Experiment -1

Deflection of beta radiation in a magnetic field

Experiment Objectives

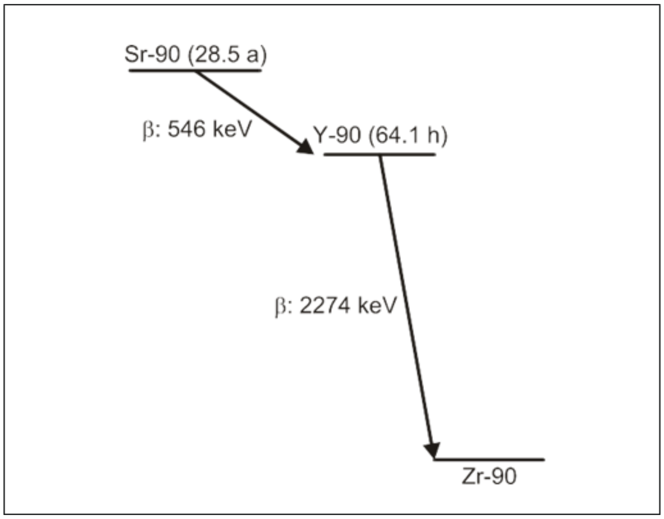
1- Setting up an electron beam passing through a magnet

2-Record the different count rates at different combinations of angle and field.

Principles

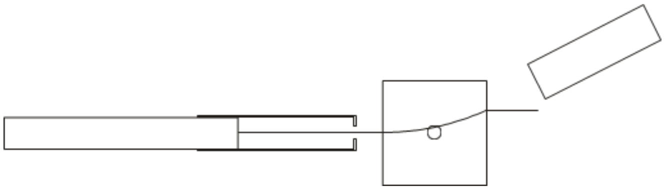
The decay of radioactive nuclei can emit different kinds of radiation, historically called a, b, and g radiation. Today, we know that each kind of radiation consists of different particles, with the big difference that g particles (called photons) carry neither charge nor rest mass. a and b particles (helium nuclei and electrons) are both charged and have a finite rest mass.

In this experiment, we will investigate the motion of b particles (electrons) in a magnetic field. The source of our electrons isa Strontium 90 radioactive source, which decays to Yttrium-90 and finally to zirconium-90. Both decays are b decays, the first has a total energy of 546 keV, the latter 2274 keV. Since the Sr-90 is encapsulated in some metal foil, electrons from the first decay will not leave the foil, only those from the second decay will be visible.



Since the beta decay is a three-particle decay involving an anti-neutrino, the energy spectrum of the electron is not one value but is distributed over a full energy range up to the maximum energy.

When a beam of charged particles passes through a static magnetic field, Lorentz force influences the motion of the beam and in a homogeneous field the particles start a circular motion.



Particles emitted from a radioactive preparation (left) follow linear trajectories, until they reach the magnetic field (middle), where they start to follow circular paths. After leaving the magnetic field, they travel linear again until reaching the detector (right).

Since the energy of the electrons (up to 2274 keV) is much larger than the rest mass (511 keV) of an electron, we need a relativistic calculation.

Theory

Inside the magnetic field, the electrons will follow a path where the sum of centrifugal force vector and Lorentz force vector is zero.

$$\frac{m.v^2}{r} = ev\ B$$

The circular path has radius $r = \frac{mv}{eB}$

The angular deflection of a beam passing through a magnetic field of length *l* (short compared to the radius r) is

$$\alpha \approx \frac{l}{r} = \frac{l\ e\ B}{mv} \quad \text{in radians}$$

The equations are still valid for the relativistic case, as long as the mass and velocity of the particle are handled correctly.

The term *mv* is the impulse of the moving particle, which is

$$mv = P = \sqrt{\frac{E^2}{c^2} - m_\circ^2 c^2}$$

and the total Energy

$$E = E_{kin} + m_\circ c^2$$

Setup

The experiment's core setup is represented in Fig. 1. The U-core holds two coils and on top two bored pole pieces, one carrying the swiveling clamp.

This is detailed in Fig 2, the bored pole piece (3) carries the scale (2) and the clamp (1) on one side. The round rod goes through the pole piece and is secured on the other side with a ring (4), a spring washer (5) and finally a fastening screw (6). Tighten the screw (6) so much that the swiveling clamp can be moved, but does not turn on its own weight.

The end window counter is placed in the swilling clamp and fixed with screw (1.1).

Finalize the setup as shown in Fig 3. The preparation is held by the multiclamp and attach the collimator from 559 18, with a 5 mm diameter plate in the end. Since we'd like to have a highly collimated beam, insert the radioactive preparation only halfway into the collimators tube, as indicated in Fig 4.

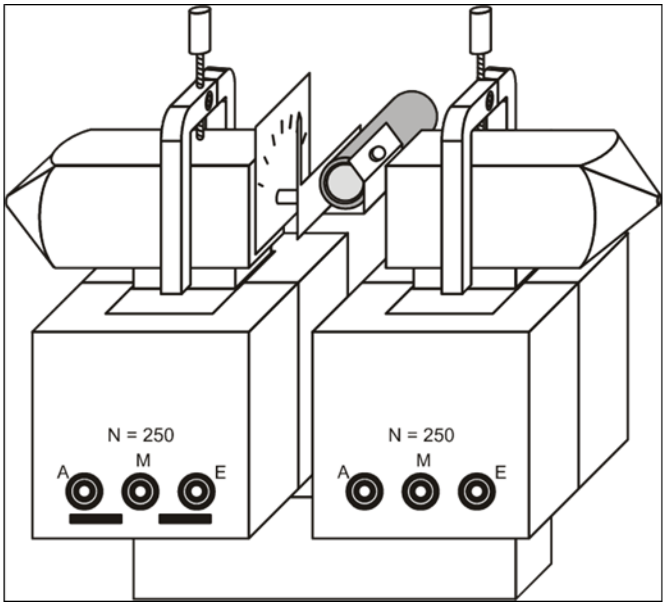


Fig 1: Setup of the pole pieces

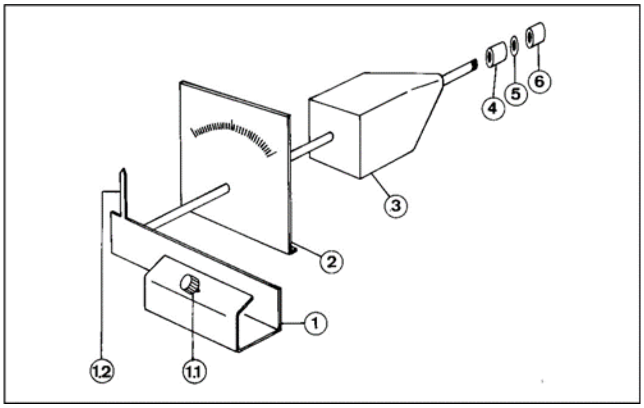


Fig 2: Mounting the swivel clamp to one pole piece

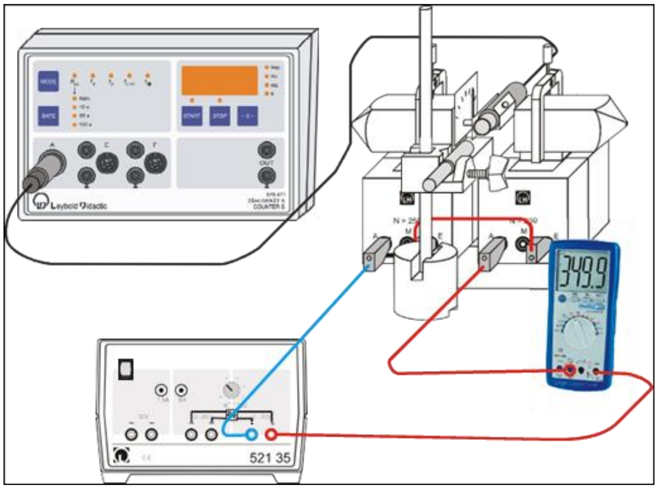


Fig 3: Complete setup of the experiment

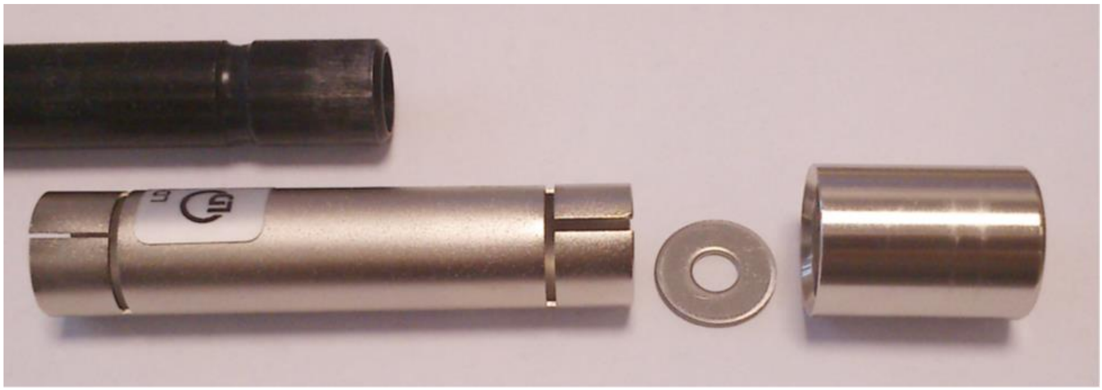


Fig 4: silver: Parts holder with absorber foils required to assemble the collimator, black: the preparation.

Carrying out the Experiment

First calibrate the magnetic field. Attach the combi B sensor to the included stand rod and put it into the multiclamp, replacing the preparation. Put the tip of the magnetic field sensor in the center of the magnetic field between the pole pieces. Connect the extension cable between Combi B sensor and Mobile Cassy. Switch on the mobile CASSY. Now vary the current through the coils in a range from zero to 2 A, and take readings of the current from the multimeter and the magnetic field from the mobile CASSY.

The magnetic field will follow the current linearly and in the example measurement we get approximately 20 mT per Ampere. The exact value strongly depends on the separation of the pole pieces.

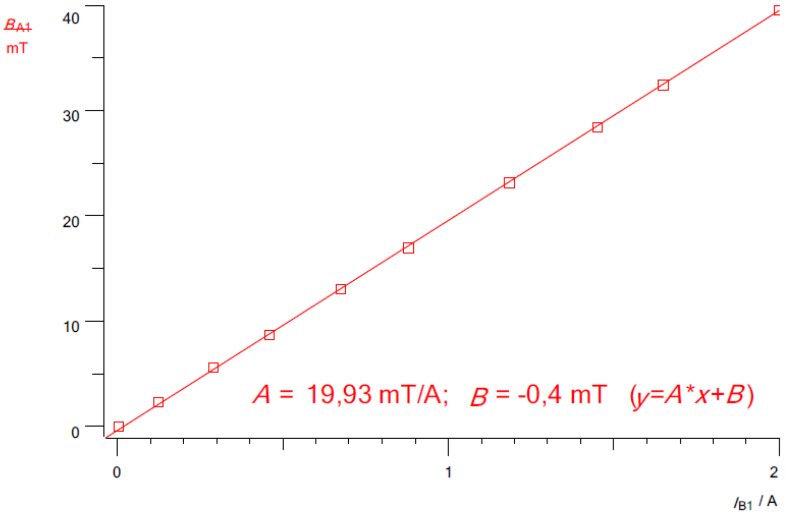


Fig 5: Field calibration

Remove the Combi B sensor and Mobile CASSY from the setup and put the radioactive preparation with collimator back in place.

Put the swivel arm to zero and set the current also to zero.

On the counter S, select a gate time of 100 seconds and press the start button. Once the counter stops read the number of particles detected by the GM tube.

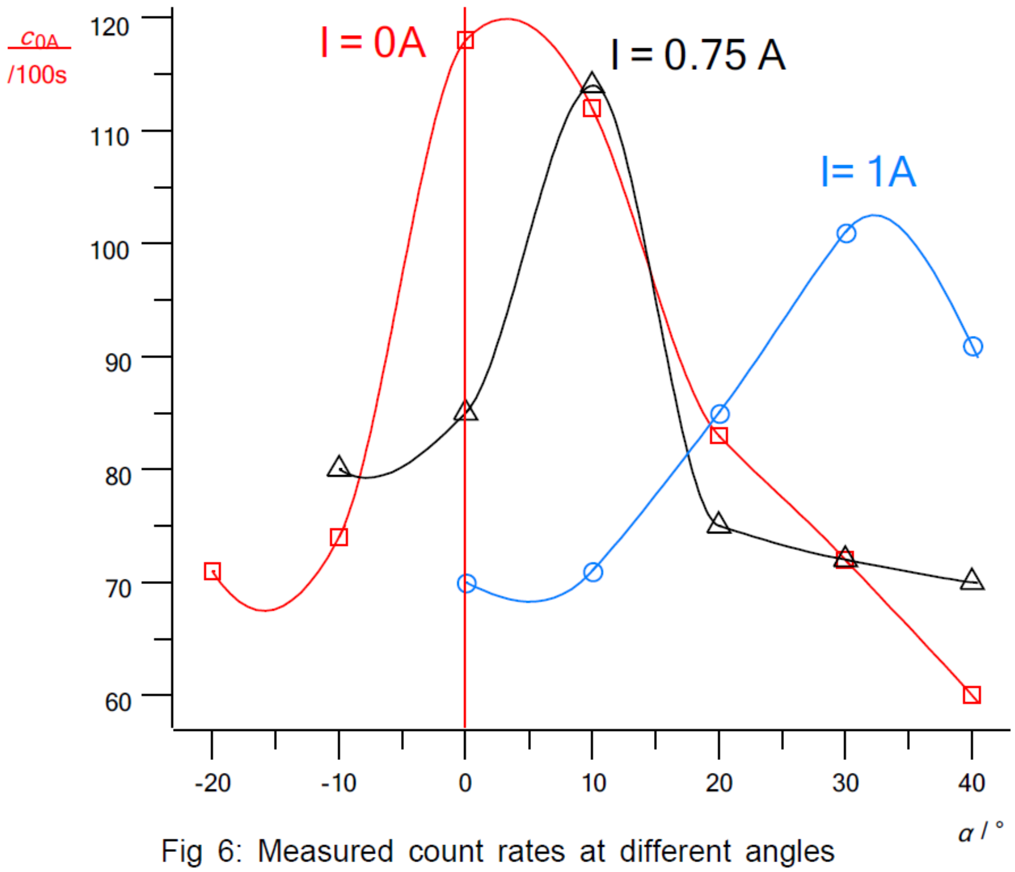


Fig 6: Measured count rates at different angles and currents

Move the swivel arm into different positions for one current setting, for example in 10 degree steps from 40 down to –10 degree. If connected as shown in Fig 3, electrons will be deflected upwards.

Suggested current setting are around 1 A, giving 20 mT of field and 1.5 A (30 mT) or 0.75 A (15 mT).

Measurement Example

Plotting the count rates versus angle for zero magnetic field should give a curve symmetrically to zero.

A magnetic field will shift the maximum of the count rate distribution to higher angles, as can seen in Fig. 6 Due to the statistical noise, a measurement time of 100 seconds per point is enough to see the shift of the maximum, but the curves do not resemble normal distributions.

Evaluation

We found a shift of the maximum counting rate with magnetic

field.

From the introduction, we know

$$\alpha \approx \frac{l}{r} = \frac{l\,e\,B}{mv}$$

$mv = P = \sqrt{\frac{E^2}{C^2} - m_\circ^2 c^2}$

$E = E_{kin} + m_\circ c^2$

The total energy of the electrons is up to 2274 keV + 511 keV, but due to the beta decay involving three particles the electron can be emitted at any kinetic energy from zero to 2274 keV. For a rough calculation, the most probable energy

is about one third of the maximum energy, so we have 758 +511 keV,

With 1 keV = 1.602E-16 J we get

E = 2.033 e –13 J

The rest mass is worth 8.186E-14 J, the electrons mass is

9.11 E –31 kg

So, the relativistic impulse is 6.2E-22 kg m/s

With l= 0.04 m, e=1.602E-19 C and B=0.02 T we calculate an expected deflection of about 12 degree.

In the measurement, the real value is more in the 20-degree range.

Experiment 2

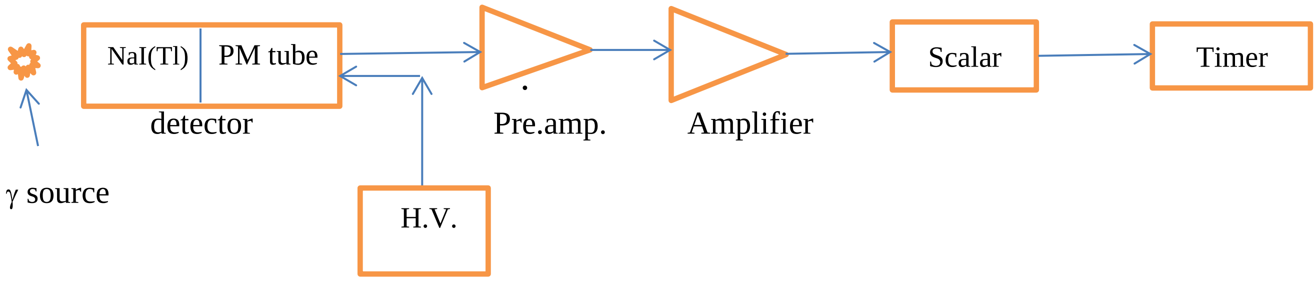
The relative stability region of scintillation detector

The purpose of the experiment

Study the relative stability region of scintillation detector and the effect of various factors such as:

1- the effect of preamplifier Capacitor.
2- the effect of amplifier gain.

Experimental setup



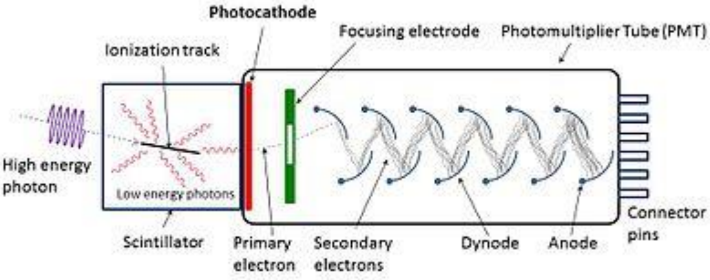
Theory

A **scintillation counter** is an instrument for detecting and measuring ionizing radiation by using the excitation effect of incident radiation on a scintillator material, and detecting the resultant light pulses.

It consists of a scintillator which generates photons in response to incident radiation, a sensitive photomultiplier tube (PMT) which converts the light to an electrical signal and electronics to process this signal.

Scintillation counters are widely used in radiation protection, assay of radioactive materials and physics research because they can be made inexpensively yet with good quantum efficiency, and can measure both the intensity and the energy of incident radiation.

Schematic showing incident high energy photon hitting a scintillating crystal, triggering the release of low-energy photons which are then converted into photoelectrons and multiplied in the photomultiplier



Detection materials

The scintillator consists of a transparent crystal, usually a phosphor, plastic (usually containing anthracene) or organic liquid, that fluoresces when struck by ionizing radiation.

Cesium iodide (CsI) in crystalline form is used as the scintillator for the detection of protons and alpha particles. Sodium iodide (NaI) containing a small amount of thallium is used as a scintillator for the detection of gamma waves and zinc sulfide (ZnS) is widely used as a detector of alpha particles. Zinc sulfide is the material Rutherford used to perform his scattering experiment. Lithium iodide (LiI) is used in neutron detectors.

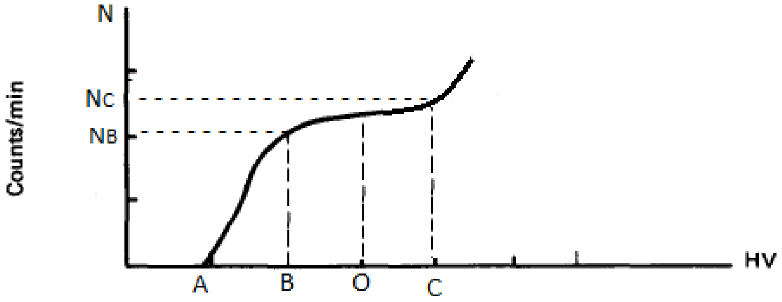
Operation

When an ionizing particle passes into the scintillator material, atoms are ionized along a track. For charged particles the track is the path of the particle itself. For gamma rays (uncharged), their energy is converted to an energetic electron via either the photoelectric effect, Compton scattering or pair production. The chemistry of atomic de-excitation in the scintillator produces a multitude of low-energy photons, typically near the blue end of the visible spectrum. The number of such photons is in proportion to the amount of energy deposited by the ionizing particle. Some portion of these low-energy photons arrive at the photocathode of an attached photomultiplier tube. The photocathode emits at most one electron for each arriving photon by the photoelectric effect. This group of primary electrons is electrostatically accelerated and focused by an electrical potential so that they strike the first dynode of the tube. The impact of a single electron on the dynode releases a number of secondary electrons which are in turn accelerated to strike the second dynode. Each subsequent dynode impact releases further electrons, and so there is a current amplifying effect at each dynode stage. Each stage is at a higher potential than the previous to provide the accelerating field. The resultant output signal at the anode is in the form of a measurable pulse for each group of photons that arrived at the photocathode, and is passed to the processing electronics. The pulse carries information about the energy of the original incident radiation on the scintillator. The number of such pulses per unit time gives information about the intensity of the radiation. In some applications individual pulses are not counted, but rather only the average current at the anode is used as a measure of radiation intensity.

The scintillator must be shielded from all ambient light so that external photons do not swamp the ionization events caused by incident radiation. To achieve this a thin opaque foil, such as aluminized mylar, is often used, though it must have a low enough mass to minimize undue attenuation of the incident radiation being measured.

The high-voltage power supply (HVPS) provides a positive or negative voltage necessary for the operation of the detector. Most detectors need positive high voltage (HV). . The HVPS is constructed in such a way that the HV at the output changes very little even though the input voltage may fluctuate. The amount of processed voltages and its polarity depends on the detector composition and properties.

Before doing measurements of spectral, are initialized to the detector and electronics devices that associated conditions of these measurements to get the best stability of the devices during the collecting time, especially finding the best voltage operation of the detector according to the values magnification mixed amplifier within a certain range called the relative stability of the region, as shown in the figure below, where A called start voltage and the specific region between B and C is the relative stability region and the operating voltage at O.



The slope of this region is given by the relation below:

$$\text{Slope } \left(\frac{\%}{100V}\right) = \frac{\frac{N_C - N_B}{\frac{N_B + N_C}{2}}}{} \times \frac{100}{\frac{C-B}{100}} = \frac{2(N_C - N_B)}{N_C + N_B} \times \frac{10^4}{C-B}$$

The primary purpose of the preamplifier is to provide an optimum coupling between the detector and the rest of the counting system. A secondary purpose of the preamplifier is to minimize any sources of noise, which will be transmitted along with the pulse and thus may degrade the energy resolution of the system.

A current-sensitive preamplifier is used to transform fast current pulses produced by a photomultiplier into a voltage pulse. The current-sensitive preamplifier is an amplifying instrument. The sensitivity (or gain) of such a unit is expressed as V_{out} /I_{in} i.e., in mV/mA with typical values of the order of 500 mV/mA. The rise time of the pulse is~1 ns. Where amplification and sensitivity (V/E) dependent on the total charge Q accumulated on the capacitor C of the radiation energy E:

$$\frac{V}{E} = \frac{Q}{CE}$$

The main amplifier who Magnifies pulse amplitude resulting from the preamplifier for use in the next circuits. Where linear amplifier provides a direct linear relationship between external pulse amplitude and internal pulse amplitude and this is called the gain.

amplifiers have two dials for adjusting the amplification .Coarse gain: This dial adjusts the amplification in steps, each step is a fraction of the maximum amplification. Fine gain: This dial adjusts the amplification continuously within each step of the coarse gain.

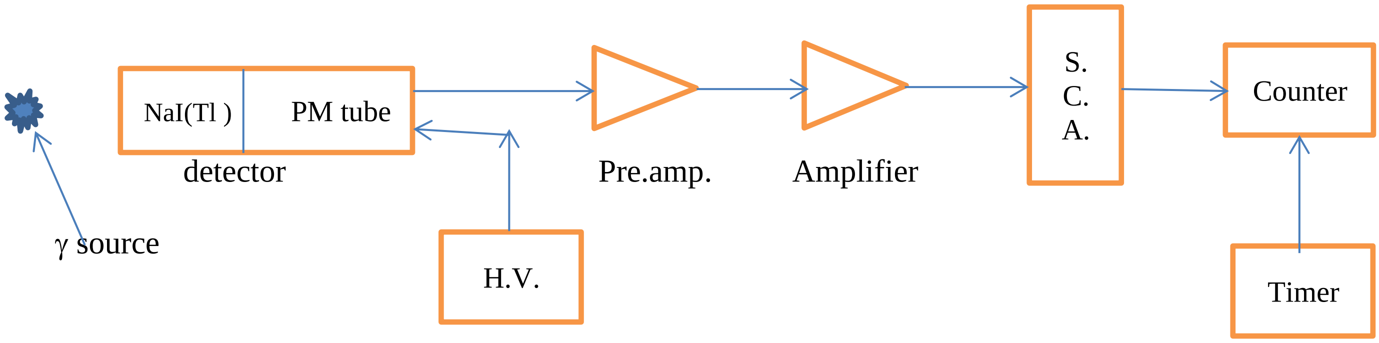
Experiment 3

Study the differential spectrum of gamma ray and the effect of the window aperture of single channel analyzer on it

The purpose of the experiment

1- draw and study differential spectrum of gamma ray for radiation source that used in this experiment.
2- Learn how to use the single channel analyzer S.C.A. To support this purpose.
3- Study the effect of window aperture (upper level) and increases values of the lower level on this spectrum.

Experimental setup



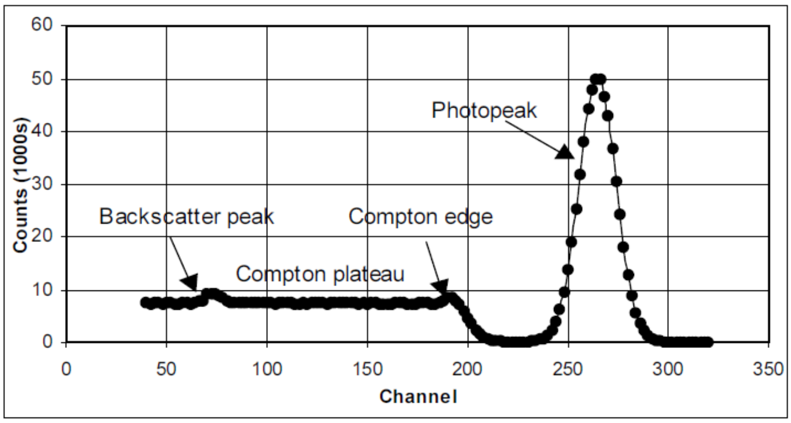
Theory

Photons are detected by means of the electrons they produce when they interact
in the material of which the detector is made. The main interactions are photoelectric effect, Compton scattering, and pair production. The electrons (or positrons) produced by these interactions deposit their energy in the counter and thus generate a voltage pulse that signifies the passage of the photon. The height of the voltage pulse is proportional to the energy deposited in the detector. Since the objective is to measure the energy of the incident photon, the question arises: Is this voltage pulse proportional to the energy of the incident particle? To provide an answer, one must examine how the photon interacts and what happens to its energy.

The measurement of the height of the pulses produced by a radiation detector provides the information about the energy of the incident radiation, because in most of the cases, the pulse height is proportional to the energy delivered in the detector. When a selection of defined pulses according with its amplitude is required, the Single Channel Analyzer SCA can make this selection

(SCA) is the unit that can make the selection of the desired pulses. Modern SCA works with three modes In the INTEGRAL mode, all input pulse amplitudes above the lower level produce an SCA output logic pulse. This mode is useful for counting all pulses above the noise level, or above a well-defined lower amplitude limit. The INTEGRAL mode can also be used for leading edge timing, or pulse routing logic. In the NORMAL mode, the upper- and lower-level discriminators are independently variable over the full +20 mV to +10 V range. The SCA output is generated only for pulse amplitudes that occur between the upper and lower levels. This mode is useful when a wide range of pulse heights must be selected for counting. In the WINDOW mode, the upper-level dial becomes a window width control with a 0 to +1 V range. The lower level dial controls the lower limit of the window over a +20 mV to +10 V range. Pulse amplitudes between the upper and lower limits of the window produce an

(switch position: **win).** Both E and ΔE dials operate. Only pulses with heights between E and E + ΔE are counted. The two dials form a "channel"; hence the name single-channel analyzer. If the E dial is changed to E_l, then pulses with heights between E_l and E_1 + ΔE will be counted. In other words, the width ΔE, or window, of the channel is always added to E.



The differential spectrum of gamma ray

Experiment 4

The differential and the integral spectrum of gamma ray

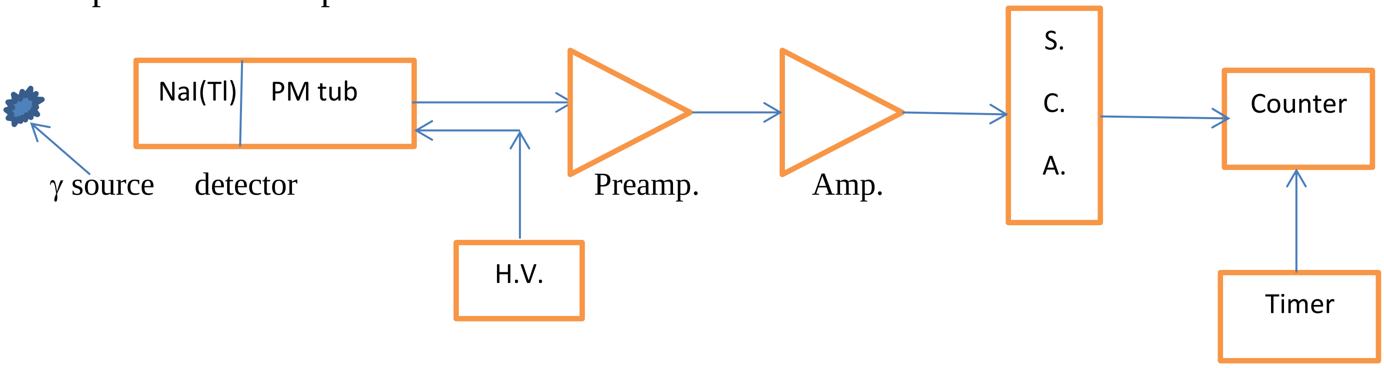
The purpose of the experiment

1 Study the different window aperture (win=U.L.) for the increase in the value of the lower level (ΔL.L.=Δh) on differential spectrum.

2- Learn how to use the single channel analyzer and its work on window, Integral and normal mode.

3- study and draw integral spectrum of gamma ray for radiation source that used in this experiment and get the differential spectrum from it.

Experimental setup



Theory

Spectroscopy is the aspect of radiation measurements that deals with measuring
the energy distribution of particles emitted by a radioactive source or produced by a nuclear reaction.

A particle energy spectrum is a function giving the distribution of particles in terms of their energy. There are two kinds of energy spectra, differential and integral.

The differential energy spectrum, the most commonly studied distribution, is also known as an energy spectrum. It is a function n(E) with the following meaning:

n(E) dE = number of particles with energies between E and E+dE

or

n(E) = number of particles with energy E per unit energy interval

The integral energy spectrum is a function N(E), where N(E) is the number of particles with energy greater than or equal to E. The integral energy spectrum N(E) and the differential energy spectrum n(E) are related by

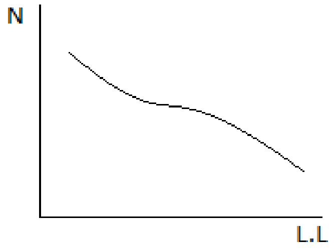
$$N(E) = \int_E^\infty n(E)dE$$

The two examples that follow illustrate the relationship between a differential spectrum and an integral spectrum.

Measurement of a differential energy spectrum amounts to the determination of the number of particles within a certain energy interval ΔE for several values of energy; or, equivalently, it amounts to the determination of the number of pulses within a certain interval ΔE, for several pulse heights. A SCA operating in the differential mode is the device that is used for such a measurement.

If the lower Level of the SCA is set at E_l and the window has a width ΔE, then only pulses with height between E_l and E_l+ ΔE are recorded. All pulses outside this range are rejected. To measure the pulse spectrum one starts by setting the lower Level at E_l, where $E_l > E_o$, with a certain window ΔE (e.g., ΔE = 0.1 V) and then keeps lowering the lower Level of the SCA.

Measurement of an integral spectrum means to count all particles that have energy
greater than or equal to a certain energy E or, equivalently, to record all particles that
produce pulse height greater than or equal to a certain pulse height V.
A device is needed that can out pulses according to height. Such a device is a single-channel analyzer (SCA) operating as a discriminator (integral mode). If the discriminator is set at V, volts, all pulses with height less than Vo will be rejected, while all pulses with heights above Vo will be recorded.



The integral spectrum of gamma ray

Experiment 5

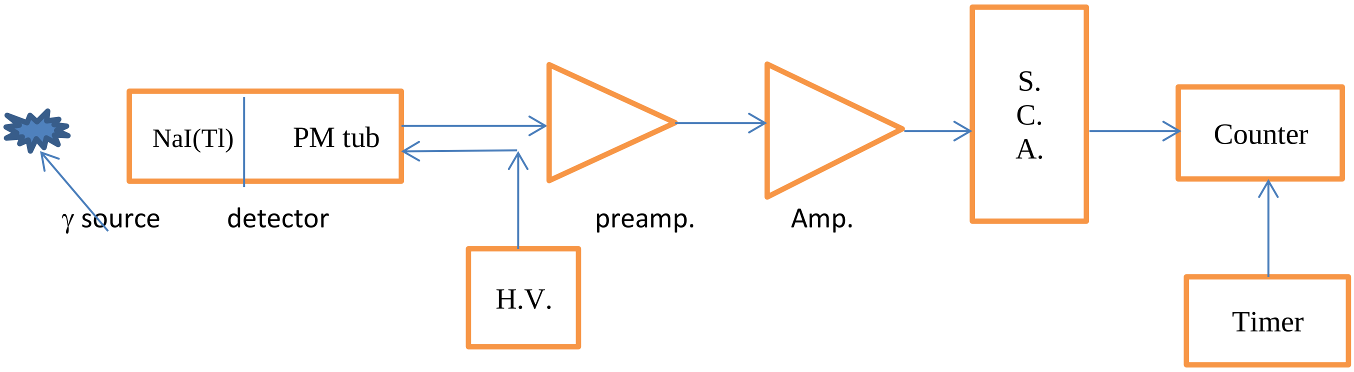
Effect the high voltage for scintillation detector in gamma-ray spectrum

The purpose of the experiment

Study effect the high voltage for scintillation detector in:

1- Spectrum peak position.
2- Its amplitude.
3- Its expansion.

Experimental setup



Theory

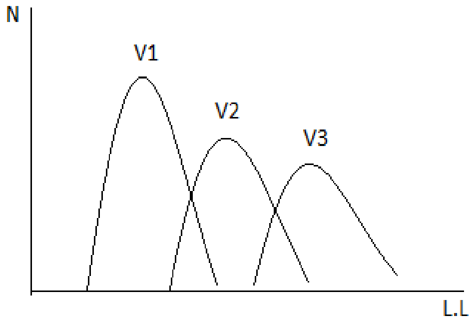
Through various processes, a gamma ray passing into the crystal may interact with it creating many visible and ultraviolet photons (scintillations).To detect the scintillation photons, the crystal is located next to a photomultiplier tube (PM) The PMT consists of a photocathode followed by a series of dynodes (6-10 is typical) followed by and ending with a collection anode. Scintillation photons striking the photocathode eject electrons via the photoelectric effect. A high voltage (HV) power supply and a resistor chain (not shown) bias the cathode, dynodes, and anode so as to accelerate electrons from the cathode into the first dynode, from one dynode to the next, and from the final dynode to the anode collector. Each incident electron strikes a dynode with enough energy to eject around 5-10 (secondary) electrons from that dynode. For each initial photoelectron, by the end of the chain, there are on the order of 106 electrons reaching the anode. The anode is connected to a charge sensitive preamplifier which converts the collected charge to a proportional voltage pulse. The preamp pulse is then shaped and amplified by a linear amplifier before processing continues. Because the amount of light (number of photons) produced in the scintillation crystal is proportional to the amount of gamma ray energy initially absorbed in the crystal, so also are the number of photoelectrons from the cathode, the final anode charge, and the amplitude of the preamp and amplifier voltage pulses. The overall effect is that the final pulse height is proportional to the gamma ray energy absorbed in crystal.

Single-Channel Analyzer is ideally suited for selecting a range of output pulse amplitudes from a spectroscopy amplifier for subsequent counting on a counter/timer. After many pulses of various sizes have been processed, a plot of the counts versus the lower level can be displayed to show the distribution of pulse heights. With some caveats to be described shortly, the pulse height distribution from a scintillation detector can be interpreted as a plot of the number of gammas versus the energy of the gammas from the source, i.e., a gamma ray spectrum of the (radioactive) source.

Differential spectrum is curved, which we get from the drawing number of pulses as a function of its height or its capacity, or its energy, and this proportional with value of lower level for single channel analyzer.

To increase the voltage difference between the cathode and the anode and dynodes will lead to increase the kinetic energy of the electrons liberated and consequently increase their ability to free up additional electrons when colliding with dynode which means increasing the number of electrons liberated .it means the increase in detector voltage leading to increase the height and the widening pulse emerging from the detector as a result of increasing the number of electrons and energy with increased voltages.

The increase in the value of voltage causes the change in the peak position of the spectrum.



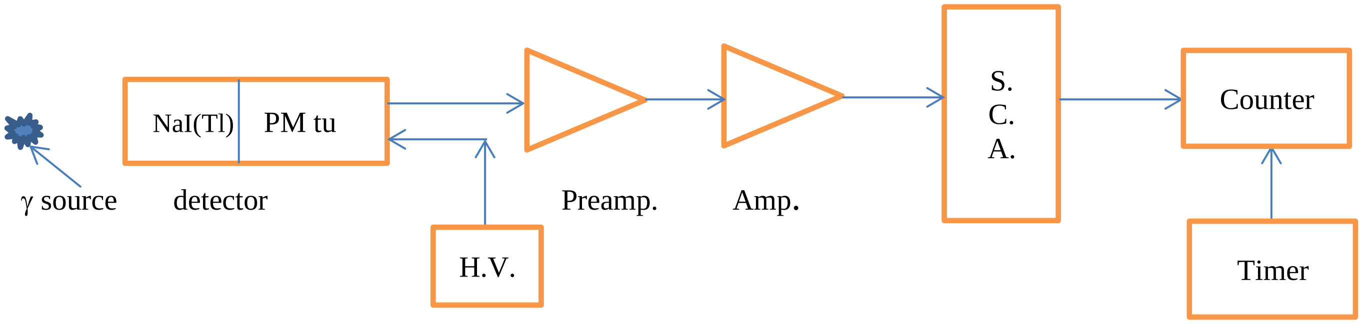
Experiment 6

Effect the gain of the amplifier in gamma-ray spectrum

The purpose of the experiment

Study effect the gain on gamma ray spectrum

Experimental setup

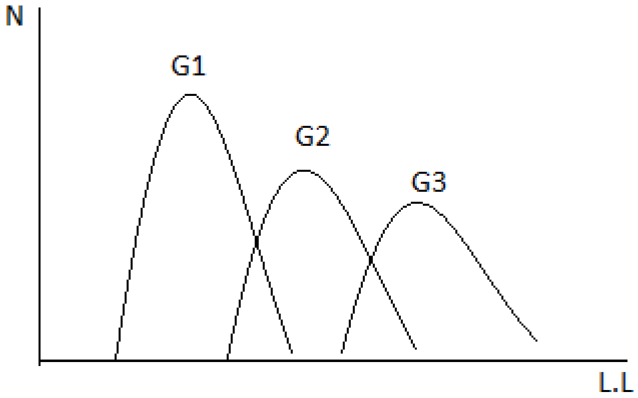


Theory

The signal that comes out of the detector is very weak, in the millivolt (mV) range. Before it can be recorded, it will have to be amplified by a factor of a thousand or more. To achieve this, the signal will have to be transmitted through a cable to the next instrument of the counting system, which is the amplifier. Transmission of any signal through a cable attenuates it to a certain extent. If it is weak at the output of the detector, it might be lost in the electronic noise 'that accompanies the transmission. This is avoided by placing the preamplifier as close to the detector as possible. The preamplifier shapes the signal and reduces its attenuation by matching the impedance of the detector with that of the amplifier. After going through the preamplifier, the signal may be safely transmitted to the amplifier, which may be located at a considerable distance away. Although some preamplifiers amplify the signal slightly, their primary function is that of providing electronic matching between the output of the detector and the input of the amplifier.

The main amplification unit is the amplifier. It increases the signal by as many as 1000 times or more. amplifiers have two dials for adjusting the amplification. Coarse gain: This dial adjusts the amplification in steps. Each step is a fraction of the maximum amplification. Fine gain: This dial adjusts the amplification continuously within each step of the coarse gain.

The increase in the value of the gain causes the change in the peak position of the spectrum.



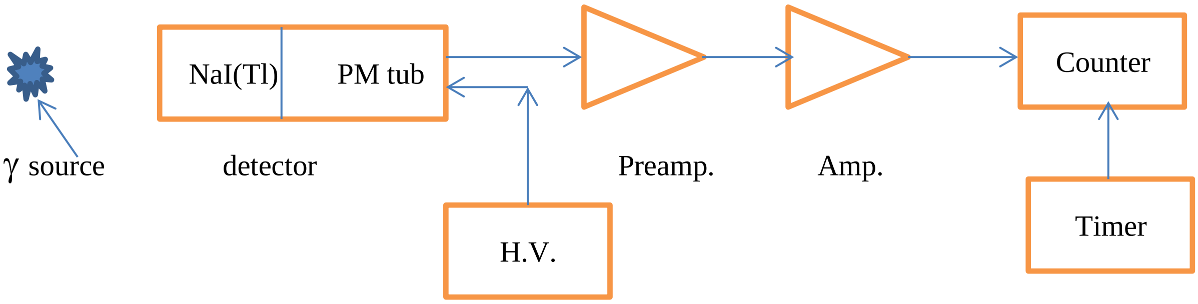
Experiment 7

Statistical fluctuation in random processes

The purpose of the experiment

1- Demonstrate the Statistical nature of random events by observing the radiation for a foxed time interval.
2- Study the effect of the number of readings.

Experimental setup



Theory

Radioactive decay is a random process. consequently ,any measurement which is based on observing the radiation emitted in nuclear decay is subject to some degree of Statistical fluctuations represent an unavoidable source of uncertainty in all nuclear measurement , and often can be the predominant source of imprecision or error.

The term counting statistics includes the frame work of statistical analysis required to process the results of nuclear counting experiments and to make prediction about the expected precision of quantities derived from these measurements.

If we have n of readings, the rate of this readings N_{ave} is:

$$N_{ave} = \frac{N_1+N_2+N_3+------+N_n}{n} = \frac{\sum N_i}{n} \quad \text{------------------} \quad (1)$$

The deviation for any reading from the average is $N_i - N_{ave}$. Since some of the deviations are positive and some are negative so sum for these deviations is zero

To calculate the approximate deviation σ_a from reading such as N use:

$\sigma_a = \sqrt{N}$

The standard deviation (experimental) is defined as the square root of the rate of the sum of squares deviation readings for readings rate i.e.:

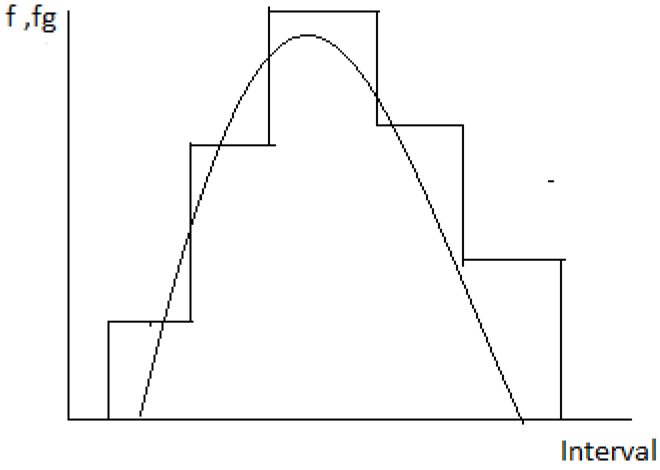
$$\sigma = \sqrt{\frac{\sum(N_i - N_{ave})^2}{n}} \quad \text{----------} \ (2)$$

Gaussian or Normal Distribution (G.D.)

This is a further simplification if the average number of successes is relatively large. That condition will apply for any situation in which we accumulate more than a few counts during the course of the measurement. This is most often the case so that the G.D. model is widely applicable to many problems in counting statistics

On the other hand, curve repeat readings as a function of the readings shall be subject to what is called gausses distribution where

$$f \longrightarrow P \equiv f_g = \frac{A}{\sigma\sqrt{2\pi}}\, e^{-\frac{(N_i - N_{ave})^2}{2\sigma^2}}$$



Where A = $\sum f \times$ interval.

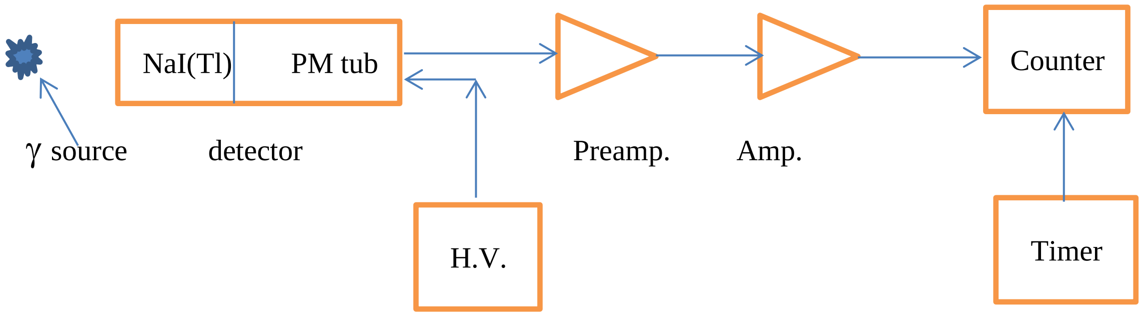
Experiment 8

Least Square Linear Fitting

The purpose of the experiment

1- Demonstrate the method of least square fitting for experimental data.
2- Drawing a best straight line between experimental points for a linear relationship between two variables

Experimental setup



Theory

It often happens that we wished to determine one characteristic of an experiment (y) as a function of another quantity (x). That is y=f(x). Instead of making a number of measurements of y for one particular value of x, we make a series of N measurements y_i , one for each of several values of the quantity $x=x_i$, where i is an index that runs from 1 to N. to identify the measurements, we indicate which pair of values (x_i, y_i) corresponds to each other using the same subscript. The functional relationship between the variables y and x can be approximated by a linear function such as a straight line or a polynomial of order N (=3,4,….) or nonlinear function such as exponential, sine, …etc. we shall consider here a method for determining the most probable values for the coefficients a and b considering the functional relation y= f(x) to be linear and of the form : y=a+bx, to fit the pairs of measurements (x_i, y_i) with linear equation, we must minimize the discrepancy between the values of our measurements y_i and the corresponding values y=f(x) given by the equation. Δy_i

is the deviation between the observed value y_i and the corresponding calculated value

$$\Delta y_i = y_i - (a + bx_i) = D \text{ ---------------- } (1)$$

If the coefficients are well chosen, these deviations should be relatively small. The sum of the square of deviations is given by:

$$x^2 = \sum_{i=1}^{N} (\Delta y_i)^2 = \sum (y_i - a - bx_i)^2 \quad \ldots\ldots (2)$$

In order to find the values of the coefficients a and b which yield the minimum value for x^2, the partial derivatives with respect to each of the coefficients must set equal to zero.

$$\frac{\partial}{\partial a} x^2 = \frac{\partial}{\partial a} \left[\sum (y_i - a - bx_i)^2 \right] = -2\sum (y_i - a - bx_i) = 0 \;\ldots\ldots..(3)$$

$$\frac{\partial}{\partial b} x^2 = \frac{\partial}{\partial b} \left[\sum \; (y_i - a - bx_i)^2 \right] = -2\sum x_i (y_i - a - bx_i) \;\; 0 \;\ldots..(4)$$

These equations can be rearranged to yield a pair of simultaneous equations:

$$\sum_{i=1}^{N} y_i = \sum_{i=1}^{N} a + \sum_{i=1}^{N} bx_i = aN + \sum x_i \ldots\ldots (5)$$

$$\sum x_i \, y_i = \sum ax_i + \sum bx_i^2 = a\sum x_i + b\sum x_i^2 \;\; \ldots (6)$$

Solving equations 5 and 6 for the coefficients a and b, the values of a and b for which x^2 is minimum, are:

$$a = \frac{\sum x_i^2 \sum y_i - \sum x_i \sum x_i \;\; y_i}{N \sum x_i^2 - (\sum x_i)^2} \;\; \ldots\ldots (7)$$

$$b = \frac{N \sum x_i \, y_i - \sum x_i \sum y_i}{N \, \sum x_i^2 - (\sum x_i)^2} \; \ldots\ldots\ldots \; (8)$$

Notice the same denominator in eq. (7) and (8)

Of all curves the property of $D_1^2 + D_2^2 + \ldots\ldots + D_N^2$ is minimum is called a best fitting curve.

Standard error of estimate: (δ y x)

$$y = a + b\,x \text{ -------------------- } (9)$$

$$a = \frac{(\sum y)\,(\sum x^2) - (\sum x)\,(\sum xy)}{N \sum x^2 - (\sum x)^2} \text{ ------------- } (10)$$

$$b = \frac{N(\sum xy) - (\sum x)\,(\sum y)}{N \sum x^2 - (\sum x)^2} \text{ --------------------------- } (11)$$

$$\delta^2 \, x \, y = \frac{\sum y^2 - a \sum y - b \sum xy}{N} \text{ ----------------------- } (12)$$

Or :

$$\delta^2 \, x \, y = \frac{\sum (y - y_{est})^2}{N} \text{ ------------------------- } (13)$$

Or:

$$\delta_{ave} = \sqrt{\frac{\sum D^2}{N}} \text{ --------------------------- } (14)$$

Where N number of reading.

Make the following table for calculating.

Distance (cm)	$1/d^2 = x$	Net count rate (y)	x^2	Xy
10 11 . . 20				
sum	$\sum x_i$	$\sum y_i$	$\sum x_i^2$	$\sum x_i \, y_i$

d	$1/d^2=x$	y_{exp}	Calculated y	$(\Delta y)^2=D^2$
10 11 . . 20				
sum				$\sum(\Delta y)^2 = \sum D^2$