UNIVERSITY OF SURREY
DEPARTMENT OF PHYSICS

LEVEL 1 PHYSICS LABORATORY

INTRODUCTION TO IONISING RADIATION

AIM

In this experiment you will investigate the detection of Beta particles using a Geiger-Müller (GM) tube. You will observe the effects of counting statistics in radiation detection and verify the inverse square law for radiation.

RADIOACTIVE SOURCES AND SOURCE HANDLING

The radioactive sources used in these investigations are two strontium-90 (^{90}Sr) sources, emitting beta particles of maximum energy 2.25 MeV.

The sources are sealed, so there is no risk of contamination. Remember the three most important factors of radiation dose limitation: time of exposure, distance from the source, and shielding.

There are two different types of sources used in this experiment. One type are small semi-circular plastic discs, which must be handled using tweezers and <u>not</u> manually. In the other type, the sources are encased in a polymer shield to allow their manual handling. In the case of the second type of source, adding shielding to allow quicker manual handling removes the need to use tweezers or tongs. If you are in any doubt at all as to the correct procedures to be followed consult the demonstrator.

APPARATUS

You will be using one of two sets of apparatus, which can be seen in Figures 1 and 2 respectively.

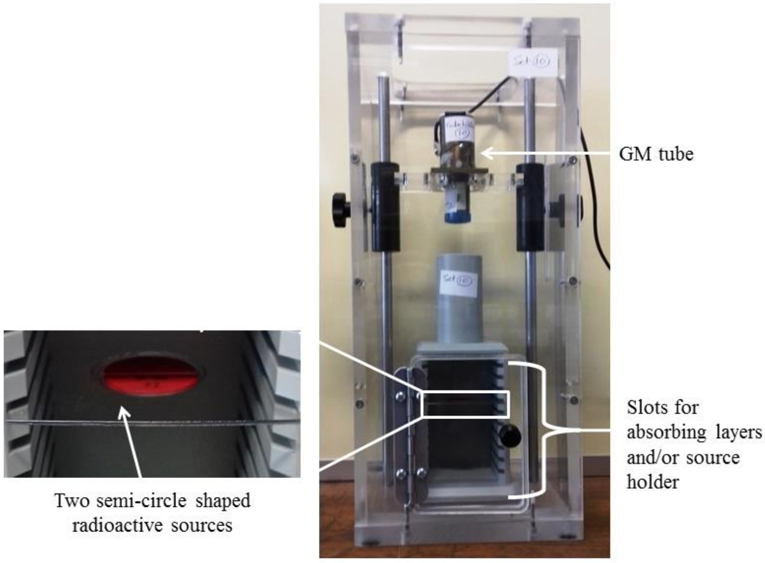

Figure 1: Set Type (I) where semi-circular sources are placed below the GM tube.

The Geiger-Müller (GM) tube is mounted vertically in a height-adjustable stage, as seen in Figures 1 and 2 for Set Types (I) and (II), respectively. Each set has a dedicated source holder, which is designed to match the source shape dedicated to that Set Type: *i.e.* two semi-circular red discs for Set I (handled with tweezers) and more bulky polymer-coated sources for Set II (handled manually). Additionally slots are provided in the tower to enable various thicknesses of aluminium absorber to be placed between the GM tube and the sources. Both sets use a ST360 scaler/timer.

The GM tube is connected to the Scaler-Timer which provides the HV supply as well as counting the ionisation events occurring in the GM tube in pre-set time periods.

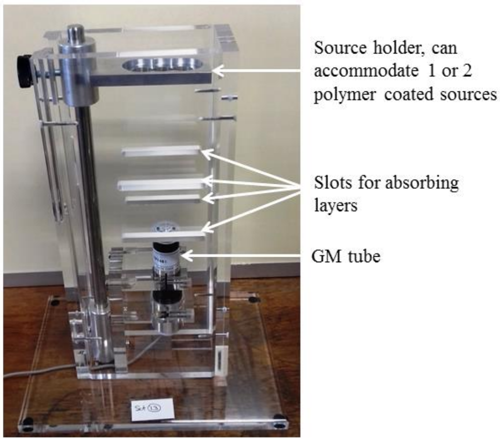

Figure 2: Set Type (II) where coated sources are placed above the GM tube

The only controls on the ST360 you will need to alter are as follows:

(i) The red **on-off switch,** at the back
(ii) **DISPLAY SELECT** button to select the mode to adjust the pre-set time, the high voltage, and display counts or count rate
(iii) **UP** and **DOWN** buttons to adjust the pre-set time and the high voltage
(iv) **RESET**, **COUNT** and **STOP** buttons

EXPERIMENT

PART 1: Geiger-Müller Tube Ionising Event Detection

The GM tube is very widely used for detecting ionising radiation. It is relatively cheap and very sensitive, being able to respond to the arrival of a single ionising particle or quantum, and to produce a resulting output pulse of several volts. An inherent disadvantage of the tube is that the height of its output pulse is independent of the energy of the detected radiation

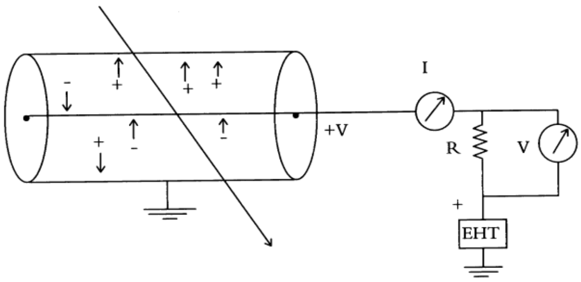

Figure 3: *Diagram of a GM tube showing charge generation when irradiated.*

A diagram of a GM tube is shown in Fig 3. The tube has co-axial electrodes. The inner electrode is an anode wire, and the outer electrode is a metal case, which acts as the cathode. A high voltage (HV) supply of several hundred volts is maintained between these electrodes. The tube is fitted with a very thin end-window which allows particles of low penetrating power to enter, and the interior contains a low-pressure mixture of a rare gas and a halogen gas.

An ‘ionisation event’ occurs when a particle or photon causes an ion pair to be formed in the gas. The electrons from the gas molecules will quickly move to the tube anode, while the positive ions will move slowly (because of their greater mass) to the cathode.

If the voltage applied to the tube is large enough, the electrons will gain enough energy to produce more ion pairs when they collide with atoms of gas. Secondary electrons from these collisions in turn produce more ionisation, and in a short time the whole of the gas within the tube becomes ionised. This accumulation of ionisation is called the ‘avalanche effect’.

The ionised gas is now a good conductor of electricity, and a large output pulse of current can be detected, all triggered by the incident particle or photon. When a high enough HV has been applied, even the smallest ionisation events may be detected. Once the threshold has been reached, moderately increasing the voltage does not increase the detection rate; however, if too much HV is applied, electrical breakdown occurs due to the resulting continual discharge. The tube's HV *versus* count rate characteristically therefore shows an almost flat 'plateau' region, in which count rate varies very little with applied tube voltage. Follow this method in your experiment.

A Adjust the height of the source holder and the end-window of the GM tube so that the distance between them is about 10 cm. In Set Type II, place a single polymer encased Strontium-90 (^{90}Sr) beta source in the **central position** of the source holder. If using apparatus Set Type I, use two semi-circular discs together.

B Bring the HV to 260 V and set the count period to 60s on the Scaler-Timer. It is possible that you will not see any counts at this voltage. This is not a problem – just continue to the next step.

C Start a single cycle count period and gradually increase the value of the HV until counting just begins. (The voltage can only be changed in 20 V steps.) Note the voltage at which counting first occurs. This is called the threshold voltage for your GM tube.

D Reduce the HV by 20 V. Record the number of counts, *N* as a function of tube voltage as the latter is increased in 20 V steps, until a sudden increase in counts is observed. This increase will usually be in the range between about 200 V to 300 V above the threshold voltage. You should then calculate the expected error on the counts and convert to a rate *R* in units of counts per second, including error on *R* (see Appendix 1). An example table for your data is shown below:

Voltage (V)	Number of counts in 60 s, *N*	Count rate, *R* (s^{-1})
300	2036 ± 45	33.9 ± 0.8
320	4267 ± 65	71 ± 1
Etc…		

E Plot a graph of count rate against tube voltage, including vertical error bars on each point, and note the plateau region of the characteristic curve. Select from your graph a value of HV which corresponds to the middle of the plateau. This is a suitable working voltage for the tube, and it should be used in all subsequent experiments.

F Record your values for the threshold and working voltages. The tube manufacturer states that the gradient of the plateau region should be $< 0.15\ s^{-1}\ V^{-1}$, in order that small changes in HV do not significantly affect the count rate. How much does the count rate change over the plateau of your graph? How wide is the plateau in volts? Use these numbers to find the gradient per second per volt for your tube. Comment on whether your result is within the manufacturer's specification.

PART 2: Measuring the 'Dead Time'

In order for a succession of ionising events to be counted the tube must be re-set after each radiation interaction. The tube will be ready to count another pulse as soon as this so-called *dead time* has elapsed. Any particle entering the tube during this dead time will not be counted. Therefore, in accurate work with high count rates, it is necessary to correct observed counts for the tube dead time.

In this investigation, the 'two source' method is used to measure the dead time of the tube. You will be measuring the radiation from two different sources and then both of them together. Since the calculations involve the subtraction of similar quantities, it is essential to determine the count rates to a high degree of accuracy.

A Set the HV to the working voltage you have chosen in Part 1 and mount a ^{90}Sr beta source in the source holder. (For Set Type (II) this source needs to be placed in one of the outer holes, either to the left or right side. For Set type (I), place TWO semi-circular shaped sources into the holder on top of each other - to ensure you obtain enough counts.) Switch the Scaler-Timer display select to rate mode, and adjust the source detector distance so that the count rate is of the order of 200 -250 s^{-1} (or as high as your set-up allows, if 200 s^{-1} cannot be reached). Now switch back to the Counts mode, set the count time to 60 s, and measure the count R_1 per second using the mean of **at least** two 60 s counts.

B Without moving the source holder position, fix a second ^{90}Sr source alongside the first and again find the counts per second, R_{1+2}. If you are using Set Type (II), ask the lab supervisor for a second polymer-encased ^{90}Sr source. If you are using Set Type (I), ask the lab supervisor for a second pair of sources and put them on top of each on the other side of the holder. There are a limited number of radioactive sources so try and organise with those around you an effective way of sharing the sources and please wear gloves if handling the sources for Set Type II.

C Finally remove the first source(s) and determine the count due to the second source alone, R_2.

D Calculate the associated error for each of the three data sets as described in Appendix A. (Remember that you are averaging two or three measurements for each set and include them in your error calculations.)

E Use your measurements to calculate the dead time. If we call the dead time τ, then for an observed count rate of R per second the tube will be only counting for $(1 - R\tau)$ seconds, and the true count rate R_t will therefore be

$$R_t = \frac{R}{1 - R\tau} \quad . \tag{1}$$

So for your observations, we can write:

$$R_{t_1} = \frac{R_1}{1 - R_1\tau} \qquad R_{t_2} = \frac{R_2}{1 - R_2\tau} \qquad R_{t_{1+2}} = \frac{R_{1+2}}{1 - R_{1+2}\tau} \quad . \tag{2}$$

Equations (2) can be solved as simultaneous equations, using an approximation based on the fact that τ is very small, to yield the following relationship:

$$\tau = \frac{R_1 + R_2 - R_{1+2}}{2R_1R_2} \quad . \tag{3}$$

F Calculate the error on τ. This is not trivial as R_1 and R_2 appear in the formula twice. It can be shown by differentiation and using the general formula for combination of errors that

$$\Delta\tau = \left(\frac{1}{2R_1R_2}\right)\left[\left(R_{1+2} - R_2\right)^2\left(\frac{\Delta R_1}{R_1}\right)^2 + \left(R_{1+2} - R_1\right)^2\left(\frac{\Delta R_2}{R_2}\right)^2 + \left(\Delta R_{1+2}\right)^2\right]^{\frac{1}{2}} \quad . \tag{4}$$

Substitute your observations into these equations and thus find the value for the dead time of the G-M tube and its error. Comment on your result, and what implications it has for your measurements. *Remember to correct all your following measurements for the dead time!*

PART 3: Taking a background count

Now that you have found the correct working voltage for your GM tube, you should attempt to correct for the **background** radiation level in the laboratory. With your sources moved at least 1m from the equipment, and keeping the count time at 60 s, take several readings to get an average background count rate. *You should correct for background in your experiment from this point on.*

PART 4: The inverse square law

Point sources emit radiation in all directions, so their intensity (*i.e.* the number of photons per second) must reduce as the rays spread over a greater surface area of a sphere as the distance from the source increases. This decrease is distinct from that produced by absorption of the radiation as it travels through a medium.

Consider a point source of radiation situated in a vacuum so that there is no absorption. If the radius of the spherical surface subtended by the source is d, then

$$I = Power/surface\ \ area = Power/4\pi d^2$$

i.e. $$I \propto 1/d^2 \tag{5}$$

Thus the intensity of the radiation detected through the finite surface area of a GM tube would be expected to vary as the inverse square of its distance, d, from the source.

The experimental arrangement for investigating how applicable this hypothesis is to a sealed ^{90}Sr beta source in air is shown in Figure 4. Radiation emitted from any point within the source may be detected at any point in the GM tube. Neither the location of its origin within the source (A), nor the precise point of detection (B), are known.

This makes it impossible to measure d directly. You can, instead, measure the distance x using a ruler, and assume that $d = x + c$, where c is an unknown constant.

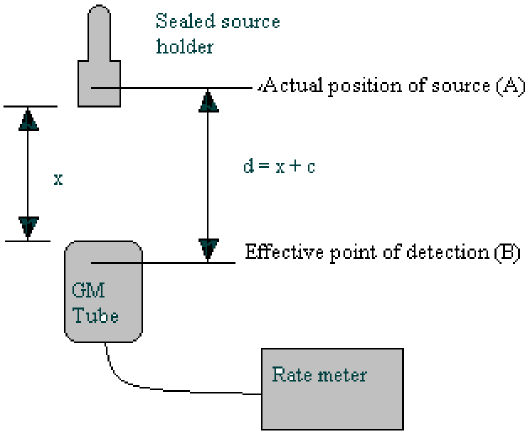

Figure 4: *Schematic diagram to verify the inverse square law*

A Raise the HV to your selected working voltage.

B If you have not already done so, measure the background counts as accurately as you can (minimum of two 60 s counts), ensuring that no exposed sources are close to the detector. You will use your background count rate to correct your readings during this experiment.

C Mount the ^{90}Sr source in its **central location**, or two semi-circular sources as in Part 1. Adjust the distance between the GM tube and source to the maximum value possible that still gives you a reading above the background. You can move either the source or the GM tube, as appropriate. Measure the count rate in one 60 s period. Calculate the error on the mean count rate $\sqrt{N}$. Identify a good sampling of distances, and repeat for an adequate number of distances (you should aim for 6-8 points).

D Correct your data for the dead time and background. Then plot a graph of your corrected count rate against $1/d^2$. Comment on why your data deviate from linearity, and how the experiment might be modified to effectively demonstrate the inverse square law.

E ***Return your source(s) where you originally found it.*** Note that all sources have unique number identifiers. You should wash your hands before leaving the laboratory.

References

1. G.F. Knoll, *Radiation Detection and Measurement*, J. Wiley & Sons, New York (1989).

   N.C. Barford, *Experimental Measurements: Precision, Error and Truth*, J. Wiley & Sons, New York (1985)

APPENDIX A

Standard Deviation and Errors

Most radioisotope decay experiments involve the measurement of a number of events N occurring within a given time interval t. The random nature of the radioactive decay process means that for n identical measurements taken with the same time interval, the number of events recorded in each interval (N_1, N_2, $N_3 \ldots N_n$) will differ by an amount governed by Poisson statistics. This distribution has a standard deviation $\sqrt{<N>}$ if the expected value is $<N>$. If a *single measurement* is made, the best estimator for the expected value is just N, so the best estimator for the expected error $<\Delta N>$ is $\sqrt{N}$. You should therefore quote

$$N \pm \sqrt{N} \, .$$

The expected fractional error in *N* is

$$\left\langle \frac{\Delta N}{N} \right\rangle = \frac{\sqrt{N}}{N} = \frac{1}{\sqrt{N}} \quad .$$

Clearly there is an advantage in measuring events over a longer time interval, or in using a stronger source, because when the number of counts increases the expected fractional uncertainty decreases. In radioactivity counting experiments, you are often interested in the number of counts N in a time interval t, *i.e.* the rate of counts R, where

$$R = N / t \, .$$

In this case, the error in the rate is calculated simply as:

$$\langle \Delta R \rangle = \sqrt{N} \big/ t \quad .$$

The error is expected to be no different doing *n* short intervals of t seconds, or one long averaging period of nt seconds, if the statistics are truly Poissonian. Check this by calculating the experimental background rate and its experimental error for the six 10 s periods, for two 30 s periods, and for a 60 s period. The errors should be similar in each case.

If you perform *n* measurements and obtain an average value $\overline{N}$, the associated error will be $(\overline{N}/n)^{1/2}$**.** Why is that?