The GEIGER-MÜLLER detector

Introduction

The Geiger-Müller (GM) belongs to a group of detectors which operation principle is based on the fact that charged particle crossing a gas medium deposit energy and create electron-ion pairs. In the case of the GM, the difference between the voltage applied to the anode (wire) and to the cathode (container walls) is large enough for the charged particles produced under the effect of the incident radiation to be accelerated, producing secondaries and giving rise to an avalanche phenomenon. This kind of detectors work in saturation mode. The GM tube does not allow to distinguish different particle types or energies. It simply gives a signal whenever an ionizing particle produces and avalanche. These signals are registered using a counter.

In this work the GM detector will be used to measure β and γ radiation. Its thin window is conceived for the β particles (electrons), with a low penetration power, not to be absorbed when entering the detector. On the other hand, γ radiation (photons) must convert before it can be detected, which makes the efficiency for its detection in a GM tube much lower.
Two different sources will be used: a ^{204}Tl (emitting β particles) and a ^{137}Cs source (in which the β decay is followed by the emission of a 662 keV γ in the transition to the fundamental state). The decay schemes can be found at the end of this guide.

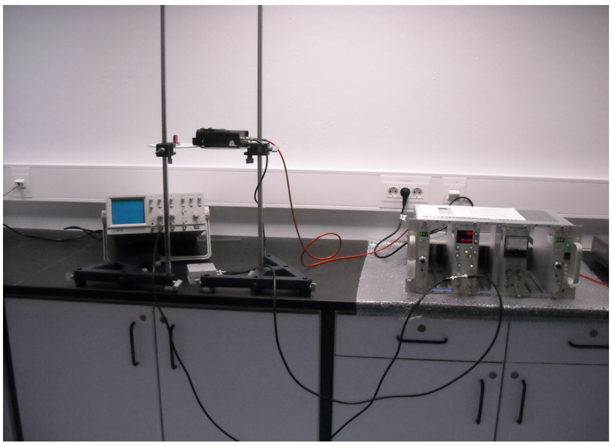
The measurements of the number of disintegrations of a radioactive source that will be performed are counting experiments, in which the obtained value fluctuates. This process is well described by a Poisson distribution. To each measurement of the number of events, n, a dispersion $\sqrt{n}$ will be associated.

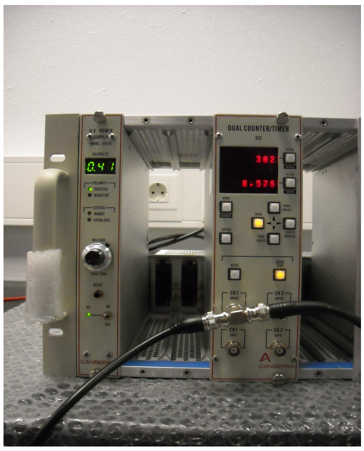
The work is divided in the following sections:

1. Study of the detector response curve as a function of the applied voltage and choice of the operation region.

2. Study of the detector efficiency for β and γ radiation.

3. Study of the variation of the counting rate as a function of the distance between the source and the detector.





1. Study of the detector response curve as a function of the applied voltage and choice of the operation regions

a) Mounting of the setup. Place the source at a distance of 10 cm from the GM tube, with the side without sticker facing the detector (in order to minimize the β absorption). The lid of the box where the detector is located must be open.

b) Using the ^{204}Tl source set the high-voltage (HV) applied to the GM tube at 500 V. Locate the beginning of the GM plateau region, by first decreasing and then increasing the applied voltage and observing the variation in the counting rate. Select a HV such that the count rate is zero. Locate the GM plateau region, by measuring the count rate in function of the applied HV, increasing the HV in steps of 50 V (or smaller, in the regions where you think it is appropriate). Stop the procedure whenever there are signs of continuous discharge, corresponding to the upper edge of the plateau. Choose a time interval large enough for the statistical error on the number of counts to be below 3%.. For each case, register the amplitude of the signal observed in the oscilloscope and the number of counts, and locate the lower and upper edge of the plateau. **Fill in the table and plot the results in a graph.**

HV (V)	**Signal amplitude in oscilloscope (V)**	**Time interval Δt (s)**	**Counts $N \pm \Delta N$**	**Counting rate $R \pm \Delta R$ (s^{-1})**

c) Choose your operation voltage approximately in the middle of the plateau. All subsequent measurements should be performed at this working voltage. Register the shape, amplitude and time length of the signal observed in the oscilloscope

d) In order to estimate the ambient background, which will be useful below, perform a long measurement with no source placed in the setup. Collect a number of counts large enough for the statistical error to be of the order of 5%.

Time interval Δt (s)	**Counts $N \pm \Delta N$**	**Count rate $R \pm \Delta R$ (s^{-1})**

2. Study of the detector efficiency for β and γ radiation

The efficiency of the GM tube for β and γ particles will be studied using a ^{137}Cs source, in which the β decay is followed by the emission of a γ, in the transition to the fundamental state (see decay scheme).
As a first step, it is necessary to define a system configuration in which the two types of radiation can be "separated". While the γ radiation is quite penetrating, the β radiation can easily be shielded.
Always place the **sources 10 cm away from the GM tube**, with the side without a sticker facing the detector. Choose a time interval allowing for a (relative) statistical error in the number of counts of the order of **3%-5%. Take into account that the background rate computed above has to be subtracted and its error propagated.**

a) Using the ^{204}Tl (Talium) source (which emits β radiation only, with an energy similar to that of the β particles emitted by the ^{137}Cs source we will study afterwards), compare the counting rate obtained with the lid open and closed, to check whether one obtains an effective shielding of the β particles by closing the lid of the box where the GM detector is placed. Fill the table :

Source	GM box lid	Time (s)	Counts $N \pm \Delta N$	Count rate $R \pm \Delta R$ (s^{-1})	Count rate (background subtracted) $R \pm \Delta R$ (s^{-1})
^{204}Tl	Open				
^{204}Tl	Closed				

b) Using the ^{137}Cs source and the GM box lid open, obtain the total counting rate (in the presence of the β and γ radiation emitted by the source), $R_{\gamma+\beta}$. Fill the table below.

c) Taking into account the different range of the β and γ radiation in matter and the conclusions from (a) obtain, using the ^{137}Cs source, an almost pure γ beam and determine the counting rates R_γ and R_β. Fill the table :

Source	GM box lid	Radiation type	Time (s)	Counts $N \pm \Delta N$	Count rate $R \pm \Delta R$ (s^{-1})	Count rate (background subtracted) $R \pm \Delta R$ (s^{-1})
^{137}Cs	Open					
^{137}Cs	Closed					

d) Assuming that in the Cesium decay chain the emission of a β is always followed by the emission of a γ[1], how does the GM tube efficiency for γ radiation compare to its efficiency for β radiation ?

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1 In fact, a correction should be taken into account: in 15% of the cases the emission of a β is not followed by the emission of a γ (because the decay occurs via internal conversion, in 10% of the cases, or because the nucleus goes directly to the ground state, in another 5% - see decay scheme).

3. Study of the variation of the counting rate as a function of the distance between the source and the detector

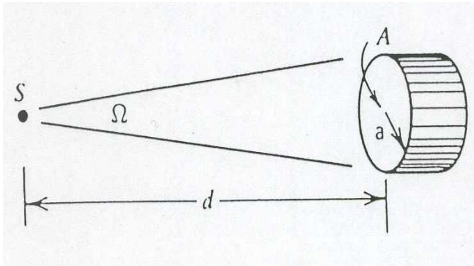
The counting rate of the GM detector depends on the activity of the source, on the detector efficiency for that type of radiation and on the distance between the source and the detector. This distance determines the geometrical acceptance (the fraction of the solid angle of particle emission that is covered by the detector). The geometrical effect of the angular coverage of the detector determines a law of variation of the counting rate with the inverse square of distance:

$$d\Omega = ds/d^2 = \sin\theta \, d\theta \, d\phi$$

$$\Delta\Omega = \int d\Omega = 2\pi(1-\cos\theta_{max})$$

$$\cos\theta_{max} = d/\sqrt{d^2+a^2} = 1/\sqrt{1+(a/d)^2}$$

$$a \ll d \Rightarrow \Delta\Omega \approx A/d^2$$



On the other hand, part of the radiation will be absorbed in the air before it reaches the detector. This effect depends on the type of radiation and on the distance, and it might distort the $1/d^2$ law of variation.

a) Using the ^{204}Tl source obtain the counting rate for different distances between the source and the detector. **Choose an appropriate time interval for the statistical error in the number of counts to be of the order of 5%.** Take into account that the background has to be subtracted and the corresponding error propagated. Perform measurements for d = 5 cm, 7.5 cm, 10 cm, 15 cm, 20 cm, 30 cm. Fill in the table:

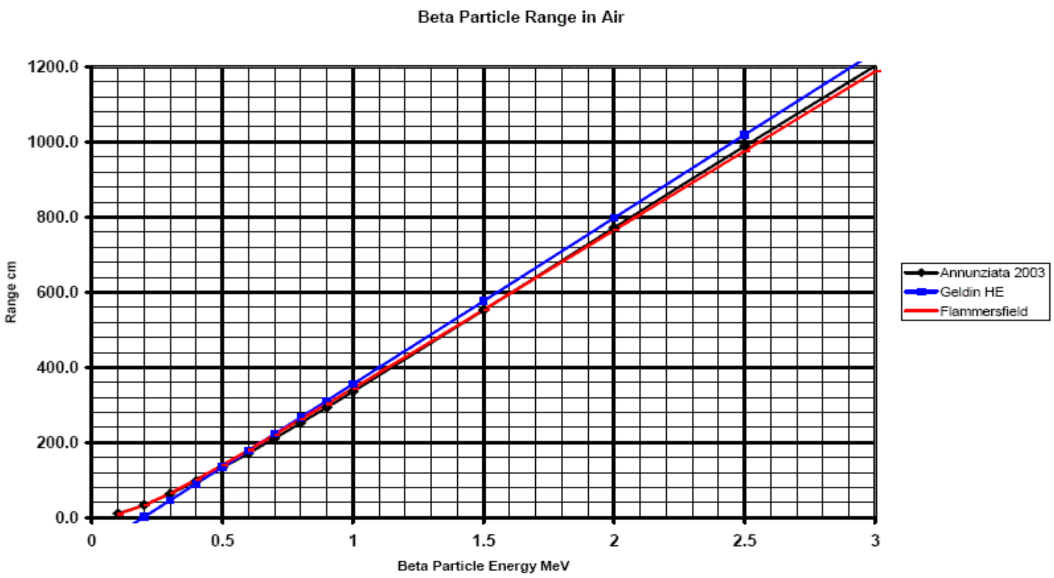
Distance (cm)	**Time (s)**	**Counts $N \pm \Delta N$**	**Count rate $R \pm \Delta R$ (s^{-1})**	**Count rate (background subtracted) $R \pm \Delta R$ (s^{-1})**

b) Check whether the collected data follows the expected $1/d^2$ variation law, by performing a χ^2 fit to the data. Remember to choose the appropriate variables in order for the fit to be a linear one.

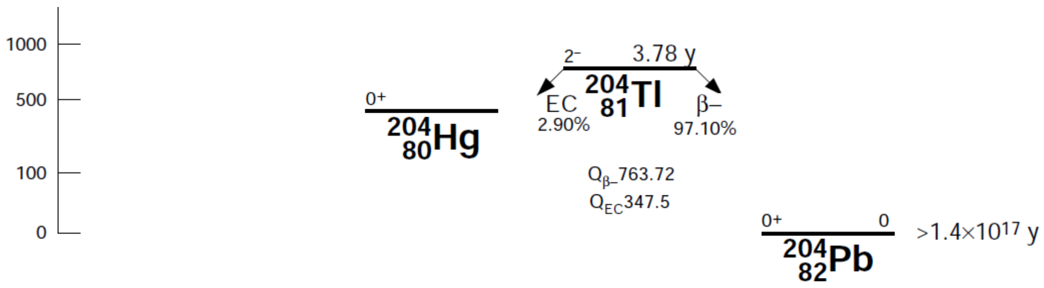
c) What can be said about the attenuation of β radiation in air for this range of energies and distances? Compare your conclusions with the range estimated from the graph in the following page.

e) Up to now we have considered only the statistical uncertainty associated to our measurements. Non-negligible systematic uncertainties could however be present, for example a systematic error on the positioning of the source at a given distance from the

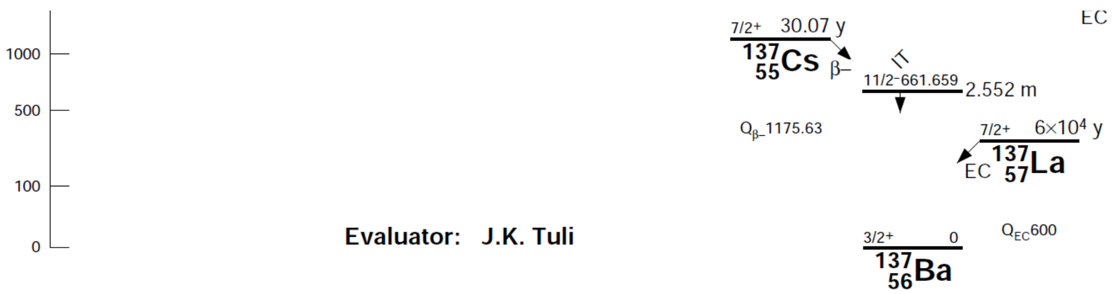
GM detector. Placing the ^{204}Tl source at d=10 cm from the GM detector, measure the count rate three times, re-positioning the source before each measurement. Compute the average and standard deviation of these measurements. Compare the order of magnitude of the obtained standard deviation with the estimated statistical error. What can be said about the systematic uncertainty arising from the positioning of the source ?



^{204}Tl decay scheme



^{137}Cs decay scheme



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