KAZAN FEDERAL UNIVERSITY
INSTITUTE OF PHYSICS

DETECTING RADIOACTIVITY

RECORDING THE CHARACTERISTIC OF A GEIGER-MÜLLER COUNTER TUBE

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Destination:

The methodical guide is intended for students of the Institute of Physics, Institute of Geology Petroleum Technologies, as a support to the general physical practicum to the courses «Physics of particles and atomic nuclei», «Nuclear physics» and «Physics».

Introduction

Radioactivity is the process in which unstable atomic nuclei spontaneously decompose to a nuclei with a higher stability by release of energetic sub-atomic particles (α-, β-, γ-photons). The above definition tells us that radioactivity is a random or spontaneous naturally occurring process. The process cannot be influenced by external factors such as heat, pressure or exposure to a magnetic field. This showed not be confused with the radiation that arises from nuclear fission in nuclear power stations. Here the fission is not spontaneous but triggered in a nuclear reactor by the bombardment of neutrons. Secondly, it occurs in unstable atoms or, more accurately, unstable isotopes called radioisotopes. These atoms are unstable because of unbalanced nuclear forces within their nuclei.
The sub-atomic particles and their associated energy, that are released during the decomposition of the unstable nuclei, are referred to as radiation.

There are 3 main types of radiations:

- Alpha particles
- Beta particles
- Gamma rays

Alpha particles are released by high mass, proton-rich unstable nuclei. The alpha particle is a helium nucleus; it consists of two protons and two neutrons. It contains no electrons to balance the two positively charged protons. Alpha particles are therefore positively charged particles moving at high speeds.
Beta particles are emitted by neutron-rich unstable nuclei. Beta particles are high energy electrons. These electrons are not electrons from the electron shells around the nucleus, but are generated when a neutron in the nucleus splits to form a proton and an accompanying electron. Beta particles are negatively charged.
Gamma rays are electromagnetic waves of very short wavelength and high frequency. Gamma rays are emitted by most radioactive sources along with alpha or beta particles. After alpha or beta emission the remaining nucleus may still be in an excited energy state. By releasing a gamma photon it reduces to a lower energy state. Gamma rays have no electrical charge associated with them.
Radioactivity was discovered by A. H. Becquerel in 1896. The radiation was classified by E. Rutherford as alpha, beta, and gamma rays according to their ability to penetrate matter, ionize air and interact with electromagnetic field. Because ionizing radiation is harmful to human and other organisms, it is very important to be able to detect it and measure how much it is present. Such measurements are complicated by two factors. First, we cannot see, hear, smell, taste, or touch radiation, and so special instruments are required to measure it. Second, different types of radiation are more dangerous than others, and corrections must be made for the relative harm done by α particles as opposed to, say, γ rays. At the same time α-, β-, γ- radiations are all ionizing radiations. This means that all three forms of the radiations have enough energy to pull electrons from atoms turning them into ions. The Geiger-Muller (GM) tube makes use of this fact. It detects the emission of nuclear radiation - α-, β-particles, and γ-gamma rays — by the ionization produced in a low-pressure gas in a GM tube.

Geiger-Muller tube

Until today the Geiger-Müller counter tube, developed in 1928 by Hans Geiger and Walther Müller (a PhD student of Geiger) is an indispensable tool for detecting radioactivity. It even registers radiation with minute ionizing power. The tube has a property of being able to amplify each ionization event by means of the ***Townsend avalanche effect***, and produces an easily measured current pulse which passes to the processing electronics. It is the basic physical phenomenon making Geiger-Müller tube a widely used instrument in radiation dosimetry, health physics, experimental physics, nuclear industry, geological exploration and other fields, due to its robust sensing element and relatively low cost. However, there are limitations in measuring high radiation rates and in measuring the energy of incident radiation.

A Geiger-Muller tube consists of a sealed metallic tube filled with argon or another noble gas mixed with a small amount of alcohol vapour or bromine gas. The argon gas is called the *detecting gas* whereas the bromine gas or alcohol vapour are referred to as the *quenching gas*. The gas mixture inside the tube is at a pressure below atmospheric pressure (~ 100 mbar). A thin metal wire runs through the centre of the tube (Fig. 1). An electric potential of up to several hundred volts is maintained between the metal wire (the anode) and the cylinder (the cathode).

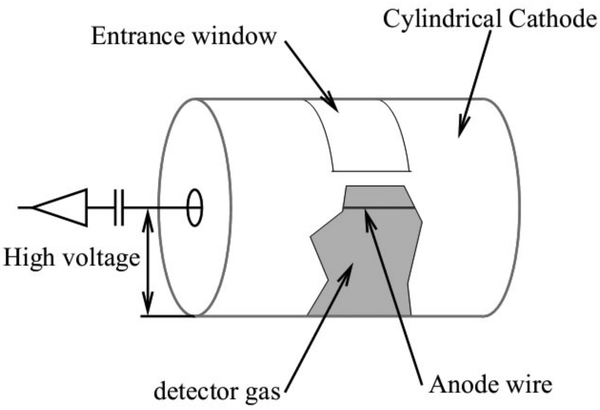

Figure 1. Schematic diagram of a Geiger-Müller tube.

Behavior of gas-filled detectors

Current in the external circuit of gas-filled detectors is governed by conductivity of the gas inside the tube and consequently by its ionization.

If none of the gas molecules are ionized, the gas behaves as an insulator and no current flows in the external circuit, in other words, in the absence of any radiation no current flows between the wire and the cylinder.

If some of the gas molecules are ionized by a particle or radiation quantum having recently entered the detector, some current could flow. The immediately subsequent events, however, depend on the electric field applied between the electrodes:

- If the field is weak, newly-produced ions and electrons simply recombine.
- If the electric field is high enough, the positive ions and the electrons become fully separated, being attracted towards the electrodes. Those ions that reach the cathode will be neutralized by electrons from the cathode. These transfers of electrons, and the arrival of electrons at the anode, cause a current pulse in the external circuit. Provided that sufficient ions and electrons arrive more or less simultaneously, the current pulse can be detected by sensing the associated voltage across the resistor in the external circuit.

Figure 2 shows the characteristic curves for gas-filled detectors subjected to radiation. The form of this curve does not depend on the type of radiation (α-, β-, γ-), the energy of radiation and is mainly determined by:

- the design of the detector;
- the gas used;
- the gas pressure.

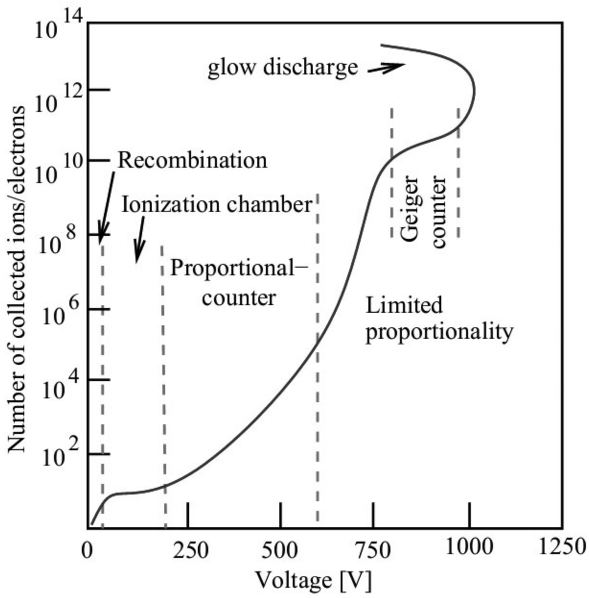

Figure 2. Variation of charge collected due to ionizing particles as a function of the applied voltage.

Both the radiation permeability and the thickness of the window material of GM tube determine the energy threshold for radiation particles (α-, β-, γ-), which can penetrate into the volume of a tube and can be detected by the counter.

In general, however, the increasing voltage reveals five regions (see Fig. 2).

The low electric field in the *recombination region* has negligible effect. Most ions recombine and current is small. Detectors do not usually operate in this region.

Separated ions and electrons are forced to drift towards the electrodes in the *ionization chamber region*, and because recombination is delayed or prevented, many of them reach the electrodes. Current in this region depends almost exclusively upon the number of ions generated by the radiation, and is almost independent on the exact value of the applied voltage. Ionization chambers operate in this region.

In the *proportional-counter region*, electrons are accelerated to high velocities and produce secondary ions by collisions, leading to a multiplication of charge. Particles moving through the counter can produce a large current and voltage pulse in suitable circuitry, with an amplitude proportional to the energy of the ionizing particles. Proportional counters operate in this region. The ion multiplication gains of up to 10^6 are attainable in this regime of operation.

The upper end of the *proportional-counter region* is generally known as the *region of limited proportionality*, where the output becomes more dependent on applied voltage than on initial ionization.

The ion multiplication escalates in *Geiger counter region* and, in the ensuing *avalanche*, virtually all primary and secondary electrons are accelerated sufficiently to create more secondary and ternary ions. Though the detector can no longer distinguish between the different kinds of radiation or between different energies in this region, the detection sensitivity is excellent. Geiger-Müller tubes operate in this region which is also often called the ***Geiger-Müller plateau***.

Further escalation of the avalanche in the *glow discharge region* produces total ionization of the gas between the electrodes. A self-sustaining discharge, which will continue as long as a voltage is applied, can be instigated by a single pulse. This type of discharge can be harmful to the detector and lengthy operation in this region should be avoided.

Operation of Geiger-Müller tube

All Geiger-Müller tubes are designed to operate under the conditions of Geiger counter region (Fig. 2).

When a particle or an energy quantum enters the detection gas (usually neon, argon, or helium, and sometimes krypton), some initial gas ionization may occur, creating electrons and positive ions. If correct operating voltage is applied to the tube, electrons in the gas near the anode, and positive ions in the gas near the cathode, are collected almost instantaneously. The remainder of the electrons and ions, together with products of the ion multiplication, follow in rapid succession. The resulting current pulse produces a fast-rising voltage pulse across the series resistor chain in the external circuit, and the pulse can be detected by a “scaler” or counter.

The main energy for the discharge is derived from the self capacitance of the tube and from stray capacitances. When these are significantly discharged, the tube current collapsed and gas de-ionization follows. While this de-ionization continues, the recharging of the capacitances gives an almost exponential tail to the pulse in the external circuit, the rate of the fall depending on the RC values.

When the primary discharge is completed, residual positive ions drift towards the cathode and recombine with electrons from the cathode surface. Residual positive ions near the anode weaken the field strength temporarily, and this reduces the tube sensitivity for a short period after each discharge.

Together with detecting gas selected for the discharge, a small amount of additional *quenching gas* is also included.

If the tube were allowed to operate as outlined above, then the impact of some of the residual high energy positive ions on the cathode cause of some secondary electrons. These newly-released electrons would be accelerated towards the anode, and the subsequent high energy collisions with gas atoms would trigger a spurious repetition of the discharge.

This process would be repeated several or many times, and so a string of spurious discharges would follow the single ionization. Such triggering or oscillation is avoided by the addition of a *quenching gas*.

The quenching gas has an ionization potential less than that of the main detection gas. De-ionization of the main gas is hastened because the slow-moving residual ions of the main gas combine with electrons taken from the quenching gas. The newly-

formed positive ions of the quenching gas drift towards the cathode, and on impact they are merely neutralized, there having insufficient total energy to cause emission of the secondary electrons.
Figure 3 shows a simplified version of part of the characteristic curve of a Geiger- Müller tube. This characteristic is obtained by plotting the count rate in pulses per second as a function of the supply voltage in a constant radiation field. Note that the constant radiation field strength used for obtaining this curve is fixed so that a rate of 100 to 300 counts per second is obtained at the operating voltage (the centre of the Geiger-Muller plateau). The main features of this characteristic are given in Fig. 3.

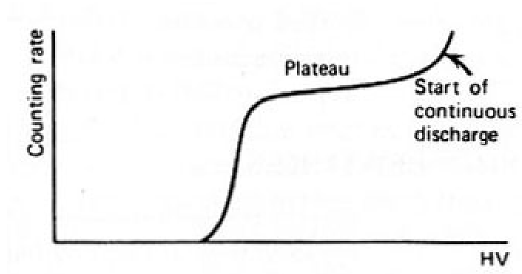

Figure 3. Characteristic curve of a Geiger-Müller tube showing the counting rate as a function of the applied anode high voltage (HV).

Experimental Setup

Note:
The window of the end-window counter (12-15 μm mica) can easily be damaged mechanically. If the window is damaged the end-window counter tube is rendered unusable:
Do not touch the mica window; store end-window counter only with protective cover in place. Remove the protective cover for making measurements only. Carefully remove and replace the protective cover without twisting and without covering the air hole.
If the operating voltage is too high, the end-window counter will be damaged by self-activated gas discharge:
Do not permanently exceed the maximum operating voltage of 650 V.

The setup for the experiment is shown in Fig. 4. One consists of end-window counter 3 for α-, β-, γ- and X-rays, digital counter 2, radioactive source 1 (see Fig. 4).
Undesignated apparatuses in Fig. 4 are related to other laboratory work.

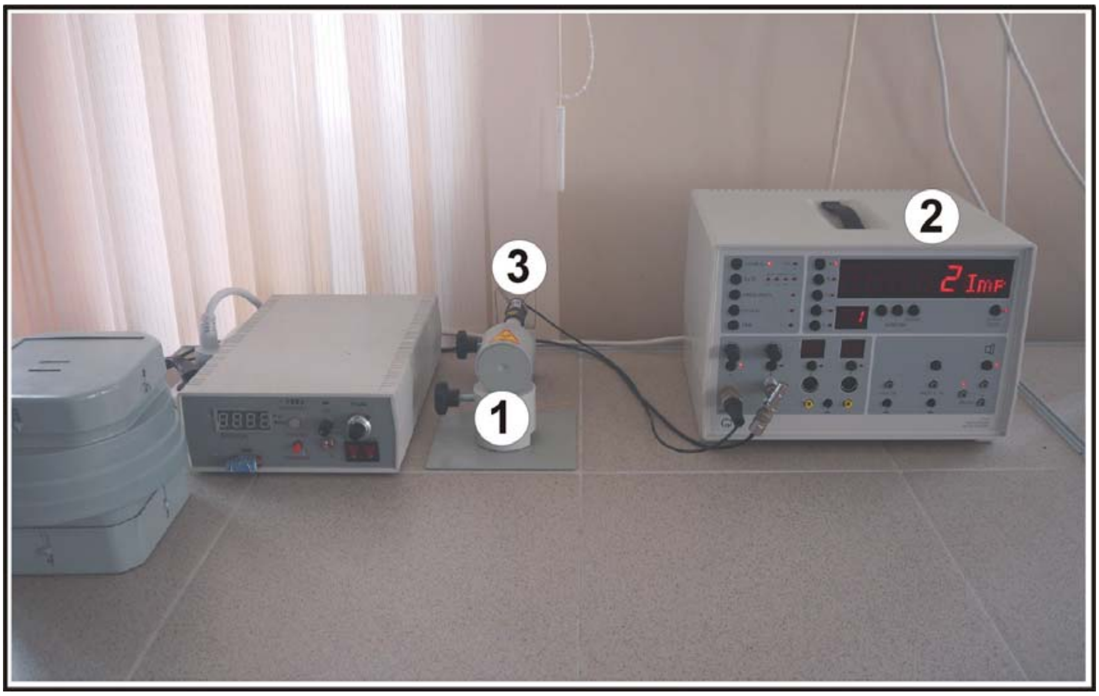

Figure 4. Experimental setup. 1 – shielded radioactive source; 2 – digital counter module; 3 – Geiger-Müller tube.

Carrying out the experiment

- Make sure that end-window counter 3 is fastened with the brackets and connected to inlet A of the digital counter 2.
- Carefully guide radioactive source (^{226}Ra) to a distance of about 1 mm from the end-window counter.
- Switch on the digital counter or, if available, push the button A.
- Switch on the loudspeaker, once press the button Rate (gate time: 1 sec) and press the button Start/Stop.
- To reduce the potential of the counter tube, turn the potentiometer A to the left until the acoustic signal disappears and the display shows zero; read the voltage of the counter tube in the measuring display and record as Geiger threshold U_0.
- Reduce the counter tube voltage by about 100 V and press again the button Rate in order to raise the gate time to 10 sec.
- Start the counting rate measurement with the button Start Stop; after the gate time has passed, read the counting rate *R,* and record it together with the counter tube voltage *U*.
- Push the button Start Stop to stop counting rate measurement, raise the counter tube voltage by 40 V and restart counting rate measurement.
- To record additional measurements raise the counter tube voltage to a total of 640 V (choose small increments in the range of the Geiger threshold U_0).
- Widen the distance between the radioactive source and the counter tube to 10 mm or 20 mm and record additional series of the measurements.

Measuring example

Optimal operating voltage: U = 400 V.

Table 1. Counting rate *R* as a function of the counter tube voltage *U* at three different distances *d* between the preparation and the counter tube.

	d = 1 mm	d = 10 mm	d = 20 mm
$\frac{U}{V}$	$\frac{R}{s^{-1}}$	$\frac{R}{s^{-1}}$	$\frac{R}{s^{-1}}$
240	0.0	0.0	0.0
280	0.0	0.0	0.0
320	0.0	0.0	0.0
352	0.0	0.0	0.0
356	0.2	0.8	0.4
360	526.2	307.6	101.1
364	1012.4	627.0	149.1
368	1090.7	690.3	146.2
372	1156.7	691.6	145.0
380	1132.6	725.9	148.9
400	1220.4	727.7	145.4
440	1210.4	732.2	156.6
480	1223.1	743.2	152.6
520	1224.6	744.9	150.9
560	1205.1	737.3	153.0
600	1191.8	740.6	152.5
640	1219.4	747.8	154.9

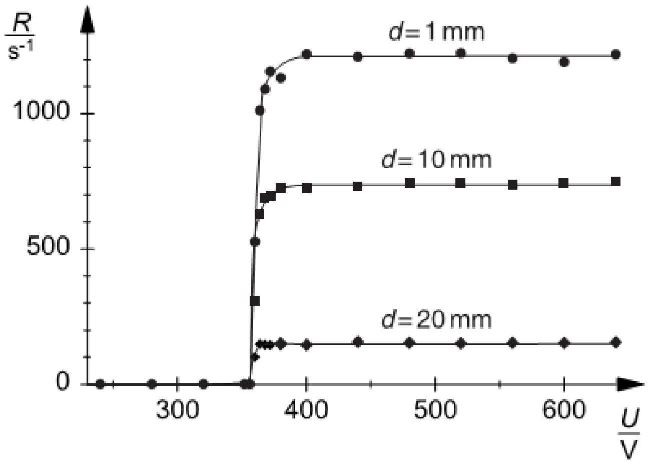

Figure 5. Characteristic of the counter tube (counting rate *R* as a function of the counter tube voltage *U*) at three different distances between the preparation and the counter tube.

Evaluation and results

The Geiger threshold is approx. 356 V. Between 380 V and 640 V the counter tube works as Geiger-Müller counter tube. The characteristics of the counter tube show a plateau. The counting rate on that plateau depends, for instance, on the distance between the radioactive source and the counter tube, i.e. on the activity at the location of the counter tube.

Report

Analyze the data obtained and determine position and width of the plateau of the Geiger-Müller tube. Represent the results in print including all estimations and graphs in arbitrary form.

Safety notes

The following safety rules must nevertheless be kept to:

- Prevent access to the preparations by unauthorized persons.
- Before using the preparations make sure that they are intact.
- For the purpose of shielding, keep the preparations in their safety vessel.
- To ensure minimum exposure time and minimum activity, take the preparations out of the safety vessel only as long as is necessary for carrying out the experiment.
- To ensure maximum distance, hold the preparations only at the upper end of the metal holder and keep them away from your body as far as possible.

Self-test problems

1. What is Geiger-Müller counter?
2. What are physical phenomena initiated by passage of an ionizing particle in the GM tube in the working range of voltages?
3. How does Geiger-Müller counter work?
4. Clarify the meaning of ionizing radiation (radioactivity).
5. Describe what kinds of ionizing radiation are possible to detect by Geiger-Müller counter.
6. Show and explain the characteristic curve for Geiger-Müller counter.
7. What factors do determine the energy threshold of GM tube?
8. Are there limitations in measuring high radiation rates or in measuring the energy of incident radiation by Geiger-Müller counter?
9. Explain how the counting rate for Geiger-Müller counter should be changed with decreasing/increasing of *distance between the radioactive source and the Geiger-Müller counter.*
10. Explain how the counting rate for Geiger-Müller counter should be changed with decreasing/increasing of *activity of the radioactive source*.

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РЕЦЕНЗИЯ

на учебно-методическое пособие

Вагизова Ф.Г., Дулова Е.Н., Гайнова Р.Р.

«Detecting radioactivity. Recording the characteristic of a Geiger-Müller counter tube »

Рецензируемое учебно-методическое пособие «Detecting radioactivity. Recording the characteristic of a Geiger-Müller counter tube» разработано авторами в рамках общефизического лабораторного практикума к лекционным курсам «Ядерная физика», «Физика ядра и частиц» и «Атомная и ядерная физика», и предназначено для англоязычных студентов, проходящих ядерно-физический практикум на материально-технической базе лаборатории ядерной физики кафедры ФТТ Института физики КФУ.

Пособие начинается с обзорной вводной части, в которой даются основные представления о природе радиоактивности, видах ионизирующего излучения (α-, β- и γ-излучение). Рассмотрены основные режимы работы газонаполненных детекторов, приведено описание конструкции счетчика Гейгера-Мюллера, и особенности работы в режиме Гейгера-Мюллера. Затем следует часть с описанием экспериментальной лабораторной установки, в которой показаны основные узлы и их назначение. Далее приводится описание порядка выполнения работы, даются рекомендации по анализу и представлению экспериментальных результатов.

Практическая часть задания даёт наглядное представление о физических процессах, происходящих в газонаполненных детекторах. Выполнение лабораторных заданий по экспериментальному определению порога срабатывания и оптимального рабочего напряжения счетчика Гейгера-Мюллера, несомненно, будет полезным для получения навыков работы на установках по регистрации ионизирующего излучения.

Рецензируемое пособие актуально и представляет несомненный интерес для преподавателей и студентов, сталкивающихся с регистрацией ионизирующего излучения в учебной и научно-исследовательской работе.

Считаю, что учебно-методическое пособие Вагизова Ф.Г., Дулова Е.Н., Гайнова Р.Р. «Detecting radioactivity. Recording the characteristic of a Geiger-Müller counter tube» может быть рекомендовано в качестве пособия для англоязычных студентов.

В.н.с. КФТИ КазНЦ РАН,
д.ф.-м.н. Шахмуратов Р. Н.

КАНЦЕЛЯРИЯ
ОГРН 1021603630025
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ЗАВЕРЯЮ
ПОДПИСЬ Шахмуратова Р.Н.
Зав.канцелярией КФТИ КазНЦ РАН
Л.Г. Куркина

ВЫПИСКА ИЗ ПРОТОКОЛА № 9
от 18 декабря 2013
заседания Учебно-методической комиссии Института физики КФУ

ПРИСУТСТВОВАЛИ: проф. Таюрский Д.А. (председатель комиссии), доц. Шерстюков О.Н. (зам. председателя комиссии), Хуснутдинов Н.Р., Ильясов К.А., Воронина Е.В., Тюрин В.А., Корчагин П.А., Дуглав А.В., Мокшин А.В., Гарнаева Г.И., Шиманская Н.Н., Соколова М.Г.

СЛУШАЛИ: рекомендацию в печать методического пособия «Detecting radioactivity – Recording the characteristic of a Geiger-Mueller counter tube» (авторы: Вагизов Ф.Г., Дулов Е.Н., Гайнов Р.Р.)

ПОСТАНОВИЛИ: на основании положительной рецензии к.ф.-м.н., ведущего научного сотрудника КФТИ им. Е.К. Завойского КНЦ РАН Шахмуратова Р.Н. рекомендовать вышеуказанное методическое пособие к опубликованию в электронном виде на сайте Института физики.

Председатель Учебно-методической комиссии
Института физики, профессор Таюрский Д.А.