EXPERIMENTS WITH G.M COUNTER

G.M Counting System with G.M (End window) stand and G.M Detector / source holder bench

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PREFACE

This is the second revised experimental manual for a product which is manufactured and fully supported in all respects. Nucleonix Systems supplied for studies in Physics and and an experimental manual of to enable university faculty to utilize the equipment both for teaching and research labs.

Considerable efforts have been put in preparing the manuscript for this experimental manual. Editors have gone through this and reviewed the manuscript thoroughly and made corrections. However if there are any errors or omissions, you are requested to write to us.

There may be still scope to add a few experiments to this manual. We welcome feedback on new additions to this, from professors and others from scientific community. We may include such additional experiments in future editions, if found suitable.

This manual on **'Experiments with G.M. counter'** has been written to include the important information such as basic definitions on radiation units and fundamentals of Nuclear & Radiation Physics, general information on G.M. Tubes and their characteristics, working principle and a list of G.M. Detector experiments which illustrate some of the important fundamentals of Nuclear Radiation & its characteristics.

There is also condensed information provided on various **G.M. Counting System models** along with accessories, which will help in having better understanding while going through this experimental manual. Of course, for more detailed information one can go through **counting system** user manual, for operation and commands description.

Additionally, basic calculation procedure on **activity** and **dose rate** as on a given date by knowing the activity on the date of manufacture of source are also given in this manual.

Apart from understanding the Physics principles by doing these experiments, one will also know that there are quite a few Engineering and Industrial applications where nuclear techniques are employed using nuclear radiation detectors such as G.M. Detectors and NaI Scintillation detectors. Typically applications are given below :

(i) Nucleonic level gauging in steel and cement Industries using G.M. detector and a radiation source.

(ii) Gamma column scanning in petrochemical industries using NaI Scintillation detector based system and other applications include detection of Liquid fill, height for beverages, soups, pharmaceutical products, baby foods, Match boxes, yogurt cartons etc, for sorting or counting items, in a process or pharmaceutical industry.

Two experiments Sl.No. C(9) and (10) included in this manual illustrate engineering and industrial applications.

These experiments Sl.No. (9) and (10) when demonstrated to Engineering students will illustrate the possible real time applications and scope of nuclear techniques for industrial and engineering applications.

These experiments will be of interest to Engineering stream students in their Engineering Physics/ Instrumentation labs. It may be noted that some of NITs, IITs and Technological universities have included **G.M. counter experiments, in Engineering physics labs.** Editorial board is of the opinion that when these physics experiments are done for Engineering streams, emphasis should be with Engineering applications to the particular branch/ stream, so that the student appreciates and understands the application well.

In this second revised edition two new experiments Sl.No (6) and (7) have been added which are primarily to cover Backscattering of Beta particles and Production and Attenuation of Bremsstrahlung.

We also thank all our staff at NUCLEONIX SYSTEMS who have helped us in preparing this manuscript for releasing to Press.

Finally, Editors will be happy if this manual has served the purpose for which it is written. Efforts will go on continuously to improve on this in the next edition. Suggestions and feedback are welcome from all concerned with this subject.

J. Narender Reddy

Dr. M.S.R. Murty

Editors

EQUIPMENTS REQUIRED FOR DOING THE EXPERIMENTS:

(Most of these items mentioned below are manufactured and or supplied by NUCLEONIX SYSTEMS)

EQUIPMENT / SYSTEM:	TYPE
1. Geiger Counting System	**GC601A (or) GC602A**
2. End Window G.M.Tube (Halogen Quenched) in cylindrical PVC enclosure	**GM 120**
3. G.M. Detector (End window) stand. (or)	**SG200**
4. Sliding bench for G.M experiments	**SB201**
5. Radioactive Source Kit-1 (containing one Beta & one Gamma Source)	**SK210**
6. Lead Shielding (Optional)	**LS240**
7. Aluminium Absorber Set	**AA270**
8. Absorber Set (for scattering of Beta particles experiments)	**AS271**
9. Absorber Set (for production and attenuation Bremsstrahlung experiment)	**AS272**
10. Cs-137/Ba-137m isotope generator or Indium foil and Neutron Howitzer (for generating short lived isotope)	

Note : Item No. (10) is not offered by Nucleonix systems.

CONTENTS

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

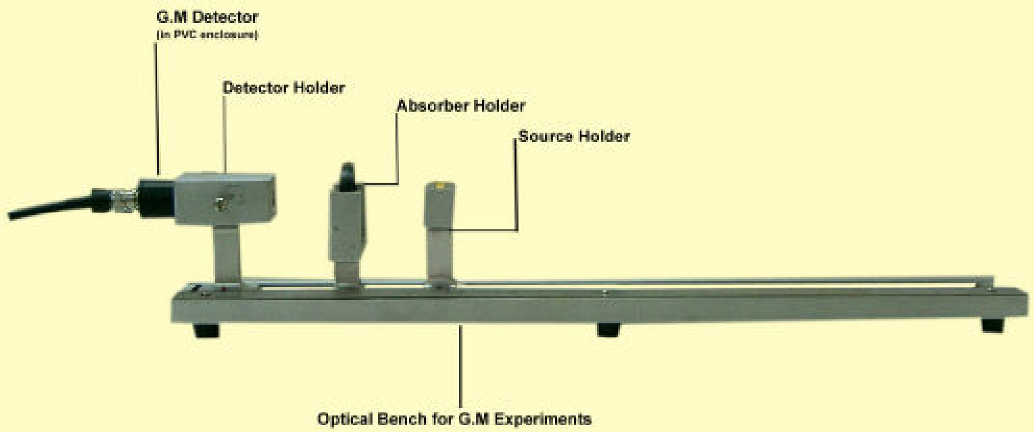


Fig. 2: Sliding bench for G.M Experiments (SB201)

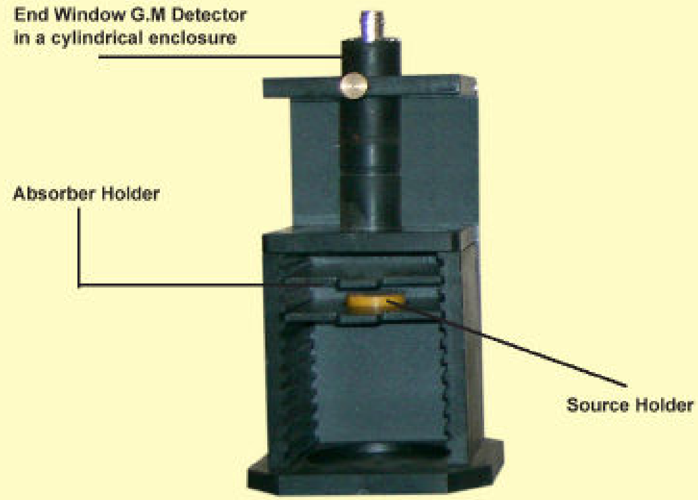


Fig 3 : G.M. Detector stand (SG200)

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.

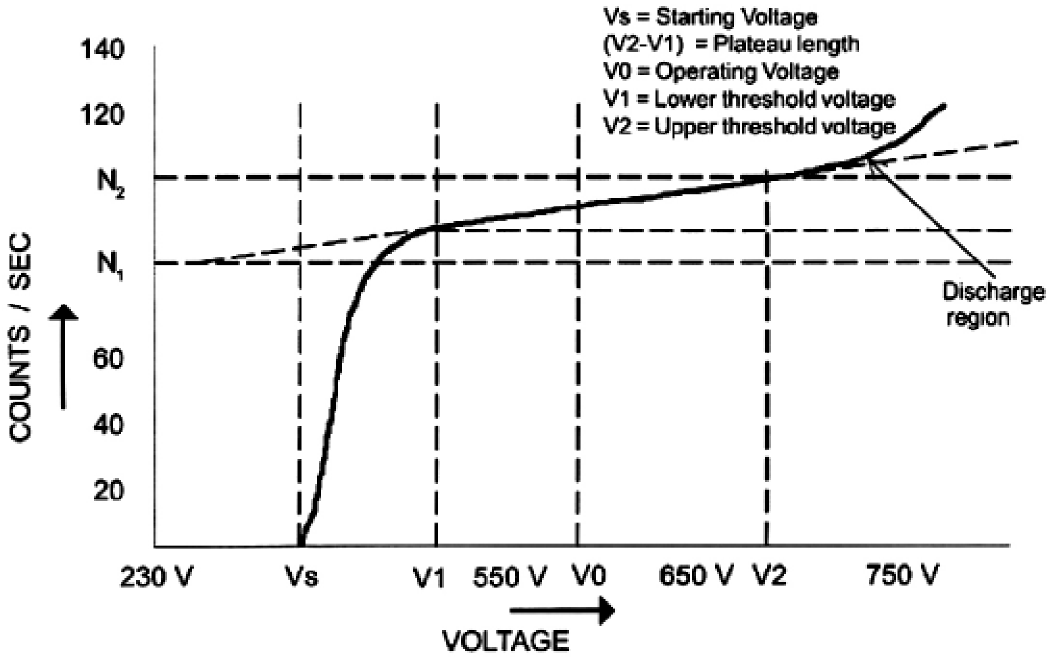


FIG 4 : TYPICAL G.M. CHARACTERISTICS

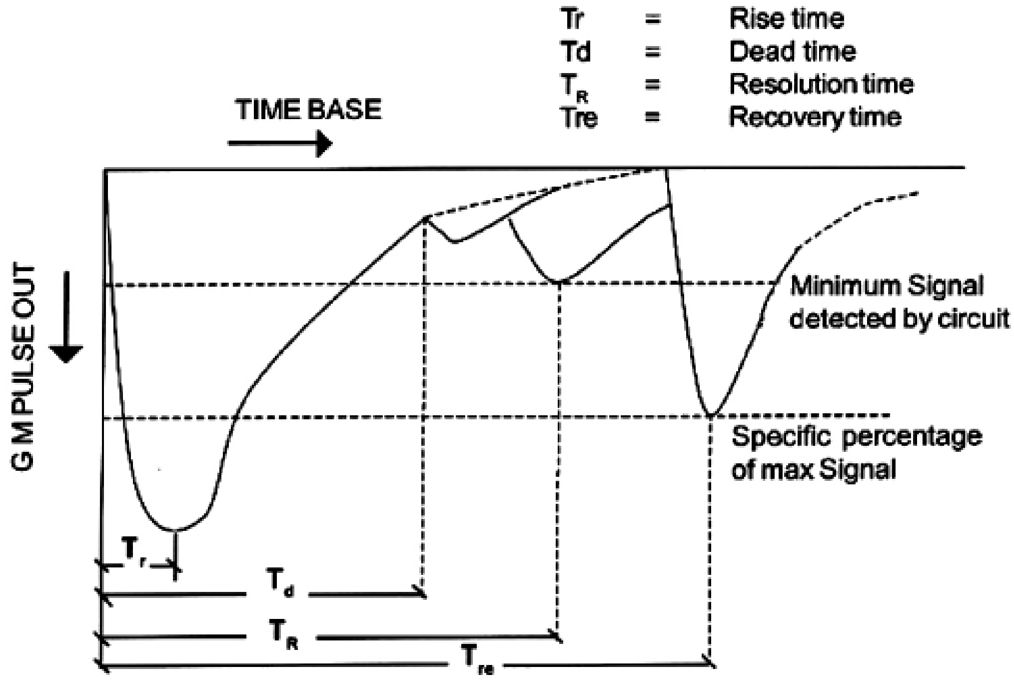


FIG 5 : TYPICAL G.M. PULSE OUTPUT SEEN ON AN OSCILLOSCOPE

- **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 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 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/602A

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.

- **High voltage output :** (0 to 1500V) @ 2mA, ripple less than 20mV.
- **Visual display :**16x2 LCD dotmatrix character display indicates HV, preset time, Time counts, and other parameters.
- **Counts capacity :** 999999 counts.
- **Preset time :** (1-9999) sec
- **User interface :** Through front panel keypad . Command buttons provided are START, STOP, PROG, STORE, INC (▲) & DEC (▼)
- **G.M. pulse output :** (BNC G.M. detector output is provided on the rear panel). BNC (Inverted output)
- **Power :** Unit works on 220V + 10% A.C., 50Hz.
- **RS232C :** Serial port for data communication to PC is built-in.
- **Printer port (centronics) :** For data printing is built-in.
- **Paralysis time :** Variable paralysis time OFF, 250, 350 & 550 sec
- **Memory storage :** Built-in memory to store data readings upto 1000.

ADDITIONAL FEATURE AVAILABLE ON GC602A ONLY :

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)

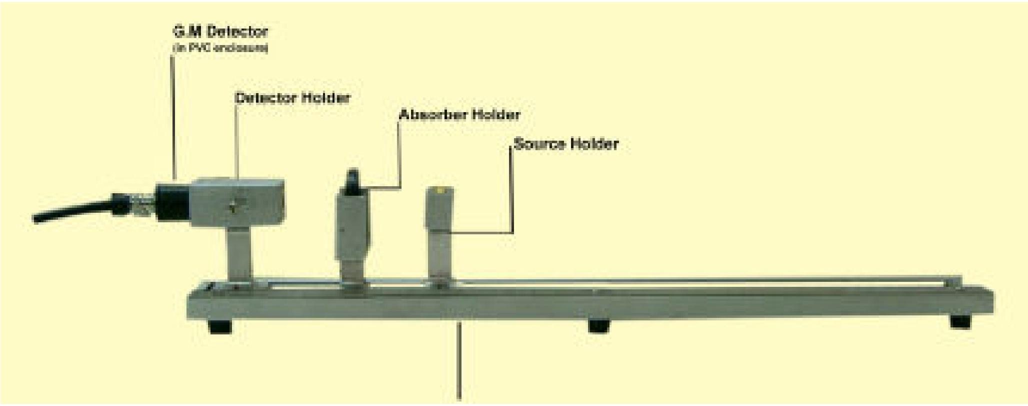
STAND FOR G.M. DETECTOR
TYPE : SG200

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.

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.
	=	$3.1 X 3.7 X 10^{10} X 10^{-6}$
	=	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.
	=	$3.7 X 3.7 X 10^{10} X 10^{-6}$
	=	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 (for Gamma source) or 4 cms (for Beta source) approximately, from the end window 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 601A / 602A 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. 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.

- 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 $V_0 = \dfrac{(V2 + V1)}{2} = \dfrac{(570+360)}{2} = 465$ 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.

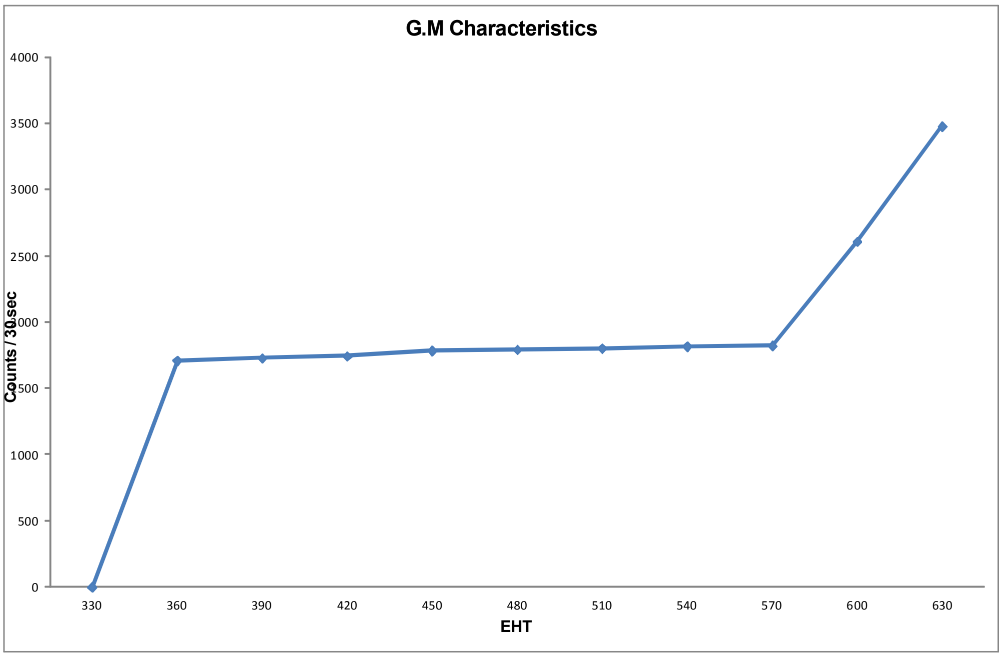


Fig. 6 : Plot of counts Vs EHT

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.

Exp: 2. INVERSE SQUARE LAW: Gamma Rays

2.1 PURPOSE

The Inverse Square Law is an important concept to be understood. It states that intensity of gamma radiation falls inversely as square of the distance.

2.2 EQUIPMENT / ACCESSORIES REQUIRED

- G.M. Counting System 601A / 602A with A.C. main chord.
- G.M Detector (End window) stand (or) G.M Detector/source holder bench
- G.M. Detector (in PVC cylindrical enclosure), with connecting cable.
- A gamma source

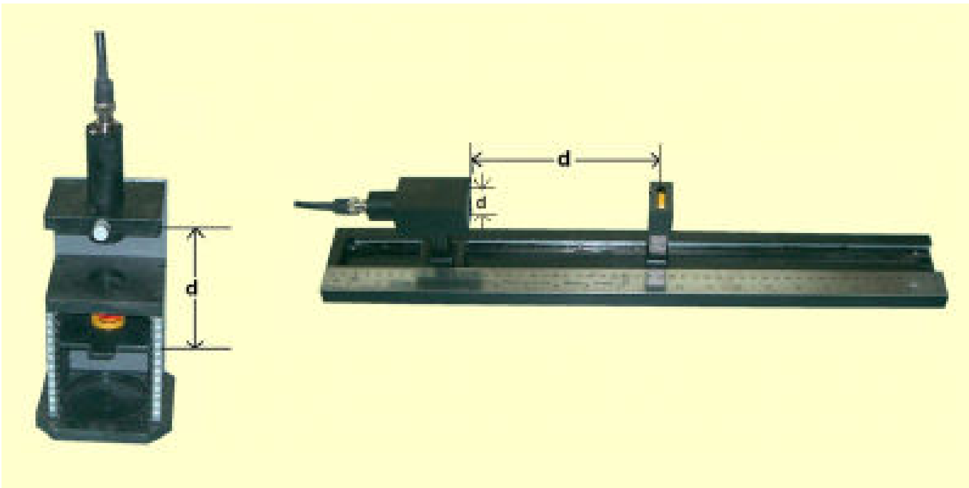


Fig. 7 : Detector, G.M. stand / holder and source arrangement

2.3 PROCEDURE

- Make detector-source arrangement as shown in the (Fig.7) and powerup the unit.
- Without source, make few (about 5 readings) background measurements and take an average of them for a preset time of say 60 sec.
  Compute Average background counts in 60sec Ba = $(b_1+b_2+b_3+b_4+b_5)$ / 5.
  Compute Background rate = Ba/t (t = 60sec)
- Place a gamma source in the source holder and adjust the distance (d) from the detector end window to be 2 cm away from the centre of the source holder.
- If you have an End window detector stand, keep the source holder in the 1^{st} slot & raise the end window detector enclosed in a cylindrical shell by unscrewing the captive screw such that you get 2 cm distance from the end window to 1^{st} slot as shown in Fig.7.
- Set the HV to Operating Voltage (say 500 V), program 'preset time' to 60 sec and record the data counts by pressing 'START' button.
- Increase the Distance (d) in steps of 0.5cm (5mm) and for each step record the observations and tabulate (table 2) the data as given below till you reach a distance of 8 to 10 cms from the detector face.
- Subtract the background counts from the recorded counts which results in “corrected counts” (N) in 60sec. From this obtain Net Count Rate (R) per sec.

2.4 COMPUTATION & ANALYSIS

(a) Compute and tabulate 'Net count rate' (R), 'Distance' (d), product of ($C=R.d^2$), transformation ($1/d^2$) etc. as shown in table. (2)

Plot a graph of Net count rate (R) Vs. distance (d) in cm. (Fig 8)

Table (2) : Data for Inverse Square Law Experiment

S.No.	Distance in cm (d)	Corrected Counts N in 60sec.	Net Count Rate R in 1 sec.	Product $C=R.d^2$	Transformation $1/d^2$ in $1/m^2$
1	2.0	13440	224.0	896	2500
2	2.5	9216	153.4	954	1600
3	3.0	6133	102.2	920	1111
4	3.5	4663	77.38	952	816
5	4.0	3525	58.75	940	625
6	4.5	2750	45.83	929	493
7	5.0	2125	35.42	886	400
8	5.5	1768	29.46	891	330
9	6.0	1469	24.83	882	278
10	6.5	1194	19.90	840	236
11	7.0	1002	16.60	851	204

If the count rate obeys the inverse square law, it can be easily be shown that the product $R.d^2$ is a constant. The results of the product ($R.d^2$) are shown in the table above; allowing for statistical fluctuations, the results obey this law, with a mean value of C = 904. The observed net count rate as a function of distance is given by

$$R_d = \frac{904}{d^2}$$

(b) An alternative analysis method involves transforming the data so that the results lie on a straight line. For this purpose “Net Count Rate” (R) Vs. “Reciprocal of the distance square” ($1/d^2$) are plotted (refer to Fig.9). This will be a straight line passing through the origin (0, 0) as this point corresponds to a source-detector distance of infinity. Gradient can be estimated easily from the “net count rate” (R) corresponding to a value of ($1/d^2$) of 400 m^2.

In this example: c = 886 which is in agreement with the results of the previous method at 5cm.

$$C = Rd^2 = 35.42 \times 25 = 886$$

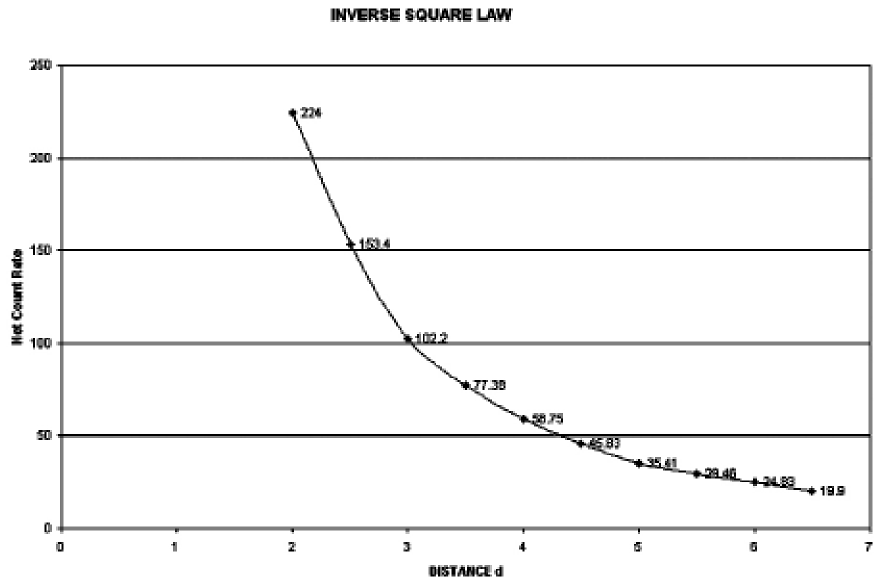


Fig (8). Plot of Net Count Rate (R) Vs Distance (d)

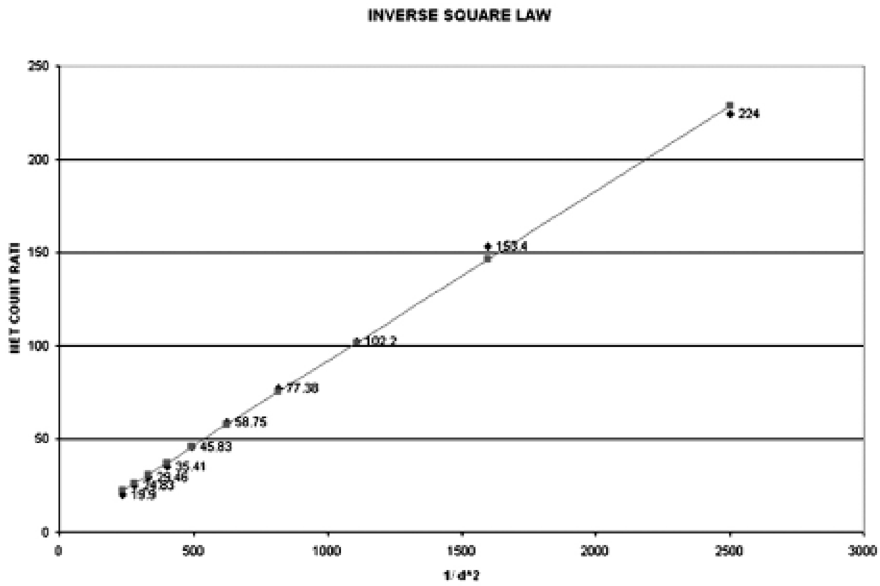


Fig (9). Plot of Net Count Rate (R) Vs Inverse Square of Distance (d)

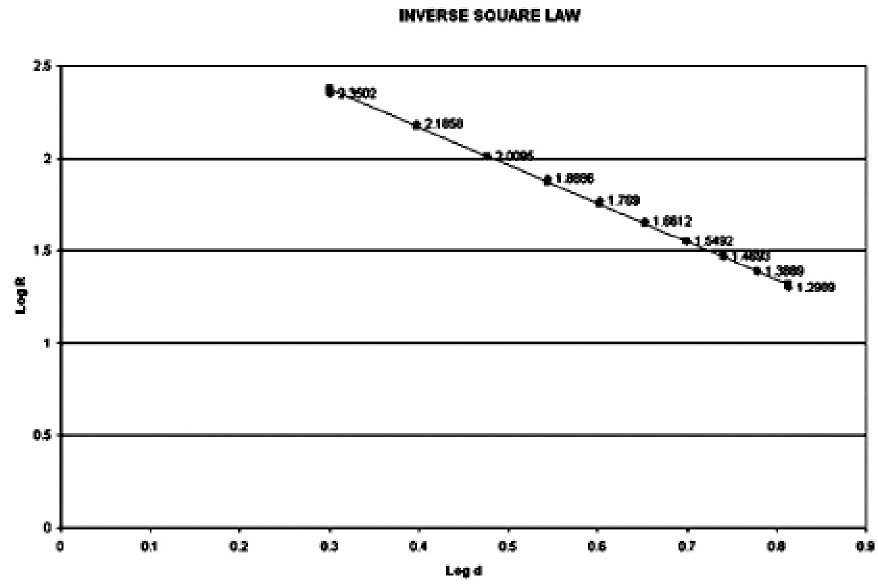


Fig (10). Plot of Log R Vs Log d

(c) Another way of data analysis is by plotting these values on a log log graph sheet or compute log values & plot them on a linear graph sheet (log R Vs. log d) as shown in fig.(10) .

Table (2.b): Table with Log R & Log d values computed

S.No.	d (cms)	Log d	R	Log R
1	2.0	0.3010	224	2.3502
2	2.5	0.3979	153.4	2.1858
3	3.0	0.4770	102.2	2.0094
4	3.5	0.5440	77.38	1.8886
5	4.0	0.6020	58.75	1.7690
6	4.5	0.6532	45.833	1.6611
7	5.0	0.6989	35.416	1.5491
8	5.5	0.7403	29.466	1.4693
9	6.0	0.77815	24.483	1.3888
10	6.5	0.8125	19.9	1.2988
11	7.0	0.8450	18.2	1.27646

Draw a line through the data points. If this is a straight line with a gradient of 2, then it proves that Inverse Square Law is obeyed.

$$\text{Gradient} = -\frac{\log R\,(d2) - \log R\,(d1)}{\log d2 - \log d1} = -\frac{1.5491-2.0094}{0.6989-0.4770}$$

$$= -2.07$$

Exp: 3. STUDY OF NUCLEAR COUNTING STATISTICS

3.1 INTRODUCTION

Systematic errors control the accuracy of a measurement. Thus, if the systematic errors are small, or if you can mathematically correct for them, then you will obtain an accurate estimate of the "true" value. The precision of the experiment, on the other hand, is related to random errors. The precision of a measurement is directly related to the uncertainty in the measurement.

Random errors are the statistical fluctuations during a measurement. If these values are too close to each other, then the random errors are small. But, if the values are not too close, then random errors are large. Thus, random errors are related to the reproducibility of a measurement.

3.2 STATISTICAL ANALYSIS OF DATA

To minimize these errors, one should have good understanding on "Statistical analysis of data".

3.3. DEFINITIONS

- Mean : Mean is the average value of a set of (n) measurements in an experiment. Mathematically it is defined as

$$\overline{N} = \frac{N_1 + N_2 + N_3 + \ldots\ldots\ldots\ldots + N_n}{n}$$

$$= \frac{1}{n} \sum_{i=1}^{n} N_i$$

Mean, is also called as average value.

- Deviation : Deviation is the difference between the actual measured values and the average value. Deviation from the mean, d_i is simply the difference between any data point N_i, and the mean. We define this by

$$d_i = N_i - \overline{N}$$

When we try to look at the error or average deviation, the value probably will become zero because, we may have both positive and negative values which get cancelled. Yet an average value of the error will be desirable, since it tells us how good the data is in a quantitative way. Therefore we need a different way to obtain the measure of the scatter of the data.

- Variance (σ^2) & Standard Deviation (σ) :
  One way is to obtain standard deviation (σ) which is defined as

$$\sigma^2 = \frac{d_1^2 + d_2^2 + \ldots\ldots\ldots + d_n^2}{(n - 1)}$$

$$= \frac{1}{(n\;\;1)} \sum_{i=1}^{n} d_i^2$$

From this $\sigma = (\sigma^2)^{½}$, we see no negative sign and indicates average error contribution. We find that all the deviations make a contribution. We call the term σ^2 as variance.

Standard deviation is a square root of the **variance**, which is widely used to indicate about the spread of our data.

$$\sigma^2 = \frac{1}{n} \sum_{i=1}^{n} d_i^2 \quad \text{(for large samples)}$$

The definition of the standard deviation differs slightly for small samples. It is defined as follows:

$$\sigma^2 = \frac{1}{(n-1)} \sum_{i=1}^{n} d_i^2 \quad \text{(for small samples)}$$

3.4 MEASURING BACKGROUND RADIATION

In this section, several basic experiments are described to demonstrate the statistical nature of radioactive processes. The importance of statistical methods in analyzing data and estimating measurement uncertainties is also covered.

The G.M. detector registers pulses even when not exposed to radioactive sources. These pulses are caused by natural and man-made radioactive isotopes found in our environment, and also by cosmic radiation. The background radiation varies with time and depends on the local environment, the building material, shielding and the weather. Hence, the background count rate (counts per second) should be recorded before and after carrying out measurements.

In the following discussion, the total number of counts recorded for a counting period will be indicated by N (for countrate : N_0) and background counts by B (background rate : B_0). The net count rate is given by N_R = (N-B)/T (where T is the counting period in seconds).

3.5 EXPERIMENT (A)

- Make standard set up by connecting G.M. Counting System GC 601A/602A with G.M. Detector placed in the optical bench or G.M stand as shown in figure (2 or 3).
- Remove the radioactive source from the source holder and set the preset time to 10 sec and take a set of 100 readings and tabulate them as shown in table no. (3a).
- Now plot a bar graph for number of counts registered versus the Index Number say for group no. (1) as shown in fig 11.

Index No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
BG Counts/10 sec	6	6	3	5	10	6	3	13	6	11

Table 3.a : Background counts registered for 10 seconds.

Now repeat the experiment, to have large data counts. Store the data for 100 sec. & take a set of ten such measurements as shown in table (3.b)
Plot these no. of counts Vs index no. as shown in fig (12)

Index No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
BG Counts/100 sec	69	63	68	62	63	61	66	70	61	67

Table 3.b : Background counts registered for 100 seconds.

By comparing these two figures (11&12) we can deduce one of the most important laws of the measurement of radiation.

The spread in measured values decreases as the number of pulses registered increases.

3.6 STATISTICAL ANALYSIS OF RESULTS

We have already defined mean, variance and standard deviation at the beginning of this chapter.

These parameters for the above set of tabulated background readings can be calculated as follows :

Mean Value : $\bar{N}$ = 6.5

Variance : σ^2 = 6.53

Standard Deviation : σ = 2.55

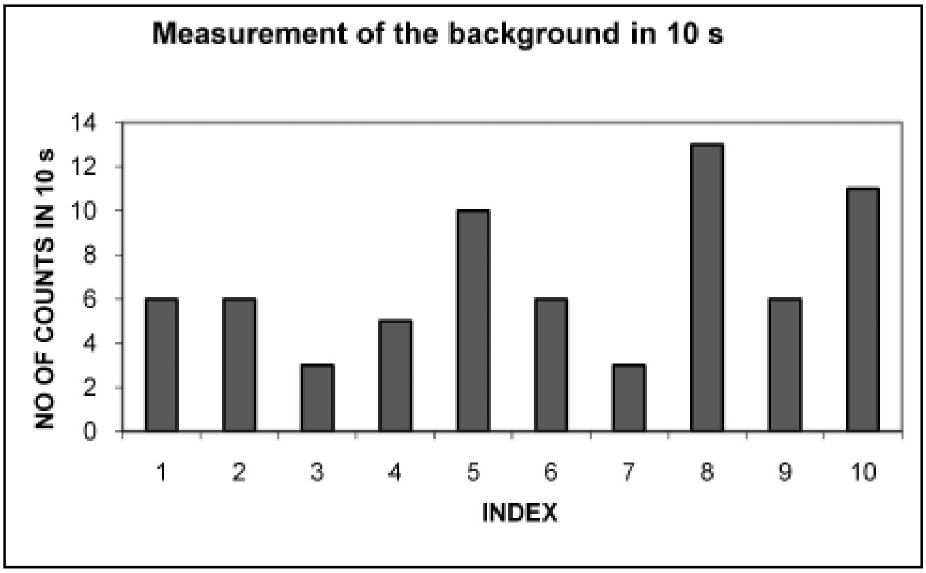


Fig (11) Plot of no. of pulses Vs. Index Number

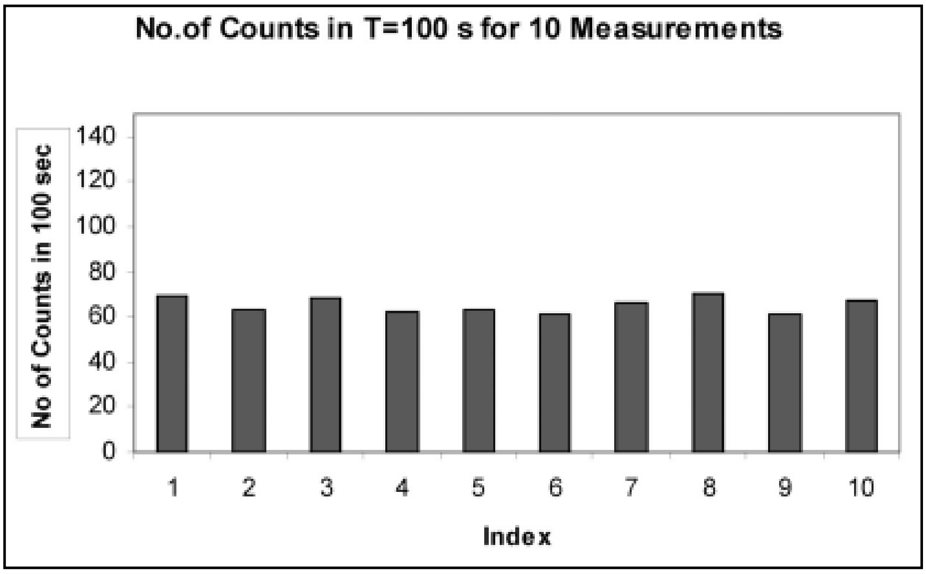


Fig (12) Plot of no. of counts T = 100S for 10 measurements

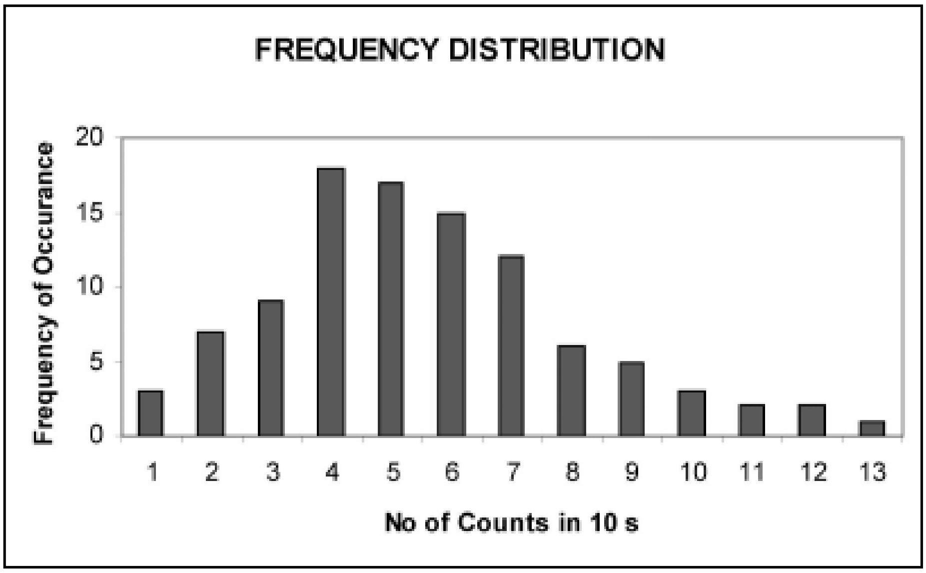


Fig (13) Frequency distribution for 100 measurements of the back ground with T=10s

The sample variance is calculated with the divisor (n-1) to give an unbiased estimated value for variance of the process.

3.7 INTERPRETATION OF THE RESULTS

- The results follow a Poisson distribution on which practically all radioactivity measurements are based. The results show that the mean value N is equal to the variance s^2; this is characteristic of the Poisson distribution.

  The variance in any measured number of counts is therefore equal to the mean value of counts.

- The square root of variance, the standard deviation is a measure of the scatter of individual counts around the mean value. As a thumb rule we can say that approximately 2/3 of the results are within one standard deviation of the mean value i.e., within the interval [$(N-\sigma)$ and $(N+\sigma)$, where $\sigma = \sqrt{N}$]

  Conversely, given the result from an individual measurement, the unknown 'true' count lies within the interval [$N - \sqrt{N}$ and $N + \sqrt{N}$] with a probability of approximately 2/3.

  The above measured results of mean, variance and standard deviation follow **Poisson distribution**. Results show that the mean value (N) is almost equal to the variance (σ^2) which is characteristic of the Poisson distribution.

  The variance in any measured number of counts is therefore equal to the mean value of counts.

3.8 EXPERIMENT (B)

To illustrate that for number of counts recorded being high, Poisson distribution follows closely normal or Gaussian Distribution.

PROCEDURE

- Make standard counting setup as shown in figure (1)
- Place a Beta source about 2cm from the end window of the detector.
- Record counts typically for a preset time of 25sec, and take 50 data readings.
- Compute Mean, Deviation and Standard Deviation and tabulate the readings. Also compute other values, as indicated in the table.

S.No.	N_i	$(N_i - N)$	$\sqrt{N} = \sigma$	$(N_i - N)/\sigma$	$(N_i - N)/\sigma$ (Rounded off)
1	803	13	28.1	0.46	0.5
2	782	-8	28.1	-0.25	0
3	802	12	28.1	0.42	0.5
4	775	-15	28.1	-0.53	-0.5
5	780	-10	28.1	-0.35	-0.5
6	803	13	28.1	0.46	0.5
7	800	10	28.1	0.35	0.5
8	841	51	28.1	1.81	2
9	802	12	28.1	0.42	0.5
10	763	-27	28.1	-0.96	-1.0
11	793	3	28.1	0.10	0
12	783	-7	28.1	-0.24	0
13	773	-17	28.1	-0.60	-0.5
14	785	-5	28.1	-0.17	0
15	810	20	28.1	0.71	0.5
16	802	12	28.1	0.42	0.5
17	796	6	28.1	0.21	0
18	796	6	28.1	0.20	0
19	824	34	28.1	1.20	1.0
20	786	-4	28.1	-0.14	0
21	771	-19	28.1	-0.68	-0.5
22	741	-49	28.1	-1.74	-2
23	762	-28	28.1	-0.99	-1
24	809	19	28.1	0.67	0.5
25	764	-26	28.1	-0.92	-1

S.No.	N_i	$(N_i - N)$	$\sqrt{N} = \sigma$	$(N_i - N)/\sigma$	$(N_i - N)/\sigma$ (Rounded off)
26	773	-17	28.1	-0.60	-0.5
27	779	-11	28.1	-0.39	-0.5
28	792	2	28.1	0.07	0
29	818	28	28.1	0.99	1
30	779	-11	28.1	-0.39	-0.5
31	745	-45	28.1	-1.60	-2
32	769	-21	28.1	-0.74	-0.5
33	791	1	28.1	0.03	0
34	823	33	28.1	1.17	1
35	763	-27	28.1	-0.96	-1
36	767	-23	28.1	-0.82	-1
37	807	17	28.1	0.60	0.5
38	853	63	28.1	2.24	2
39	790	0	28.1	0	0
40	764	-26	28.1	-0.92	-1
41	762	-28	28.1	-0.99	-1
42	825	35	28.1	1.24	1
43	775	-15	28.1	-0.53	-0.5
44	791	1	28.1	0.03	0
45	822	32	28.1	1.13	1
46	784	-6	28.1	-0.21	0
47	780	-10	28.1	-0.35	-0.5
48	783	-7	28.1	-0.24	0
49	813	23	28.1	0.82	1
50	785	-5	28.1	-0.17	0

The average count rate for 'n' independent measurements is given by

$$\overline{N} = \frac{N_1 + N_2 + \ldots\ldots\ldots\ldots\ldots + N_n}{n} = 790$$

The deviation of an individual count from the mean is $(N_i - \overline{N})$. From the definition $\overline{N}$, it is clear that

$$\sum_{i=1}^{n} (N_i - \overline{N}) = 0$$

The Standard Deviation $\sigma = \sqrt{\overline{N}}$

3.9 EXERCISE

Make a plot of the frequency of rounded off events (Ni - N) Vs. the rounded off values. Fig (14) Below shows ideal situation which is a Gaussian or Normal Distribution.

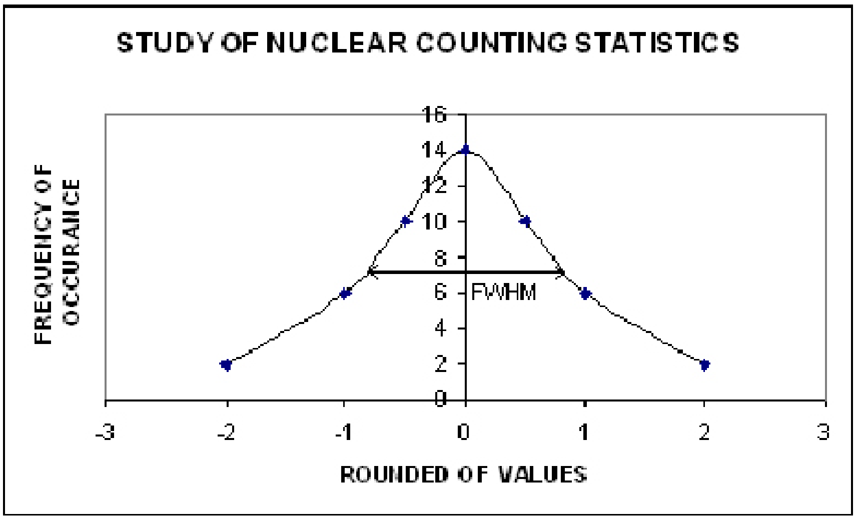


Fig (14). Plot of Frequency of Occurrence Vs Rounded of Values

Two important observations can be made at this point, about gaussian distribution & figure obtained above.

- The distribution is symmetric about the mean value.
- Because the mean value is large, the adjacent values of the function are not greatly different from each other. i.e., the distribution is slowly varying which is the expected behavior of a normal distribution.

3.10 EXAMPLES

- If a measurement of 10s duration yields 3 pulses, the result is correctly expressed as N = 3 + 1.7 in 10s or Z = (0.3 + 0.17) 1/s as $\sqrt{3}$ = 1.7.
- In experiment 1 in the first 10 measurements, i.e., after 100 s, 30 pulses were counted. The result would be N = 30 + 5.5 in 100 s or Z = (0.30 + 0.055) 1/s.
- After 100 measurements in Experiment 1, i.e., 1000 s, 286 pulses were counted. The result would be N = 286 + 17 in 1000 s or Z = (0.286 + 0.017) 1/s.

  If you compare the errors indicated for the count rate Z in the examples 1 and 3 you can see that a counting period which is 100 times longer (or 100 measurements) leads to a result where the measurement uncertainty is 10 times smaller. If the result is divided by the count time T :

$$\frac{N}{T} + \frac{\sqrt{N}}{T} = \frac{N}{T} + \sqrt{\frac{N}{T}} \times \frac{1}{\sqrt{T}} = Z + \frac{\sqrt{Z}}{\sqrt{T}}$$

  The uncertainty in the count rate Z is therefore proportional to one over the square root of the counting period T (or, equivalently, to the square root of the number of readings taken)

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

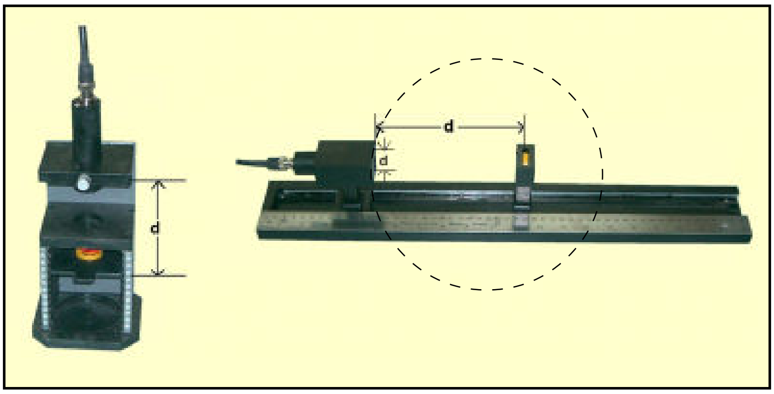


Fig. 15 : Detector source arrangement for efficiency calculation for a gamma source

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

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

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.

Exp: 5. TO STUDY DETERMINATION OF BETA PARTICLE RANGE AND MAXIMUM ENERGY (BY HALF THICKNESS METHOD)

5.1 PURPOSE

To carry out the absorption studies on β-rays with the aid of a GM Counter and hence to determine the end point energy of β-rays emitted from a radioactive source.

5.2 EQUIPMENT/ACCESSORIES REQUIRED

- G.M Counting System 601A/602A with A.C main cord.
- G.M Detector (End window) stand (or) G.M Detector/source holder bench
- Radioactive source kit
- Aluminium absorber set

5.3 PROCEDURE

- Make standard connections and arrangement between G.M. Counting system, detector, absorber and source.
- Place a Beta source in the source tray at about 3 cm from the end window of the GM tube.
- Set the GM voltage at the operating voltage of the GM tube.
- Without source, make a few (about 5 readings) background measurements and take an average of them for a preset time of say 60 sec.
- Compute Average background counts in 60sec ($Ba = (b_1+b_2+b_3+b_4+b_5) / 5$).
- Compute Background rate = Ba/t (t = 60sec).
- Place a Beta source in the source tray at about 3 cm from the end window of the GM tube.
- Take the Aluminium absorber set.
- Place an aluminium absorber of zero thickness in the absorber holder at about 2 cm from the end window of the GM tube and record the counts.
- The absorber thickness is increased in steps of 0.05mm and every time counts are recorded.
- This process is repeated until the count rate becomes equal to or less than half the count rate with zero absorber thickness.
- Data is to be collected for the standard source and the second source.
- Here in this case the standard source is Tl - 204 and the second source is Sr - 90.
- Tabulate the data as shown in table.
- Density of Aluminium = 2.71g/cm_3 (g/cm. cube).
- The below data is taken with Thallium (Tl - 204)

Table : 1

Counting Time : 180 sec

Background : 146 counts

Absorber : Aluminium

Source : Tl-204 (4 KBq)

Absorber Thickness (in mm)	Absorber Thickness in mg/cm^2	Counts	Net counts (counts-BG)
0	0	2620	2474
0.05	13.55	2003	1857
0.10	27.10	1556	1410
0.15	40.65	1293	1147
0.20	54.20	1054	908
0.25	67.75	835	689
0.30	81.30	676	530
0.35	94.85	597	451
0.40	108.40	499	353
0.45	121.95	448	302

The below data is taken with Strontium (Sr^{90} - Y^{90})

Table : 2

Counting Time : 100 sec

Background : 79 counts

Absorber : Aluminium

Source : Sr-90

Absorber Thickness (in mm)	Absorber Thickness in mg/cm^2	Counts	Net counts (counts-BG)
0	0	5828	5749
0.05	13.55	5130	5051
0.10	27.10	4589	4510
0.15	40.65	4252	4173
0.20	54.20	3893	3814
0.25	67.75	3618	3539
0.30	81.30	3458	3379
0.35	94.85	3189	3110
0.40	108.40	3092	3013
0.45	121.95	2877	2798
0.50	135.50	2773	2694
0.55	149.05	2612	2533
0.60	162.60	2582	2503
0.65	176.15	2367	2288
0.70	189.70	2222	2143

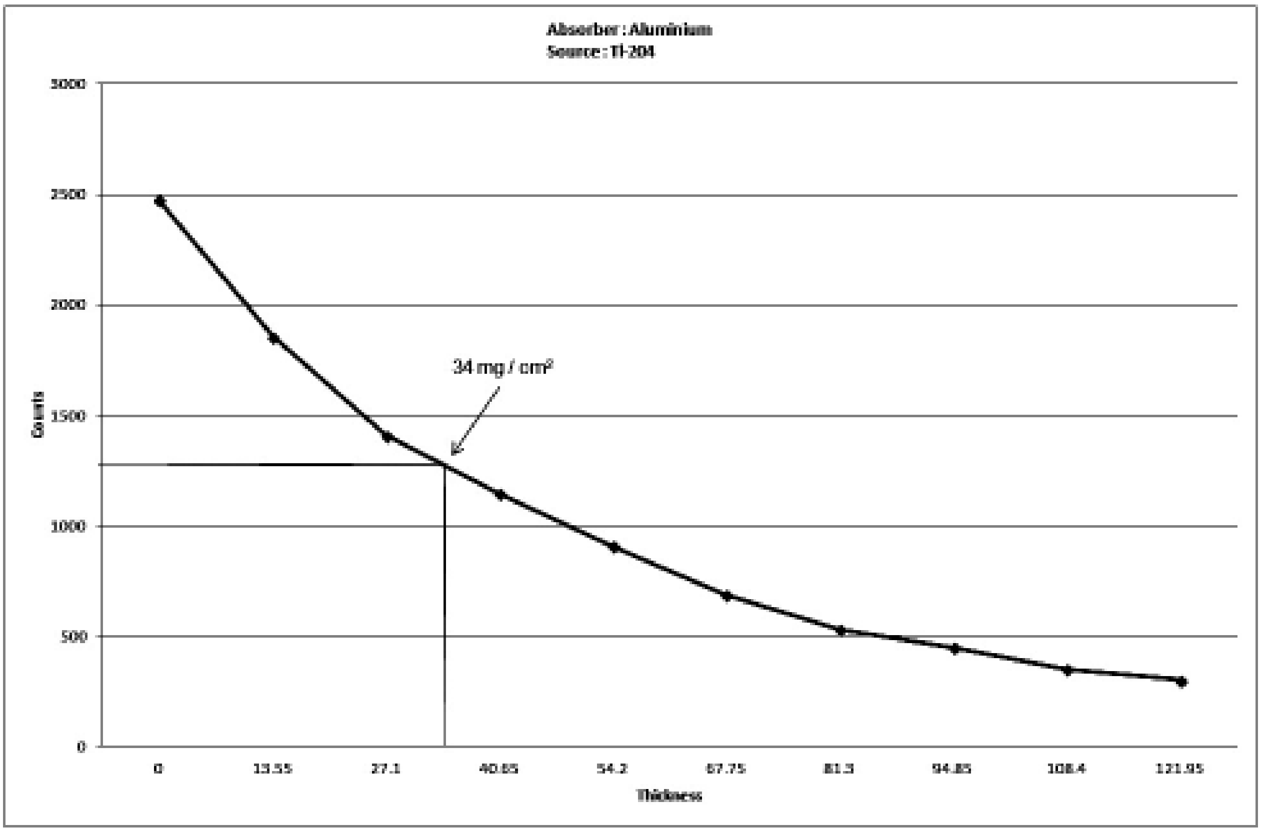


Figure : 16

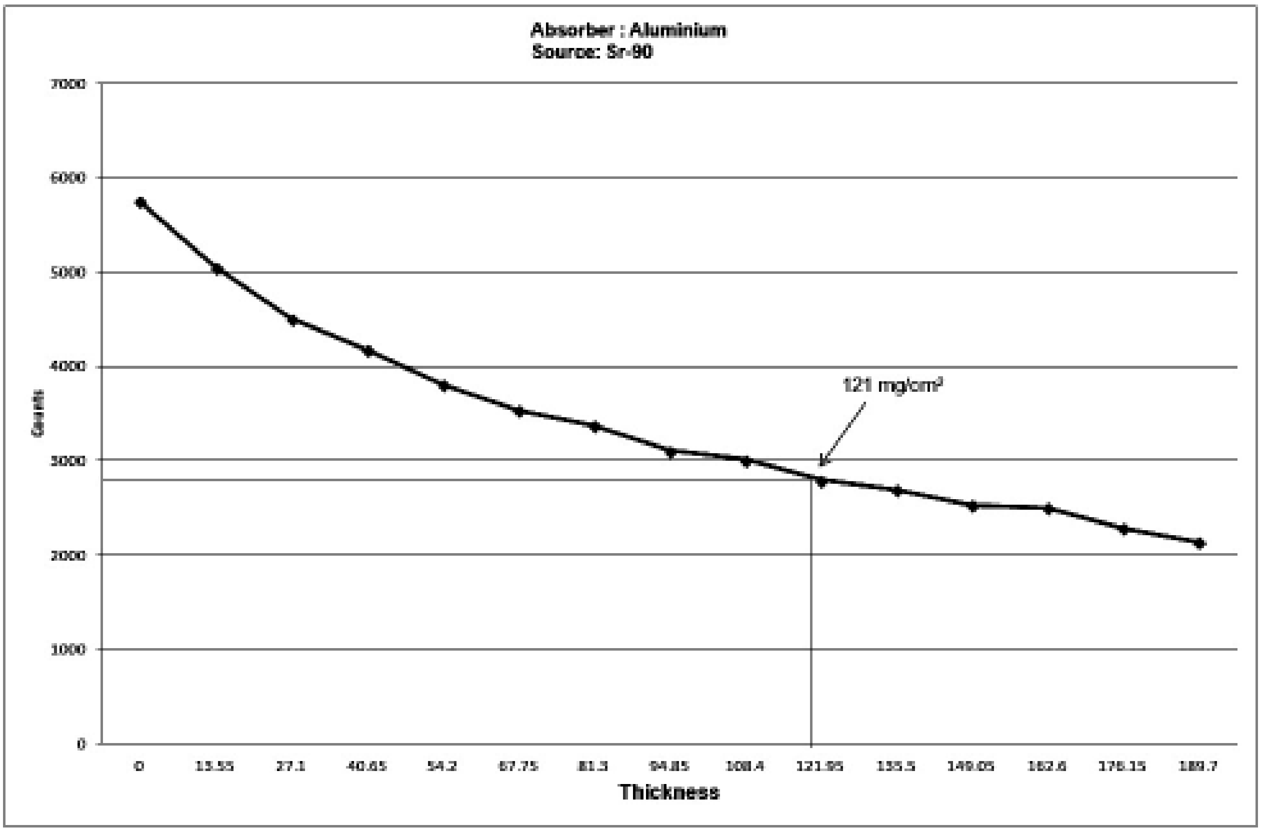


Figure : 17

5.4 ANALYSIS & COMPUTATIONS:

5.4.1 PRINCIPLE

The range of Beta particles is given by

$R_0 = (0.52\ E_0\ - 0.09)\ g/cm^2$ -- (1)

Where E_0 is the end point energy of of Beta rays from the radioactive source in MeV.

We have the ratio of thickness required to reduce the counts of Beta rays from one source to half to the thickness required for the other source is given by

$$\frac{t_1½}{t_2½} = \frac{\text{Range of Beta rays from first source}}{\text{Range of Beta rays from second source}}$$

$$\frac{t_1½}{t_2½} = \frac{R_1}{R_2} \qquad \text{-- (2)}$$

5.4.2 EXERCISE

- Subtract the background count rate from each measured count rate.
- Plot a graph of Net countrate (CPS) Vs absorber thickness (mg/cm^2) for both sources.
- Draw the curve through these points as shown in Figures 16 & 17.
- From the plotted graph extrapolate and obtain thickness of aluminium absorber required to reduce the countrate of Thallium and Strontium Beta rays by half ($t_1½$ and $t_2½$).
- Substitute $t_1½$ and $t_2½$ in the above equation (2) and calculate the range of βrays (R_2) from Sr90 source.
- Once we know the R_2, we can find out the energy (E_2) of Sr^{90} from equation-1

5.4.3 For Thallium-204

End point energy of Tl-204 = 0.764 MeV

$\therefore$ Range of ^{204}Tl $= R_1 = (0.52\,E_0 - 0.09)\ g/cm^2$

$= (0.52 \times 0.764\ Mev - 0.09)\ g/cm^2$

$= 0.30728\ g/cm^2$

- Thickness of Al absorber required to reduce the count rate of ^{204}Tl by half, $t_1½$ = 34mg/cm square
- Thickness of Al absorber required to reduce the count rate of Sr-90 by half $t_2½$ = 121mg/cm²

From Equation (2).

$$\frac{t_1½}{t_2½} = \frac{R_1}{R_2}$$

$$\Rightarrow \quad R_2 = R_1 \times \frac{t_2½}{t_2½} = \frac{0.30728 \times 121 \times 10^{-3}}{34 \times 10^{-3}}$$

$$R_2 = \frac{0.30728 \times 121}{34} = 1.09355\ gm/cm^2$$

$\therefore$ End point energy of $^{90}Sr/\,^{90}Y$

$$E_2 = \frac{R2 + 0.09}{0.52} = \frac{1.09355 + 0.09}{0.52}$$

$$E_2 = 2.276\ Mev$$

5.4.4 RESULT

End point energy of β-rays from ^{90}Sr = 2.28 MeV.

Exp: 6. BACK SCATTERING OF BETA PARTICLES

6.1 INTRODUCTION

When Beta Particles collide with matter, absorption may occur. Another possible result is the occurrence of scattering by collisions of Beta particles with electrons in the material. Such a collision changes the speed and direction of the Beta particles. With increasing atomic number Z of the material, the chance that a collision results in a scattering of the Beta particle increases too. Back scattering occurs, when the angle of deflection is greater than 90°. The Back-scattering rate is predominately dependent on the atomic number Z of the back scattering material. With an atom of high atomic number, the scattering occurs at a large angle and with little loss of energy. The back scattering factor is approximately proportional to the square root of atomic number. The mass per unit area (thickness x density) or the thickness of the irradiated material only influence the back scattering factor up to a saturation value. The maximum back scattering is practically attained at a mass per unit area which is smaller than half the range of the Beta particle in the material, because large layer thicknesses lead to absorption of the scattered electrons. The saturation value is less than 200 mg/cm^2 for all materials. This corresponds to a saturation larger thickness of x < 0.74 mm for Aluminum and < 0.17 mm for Lead.

6.2 EQUIPMENT AND ACCESSORIES REQUIRED

i. Electronic Unit

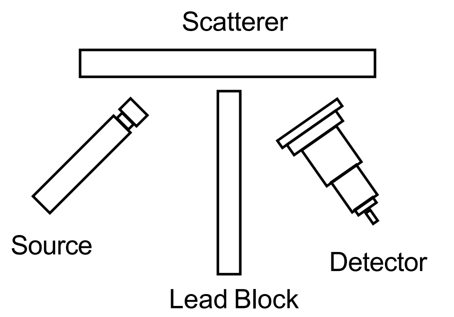
ii. Wide end window GM Detector (GM125)

iii. Absorber stand for Back scattering of Beta (AS275)

iv. Absorber set (Beta particle scattering experiment)

v. Beta source (Sr-90)

vi. Lead Block for Isolation



Schematic diagram

Fig. 18: Experimental setup

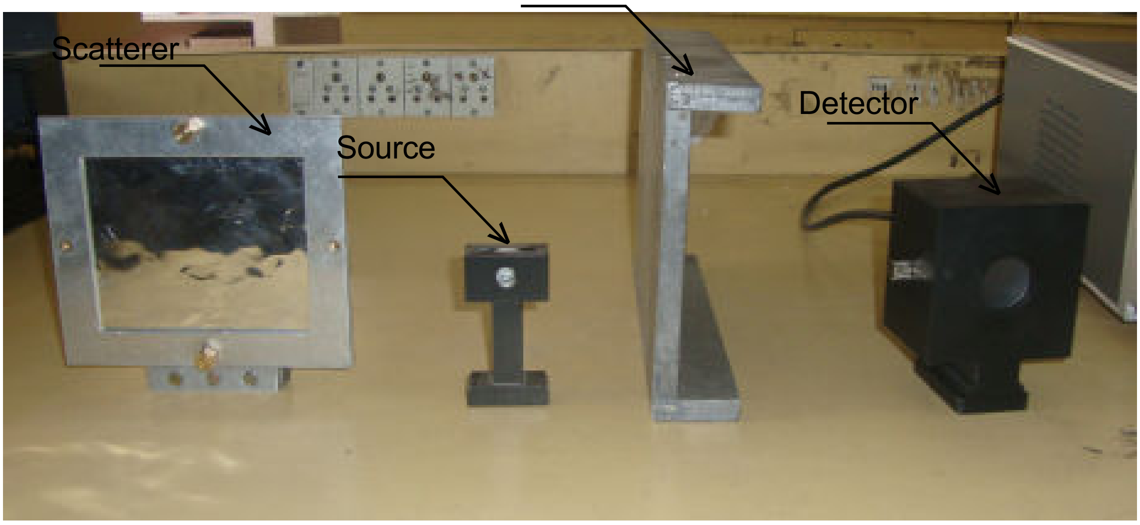


Fig. 19 : Individual blocks of experiment setup

6.3 PROCEDURE

Make standard setup by connecting G.M. Counting System (GC602A) with G.M Detector (GM125)

In this experimental setup, the detector, Beta source and scatterer stand with scatterer are placed as shown in Fig.18.

A lead block is placed in between the Beta source and Detector, so that the detector does not receive any direct radiation from the Beta source.

Switch ON the GC602A Electronic Unit and set the operating High voltage at 500V. To start with, remove the scatterer stand and measure the counts for 200 secs. Now place the scatterer stand and load Aluminum foil (scatterer) of thickness 0.05mm. The apparatus is first set up to give maximum count rate by adjusting the source / detector positions.

After doing this, record the counts for 200 secs. Then increase the thickness of the scatterer in steps of 0.05mm by adding one foil to the previous scatterer, and observe the counts each time for 200 secs. Tabulate the data.

6.4 EXPERIMENTAL DATA

Source : Sr-90

Activity : 0.1mCi

Preset Time : 200 secs.

Unit: GC602A

Detector: GM125

Sliding Bench

Sl.No	Material	Thickness (mm)	Counts			Net counts
			I	II	Average	
1	Al	0	361	401	381	-
2	Al	0.05	621	645	633	252
3	Al	0.10	676	657	666.5	285.5
4	Al	0.15	789	737	763	382
5	Al	0.20	858	834	846	465
6	Al	0.25	1032	985	1008.5	627.5
7	Al	0.30	1107	1174	1140.5	759.5
8	Al	0.35	1250	1246	1248	867
9	Al	0.40	1226	1400	1313	932
10	Al	0.45	1508	1629	1568.5	1187.5
11	Al	0.50	1696	1707	1701.5	1320.5
12	Al	0.55	1708	1668	1688	1307
13	Al	0.60	1791	1699	1745	1364
14	Al	0.65	1798	1678	1738	1357

6.5 RESULTS & CONCLUSIONS

From the obtained results, it can be concluded that the counts due to Back scattering increases upto certain thickness of the scattering material and almost remains constant beyond that thickness. The thickness of the scatterer, where the counts reach their maximum is called the Saturation thickness.

Exp 7 : PRODUCTION AND ATTENUATION OF BREMSSTRAHLUNG

7.1 INTRODUCTION

Bremsstrahlung is electromagnetic radiation produced by the deceleration of a charged particle when deflected by another charged partice, typically an electron by an atomic nucleus. The moving particle loses kinetic energy, which is converted into a photon because energy is conserved. The term is also used to refer to the process of producing the radiation. Bremsstrahlung has a continuous spectrum which becomes more intense and whose intensity shifts toward higher frequencies as the change of the energy of the accelerated particles increases.

Beta – particle emitting substances sometimes exhibit a weak radiation with continuous spectrum that is due to Bremsstrahlung. In this context, Bremsstrahlung is a type of "secondary radiation", in that it is produced as a result of stopping (or slowing) the primary radiation (Beta particles). It is very similar to x-rays produced by bombarding metal targets with electrons in X-ray machines.

The amount of Bremsstrahlung increases as the atomic number/density of the absorbing material goes up. If the mass per unit area (thickness X density) of the plates used as absorbers is such that the beta particles are completely absorbed, then for materials of higher atomic number/density, correspondingly higher bremsstrahlung count rates are obtained.

7.2 EQUIPMENT AND ACCESSORIES REQUIRED

- Electronic Unit (GC 602A)
- G.M Detector (GM125)
- G.M. Detector Holder
- Sliding Bench
- Source Holder
- Absorber Holder for Bremsstrahlung experiment
- Beta Source (Sr-90)
- Al (0.7mm), Cu (0.3mm) & Perspex (1.8mm) absorber set

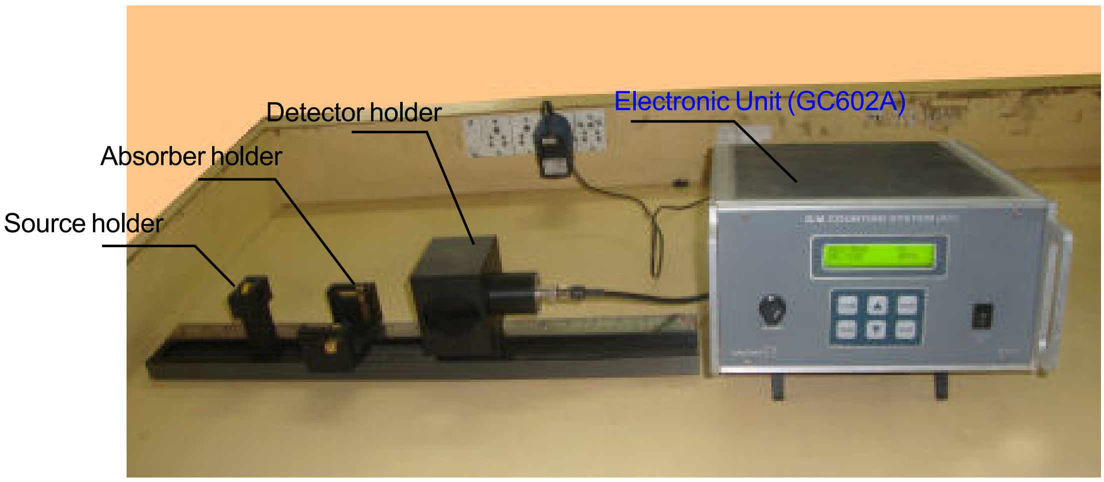


Fig. 20: Expermental setup

7.3 PROCEDURE

Make standard setup by connecting G.M Counting system GC602A with G.M Detector (GM125) placed in the optical bench as shown in Fig.20 above. The GM Detector, Absorber and the Source are mounted as shown in Fig.20.

Switch ON the GC602A Electronic Unit and set the operating High Voltage at 500V.

An absorber consisting of two materials with widely different atomic numbers, say, Perspex (1.8mm thick) and Aluminum (0.7 mm thick) is used and the count rate is measured with the absorber and then with the absorber reversed.

The absorber thickness must be such that each sheet of absorbent material has about the same mass per unit area.

The experiment is conducted with following three combinations of materials

i. Al (0.7mm) & Perspex (1.8mm)

ii. Perspex (1.8mm) & Cu (0.3mm)

iii. Al (0.7mm) & Cu (0.3mm)

7.4 EXPERIMENTAL DATA & RESULTS

Source : Sr-90 Distance between source and detector : 6cms

Activity : 0.1mCi Preset Time : 300Sec BG : 1065 counts

For Al (0.7mm) & Perspex (1.8mm) combination:

S.No	Absorber position	Counts	Net Counts
1	-	40342	39277
2	Perspex facing source	6400	5335
3	Al. facing source	9122	8057

For Perspex (1.8mm) & Cu (0.3mm) combination:

S.No	Absorber position	Counts	Net Counts
1	-	40342	39277
2	Cu facing source	4749	3681
3	Perspex facing source	4183	3118

For Al (1.8mm) & Cu (0.3mm) combination:

S.No	Absorber position	Counts	Net Counts
1	-	40342	39277
2	Al facing source	5100	4035
3	Cu facing source	5858	4793

7.5 RESULT & CONCLUSIONS

The count rate for the bremsstrahlung produced depends on the order in which the absorbent materials are arranged. If, firstly, the sheet of metal faces towards the source, then a higher count rate is measured since bremsstraulung is generated in the aluminium but is absorbed to a very small extent in the sheet of “Perspex “which follows.If, however, the beta rays first strike the sheet of plastic, then the bremsstrahlung generated is of low energy and a large proportion of it is absorbed in the sheet of metal which follows.

These conclusions can be extended to other combinations of materials also.

Exp: 8. MEASUREMENT OF SHORT HALF-LIFE

8.1 PURPOSE

To determine short half-life of a given source, which can be obtained from a mini generator or produced with a neutron source by activation.

8.2 EQUIPMENT/ACCESSORIES REQUIRED

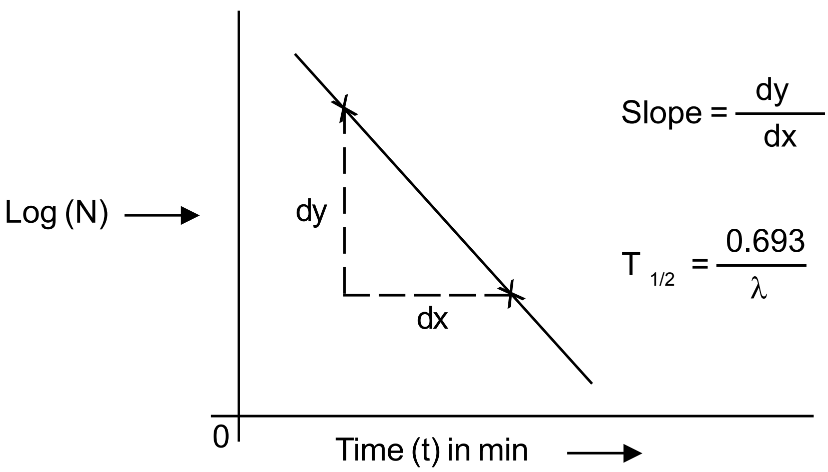
G.M. Counting system	Type: GC 601A/602A
G.M. Stand	Type: SG 200
End window G.M. detector	Type: GM 120

Short Half life source (Neutron activated Indium foil or Cs-137/Ba-137m isotope generator, flask with eluting solution for generator)

8.3 PROCEDURE

An Am-Be neutron source of strength of about 5Ci is in the Neutron Howitzer. The maximum thermal neutron flux produced by this neutron source is about 4×10^4 n/cm^2-sec.

- Irradiate the given indium foil for about 12 hours by placing it in appropriate position in the Neutron Howitzer (normally at the centre of the column).
- Apply the required operating voltage for the GM tube.
- Place the irradiated indium foil under the window of the GM tube at a convenient distance (1 cm) in order to get a good number of counts per second.
- Collect the counts for every 5 minutes for at least one hour.
- Note down the back ground count rate for 5 minutes, before and after the experiment in order to subtract from the observed counts and record your observations as shown in the Table below.
- Determine the count rate (N) for each interval of 300 seconds (5 minutes).
- Plot graph of log of the count rate (log N) versus time (minutes)
- It will be a straight line as shown below.



$$\text{Slope} = \frac{dy}{dx} = \text{decay constant}$$

$$T_{1/2} = \frac{0.693}{\lambda} \text{ sec}$$

- Find the slope of the straight line graph using the least square fit methods (use the formula)
  $m = (n\Sigma xy - \Sigma xy) / (\Sigma nx^2 - (\Sigma x)^2)$
  to determine the slope of the graph which gives the value of the decay constant.
  Where n = number of observations
  x = time interval, y = Log N

OBSERVATIONS

S.No.	Elapsed Time	Duration (min)	Counts Reading	Corrected counts / min	Log (N)
1	300	5	1355	252.6	5.54
2	600	10	2660	247.6	5.50
3	900	15	3862	239.06	5.47
4	1200	20	5006	231.9	5.44
5	1500	25	6047	223.48	5.40
6	1800	30	7103	218.36	5.38
7	2100	35	8138	214.11	5.36
8	2400	40	9043	207.67	5.33
9	2700	45	9923	202.11	5.31
10	3000	50	10750	196.6	5.28
11	3300	55	11593	192.38	5.26
12	3600	60	12348	187.4	5.23

Background = 92/5 min = 18.4/min

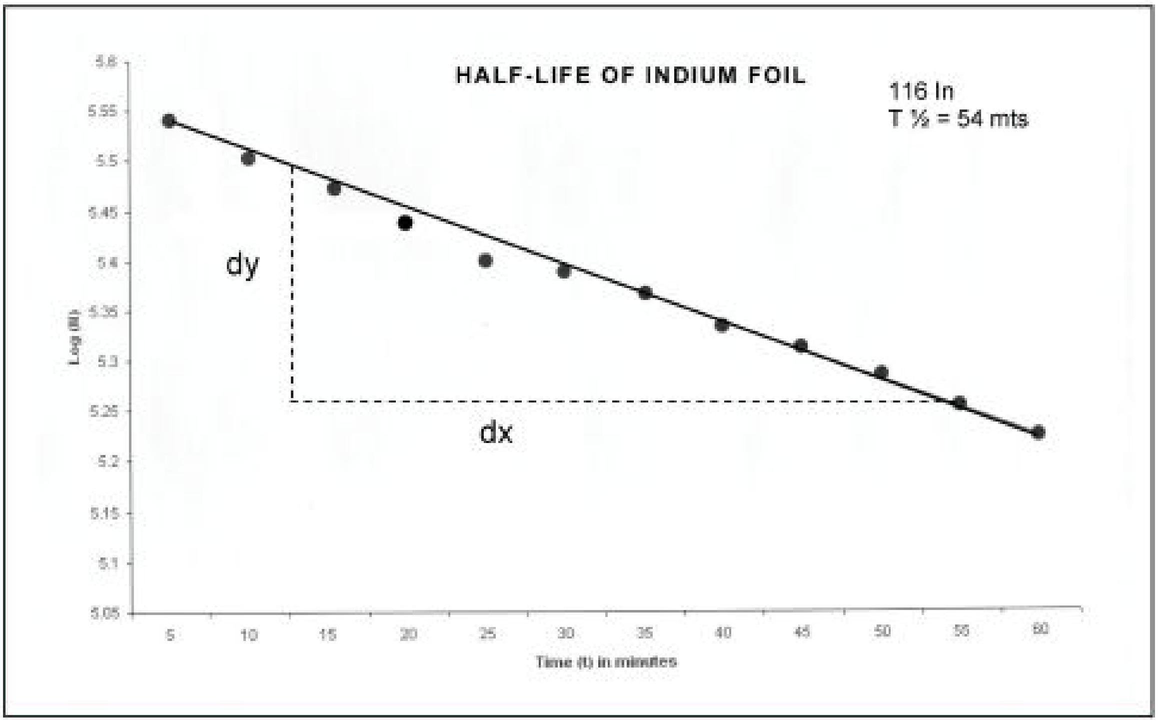


Fig.22 : Half-life of Indium Foil

8.4 ANALYSIS AND COMPUTATIONS

Intensity of radioactive source changes with time in accordance with relation

$$I = I_o e^{-\lambda t} \text{ ----- } (1)$$

λ is the decay constant,

I is the intensity at any time t and I_o is initial intensity.

The $T_{1/2}$ by definition is the time required for the intensity to fall to one half of its initial value.

Hence from equation (1) we have

$$\ln (I/I_0) = -\lambda T_{½}$$
$$\ln (0.5) = -\lambda T_{½}$$

$$\frac{0.693}{\lambda} = T_{½}$$

Where $T_{1/2}$ is half - life.

The above equation can be written as

$$\lambda = \frac{0.693}{T_{1/2}}$$

Given the value of $T_{1/2}$, one can calculate the value of λ.

8.5 HALF LIFE DETERMINATION:

The Log is actually natural Log and should be denoted by ln.

8.5 EXERCISE

- Subtract the background countrate from each measured countrate.
- Plot a graph of ln (N) vs. elapsed time (min).
- This should give a straight line graph.
- From the plotted graph extrapolate and obtain $T_{1/2}$
- Substitute $T_{1/2}$ in the above equation to calculate the decay constant λ

C. EXPERIMENTS ILLUSTRATING APPLICATIONS OF RADIONUCLIDES

9. DEMONSTRATION OF NUCELONIC LEVEL GAUGE PRINCIPLE USING G.M. COUNTING SYSTEM & DETECTOR

This experiment has been designed/ suggested for engineering streams (Mechanical / Metallurgical / Instrumentation/ Electronics & Instrumentation / Chemical Engineering steams (for illustrating Nucleonic level gauge principle)

9.1 INTRODUCTION & PRINCIPLE

Nucleonic level gauging is a very popular technique used in petrochemical, steel, cement, & other process industries where liquid / sludge / solid material levels in the reactor vessels / smelting furnaces are to be detected, once it reaches certain levels by indirect methods.

This technique using G.M. Detector involves placing of a radioactive source at the required height where it is to be measured. It is shielded all around & opening is provided as a collimated beam in the required direction for measurement. A G.M. detector is placed exactly on opposite side outside the reactor vessel such that it sees the collimated beam of radiation. Once the liquid/solid/material level reaches this height there will be change in the count rate. With material not being filled in the reactor vessel to the required level the count rate will be higher, initially. Once the material level reaches the level where it interrupts the source/ detector beam the count rate changes abruptly. This change can be detected and an alarm or relay contact could be activated.

9.2 DEMONSTRATION OF THIS PRINCIPLE IN LAB

9.3 ITEMS REQUIRED

- G.M. Counting System with A.C. Mains cord
- G.M. detector with holder & long connecting cable of 2 metres.
- A 3” PVC pipe with one end closed and other end open.
- Gamma source (2 μCi Approx.)

Fig. 23 : G. M Counting system with sand filled PVC column, detector & source arrangement

9.4 PROCEDURE

Typical arrangement is shown in the Fig. 23.

- Fill the PVC tube with sand, to half height (approx.)
- Mount the detector in the special enclosure given and connect it with cable to the counting system (as shown in Fig.23).
- Switch on the G.M. Counting System and select acquisition mode to be 'CPS / CPM' mode
- Now place a gamma source along the length (ht) of the PVC tube (which is kept vertically in standing position) and exactly diagonally opposite side, place the detector horizontally (window facing the PVC pipe)
- Now observe the count rate, on the instrument and record the observations for each ht (in steps of 1cm) or 15mm or as required.
- Ht. vs CPS data may be recorded till sand filled level is crossed.
- At the level of crossing the sand level, you will find noticeable change in count rate.
- From the above observation, it can be confirmed that this is the ht/ level to which material is filled. Electronic circuits can be modified in the G.M. Counting System to detect this transition in count rate , and alarm or relay contact can be activated at this level.
- The above experiment illustrates the principle of Nucleonic level gauge.
- To predict correct accurate level one can open a small narrow window of 2mm/ 3mm on the detector & cover the rest of the window of the detector by a lead disc (5mm thick, with 2mm central hole and 1 dia in size) to cover the face of the detector.

10. BEAM INTERRUPTION DETECTION SYSTEMS

10.1 INTRODUCTION & PRINCIPLE

With narrow beam of source, G.M. detector and electronic counting system having preset alarm facility, one can illustrate how changes in count rate observed when a bulk material passes and interrupts the beam can tell us accurately that a job has been interrupted.

There are a variety of applications in process/ manufacturing industry, where this technique could be used. Some of these include:

- Liquid fill height level for beverages, soups, pharmaceutical products, baby foods, Match boxes, yogurt cartons etc.
- For sorting or conting items in a process or pharmaceutical industry etc.

10.2 DEMONSTRATION OF THIS PRINCIPLE IN LAB

10.3 ITEMS REQUIRED

- G.M. counting system GC601/602 with A.C power cord
- G.M. detector with stand or bench
- Radioactive source 'beta'
- A set of 4/5 coins fixed with addissive and spaced equidistance on a thin Perspex sheet.

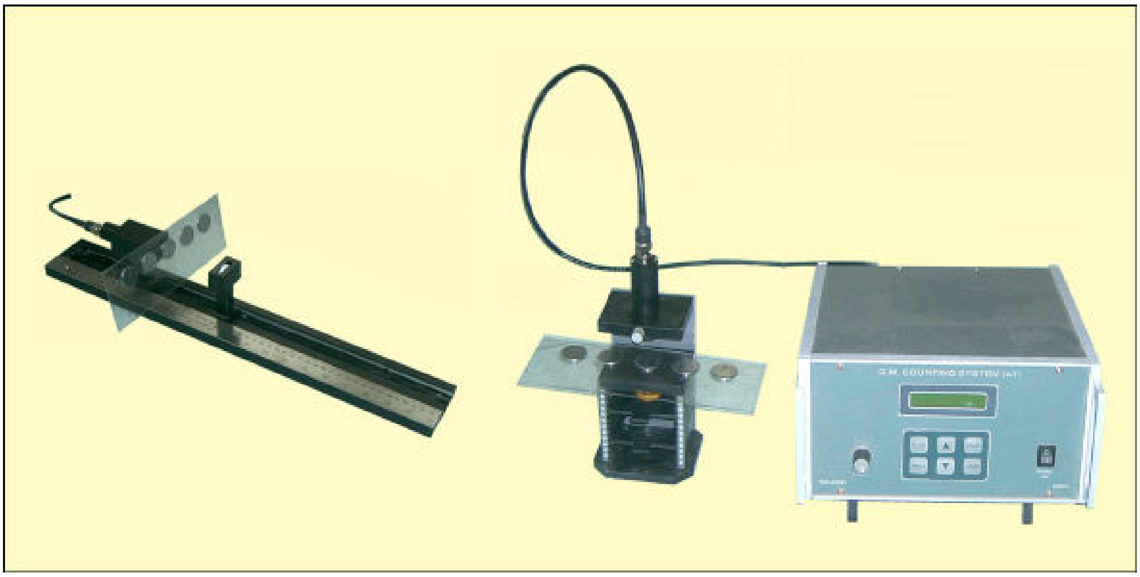


Fig. 24 : G. M. Counting System detector, source & perspex sheet fixed with coins arrangement for source beam interruption experiment.

10.4 PROCEDURE

- Make standard interconnections, for the counting system's functionality.
- Switch on the system and operate in CPS mode.
- Place gamma source in the source holder and ensure to have a distance of atleast - 2cm between the end window of the detector and gamma source holder.
- Now place this Perspex sheet affixed with coins to interrupt the source detector beam.
- On each interruption by a coin and without coin interruption (i.e. with only Perspex sheet), record the count rate changes and tabulate them.
- One can pre-set alarm level (if available as a feature in the counting system) such that on each change over of count rate, one can see annunciation of aural/ visual alarm on the electronic counting unit.

10.5 CONCLUSIONS

Using this principle, number of real time applications in a process industry could be developed or implemented for inspection, checking the fill of the items andn counting number of items under process.

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