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Radiation Detection with G.M. Counter: A Brief Review

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ABSTRACT The paper aims to present a brief and focused review regarding the mechanism of detection of radiation with GM Counter and the developments made in this field over the time since the advent of this Gas detection system. The work done in the field till now is discussed to showcase the key features of G.M. detector explored till date. This comprehensive review will stress on the significant developments in the radio-active radiation detection with GM Counter and a conclusive view-point regarding all the investigations performed in this regard. A theoretical perspective, along with the overview of recent investigations and related discussion highlighting the present understanding based on available investigations of radiation detection with G.M. counter is also presented in a systematic manner. Overall, the manuscript aims to showcase the fundamental features of G.M. counter detector system as well as provides overview regarding present understanding of the concept based on the research work available in the literature.

KEYWORDS Radioactivity, GM Counter.

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INTRODUCTION

Many years back the scientific community was fascinated by the phenomenon of emission of highly energetic radiation from the nucleus with high penetration power and other distinguished characteristics. This emission of highly energetic radiation from the nucleus is termed as - radioactivity. It is considered to be a random phenomenon in which the nucleus (combination of neutrons and protons), especially the isotopes of some elements with less stability showcase a unique property of emitting radio-active radiation. This highly energetic radiation is emitted from nuclei with transformations taking place from inside the nuclear matter which further depends on the stability factor of nuclei. Nucleus with lesser stability (which depends on the configuration of neutron proton content) has the tendency of radioactive emission in order to acquire a much stable configuration. In simple language, the stability depends on the neutron and proton content. In nuclei if configuration based on relative number of neutrons and protons does not satisfy a minimum binding energy constraint then it could result in this random phenomenon. The N/Z ratio (N = neutrons and Z = protons), are the components which determine the interplay of symmetry energy and coulomb energy in a nuclei, which decides the stability of nuclei on the basis of binding energy.

The GM Counter is an excellent detector to detect the radioactive radiation. The GM Counter at initial stages was a detector which consist a gas containing tube. This was a kind of detector which was based on the principle of ionization caused by incident radiation on the gas containing chamber of detector as describe by Geiger and Muller in 1928 [1]. The ionization (current pulse) could be amplified and could yield information about the radiation. Along with the imprints of highly energetic radiation, GM Counter could also provide somewhat information of radiation sample and attenuation coefficient (absorption of radiation) of materials which have the tendency to absorb nuclear radiation. Over the time, many investigations and modifications, transformed it into the present age G.M. counter, which has contributed a lot towards the detection of radio-active radiation. This review article aims to highlight and discuss the key developments in the G.M. counter since it came into picture as a device to indirectly detect the radiation by ionization mechanism (especially alpha and beta particles). We shall also discuss the few important aspects and review the investigations related to G.M. Counter. The topics and investigations discussed in the paper may not be exhaustive as a lot of work is done in this domain. However, we aim to shed light on the most of the crucial developments, related to its characteristics such as dead time calculations, operating voltage selection, role of temperature and other effects on its detection efficiency. In current times, we have quite a good information available regarding the external factors (like temperature) and internal factors (like manufacturing types, shapes of cylinder, and gasses inside it) affecting the precision of detection of radiation. In addition, it is evident that the technical part including the dead time calculation, choice of operating voltage also affect the detection of radiation [2,3].

For an accurate detection of radiation the detector output ought to be least dependent of the detector properties. Also, there should be least dependence of electric pulse on the external factors. The external factors like background radiation and temperature may yield a bigger electric pulse as the ionization gets affected. If the external factors enhances or reduces the ionization, we may end up getting a larger or smaller pulse which may not represent the actual ionization produced by the incident particle. In such a case, a non-realistic picture of the radiation will shadow over the realistic imprint of the radiation. We shall try to discuss all such investigations and conclude the output based on all investigation to provide the main features and key aspects of radiation detection with G.M. Counter. It will help the new researchers to have a first-hand information on the radiation detection mechanism after getting glimpse of the investigations performed in this domain.

UNDERSTANDING G. M. COUNTER

G.M. Counter in present days is one of the most extensively used detectors to measure and detect the high energy radiation emitted from the nuclei. The major developments and investigations have provided must wider information about the external and internal factors effecting radiation detection. This understanding has directed us toward much authentic picture of radiation with G.M. counter apparatus. At initial stages, the G.M. Counter was a simple container in cylindrical form with an anodic wire put inside a container having a low pressure gas. The incident radiation (radiation or sample producing the radiation to be analyzed) produces ionization, which gets amplified by application of voltage. The pulse is detected due to high resistance attached outside with anodic wire [2,3].

In present times, the G.M. Counter has made advancements which we may discuss further in this article in detail. The application of voltage produces secondary ionization and the amplified signal will produce a pulse which will provide information on the radiation (highly energetic particle incident on G.M. Tube). Fig.1, provides information that how incident particle incident on the G.M. tube gets detected. The applied voltage from the external circuit will produce secondary ionization and increase the current. The variation of current output with applied voltage is shown in Fig. 2.

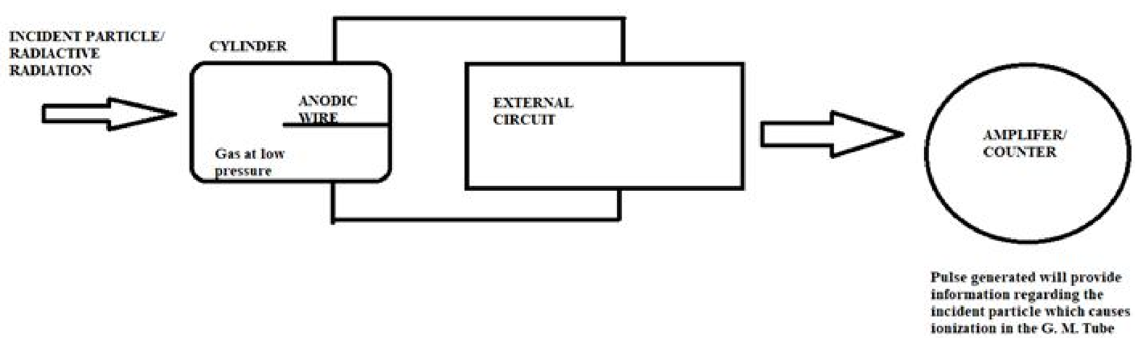

Figure 1: Simplistic block diagram of G.M. Counter detector

In G.M. Counter, the voltage from V_{x1} to V_{x2} is said to be the most accurate range of voltage because in this voltage range the pulse output (radiation picture) is least dependent of the applied voltage. GM Counter detection ability is gradually affected by the choice of operating voltage [3]. Nonetheless, the detection of radiation depends on the detector efficiency i.e. collection of electrons created by radiation (which further depends on the dead time interval in case of GM Counter). Lesser dependence on the choice of parameters of detector in detector output will provide much authentic information about the radiation [2-4]. Various attempts have been made to find the most appropriate value of operating voltage to acknowledge the actual count rate i.e. ionization produced by the radiation and not the affects based on external factors (temperature, background radiation) or internal factors like choice of G.M. Counter parameters [2-6]. Initially a two source method was devised which was commonly practiced to measure total dead time of radiation detection systems [5]. These methods were further modified by other researchers [5,6].

We would like to mention that long back a dead time determination study and related characteristics analysis was performed in Ref. [7]. GM tube or counter/detector system's dead time is signified as the minimum separation time between two independently recorded events [8].

The more the G.M. Counter output is independent of the value of applied voltage and dead time effects, much authentic and factual picture of radiation could be produced. Different values of operating voltage lead to different values of dead time, which further affects its tendency to explore other parameters like attenuation coefficient of radiation absorbing elements [2-4].

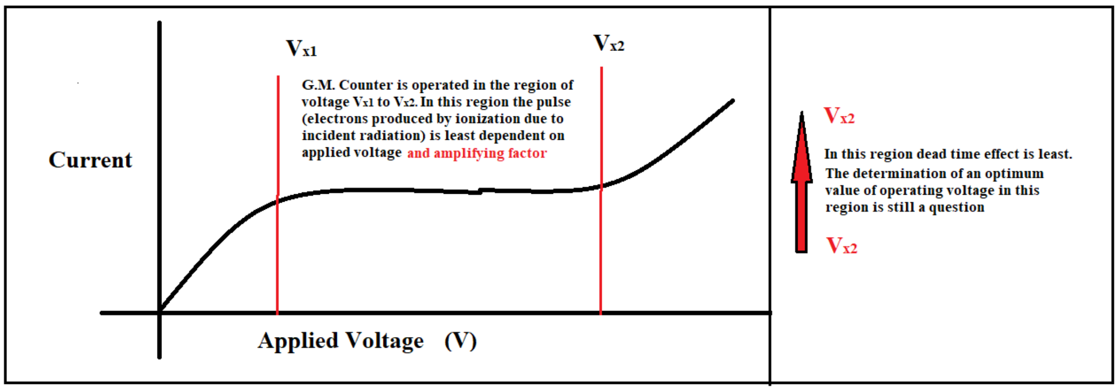

Figure 2: Current v/s applied voltage representing the basic illustration of G.M. Counter behavior. The operating voltage is chosen in the region from V_{x1} to V_{x2}

REVIEW OF EARLY DEVELOPMENTS

In 1928, when the G.M. Counter came into picture as a device to yield information about radiation emitted from nucleus many investigations over the century have explored many crucial aspects of G.M. counter. Efficient methods to detect much accurate picture of radiation are reported in the literature. Also, impact of many external factors affecting the measurement of radiation is also available in the literature. The oxidization of anode (negatively charged by heavy resistance R of external circuit) to cover it with poorly conducting layer was found to be unnecessary. The investigation with degassed electrodes was assumed to be more effective [2]. Investigations concluded that the voltages V_{x1} and V_{x2} (at the extremes where discharge takes place), shows that the discharge passes away when the voltage exceeds the later point [9-11]. The stable part between the two voltages is the region where the ionization will be least dependent on the external applied voltage. Choice of operating voltage affects the dead time, which influences the radiation detection time period (time during which anodic wire stops collecting electrons from anodic wire) and hence its efficiency to extract the realistic radiation picture. Many developments were made at that early time and in-depth investigations were performed with respect to the gasses and currents associated with the counter [12-16]. The gas characteristics and pressure inside the tube has a major role in functioning of G. M. Tube. The mono-atomic gasses like helium and argon have high ionization potential and are suitable at a given pressure at which G.M. Tube operates [14]. An investigation revealed that the mixture of neon and hydrogen is much satisfactory than either gas separately [15].

Further the mixture of Argon and alcohol vapor yielded much better results [16]. The beta ray efficiency for G.M. Counter was investigated [17, 18]. Further development was made to detect "dead time" using two source method [19]. The modifications in the fundamental circuit was proposed for much efficiency [20,21]. For the detection of highly ionizing particles like alpha particles, along with beta particles (for which G.M. counter is most effective), it was required to amplify the most primary ionization caused by the nuclear radiation. This was a much needed exercise to preserve the size of the particle and neglect the relatively high natural count of G.M. counter. Counter could be operated in certain voltage value, so that it acts as amplifier of the original ionization to distinguish the alpha particles from background of beta particles due to other radiation in external atmosphere [2]. To detect the different types of particles other than beta particles certain modifications were recommended [22-24].

Dead Time measurement:

The dead time is one of the most critical factors which affects the working mechanism and efficiency of G.M. counter. The counter intercepts the signal by providing ionization (electron count) information to the external circuit which further gets amplified to generate a considerable pulse. The pulse presents the picture of radiation (type and magnitude). The heavier ions produced by the primary and secondary ionization (due to applied voltage) move slowly and block the electrons carrying the radiation information from reaching anodic wire. This disrupts the transfer of real radiation picture before detection for a very short time period. Although the internal quenching (addition of alcohol or halogens) and external quenching (external circuit compensating the reduced electron count) help control the impact of dead time. Previous investigations have stressed on the topic of dead time which is very critical in the mechanism of radiation detection through G.M. counter.

A very comprehensive study with respect to dead time is available in Ref. [8]. Surveys and investigations pertaining to those initial times could provide preliminary information about dead time [25,26]. Few attempts regarding "dead time" calculation is available in literature [27-29]. An investigation for the accurate determination of dead time (time during which radiation detection is obstructed due to electrons path blocked by positive-ion sheath) during which and recovery characteristics emphasized on an electronic gating instrument [7]. In this communication, the dead time is described as the time interval after a pulse has occurred during which the counter is insensitive to further ionizing events. An investigation described a method to determine the dead time and recovery characteristics by Cathode Ray Oscilloscope (C.R.O) [7].Geiger tubes were said to have a dead time in the range 50 to 100 micro seconds. A comprehensive study regarding dead time is available in Ref. [30]. A hybrid G.M. counter dead time model was derived by combining two models [31].

Operating Voltage selection:

Till now it is evident that the choice of operating voltage affects the detection mechanism of G.M. counter considerably [3,4], The GM counter output must represent the ionization or magnitude of ionization initiated by the highly energetic radioactive beam. Although it need to be necessarily independent of the voltage applied to the GM tube. Operating voltage is postulated as an optimum state or pre-condition working environment for GM Counter at which the radiation detection/counts are considered as most authentic, correct and a direct reflection of the radioactive beam. The operating voltage is indeed a function of various other factors. Type of GM tube, manufacturer type and other working conditions such as temperature affect the operating voltage value [3]. A standard behavior of G.M. Counter output with respect to applied voltage is showcased in Fig. 2. The idea is to present the G.M. Counter detection under different working conditions. The voltage which is in stable region and not a part of the discharge region is chosen for detection of dead time and other parameters such as attenuation coefficient of materials [3,4]. Different methods could be taken into consideration to pinpoint a single value which could be the most appropriate value of voltage to be chosen as operating voltage in the stable region shown in Fig. 2 [2-5]. We can conclude from all the available investigations that on optimum choice of operating voltage based on best selection criteria is necessary to extract the best and authentic picture of radiation through G.M. detector. This is due to the fact that the value of operating voltage affects the dead time significantly. This influences the detector functioning as the detector efficiency depends on the principle of most appropriate recognition of ionization caused by radiation. Therefore, the radiation detection must be performed at operating voltage which yields information about the actual ionization caused by highly energetic radio-active radiation.

PRESENT STATUS

The standard two source method is considered as a useful method to explore the dead time of G.M. counter. The choice of operating voltage [4], temperature, fatigue and manufacture design affect the detection mechanism [3]. Dead time increases with an increase in fatigue and temperature [3,8,32]. The operating voltage is chosen between the stable region (shown in Fig.1, from voltage V_{x1} to V_{x2}) as in this region the dead time is least dependent on applied voltage. An ideal detector/counter need to be independent or least dependent on the environmental/outer conditions. G.M. Counter is considered to be a brilliant gas detection system for alpha and beta particles. It is not suitable for uncharged particle detection. It is also not effective to identify the type and track the energy of particles. It can be used to detect the high energy radiation (alpha and beta particles) with a voltage which ranges between two extreme points. Different methods are used to identify best operating voltage in that stable region for best detection efficiency as the choice of operating voltage also affects the dead time in G.M. counter. The counter can be used to detect the radiation absorption tendency of the different elements. The dead time factor limits its capability in a way that lower counting rates are not effectively traced. Efforts have been made to enhance the efficiency of gamma radiation detection with G.M. counter in a specific energy range [8]. Much improved response to radiation is attempted in Ref. [33]. More advance investigations has been performed for radiation detection [34]. Latest advancements for radiation detection with G.M. counter are also available in Ref. [35-38]. The advancements stresses on the enhancement of the efficiency of detection and proposed easy and effective methods to select operating voltage to propose methods to detect dead time. In all, G.M. counter is a cost effective detector to detect the radiation and to find the absorption tendency of materials which absorb nuclear radiation. This can be achieved apparently with a significant accuracy. Recently we have presented a study which signified the fact that different operating voltages chosen on the basis of two different considerations could affect the dead time considerably [4].

SUMMARY AND OUTLOOK

The G.M. counter is best positioned to provide most realistic picture when it could provide the ionization produced only due to radiation and is least dependent on other factors such as dead time, choice of operating voltage which also depend on dead time, temperature and manufacturer type. One must here consider a key aspect that the choice of operating voltage can affect the detector functioning and efficiency. External conditions influence the measurement of radiation absorption and detection mechanism of counter [2-4]. The investigations provided in the review article represent most of the critical investigations pertaining to G.M. counter detector properties and its related aspects. This review provides an overview regarding the key aspects of G.M. Counter. A brief conclusive picture is presented by taking into consideration the most relevant investigation performed in this regard. The list of investigations and information mentioned in the manuscript is not exhaustive but attempts to summarize the most of the critical aspects of GM Counter and radiation detection. The selection of most optimum value of operating voltage for radiation detection brings forth the vulnerability of this detection system to identify the imprint of radiation which may change with the choice of operating voltage. This is due to fact that ionization and mostly the secondary ionization depends on the operating voltage. Besides operating voltage, the ionization in gas chamber could be influenced by dead time and other external factors like temperature [3].

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