EXPERIMENTS
WITH
G.M. COUNTER

Fig.1: G.M. Counting System with G.M. Detector (End Window) stand and G.M. Detector / Sliding Bench

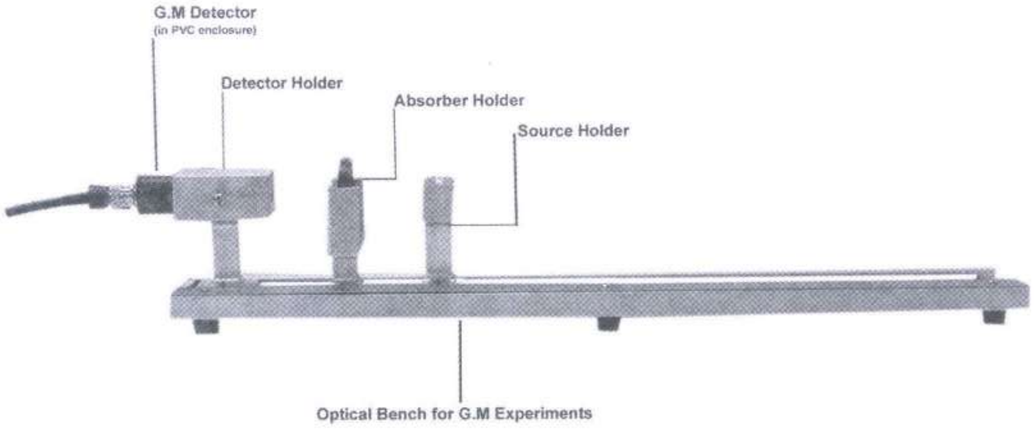


Fig. 2: Sliding bench for G.M Experiments (SB201)

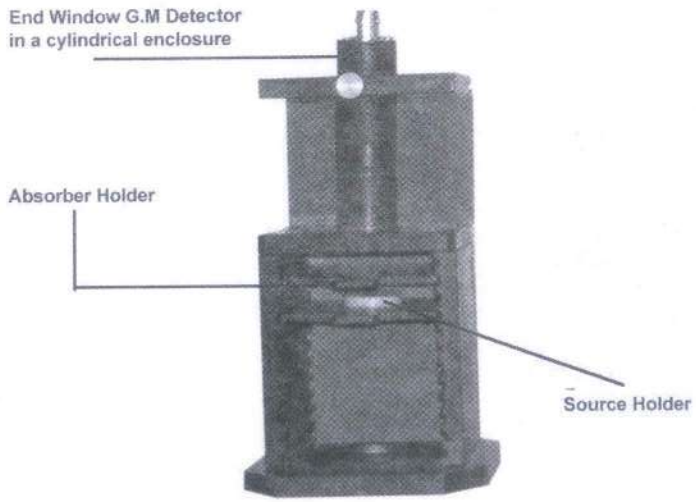


Fig 3 : G.M. Detector stand (SG200)

A. GENERAL INFORMATION

GENERAL INFORMATION ON GEIGER - MULLER TUBES

Geiger-Muller radiation counter tubes (G.M.Tubes) are intended to detect alpha particles, beta particles, gamma or X-radiation.
A G.M. tube is a gas-filled device which reacts to individual ionizing events, thus enabling them to be counted.
A G.M. Tube consists of basically an electrode at a positive potential (anode) surrounded by a metal cylinder at a negative potential (cathode). The cathode forms part of the envelope or is enclosed in a glass envelope. Ionizing events are initiated by quanta or particles, entering the tube either through the window or through the cathode and colliding with the gas molecules.
The gas filling consists of a mixture of one or more rare gases and a quenching agent.
Quenching is the termination of the ionization current pulse in a G.M.tube. Effective quenching in G.M. Tube is determined by the combination of the quenching gas properties and the value of the anode resistor.

- **The capacitance of a G.M. Tube is that between anode and cathode, ignoring the capacitive effects of general connections.**

- **OPERATING CHARACTERISTICS:**

- **Starting Voltage (V_S):**
  This is the lowest voltage applied to a G.M. Tube at which pulses just appear across the anode resistor (see Fig. 4) and unit starts counting.

- **Plateau:**
  This is the section of the GM characteristic curve constructed with counting rate versus applied voltage (With constant irradiation) over which the counting rate is substantially independent of the applied voltage. Unless otherwise stated, the plateau is measured at a counting rate of a approximately 100 counts.

- **Plateau threshold voltage (V_1) :**
  This is the lowest applied voltage which corresponds to the start of the plateau for the stated sensitivity of the measuring circuit. See Fig. 4.

- **Plateau length :**
  This is the range of applied voltage over which the plateau region extends. See Fig. 4.

- **Upper Threshold voltage (V_2) :**
  This is the higher voltage upto which plateau extends, beyond which count rate increases with increase in applied voltage.

- **Plateau Slope:**
  This is the change in counting rate over the plateau length, expressed in % per volt See Fig. 4.

- **Recommended Supply Voltage : (Operating Voltage)**
  This is the supply voltage at which the G.M.Tube should preferably be used. This voltage is normally chosen to be in the middle of the plateau. See Fig.4.

- **Background : (BG)**
  This is the counting rate measured in the absence of the radiation source. The BG is due to cosmic rays and any active sources in the experimental room.

- **NOTES :**
- **Dead Time (T_d):**
  This is the time interval, after the initiation of a discharge resulting in a normal pulse, during which the G.M.Tube is insensitive to further ionizing events. See Fig.5.

- **Resolution (resolving) time (T_R)**
  This is the minimum time interval between two distinct ionizing events which enables both to be counted independently or separately. See Fig.5.

- **Recovery Time (Tre):**
  This is the minimum time interval between the initiation of a normal size pulse and the initiation of the next pulse of normal size. See Fig.5.

- **Anode resistor :**
  Normally the tube should be operated with an anode resistor of the value indicated in the measuring circuit, or higher. Decreasing the value of the anode resistor not only decreases the dead time but also the plateau length. A decrease in resistance below the limiting value may affect tube life and lead to its early destruction.

  The anode resistor should be connected directly to the anode connector of the tube to ensure that parasitic capacitances of leads will not excessively increase the capacitive load on the tube. An increase in capacitive load may increase the pulse amplitude, the pulse duration, the dead time and plateau slope. In addition the plateau will be shortened appreciably. Shunt capacitances as high as 20 pF may destroy the tube, but lower values are also dangerous.

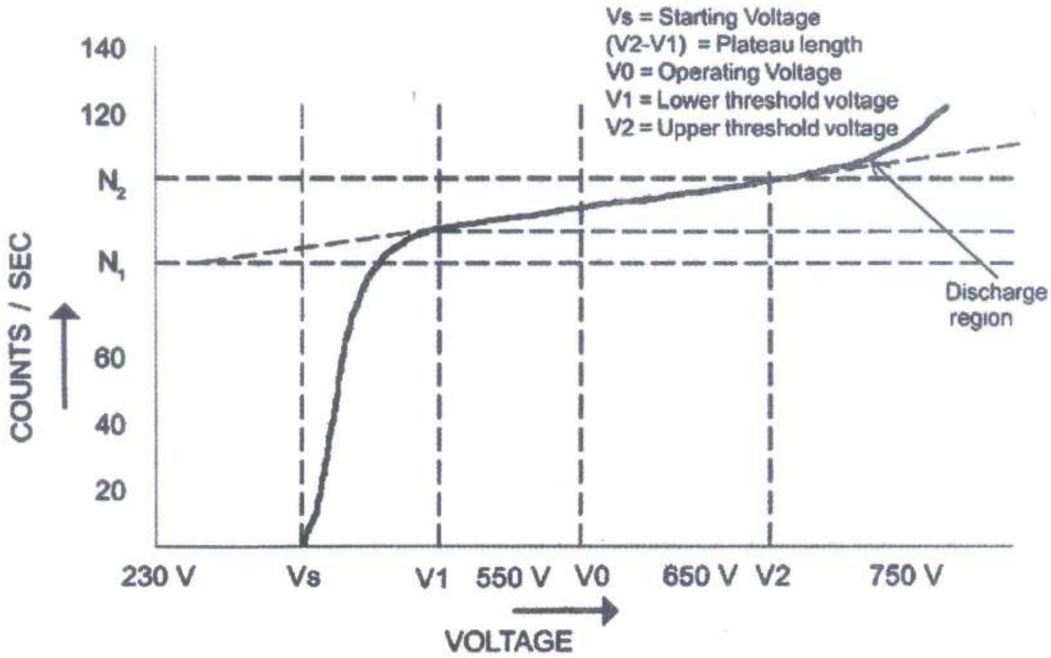


FIG 4 : TYPICAL G.M. CHARACTERISTICS

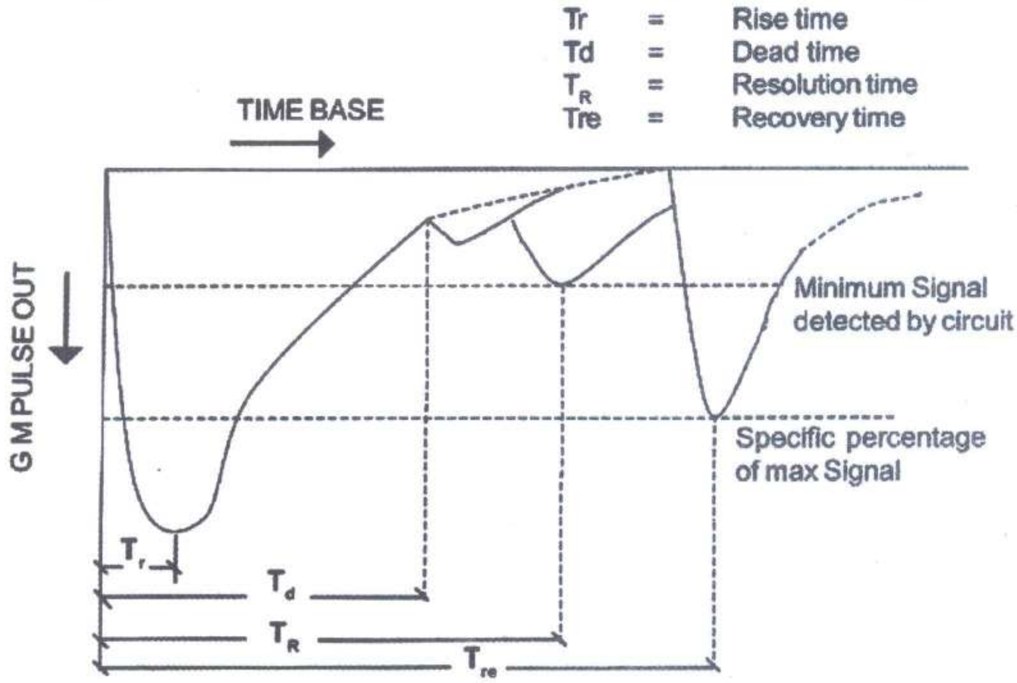


FIG 5 : TYPICAL G.M. PULSE OUTPUT SEEN ON AN OSCILLOSCOPE

- **Maximum Counting Rate :**

  The Maximum counting rate is approximately $1/T_d$ (T_d = dead time). For continuous stable operation, it is recommended that the counting rate is adjusted to a value in the linear part of the counting rate/dose rate curve.

- **Tube sensitivity at extremely high dose rates :**

  At dose rates exceeding the recommended maximum, a G.M.Tube will produce the maximum number of counting pulses per second, limited by its dead time and the circuit in which it is incorporated.

  However, due to the characteristics of a specific circuit, the indicated counting rate may fall appreciably, even to zero.

  If dose rates exceeding 10 times the recommended maximum for window tubes, or 100 times for cylinder tubes, are likely to be encountered, it is advisable to use a circuit that continuously indicates saturation.

- **Dead Time Losses :**

  After every pulse, the tube is temporarily insensitive during a period known as the dead time (T_d). Consequently, the pulses that occur during this period are not counted. At a counting rate of N count/s the tube will be dead during NxT_d of the time, so that approximately $NxNxT_d$ of the counts will be lost.

  In an experiment if the inaccuracy in counts due to dead time must be <1%, N should be less than 1/100 Td counts. Example: If T_d= 20m sec, an inaccuracy of 1% is reached at a counting rate of approximately 500 counts/sec.

- **Background:**

  The most important sources of background count are:

  a. Gamma radiation from the environment and from cosmic radiation.
  b. Mesons from cosmic radiation
  c. Beta particles from contamination and impurities of the materials from which the detector itself is made.
  d. Spontaneous discharge or pulses in the detector and the counting circuit that do not originate from radiation (Electronic noise).

  From published experimental data, the gamma contribution accounts for approximately 70% of the background and a further 25% (approximately) is due to cosmic mesons. For the majority of G.M. tube applications, the background may be reduced to an acceptable level by shielding the tube with lead or steel. Thus most of the gamma contribution is eliminated. The values given in the data in count per minute are derived from averages over a long duration.

- **LIFE:**

- **Storage life:**

  If stored in a cool dry place, free form continuous or severe vibration, there is hardly any deterioration in the tube's characteristics. A storage life of years is not unusual.

- **Warning:**

  Generally, life end of a G.M. tube is indicated by an increasing slope and a shorter plateau. For older tubes, operation is recommended at the first third of the plateau.

- **Operational life:**

  The operational life of a G.M. Tube is expressed in counts (discharge). Theoretically the quenching gas, ionized during a discharge, should be re-combined between discharges. However, minute quantities will be chemically bound, no longer taking part in the quenching process. This will lead to a gradual reduction of the plateau length and for a given working voltage to an increased counting rate. This will culminate in a continuous state of discharge of the tube rendering it useless.

  Apart from the accumulated number of counts registered the ambient temperature during operation is of prime importance to the life of the tube. At temperature above 50°C, changes in the gas mixture may occur, possibly reducing the total number of counts attainable. Short periods of operation (not exceeding 1h) up to approximately 70°C should not prove harmful, but life will progressively decrease with increasing temperature.

  Thus, depending on application and circumstances, the quenching gas could be exhausted in as little as a few hours or theoretically last for many years.

  For these reasons G.M. Tubes cannot be guaranteed unconditionally for a specified period of time.

IMPORTANT DEFINITIONS

- **Absorbed dose :** The energy transferred to a material by ionising radiation per unit mass of the material.
  Unit : J kg^{-1}; Name of unit : Gray (see also Rad)

- **Activity :** Measurement of quantity of radioactive material. It is the number of nuclear transformations or isomeric transitions per unit time.
  Unit : s^{-1} Name of unit : Becquerel (see also Curie)

- **Alpha decay : Alpha particles** consist of two protons and two neutrons bound together into a particle identical to a helium nucleus. They are generally produced in the process of alpha decay, but may also be produced in other ways. Alpha particles are named after the first letter in the Greek alphabet, α.

  A radioactive conversion accompanied by the emission of an alpha particle. In alpha decay the atomic number is reduced by 2 and the mass number by 4. Alpha decay occurs, with a few exceptions, only for nuclides with a proton number exceeding 82.

- **Alpha radiation :** Radiation that consists of high energy helium (4He) nuclei emitted during alpha disintegration of atomic nuclei. Alpha particles possess discrete initial energies (line spectra) which are characteristic of the emitting nuclide.

- **Becquerel (Bq) :** Name of the derived SI unit of activity. Number of radioactive transformations or isomeric transitions per second (S^{-1}) = Bq.

1 Bq	=	27 pCi
1 KBq	=	27 nCi
1 MBq	=	27 μCi
1 GBq	=	27 mCi
1 TBq	=	27 Ci

- **Beta decay :** Radioactive conversion accompanied by the emission of a beta particle, i.e. a negatively charged electron (β^- decay) or a positively charged electron (β^+ decay). When a negatively charged electron is emitted, a neutron in the atomic nucleus is converted to a proton with the simultaneous emission of an antineutrino, so that the proton number Z is increased by 1. When a positively charged electron (positron) is emitted, a proton in the nucleus is converted to a neutron with simultaneous emission of a neutrino, so that the proton number **Z** is decreased by 1.

- **Beta Radiation :** Radiation that consists of negative or positive electrons which are emitted from nuclei undergoing decay. Since the decay energy (or, if it is followed by gamma radiation, the decay energy less that photons energy) is statistically divided between beta particles and neutrinos (or antineutrinos), the energy spectrum of beta radiation is continuous, extending from zero to a maximum value characteristic of the nuclide concerned. The maximum beta energy is generally termed the "beta end-point energy of the nuclide".

- **Bremsstrahlung :** Radiation that results from the acceleration/deceleration of charged particles in the Coulomb field of atoms.

- **Curie (Ci) :** Name for derived unit of activity. One Curie corresponds to 3.7×10^{10} nuclear disintegrations or isomeric transitions per second $1\ Ci = 3.7 \times 10^{10}\ s^{-1}$.

1 Ci	=	37 GBq
1 mCi	=	37 MBq
1 μCi	=	37 kBq
1 nCi	=	37 Bq
1 pCi	=	37 mBq

- **Dose :** See absorbed dose, exposure value, and dose equivalent

- **Dose equivalent :** A term used in radiation protection for the radiation dose. It is the product of absorbed dose times the quality factor.
  Unit : $J\ kg^{-1}$; Name of unit: Sievert (see also Rem)

- **Dose rate :** Dose absorbed per unit time

- **Electron radiation:** Particle emission consisting of negatively or positively charged electrons.

- **Exposure dose:** The ratio of the amount of electric charge of the ions of one polarity that are formed in air by ionising radiation and the mass of the air.
  Unit : $C.\ kg^{-1}$ (see also Roentgen)

- **Gamma radiation:** Photon radiation emitted by an excited atomic nucleus decaying to a lower energy state. Gamma radiation has a line spectrum with photon energies which are specific to the nuclide concerned. Gamma and X-rays are both electromagnetic radiations and they are distinguished only by their mode of generation.

- **Gray:** Name of the derived SI unit of absorbed dose. $1\ Gy = 1J.kg^{-1}$

- **Half-thickness:** The thickness of material layer that reduces the intensity of initial radiation by a factor of two.

- **Ionising radiation:** Radiation that consists of particles capable of ionising a gas.

- **Isotopes:** Nuclides with the same atomic number but different atomic weights (Mass numbers).

- **Mass per unit area:** Product of the density of a material and its thickness.

- **Nuclide :** Generic term for neutral atoms that are characterized by a specific number of neutrons N and protons Z in the nucleus.

- **Quality factor :** A factor which in radiation, protection allows for the effects of different types of radiations and energies on people.

- **Rad :** Name for a unit of absorbed dose
  1 rad = 10^{-2} J. kg^{-1} = 10^{-2} Gy

- **Radioactivity :** The property which certain nuclides have of emitting radiation as a result of spontaneous transitions in their nuclei.

- **Rem (rem) :** (Roentgen equivalent man). Name for a derived unit of dose equivalent; a measure of the biological effect of radiation.
  1 rem = 10^{-2} J. kg^{-1} = 10 mSv

- **Roentgen (R) :** Name for a derived unit of exposure dose.
  1R = 2.58 x 10^{-4} C. kg^{-1}

- **Sievert (Sv) :** The SI unit of dose equivalent 1 Sv = 1 J. kg^{-1}

DESCRIPTION ON G.M COUNTING SYSTEM GC601A/GC602A

Nucleonix systems offers two models of G.M. Counting Systems. One an economy model GC601A with optimal features and the other GC602A with more advance features. The following paragraphs illustrate important features of both models with front & rear panel photographs.

Geiger Counting System, type **GC601A** is an Advanced Technology based, **economy** model, designed around eight bit microcontroller chip. This system with accessories is an ideal choice for teaching / demonstrating various G.M. Experiments, as a part of Experimental Physics lab to U.G., P.G. Science and U.G. Engineering students. Other streams such as Radiation Physics, Radiochemistry, Radiation Biology and Agricultural Sciences can also use this system.

This counting system can be used for carrying out a number of Nuclear Physics experiments.

Fig : G.M. Counting System GC601A Front & Rear panel view

Geiger Counting system type **GC602A** is an Advanced Technology based versatile integral counting system designed around eight bit microcontroller chip. This system is highly recommended for research work, apart from its usefulness in the academic fields for teaching. This system along with wide end window G.M. Tube Type GM125 and Lead Castle will serve as an excellent Beta Counting System useful for swipe sample counting by Health Physics Labs. This counting system is useful for carrying out a number of Nuclear Physics experiments.

Fig : G.M. Counting System GC602A Front & Rear panel view

Important features in the two models are given below.

- o **High voltage output :** (0 to 1500V) @ 2mA, ripple less than 20mV.
- o **Visual display :**16x2 LCD dotmatrix character display indicates HV, preset time, Time counts, and other parameters.
- o **Counts capacity :** 999999 counts.
- o **Preset time :** (1-9999) sec
- o **User interface :** Through front panel keypad . Command buttons provided are START, STOP, PROG, STORE, INC (▲) & DEC (▼)
- o **G.M. pulse output :** G.M. detector output is provided on the rear panel BNC Socket (Inverted output).
- o **Power :** Unit works on 220V + 10% A.C., 50Hz.
- o **Memory storage :** Built-in memory to store data readings upto 1000.

ADDITIONAL FEATURES AVAILABLE ON GC602A ONLY :

- o **Printer port (centronics) :** For data printing is built-in.
- o **Paralysis time :** Variable paralysis time OFF, 250, 350 & 550 sec
- o **RS232C :** Serial port for data communication to PC is built-in.

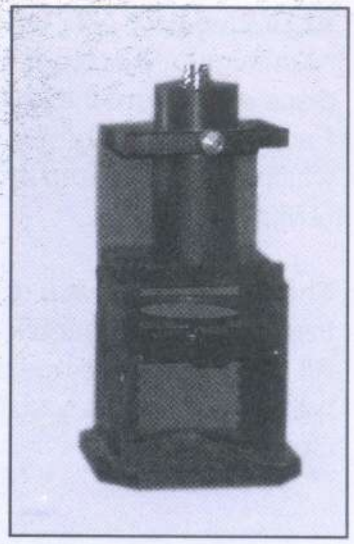
ACCESSORIES FOR GEIGER COUNTING SYSTEM :

GM 120 is a Halogen Quenched End Window GM Detector, supplied by NUCLEONIX. It is suitable for general purpose GM Counting applications & all G.M. Experiments. Its operating voltage is approximately 500V. It has got a very wide plateau length and plateau slope is better than 6% per 100V. This detector is supplied in a cylindrical PVC enclosure with MHV socket arrangement for applying HV bias voltage.

Application : Suitable for Beta & Gamma Counting.
Operating Voltage :
Range : 450 - 600V
Tube Dimensions : Max. over all length 2.125 inches.
PVC Enclosure dimensions : 25mm dia x 77mm Ht.
Max. Diameter : 0.59 inches
Gas filled : Ne + Hal
End Window : mica 2.0 mg/cm sq. (Areal density)

STAND FOR G.M. DETECTOR [TYPE : SG200]

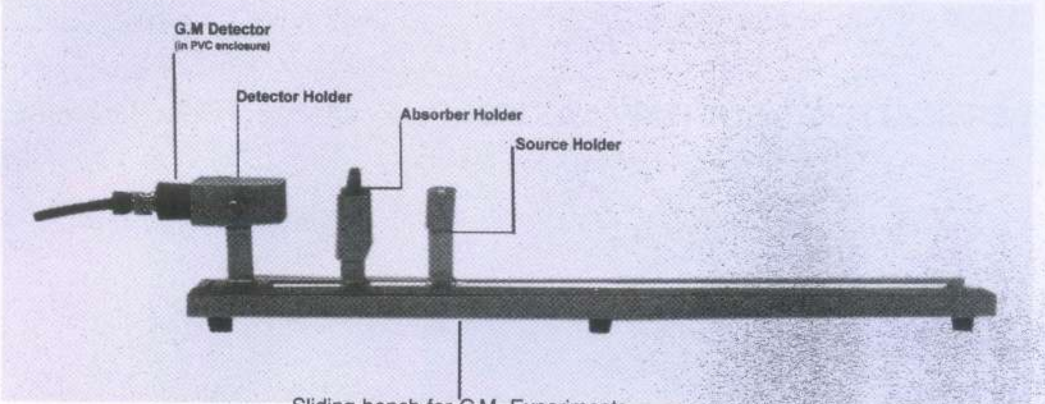
Stand for G.M. tube type SG 200 has been designed to hold PVC enclosed End Window G.M. tube, as shown in picture. This stand can be housed inside the lead shielding if required. It has both sample and absorber trays. The position of these trays can be adjusted from the end window of the detector. The stand made up of acrylic sheet is precisely milled for sliding-in of sample and absorber trays. Sample tray is designed to hold planchets or disc type radioactive standard source (Beta or Gamma). Aluminium absorber discs can be interposed between the source and the detector for attenuating the radiation as seen by the detector.



Captive screw holds the detector PVC tube to any height. To increase the distance between end window & source one can lift the PVC tube further up which can be held by captive screw.

SLIDING BENCH FOR G.M. EXPERIMENTS [TYE : SB201]

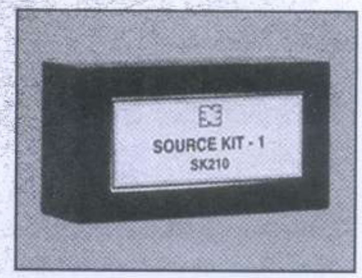
This essentially consists of a bench with sliding groves with a graduated S.S scale fixed on one side of it. Scale has graduations both in cm & inches upto 50cm/20 inches. There are three vertical sliding mounts, each for mounting of End Window G.M detector horizontally facing the absorber & source mounts. Each of these mounts can be positioned along the slide scale to have required distance between the end window to the source with absorber mount interposed in between. End Window detector is housed in PVC enclosure with MHV socket fixed on to it.



Sliding bench for G.M. Experiments

SOURCE KIT - 1 [TYPE : SK210]

Source Kit-1 type SK 210 offered by NUCLEONIX contains one each of Beta and Gamma sources. These are low active disc sources of the order of 0.2 to 3 micro curie for Beta & Gamma. Gamma source disc is evaporated and sealed inside 25mm dia X 5mm thick plastic disc. Whereas Beta source disc is evaporated & sealed in a 25mm X 10mm thick plastic disc and covered with 10mg/ sq.cm aluminised mylar foil.



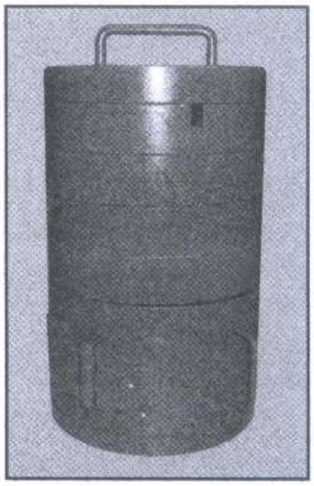
ALUMINIMUM ABSORBER SET [TYPE: AA 270]

Aluminimum Absorber Set Type : AA 270 consists of absorber discs in different thicknesses ranging from 20 to 300 mg/cm.sq. Each of these absorbers is mounted in an individual plastic frame, which exactly fits into the absorber tray holder of the G.M. stand/ G.M.sliding bench.

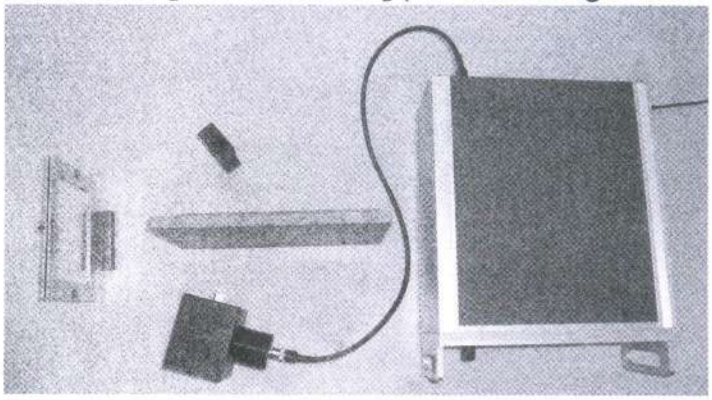
The diameter of each disc is approximately 50 mm including the frame. There is identification number for each disc printed on it. All these discs are housed in this acrylic box. This absorber set will be useful in studying the Beta absorption coefficient using G.M. Counting systems.

LEAD CASTLE [TYPE: LS240]

The Lead Castle is designed to shield the G.M. Counters from counting background radiation. Lead Castle type LS 240 can house G.M. counter mounted in a G.M stand. This shield is of 40 mm thickness and is built up of six interlocking rings. The top and bottom are covered by similar interlocking discs. A door is fitted in the bottom ring with 150 degree opening to facilitate easy access to the sample holding tray of G.M. Stand. The door is fitted with heavy duty hinges and the inside of the lead shield is lined with thin aluminium sheet to minimize scattering.



ABSORBER/SCATTERER SET [TYPE : AS 272] (For Scattering of Beta Particles Experiment)



Description : The absorber/scatterer set consists of 15 Aluminium foils, the thickness of each foil being 0.05 mm. For increasing the thickness of the scatterer, the required number of aluminium foils are to be stacked together and put in the frame provided.

ABSORBER SET [TYPE: AS 273] (For Production and Attenuation of Bremsstrahlung Experiment)

Description : The absorber set consists of the following combination of materials:
Aluminium (0.7 mm thickness) & Perspex (1.8 mm thickness)
Perspex (1.8 mm thickness) & Copper (0.3 mm thickness)
Aluminium (0.7 mm thickness) & Copper (0.3 mm thickness)

ACTIVITY & DOSERATE CALCULATION PROCEDURE

a. Activity calculation (as on date)

It is known that, given the activity at any previous date and by knowing its half-life, we can calculate the present activity by using the following equation

$$A = A_0 e^{-\lambda t}$$
$$= A_0 e^{-(0.693/T1/2)\,t}$$

Where,

A = Present activity

A_0 = Activity as on previous date

$T_{1/2}$ = Half life of source

t = Elapsed time

λ = Decay constant

TYPICAL CALCULATION OF ACTIVITY FOR TWO BETA AND TWO GAMMA SOURCES:

BETA SOURCES:

Sr-90: (3.7 KBq, Oct 2006); Half life for Sr-90 is $T_{1/2}$ = 28.5Yrs

Activity (A_0) = 3.7 KBq, as on Oct'06.
= 3700 Bq

(Elapsed time till Sept'07= 11months)

Present activity (A) = $A_0 e^{-(0.693/T1/2)\,t}$; as on Sept'07

$T_{1/2}$ = 28.5yr

t = 11/12=0.9166yr

= $3700\ e^{-(0.693/28.5)\ 0.9166}$

= 3618.6 Bq

Tl-204: (11.1 KBq, Oct 2006); Half life for Tl-204 is $T_{1/2}$ = 4Yrs

Activity (A_0) = 11.1 KBq, as on Oct'06.
= 11100 Bq

(Elapsed time till Sept'07= 11months)

Present activity (A) = $A_0 e^{-(0.693/T1/2)\,t}$; as on Sept'07

$T_{1/2}$ = 4yr

t = 11/12=0.9166yr

= $11100\ e^{-(0.693/4)\ 0.9166}$

= 9469.41 Bq

GAMMA SOURCES:

Cs-137: (3.1μCi, July'07) ; Half life for Cs-137 is $T^{1/2} = 30Yrs$

Activity (A_0)	=	3.1μCi, as on Oct'06.
	=	$3.1X3.7X10^{10}X10^{-6}$
	=	114700 Bq
		(Elapsed time till Sept'07= 2months)
Present activity (A)	=	$A_0\, e^{-(0.693/T_{1/2})\, t}$; as on Sept'07
$T_{1/2}$	=	30yr
t	=	2/12=0.1666yr
	=	$114700\, e^{-(0.693/30)\, 0.1666}$
	=	114264.14 Bq

Co-60: (3.7μCi, July'07) ; Half life for Co-60 is $T_{1/2} = 5.3Yrs$

Activity (A_0)	=	3.7μCi, as on Oct'06.
	=	$3.7X3.7X10^{10}X10^{-6}$
	=	136900 Bq
		(Elapsed time till Sept'07= 2months)
Present activity (A)	=	$A_0\, e^{-(0.693/T_{1/2})\, t}$; as on Sept'07
$T_{1/2}$	=	5.3yr
t	=	2/12=0.1666yr
	=	$136900\, e^{-(0.693/5.3)\, 0.1666}$
	=	133961.2 Bq

b. DOSE RATE CALCULATION

Dose rate can be calculated by using the following formula

$$\text{Dose rate} = \frac{\text{Source Activity x gamma constant}}{(\text{Distance})^2}$$

where

Dose rate is in mR (milli Roentgen)

Source Activity is in mCi (milli Curies)

Distance is in cm (Centimeters)

Gamma constant for Cs-137 is 3300

and gamma constant for Co-60 is 13200

B. EXPERIMENTS ILLUSTRATING THE PRINCIPLES OF NUCLEAR PHYSICS

Exp: 1. STUDY OF THE CHARACTERISTICS OF A GM TUBE

1.1 PURPOSE

To study the variations of countrate with applied voltage and thereby determine the plateau, the operating voltage and the slope of the plateau.

1.2 EQUIPMENT / ACCESSORIES REQUIRED

- G.M. Counting System GC601A / GC602A with A.C. main chord.
- G.M Detector (End window) stand (or) G.M Detector/source holder bench (optical bench).
- G.M. Detector (in PVC cylindrical enclosure) with connecting cable.

1.3 PROCEDURE

- Make the connection between counting system to G.M. Detector by MHV to UHF co-axial cable. Also connect the mains chord from the counting system to 230V A.C. Power (refer to Fig.1).
- Place a Gamma or Beta source facing the end window of the detector, in the source holder of G.M. stand or optical bench at about 2 cms (for Gamma source) or 4 cms (for Beta source) approximately, from the end window of the detector. (For Beta source ensure that countrate is less than 200 CPS at 500V)
- Now power up the unit and select menu options to PROGRAM on the keypad of the G.M. Counting System and select 30sec preset time typically (It can be in the range of 30 to 60 sec.) [For all command button functions, refer to G.M. Counting System GC601A /GC602A user manual.]
- Now press - "START" button to record the counts and gradually increase the HV by rotating the HV knob till such time, the unit just starts counting. Now, press "STOP" button.
- Now take a fresh reading at this point (STARTING VOLTAGE) and record the observations in the format as given in Table 1.
- Also record for each HV setting, corresponding background counts without keeping the source.
- Continue to take these readings in steps of 30V and for the same preset time, keep observing counts & tabulate the data, with and without source.
- Initially within 2 to 3 readings, counts will steeply increase and thereafter remain constant with marginal increase (may be within 10%). After few readings, one will find a steep increase as one enters the discharge region. Take just one or two readings in this region and reduce the HV bias to 0 volts. <u>It is important to note that operating the G.M detector in discharge region for longer time can reduce the life of tube or can result into permanent damage of the detector.</u>

- Now tabulate the readings and plot a graph of voltage against counts (corrected counts). This graph should look as shown in Fig. 6.
- Identify from the graph / tabulated data
  i) Starting Voltage
  ii) Lower threshold voltage (V_1)
  iii) Upper threshold voltage (V_2). It is called Breakdown threshold voltage
  iv) Discharge region.
- Calculate **plateau, percentage slope**, and **plateau length, operating voltage,** etc.

Table - 1 : G.M. Characteristics Data

S.No.	EHT (Volts)	Counts 30 sec N	Background Counts 30 sec N_b	Corrected Counts $Nc = (N-N_b)$ 30 sec
1	330	0	0	0
2	360 (V_1)	1710	35	1675(N_1)
3	390	1728	35	1693
4	420	1743	35	1708
5	450	1784	36	1748
6	480	1792	36	1756
7	510	1802	37	1765
8	540	1818	39	1779
9	570 (V_2)	1821	40	1781 (N_2)
10	600	2607	76	2531
11	630	3475	76	3399

1.4 ANAYSIS & COMPUTATIONS

Estimate from the tabulated readings

- V_1 = Starting voltage of plateau = 360 V
  (Just after rising edge of knee)

- V_2 = Upper threshold of the plateau = 570 V
  (Just before the start of discharge region)

- Plateau length VPL = $V_2 - V_1$ = (570-360) = 210 V

- Operating voltage $V_0 = \frac{(V2 + V1)}{2} = \frac{(570+360)}{2} = 465$ V

- The slope of the plateau is given by

$$\text{Slope (Percentage)} = \frac{N2 - N1}{N1} \times \frac{100}{(V2 - V1)} \times 100$$

$$= \frac{(1781 - 1677)}{1677} \times \frac{100}{(570 - 360)} \times 100 = 2.95\ \%$$

Where N1 and N2 are the count rates at the lower and the upper limits of the plateau and V1 and V2 are the corresponding voltages.
Slope less than 10% is desirable.

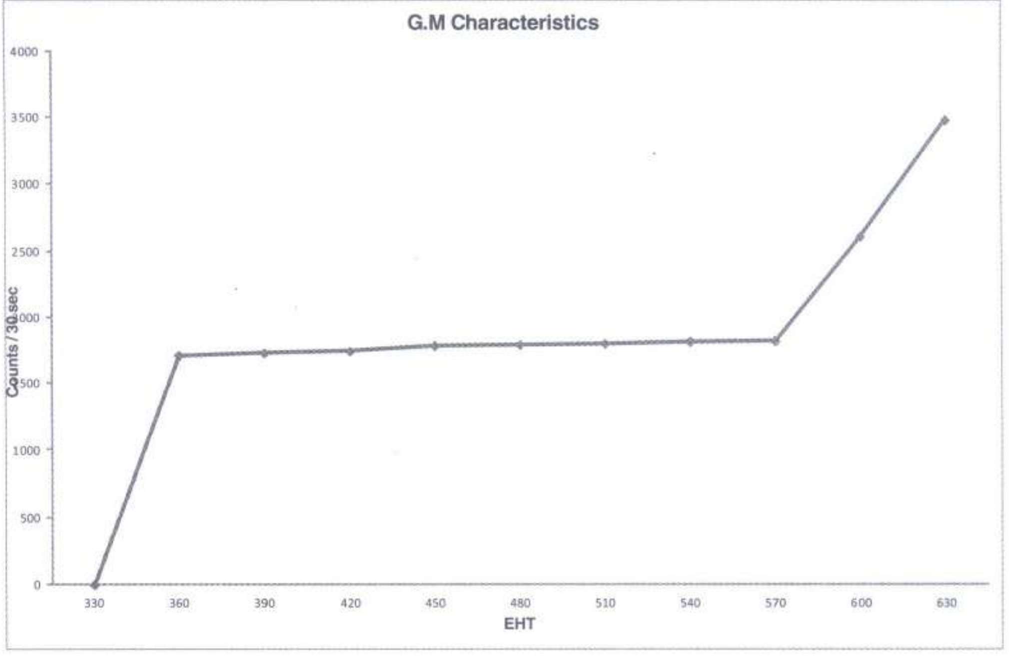


Fig. 6 : Plot of counts Vs EHT

1.5 CONCLUSIONS

- From the plateau, it can be noticed that mid point of the characteristics of the GM tube is defined as operating voltage and is to be used for counting applications. The tube is operated at this voltage when used in Radiation Monitors for measurements.

- Repeat the experiment with Beta source by keeping the source slightly away from the end window when compared to gamma source and tabulate the data. Calculate slope, plateau length etc. From this, one could notice that with Beta source, the efficiency of the detector increases. Also one can notice that with higher count rates, plateau slope increases.

Experiments #3: Dead time and nuclear counting statistics

Objective:

1. Measurement of dead time
2. To investigate the statistics related to measurements with a Geiger counter: Poisson and Gaussian distribution

Apparatus:

• Set-up for ST-350 Counter

• GM Tube and stand

• Shelf stand, serial cable, and a source holder

• Radioactive Source (e.g., Cs-137, Sr-90, or Co-60)

Fig. 1 Experimental set up for studying dead time and counting statistics

Dead Time

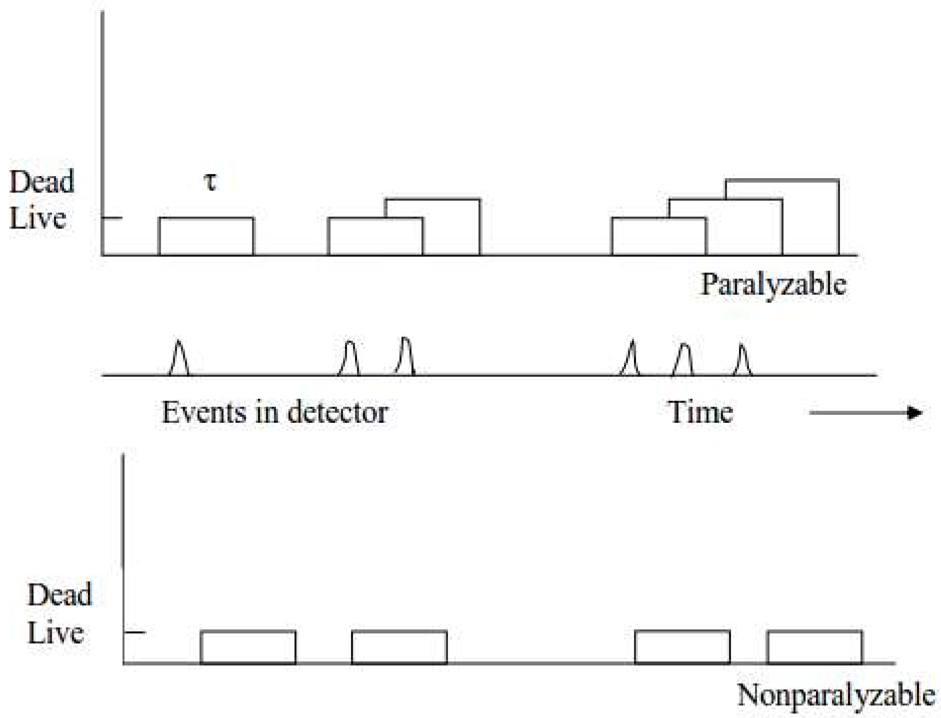
In nearly all detector systems, there will be a minimum amount of time that separates two events in order that they may be recorded as two separate pulses. In some cases the limiting time may be set by processes in the detector itself, while in other cases the limit may arise due to the delays associated with the electronics. This minimum time separation is usually called the dead time of the counting system. Because of the random nature of radioactive decay, there is always some probability that a true event will be lost because it occurs too quickly following a preceding event. Two models of dead time are in common use, categorized on the basis of paralyzable and nonparalyzable response of the detector. The fundamental assumptions of the two models are illustrated in Fig. 3. At the centre of the figure, a time scale is shown on which six randomly spaced events in the detector are indicated. At the bottom of the figure is the corresponding dead time behaviour of a detector to be nonparalyzable. A fixed time τ is assumed to follow each true event that occurs during the “live period” of the detector. True events that occur during the dead period are lost and assumed to have no effect whatsoever on the behaviour of the detector. In the example shown the nonparalyzable detector would record four counts from the six true events. In contrast, the behaviour of a paralyzable detector is shown along the top line of Fig. 3. The same dead time τ is assumed to follow each true interaction that occurs during the live period of the detector. True events that occur during the dead period are not recorded but they extend the dead time by another period τ following the lost event. In the example shown, only three counts are recorded for the six true events. The two models predict the same first-order losses and differ only when true event rates are high. They are in some sense two extremes of idealized system behaviour, and real counting system will often display a behaviour that is intermediate between these extremes. The detailed behaviour of a specific counting system may depend on the physical processes taking place in the detector itself or on delays introduced by the pulse processing and recording electronics.

If the system dead time is τ, and the measured count rate is m , then the true count rate n predicted by the two models can be expressed as

Nonparalyzable Model: $n = \frac{m}{1-m\tau}$ (1)

Paralyzable Model: $m = ne^{-n\tau}$ (2)

The derivations of the above results are given in Ref. 1. You may show that for low counting rates ($n << 1/\tau$) both models give the same expression for n . In the present experiment we will utilize the nonparalyzable model in the calculation of true counts and the dead time τ.



A commonly used method for dead time measurements is known as two source method. The method is based on observing the counting rate from two sources individually and in combination. Because the counting losses are nonlinear, the observed rate due to the combined sources will be less than the sum of the rates due to the two sources counted individually, and the dead time can be calculated from the discrepancy.

Procedure

(i) To find the dead time we have to use two γ sources say S_1 (^{137}Cs) and S_2 (^{60}Co). While performing the experiment as per the steps given below, care must be exercised not to move the source already in place and consideration must be given to the possibility that the presence of a second source will scatter radiation into the detector which would not ordinarily be counted from the first source alone. In order to keep the scattering unchanged, a dummy second source without activity is normally put in place when the sources are counted individually.

(ii) Keep source S_1 in one of the pits in the source holder made for this purpose. Keep a dummy source in the second pit. Record the counts for a preset time (say 300 s).

(iii) Without removing source S_1 remove the dummy source from the second pit and keep the source S_2 in its place. Record the number of counts for the combined sources S_1 and S_2 for the same preset time as in (ii).

(iv) Remove source S_1 and measure the counts due to source S_2 alone, for the same preset time as in (ii).

(v) Remove source S_2 as well and record the background counts for the same period. Calculate the count rates in all the cases. Let n_1, n_2 and n_{12}be the true counts (sample plus background), with sources S_1, S_2 and (S_1 +S_2), respectively. Letm_1, m_2 and m_{12}represent the corresponding observed rates. Also let $n_b$and $m_b$be the true and measured background rates with both the sources removed. Assuming the nonparalyzable model, the dead time τ is given by (see Ref. 1 for details)

$$\tau = \frac{X(1-\sqrt{1-Z})}{Y} , \quad (3)$$

where $$X \equiv m_1 m_2 - m_b m_{12} , \quad (4)$$

$$Y \equiv m_1 m_2 (m_{12} + m_b) - m_b m_{12} (m_1 + m_2) , \quad (5)$$

and $$Z \equiv \frac{Y(m_1 + m_2 - m_{12} - m_b)}{X^2} . \quad (6)$$

Table: **Data for resolving time**

	n	m	τ	Error (%)
S1				
S2				
S12				

Counting statistics:

Radioactive decay is a random process. Consequently, any measurement based on observing the radiation emitted in a nuclear decay is subject to some degree of statistical fluctuations. These inherent fluctuations are unavoidable in all nuclear measurements. The term counting statistics includes the framework of statistical analysis required to process the results of nuclear counting experiments and to make predictions about the expected precision of quantities derived from these measurements.

Although each measurement (number of decays in a given interval) for a radioactive sample is independent of all previous measurements (due to randomness of the process), for a large number of individual measurements the deviation of the individual count rates from the average count rate behaves in a predictable manner. Small deviations from the average are much more likely than large deviations. These statistical fluctuations in the nuclear decay can be understood from the statistical models utilizing Poisson distribution or Gaussian (Normal) distribution. If we observe a given radioactive nucleus for a time t and define the success as "the nucleus decays during the process" then the probability of success "p" is given by $(1 - e^{-\lambda t})$. The Poisson distribution applies when the success probability p is small and the number successes (i.e. number of counts measured) is also small (say <30). In practical terms, this condition implies that we have chosen an observation time that is small compared with the half-life of the source. When the average number of successes becomes relatively large (say > 30) we can utilize the Gaussian model of distribution. Since in most of the cases the count rates are reasonably large (few tens of counts per second) the Gaussian model has become widely applicable to many problems in counting statistics. On the other hand the Poisson distribution is applicable in the case of background counts. The details of experimental, Poisson and Gaussian distributions are given below.

Experimental distribution function

We assume that we have a collection of N independent measurements of the same physical quantity. In this particular case the quantity is the number of counts recorded by the detector in a specific time interval. We denote the result of these N measurements as

$y_1, y_2, y_3 \ldots\ldots\ldots y_i \ldots\ldots\ldots y_N$.

The experimental mean is given by

$$\bar{y} \equiv \frac{\sum_{i=1}^{N} y_i}{N} \qquad (7)$$

The data set is conveniently represented by a frequency distribution function F(y). The value of F(y) is the relative frequency with which the number appears in the collection of data. By definition

$$F(y) = \frac{number\ of\ the\ occurrences\ of\ the\ value\ y\ [\equiv v(y)]}{number\ of\ measurements\ (=N)} \qquad (8)$$

A plot of F(y) versus y gives the frequency distribution of the data (The number of occurrences can also be calculated by choosing a suitable interval for the values of y). The standard deviation of the distribution is given by

$$\sigma_{\exp} = \left(\frac{1}{N} \sum_{i=1}^{N} (y_i - \bar{y})^2 \right)^{1/2} \qquad (9)$$

Notes regarding σ $_{exp}$ and $\bar{y}$

Remember that Eq. (9) is applicable to the quantities directly measured in the experiment and not to the derived quantities. To illustrate, in the present experiment if you measure the number of counts for a preset time interval (say 30 s) and call it y_i. Then Eq. (9) is applicable to these counts only and not to the counting rates calculated using these values. To determine the deviations for the derived quantities proper error propagation methods should be used.

To be precise, $\bar{y}$ is the true mean value determined from a set having infinitely large number of measurements and cannot be determined experimentally as such. However for a reasonably large set of measurements the value of $\bar{y}$ can be set equal to $\bar{y}$ (Eq. (7).

The Poisson distribution

As mentioned above it is applicable when p <<1 and the number of successes are very few.

$$P(y) = \frac{(\bar{y})^y e^{-\bar{y}}}{y!} \qquad (10)$$

In this case the standard deviation is given by

$$\sigma_P = \sqrt{\bar{y}} \qquad (11)$$

The Normal or Gaussian distribution

When p << 1 and the successes are large one can model the experimental data using the Normal distribution which is also called Gaussian distribution (as per R.D. Evans it is erroneous to call this as Gaussian because its derivation by Gauss (1809) was antedated by those of Laplace (1774) and DeMoivre (1735)). This is given by

$$P(y) = \frac{1}{\sqrt{2\pi\,\bar{y}}} \exp\left(-\frac{(y-\bar{y})^2}{2\bar{y}}\right) \qquad (12)$$

The standard deviation in this case is the same as that for the Poisson distribution

$$\sigma_G = \sqrt{\bar{y}} \qquad (13)$$

We will denote both σ_P and σ_G as σ_{th}.

Applications of statistical models in nuclear physics

There are two major applications of counting statistics in nuclear measurements. The first application involves the use of statistical analysis to determine whether a set of multiple measurements of the same physical quantity shows an amount of internal fluctuation that is consistent with statistical predictions. In this case the motivation is to determine whether a particular counting system is functioning normally. The second application is more important in which we examine these methods to make a prediction about the uncertainty one should associate with a single measurement. The following procedure and analysis will give you a feel as to how an experimental distribution in a nuclear counting experiment looks like and how does it compare with theoretical distributions.

Procedure

(i) Set the operating voltage of the Geiger counter at its proper value.

(ii) Don't put any source in the lead castle. Also remove all the sources in the vicinity of the castle.

(iii) Take 100 independent readings of the background counts for a preset time of 10 s. (To set Preset time 10 sec. follow step (ii) of initial procedure).

(iv) Save the data by pressing **STORE** key. While taking 100 independent reading set **ITERATION** (Step (iii) of initial procedure) to 1.

(v) Place one of the γ sources (137Cs or 60Co) far enough away from the window of the Geiger tube so that approximately 2000 counts are recorded in a time period of 30 s. Take 100independent readings of the counts for a preset time of 30s.

(vi) Save the data by pressing **STORE** key. While taking 100 independent reading set **ITERATION** (Step (v) of initial procedure) to 1.

(vii) Transfer the data on PC and plot the required function.

Analysis of Background counts (data set (iii) above)

(viii) Determine frequency of occurrence ν(y) which is the number of measurements in which y = 0, 1,2 , 3, 4 ….counts have been observed and plot the experimental distribution ν(y) versus y .

(ix) Calculate the average number of counts $\bar{y}$ and the Poisson distribution

$$P(y) = \frac{(\bar{y})^y e^{-\bar{y}}}{y!}$$

(x) Calculate σ_{exp} and σ_{th} and compare. The comparison gives clue to the reliability of the measuring equipment. If σ_{exp} is larger than σ_{th} , it means that additional fluctuations have been introduced by the apparatus, such as spurious counts due to voltage surges, sparks in the tube or change of the background during the course of the experiment which can occur when you handle the sources (move from one place to another) while the measurements are going on.

(xi) Determine the actual number of intervals for which the absolute value of the deviation from the average is larger than the standard deviation $\sigma = \sqrt{\bar{y}}$ and the probable error 0.6745σ. Compare with theory.

Analysis of the counts taken with the source data set (v) above

(xii) Carry out the analysis following steps (viii) to (xi) above. However, in this case use Gaussian distribution. Also, in order to represent the distribution in the best possible manner, frequency of occurrence may be calculated by choosing equally spaced, non-overlapping, contiguous intervals for the counts. The width of the interval can be anywhere from 2 to 10 counts or more depending on the data set.

(xiii) In addition, you may use different methods of testing the "Gaussian" nature of an experimental data which are illustrated in the book: Measurement systems, Applications and Design (4th edition) by E. O. Doebelin, pages 44-58.

Table: **Data for counting statistics**

Run #	Counts

Run #	Counts

Data Set	Mean	Gaussian σ	Poisson σ
Background			
Cs-137			

References:

1. Glenn F. Knoll, "Radiation Detectors and Measurement", Chapters 3 and 7.

2. R.D. Evans, "The Atomic Nucleus", page 688.

3. R. M. Singru, "Introduction to Experimental Nuclear Physics".

4. Instruction Manual of G.M. Counting System TYPE: ST 360.

Exp: 4. ESTIMATION OF EFFICIENCY OF THE G.M.DETECTOR

(A) EXPERIMENT TO ESTIMATE EFFICIENCY FOR A GAMMA SOURCE

4.1 INTRODUCTION

By knowing the activity of a gamma source, it is possible to record counts with the source for a known preset time & estimate the efficiency of the G.M. detector

4.2 EQUIPMENT / ACCESSORIES REQUIRED

- G.M. Counting System GC 601A/ GC602A
- G.M. Detector / source holder stand (SG200) or bench (SB201)
- Radioactive source kit (SK210)
- G.M. detector in cylindrical enclosure (GM120)
- Necessary connecting cables

4.3 PROCEDURE

- Make interconnections such as mains power cord to GC601A/602A unit and connection between G.M. detector holder mount to rear panel of GC601/602, through HV cable.
- Place a gamma source in the source holder facing the end window detector. Typically the distance between the source to end window of G.M. tube can be 10 cm.
- Now record counts for about 100 sec both background and counts with source and make the following calculations and analysis.

4.4 ANALYSIS AND COMPUTATIONS

- Let 'D' be the distance from source to the end window.
- Let 'd' is the diameter of the end window
- Lt N_S = Counts recorded with source
  N_b= Counts recorded due to background
- Now make the following measurements

Background counts in 100 sec (Average of three readings)	$N_b = 71$
Distance from source holder to end window	D=10cm
Diameter of end window	d = 1.5cm
No. of counts recorded in 100sec with the source	$N_S = 432$

From the above data, the net count rate recorded N = (N_S - N_b/100) cps = 3.61CPS

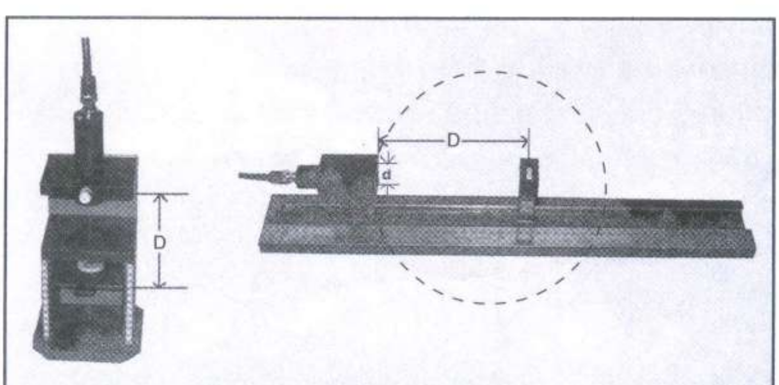


Fig. 15 : Detector source arrangement for efficiency calculation for a gamma source

Gamma source emits radiation isotropically in all directions (4Π geometry). However only fraction of it is received by the end window detector. This fraction is given by

$$= \frac{\left(\frac{\Pi d^2}{4}\right)}{4\Pi D^2} = \frac{d^2}{16D^2}$$

The present activity (A) of the gamma source used for this experiment is 111 KBQ. This gamma source is radiating isotropically in all directions. A fraction of this only is entering the G.M. Tube, which is given by

$$R = A \times \frac{d^2}{16D^2} = 111000 \times 0.001406 = 156.066$$

This is the fractional radiation entering the detector
Hence efficiency of the detector for the gamma source at a distance (D = 10 cm)

$$\text{Efficiency (E)} = \frac{CPS}{DPS} = \frac{N}{R}$$

$$= \frac{3.61}{156.066} = 0.0231 = 2.31\%$$

Note: CPS = Counts per Second
DPS = Disintegrations per Second falling on the window of the ditector.

(B) EXPERIMENT TO ESTIMATE EFFICIENCY FOR A BETA SOURCE

INTRODUCTION:

Equipment required & procedure remains the same as detailed under 5.2&5.3.

The only difference is, here we place Beta source about 2 cm close to the end window & calculate 'Intrinsic efficiency', (which do not take geometry factor into consideration)

PROCEDURE:

- Make standard arrangement & interconnections for G.M counting system, detector, G.M stand.
- Place Beta source close to End Window (approx 2cm from end window). Record counts for a minute with and without source. Take three readings; take average of them and tabulate.
- Record distance of the source from end window.
- Calculate the present day activity in DPS of the source (refer to procedure given at the end of the manual).
- Calculate net CPM/CPS counted.
- Intrinsic efficiency can be calculated as the ratio between (CPM/DPM) x 100 or (CPS/DPS) x 100. This will be efficiency of the end window detector for the given Beta Source at that distance.

DATA COMPUTATION & ANALYSIS:

Beta source used	:	Sr-90
Activity (A0)	:	5.55 KBq (as on Aug 2006)
Activity (A)	:	5.373 KBq (as on Dec 2007)
(use procedure given on pages 13 & 14)		
Background count rate	:	57 CPM
Counts recorded with source (Average)	:	14427 CPM
Corrected counts	:	14370 CPM
Net count rate	:	239.5 CPS

Efficiency (E) of the End window detector with Beta source (Sr-90) at 2.0 cm distance

$$E = \left(\frac{CPS}{DPS}\right) = 0.0446 = 4.46\%$$

4.5 EXERCISE

- By knowing the efficiency of the G.M. detector for a particular Gamma energy (at a specified distance & geometry), one can further calculate the following parameters, namely activity of the source as on the day of experimentation (of course it is assumed that activity of the standard is known as on the date of manufacture), and also the activity of the unknown source if any with the same energy.

- It can be noticed that End Window detector will have much better efficiency for Beta Source compared to a gamma source.

- By knowing efficiency for a Beta source , if an unknown activity Beta source is kept for counting one can calculate and find out its activity.

6.0 IMPORTANT DEFINITIONS OF RADIATION TERMS

- **Absorbed dose:** The energy transferred to a material by ionising radiation per unit mass of the material.

  Unit: J kg^{-1}; Name of unit: Gray (see also Rad)

- **Absolute Efficiency:** The ratio of number of pulses recorded to the number of radiations emitted by the source.

- **Activity:** Measurement of quantity of radioactive material. It is the number of nuclear transformations or isomeric transitions per unit time.

  Unit: s^{-1} Name of unit: Becquerel (see also Curie)

- **Alpha decay: Alpha particles** consist of two protons and two neutrons bound together into a particle identical to a helium nucleus. They are generally produced in the process of alpha decay, but may also be produced in other ways. Alpha particles are named after the first letter in the Greek alphabet, α.

  A radioactive conversion accompanied by the emission of an alpha particle. In alpha decay the atomic number is reduced by 2 and the mass number by 4. Alpha decay occurs, with a few exceptions, only for nuclides with a proton number exceeding 82.

- **Alpha radiation:** Radiation that consists of high energy helium (^{4}He) nuclei emitted during alpha disintegration of atomic nuclei. Alpha particles possess discrete initial energies (line spectra) which are characteristic of the emitting nuclide.

- **Anode (in electron tubes):** An electrode through which a principal stream of electrons leaves the interelectrode space.

- **Attenuation coefficient:** The probability that a photon will be removed from the incident beam per unit thickness of material traversed.

- **Background counts (radiation counters):** Counts caused by ionizing radiation coming from sources other than that be to measured.

- **Becquerel (Bq):** Name of the derived SI unit of activity. Number of radioactive transformations or isometric transitions per seconds s^{-1} = Bq.

1 Bq	=	27 x 10^{-12}	=	27 pCi
1 kBq	=	27 x 10^{-9}	=	27 nCi
1 MBq	=	27 x 10^{-6}	=	27 mCi
1 GBq	=	27 x 10^{-3}	=	27 mCi
1 TBq	=	27 Ci	=	27 Ci

- **Beta decay:** Radioactive conversion accompanied by the emission of a beta particle, i.e. a negatively charged electron (b- decay) or a positively charged electron (b+ decay). When a negatively charged electron is emitted, a neutron in the atomic nucleus is converted to a proton with the simultaneous emission of an antineutrino, so that the proton number Z is increased by 1. When a positively charged electron (positron) is emitted, a proton in the nucleus is converted to a neutron with simultaneous emission of a neutrino, so that the proton number **Z** is decreased by 1.

- **Beta Radiation:** Radiation that consists of negative or positive electrons which are emitted from nuclei undergoing decay. Since the decay energy (or, if it is followed by gamma radiation, the decay energy less that photons energy) is statistically divided between beta particles and neutrinos (or antineutrinos), the energy spectrum of beta radiation is continuous, extending from zero to a maximum value characteristic of the nuclide concerned. The maximum beta energy is generally termed the “beta end-point energy of the nuclide”.

- **Bremsstrahlung:** Radiation that results from the acceleration/deceleration of charged particles in the Coulomb field of atoms.

- **Curie (Ci):** Name for derived unit of activity. One Curie corresponds to 3.7 x 10^{10} nuclear disintegrations or isomeric transitions per second 1 Ci = 3.7 x 10^{10} s^{-1}.

  1 Ci = 37 GBq
  1 mCi = 37 MB1
  1 µCi = 37 kBq
  1 nCi = 37 Bq
  1 pCi = 37 mBq

- **Dose:** See absorbed dose, exposure value, and dose equivalent

- **Dose equivalent:** A term used in radiation protection for the radiation dose. It is the product of absorbed dose times the quality factor.

  Unit: J kg^{-1}; Name of unit: Sievert (see also Rem)

- **Dose rate:** Dose absorbed per unit time
- **Dynode:** An electrode which performs a useful function, such as current amplification, by means of secondary emission.
- **Electron radiation:** Particle emission consisting of negatively or positively charged electrons.
- **Exposure dose:** The ratio of the amount of electric charge of the ions of one polarity that are formed in air by Ionizing radiation and the mass of the air.

  Unit: C. kg^{-1} (see also Roentgen)
- **Full width at half maximum (FWHM):** The full width of a distribution measured at half the maximum ordinate.
- **Gamma radiation: Gamma radiation**, also known as **gamma rays,** and denoted by the Greek letter γ, refers to electromagnetic radiation of extremely high frequency and therefore high energy per photon. Gamma rays are ionizing radiation, and are thus biologically hazardous. They are classically produced by the decay from high energy states of atomic nuclei (gamma decay), but are also created by other processes. Paul Villard, a French chemist and physicist, discovered gamma radiation in 1900, while studying radiation emitted from radium. Villard's radiation was named "gamma rays" by Ernest Rutherford in 1903.

  Natural sources of gamma rays on Earth include gamma decay from naturally occurring radioisotopes, and secondary radiation from atmospheric interactions with cosmic ray particles. Rare terrestrial natural sources produce gamma rays that are not of a nuclear origin, such as lightning strikes and terrestrial gamma-ray flashes. Additionally, gamma rays are also produced by a number of astronomical processes in which very high-energy electrons are produced, that in turn cause secondary gamma rays via bremsstrahlung, inverse Compton scattering and synchrotron radiation. However, a large fraction of such astronomical gamma rays are screened by Earth's atmosphere and can only be detected by spacecraft.
- **Gray:** The SI unit of absorbed radiation dose. 1 Gray of absorbed dose corresponds to 1 joule of energy per kilogram of mass.

  1 Gray = 100 rad
- **Half-value thickness ($T_{1/2}$):** The thickness of material layer that reduces the initial intensity of radiation by a factor of two.