PHYS 3650L - Modern Physics Laboratory

Laboratory Advanced Sheet

Geiger-Müller Counting System

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1. Objectives. The objectives of this laboratory are to

a. Be able to connect the electronic components that make up a Geiger-Müller counting system and place the system in operation.

b. Understand how to produce a Geiger-Müller characteristic curve, and how to use it to determine the operating potential for the tube and to evaluate the quality of the tube.

c. Understand how to measure the resolving time of a Geiger-Müller counting system using the split source method.

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2. Theory.

a. General. A Geiger-Müller counting system consists of a gas-filled tube which serves as the detecting medium and electronic components to process the signal produced by the interaction of radiation in the tube. The Geiger-Müller tube (GMT) consists of two electrodes: a metal wire, the anode, surrounded by a hollow conducting cylinder, the cathode.
The two electrodes are enclosed in a metal cylinder. The gas filling the cylinder is normally a mixture of an inert gas (Ar or Ne) and a quenching gas (an alcohol or halogen).
The gas mixture is maintained at a pressure of approximately 100 mm of Hg. An electrical potential difference is maintained between the two electrodes.
Many GMT's have a thin entrance window to allow weakly penetrating radiations to be detected.

b. Pulse formation. When ionizing radiation interacts in the GMT, ion pairs are produced. The electrons are accelerated rapidly toward the positively charged central anode. This rapid acceleration is due both to the low mass of the electron and the strong electric field near the anode. The more massive positive ions move more slowly to the cathode. The rapidly accelerated electrons gain enough kinetic energy to produce secondary ionizations in the Geiger gas. Production of visible and ultraviolet photons spread the production of secondary electrons throughout the entire sensitive volume of the tube. Charge is collected on the anode for a short period of time constituting a current pulse. The pulse ends when the concentration of slowly moving positive ions becomes large enough to lower the strength of the electric field in the tube to levels below which secondary ionizations no longer take place. The current pulse, when passed through a resistor, is converted to a voltage pulse. Because the number of positive ion pairs required to end a pulse is the same for any event in the tube, all pulses produced with a fixed potential difference on the tube are of the same size, regardless of the type of particle that initiated the event or the amount of energy it deposited in the tube.

c. Characteristic curve. The lowest applied potential difference at which this pulse size limiting effect takes place is called the GM threshold. As applied potential is increased above the threshold, pulse heights first rise rapidly and then more slowly. The region of slow increase in pulse heights with increasing applied potential corresponds to a feature known as the GM plateau in the characteristic curve. The characteristic curve is a graph of the count rate produced by the GM tube exposed to a radiation source as a function of applied potential difference. The operating potential for the GMT is normally chosen at a voltage approximately one-third of the way along the plateau from its lower end. The slope of the GM plateau is an indicator of the quality of the GMT. The slope is defined as the percent change in count rate per 100 V change in potential applied to the tube. A high quality GMT will have a plateau slope of 1 to 4% per 100 V. A tube with a plateau slope of less than 10% per 100 V is adequate for many applications. The GM plateau slope is calculated using the following formula:

$$GM\ slope = \frac{(2\times 10^{4})(R_2 - R_1)}{(R_2 + R_1)(V_2 - V_1)}\ \frac{\%}{100\ V} \quad (1)$$

At even higher potentials, spontaneous discharge in the tube will cause a rapid increase in count rate. Such count rates are not related to the interactions of radiation and will damage the GMT.

d. Resolving time. The cloud of positive charge created near the anode after radiation interacts in the tube not only terminates the pulse formation (as discussed above), it also prevents a pulse being formed by another ionizing interaction until the cloud has moved far enough from the anode to allow the electric field strength to increase to a level capable of causing secondary electrons to be produced. The time period during which no pulse can be produced is known as the dead time. During the period of time when the electric field strength is increasing after a dead time period but has not yet reached its full value, smaller pulses may be produced. The timer-counter normally will include a discriminator circuit that will reject pulses until they exceed the value of the discriminator setting. The time period during which either no pulse is being produced (dead time) or pulses are too small to be counted is known as the resolving time. The minimum time between two pulses of full size is known as the recovery time. During the resolving time, radiation interactions in the GMT are not counted and a correction must be applied to determine the true count rate. The resolving time can be determined using the split source method. Two sources are counted independently and then together in the same geometry. It can be shown that

$$T = \frac{X(1-\sqrt{1-Z})}{Y} \tag{2}$$

where

$$X = R_1 R_2 - R_{12} R_b$$

$$Y = R_1 R_2 (R_{12} + R_b) - R_{12} R_b (R_1 + R_2)$$

$$Z = \frac{Y(R_1 + R_2 - R_{12} - R_b)}{X^2}$$

where R_1 is the count rate produced by source 1,
R_2 is the count rate produced by source 2,
R_{12} is the count rate produced by both sources counted at the same time, and
R_b is the background count rate.

Assuming a nonparalysable model of resolving time behavior, the corrected count rate is given by:

$$R = \frac{R'}{1 - R'T} \tag{3}$$

where *R'* is the uncorrected count rate, and
R is the count rate corrected for the effects of resolving time.

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3. Apparatus and experimental procedures.

a. Equipment.

1) Geiger-Müller tube with sample holder.

2) Radiation counter.

3) Radioactive source.

4) Resolving time set.

b. Experimental setup. To be provided by the student.

c. Capabilities. To be provided by the student.

d. Procedures. Detailed instructions are provided in paragraph 4 below.

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4. Requirements.

a. In the laboratory.

1) Your instructor will introduce you to the Geiger- Müller counting system.

2) Perform the characteristic curve measurements changing the applied potential in 25 V increments.

3) Plot the characteristic curve and determine the operating potential.

4) Perform the measurements for the determination of the resolving time using the split source method.

b. After the laboratory. The items listed below will be turned in at the beginning of the next laboratory period. A complete laboratory report is **not** required for this experiment.

Para 3. Apparatus and experimental procedures.

1) Provide a figure of the experimental apparatus (para 3b).

2) Provide descriptions of the capabilities of equipment used in the experiment (para 3c).

Para 4. Data. Data tables are included at Annex A for recording measurements taken in the laboratory. A copy of these tables must be included with the lab report. Provide the items listed below in your report in the form a Microsoft Excel™ spreadsheet showing data, calculations and graphs. The spreadsheet will include:

1) Threshold potential and counting time for the characteristic curve measurements.

2) A table with columns for applied voltage and corresponding counts.

3) A graph of the counts vs. applied voltage.

4) A calculation of the slope of the GM plateau and operating potential.

5) A table with data from the resolving time measurements.

6) A calculation of the resolving time.

Para. 5. Results and Conclusions.

a. Results.

1) A statement providing the operating potential for your GM system.

2) A statement providing the slope of the GM plateau.

3) A statement providing the values determined for the resolving time at both applied potentials.

b. Conclusions.

1) Your interpretation of the meaning of the slope of the GM plateau in terms of the quality of the GM tube you used.

2) An explanation for the difference in the values of the resolving times at the two applied potentials.

Annex A
Data

2. Characteristic curve measurements

Counting time: 50 s.

Threshold potential: ______________________________ V

applied potential (V)	counts/50 s	applied potential (V)	counts/50 s

Operating point: ________________________ V

3. Resolving time measurements.

Operating potential: ________________________ V

quantity measured	counting time (s)	applied potential (V)	
		operating potential	1200 V
R_1	100		
R_{12}	100		
R_2	100		
R_b	400		