n_1 with the first emitter and the frequency of pulses n_2 with the second emitter.

3) Similarly, measure the frequency of pulses n_{12}. from both emitters simultaneously (Fig. 1). Make sure to keep the same geometry of the experimental setup!

4) Calculate the computer dead time t_D according to relation 5 and 6. Compare the results.

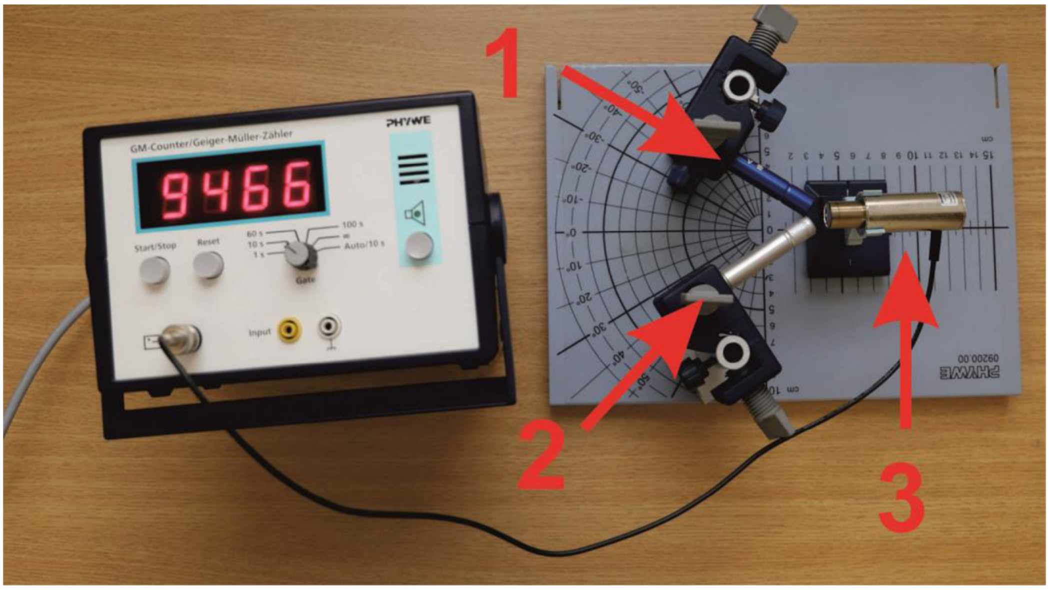

Figure 1: Example of the geometry of the experimental setup
1 - Source 1, 2 - Source 2 and 3 - Detector

Reference:

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