BIRZEIT UNIVERSITY

Faculty of Science

Physics Department

Physics 212

Radioactivity

Student's Name: Rashad Hamidi

Student's No.: 1172790

Partner's Name: Muath Hamidi

Partner's No. : 1172789

Instructor: Dr. Wael Karain

Section No.: 2

Date: 23 Mar 2019

– Abstract:

The aim of this experiment is to familiarize the student with the Geiger-Muller counter as a device for detecting radioactivity, to study counting statistics, and to estimate the range of particles emitted by some radioactive nuclei. Using Geiger-Muller (G-M) Counter and two sources of radiation $\left({}^{88}_{38}St \;\&\; {}^{59}_{27}Co\right)$ the aims were checked. From PART I, the Operation Voltage was detected and it was equal to 400V. From PART II, the range of β-particles in aluminum ≈ 1.675 g/cm^2, and the kinetic energy of β-particles were $E_0 = 3.38MeV$. Using the graph ln(N) vs σ, the mass absorption coefficient was $\mu_m = 0.00403\ cm^2/g$. From PART III, the probability distribution was plotted and it was as Gaussian distribution, so the result was accepted. Using statistical analysis $A_1 = 22.56$ and from data $A_2 = 22.17$. From PART IV, the dead time of G-M tube was $\tau_d = 0.0854s$.

– Theory:

In a radioactive sample, each atom may decay by the emission of an **α**, a **β** or a **γ** particle. It is found that the number of decays during a short time interval $\boldsymbol{dt}$ is proportional only to the number of nuclei in the sample $\boldsymbol{N(t)}$ and to the time interval. Therefore, the change in the number of nuclei in the sample is given by:

$$dN = -\lambda N(t)dt$$

Where $\boldsymbol{\lambda}$ is the decay constant. The negative sign indicates that the sample is losing nuclei. To find the number of nuclei at any given time $\boldsymbol{t}$,

$$\int \frac{dN}{N} = -\lambda \int dt$$

$$N(t) = N_0 e^{-\lambda t}$$

Where N_0 is the initial number of radioactive nuclei at t = 0. To find the decay rate,

$$-\frac{dN}{dt} = \lambda N_0 e^{-\lambda t}$$

$$\ln\left(-\frac{dN}{dt}\right) = \ln(\lambda N_0) - \lambda t$$

In graph $\ln(-dN/dt)$ vs t the slope will be $-\lambda$.

Statistics of Counting:

Consider a radioactive source with an almost constant activity which is placed in front of a radiation detector. The number of counts over a fixed short period of time ($\Delta t \gg \tau$) is measured without altering the position of the source or anything in the experimental setup. Let the average count measured in a fixed time interval $\boldsymbol{\Delta t}$ ($\Delta t \gg \tau$) be $\boldsymbol{\bar{n}}$. The probability of obtaining a count of value **n**, that is the probability that **n** nuclei will disintegrate (assuming l00% efficiency of the detector), is given by Poisson's distribution which can be written as:

$$P_n = \frac{\bar{n}^n}{n!} e^{\bar{n}}$$

The above distribution is normalized to unity, that is:

$$\int_0^{\infty} P_n dn = 1$$

It can be shown that when n is very large then the equation reduces to the Gaussian distribution. The normal distribution can be written as:

$$P_n = Ae^{\frac{(n-\bar{n})^2}{2\sigma^2}}$$

Where $\boldsymbol{A}$ is a constant whose value depends on the normalization.

$$A = \sqrt{2\pi\sigma^2}$$

σ is the standard deviation defined by:

$$\sigma = \frac{\sum_{n=0}^{\infty}(n - \bar{n})P_n}{\sum_{n=0}^{\infty} P_n}$$

And it is easy to verify that:

$$\sigma = \sqrt{\bar{n}}$$

To calculate $\boldsymbol{A}$ from this experiment, we integrate the following:

$$\int_{-\infty}^{\infty} P_n dn = A \int_{-\infty}^{\infty} e^{\frac{(n-\bar{n})^2}{2\sigma^2}} dn = A(2\pi\sigma^2)$$

The left-hand side of the above equation is the area under the curve:

$$\int_{-\infty}^{\infty} P_n dn = \sum_i f(n_i)\Delta n_i$$

Where $\Delta\boldsymbol{n_i}$ is the width of the $\boldsymbol{i^{th}}$ interval and $\boldsymbol{f}(\boldsymbol{n_i})$ is the number of times that a count in this interval was obtained. If all intervals have the same width then:

$$A\sqrt{2\pi\sigma^2} = F\Delta n$$

$$A = \frac{F\Delta n}{\sqrt{2\pi\sigma^2}}$$

Where $\boldsymbol{F}$ is the total number of runs, i.e. times when readings were taken, and $\Delta\boldsymbol{n}$ is the width of each interval.

When a charged particle traverses matter, it loses energy due to coulomb interaction with atoms. Particles' energy is transferred into kinetic energy of free electrons after the atoms are ionized. Although the energy loss in a single interaction is small compared to the initial energy of the particle, the particle might lose all of its energy through many such interactions. In that case the particle is stopped by the matter. The distance that the particle travels through matter before it is stopped is called the "range".

The range $\boldsymbol{R}$ of the particle is defined by:

$$R = \int_0^R dx = \int_{E_0}^0 \frac{dE}{dE/dx} = \int_{E_0}^0 -\frac{E}{c}\,dE$$

$$R = \frac{1}{2c}E_0^2$$

An expression for the range of β-particles in aluminum is given by Feather's formula:

$$R(g/cm^2) = 0.543E_0 - 0.160$$

$$E_0 = \frac{R(g/cm^2) + 0.160}{0.543}$$

Absorption of γ-ray by matter is characterized by the exponential attenuation which is known to occur for ordinary electromagnetic waves. The number of transmitted particles through the slab of width x is given by:

$$N = N_0 e^{-\mu x}$$

If the density of the radiated material is $\boldsymbol{\rho(g/cm^2)}$, then,

$$\mu x = \mu_m(\rho x) = \mu_m \sigma$$

Where $\boldsymbol{\mu_m}$ is called the mass absorption coefficient and $\boldsymbol{\sigma}$ is the density thickness $\boldsymbol{(g/cm^2)}$. Therefore,

$$N = N_0 e^{-\mu_m \sigma}$$

$$\ln(N) = \ln(N_0) - \mu_m \sigma$$

In graph $\boldsymbol{\ln(N)}$ vs $\boldsymbol{\sigma}$ the slope will be $\boldsymbol{-\mu_m}$

The dead time of G-M tube is found to be given by:

$$\tau_d = \frac{R_1' + R_2' - R_{12}'}{2R_1' R_2'}$$

– Procedure:

Prepare the apparatus: Geiger-Muller (G-M) Counter, sheets of aluminum, two sources of β-particles $\left({}^{88}_{38}St \;\&\; {}^{59}_{27}Co\right)$.

<u>PART I:</u> Determination of the G-M Region:

1. Connect the G-M tube to the scaler. Set the voltage at its lowest value and switch on the power. Set the scaler on 'COUNT' mode.
2. bring the source $({}^{88}_{38}St)$ in front of the tube so that it faces its window. Increase the voltage slowly until counts are displayed by the scaler.
3. Measure the number of counts as a function of voltage for fixed time interval (2min).
4. Plot the count rate as a function of voltage. Determine the operation point and the slope of the plateau.

<u>PART II:</u> Absorption of Radiation:

1. Set the voltage at the middle of the plateau region.
2. Place sheets of aluminum in front of the source and measure the transmitted intensity as a function of the density thickness. Make the time of measurement long enough (2min) to obtain a reasonable number of counts in each measurement.
3. Remove the radioactive source and measure the count rate due to background.

PART III: Statistics of Counting:

1. Switch the scaler to COUNT RATE.
2. Advance the source towards tile tube until a count rate of around 80 counts/s is obtained. Record about a 100 successive displayed readings.

PART IV: Measurement of the ‘Dead Time’:

1. Place two different sources $\left({}^{88}_{38}St \,\&\, {}^{59}_{27}Co\right)$ in front of the counter. Measure the count rate R'_{12}.
2. Remove one of the sources $\left({}^{59}_{27}Co\right)$ and measure the count rate R'_1. Now put back the removed source $\left({}^{59}_{27}Co\right)$ and remove the other source $({}^{88}_{38}St)$. Measure the count rate R'_2.

– Data:

PART I:

Time : 2 min

V(Volt)	N
300	9267
320	9440
340	9502
360	9585
380	9552
400	9710
420	10080
440	12466
460	13011
480	42613
500	38145

PART II:

V = 400 Volt

σ (mg/cm^2)	N
4.05	9182
27.0	8692
55.0	8249
65.0	7586
141	5704
185	4850
236	3868
543	461
896	34
1675	29

Count due to background = 27 counts/120s

PART III:

Count Rate (counts/2.5s)				
69	88	74	74	63
64	70	89	75	94
93	68	77	77	91
88	82	76	87	77
85	87	89	75	95
79	85	78	64	84
93	68	79	82	94
76	80	83	72	80
67	90	89	71	100
87	100	86	82	82
94	62	76	84	77
78	66	77	78	88
72	82	89	88	64
83	78	86	70	91
71	82	80	99	82
82	91	85	79	66
72	92	90	83	85
67	88	66	86	71
89	97	81	78	87
64	84	88	77	85

PART IV:

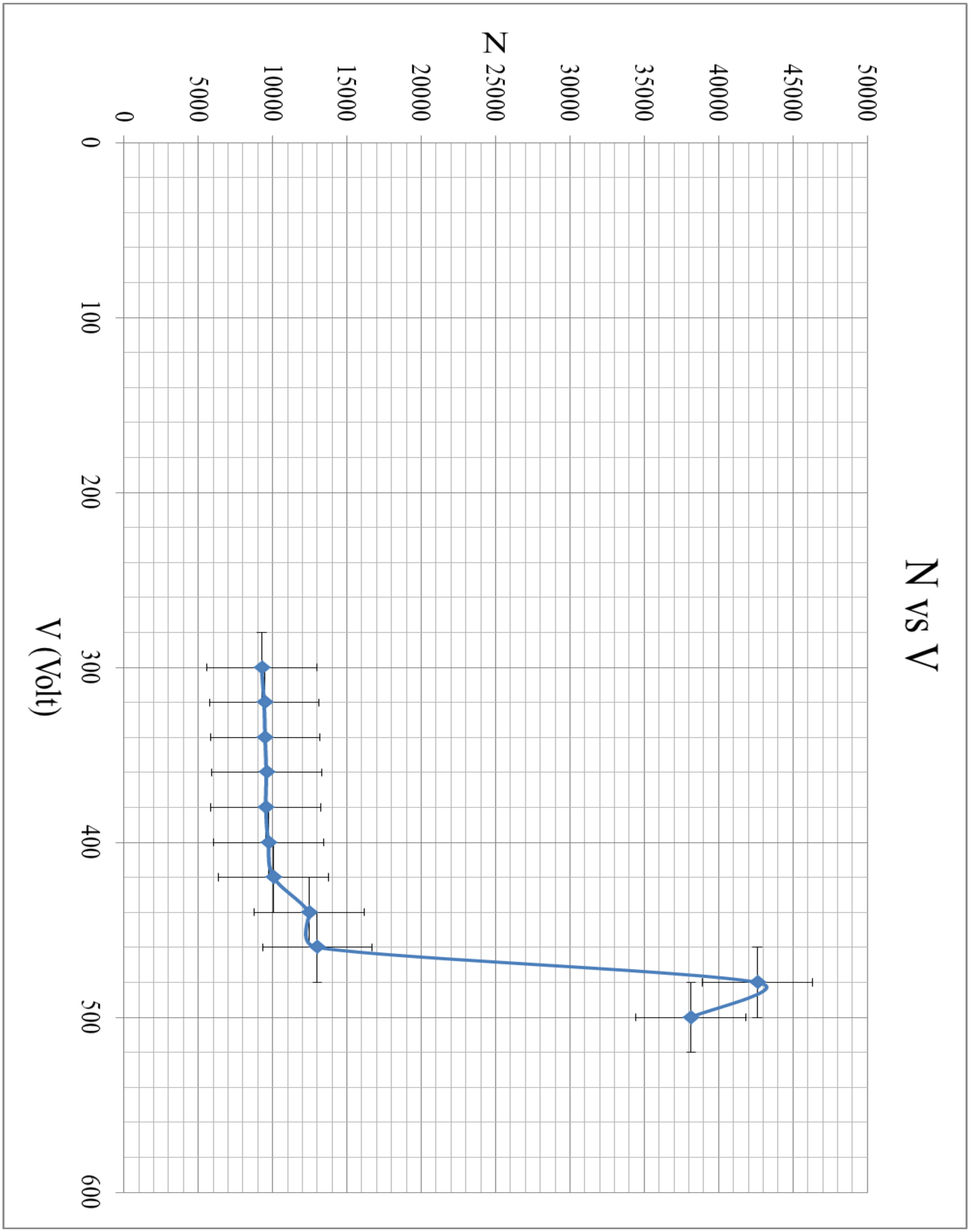
Source	Count Rate (counts/2.5s)
St-Co	43
St	82
Co	3

– Calculations:

PART I:

V(Volt)	N	Count Rate (counts/s)
300	9267	77.23
320	9440	78.67
340	9502	79.18
360	9585	79.88
380	9552	79.60
400	9710	80.92
420	10080	84.00
440	12466	103.9
460	13011	108.4
480	42613	355.1
500	38145	317.9

Operation Voltage = 400V


N vs V
N
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
0
100
200
300
400
500
600
V (Volt)

PART II:

σ (mg/cm^2)	N	ln(N)
4.05	9182	9.125
27.0	8692	9.070
55.0	8249	9.018
65.0	7586	8.934
141	5704	8.649
185	4850	8.487
236	3868	8.260
543	461	6.133
896	34	3.526
1675	29	3.367

Graph N vs σ:

Equation: $y = 8107.4e^{-0.004x}$

Graph ln(N) vs σ:

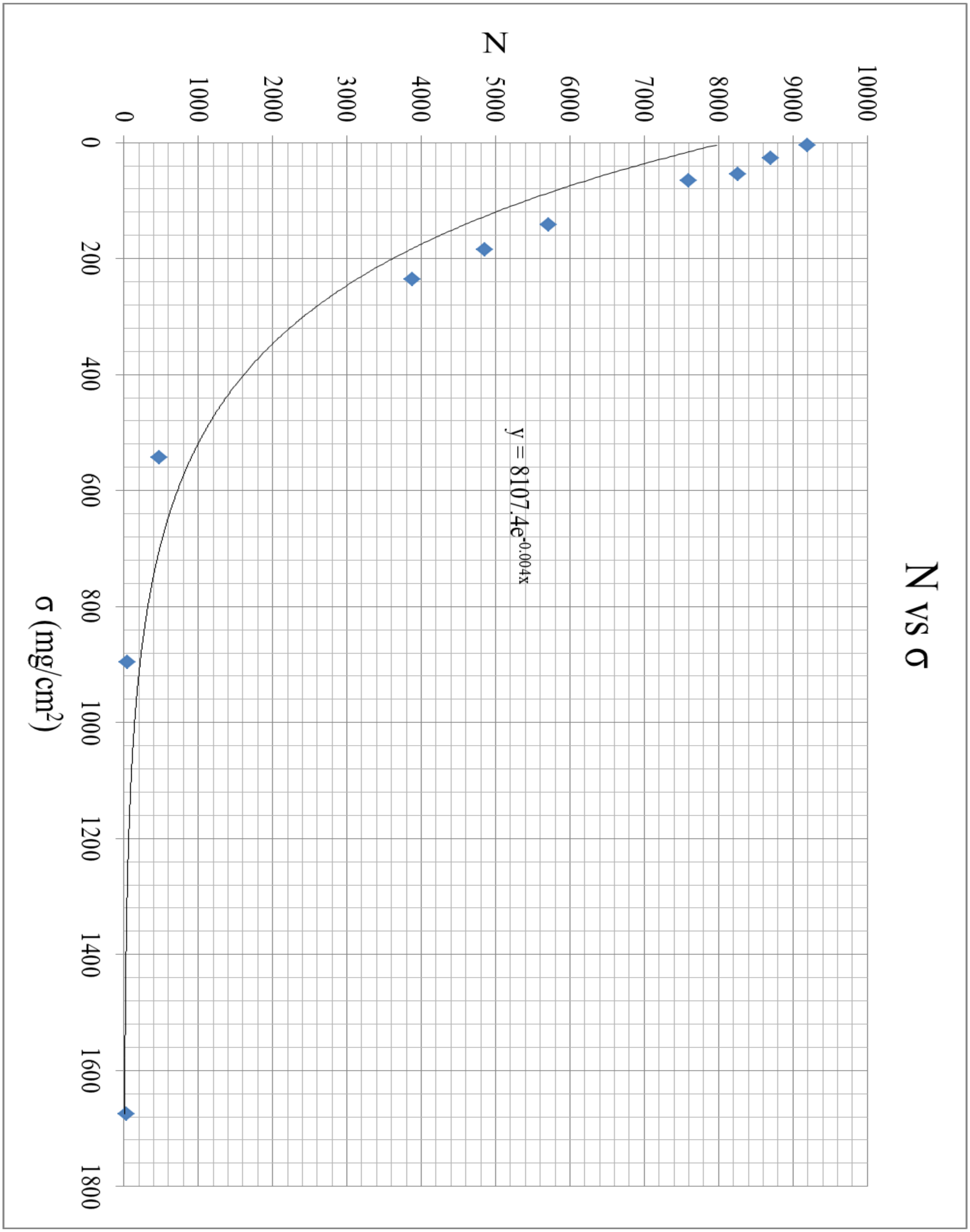
	Slope	y-int
Value	-0.004033151	9.000534066
Error	0.000517284	0.328020509

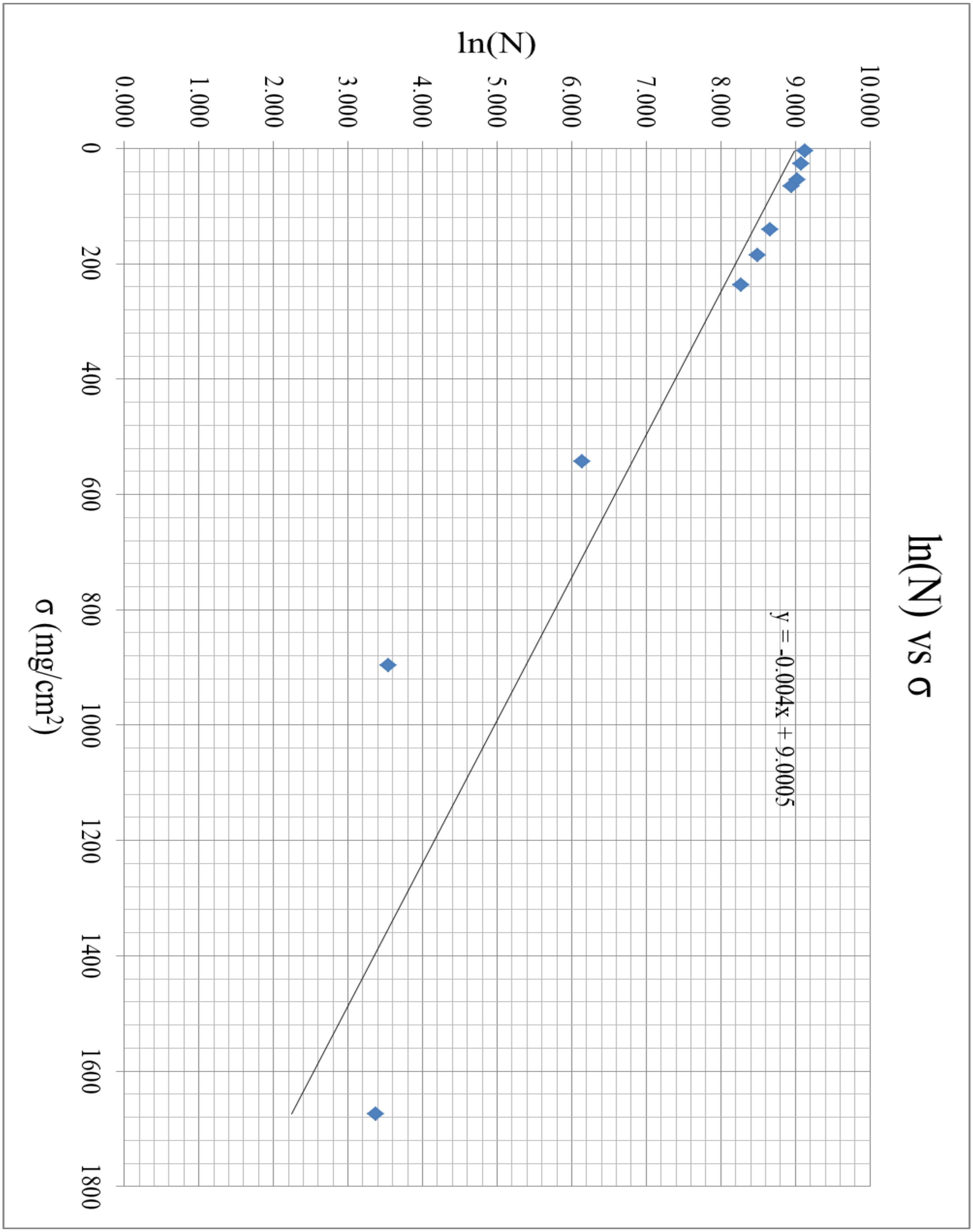
Equation: $y = -0.004x + 9.005$

Range ≈ 1675 mg/cm^2 = 1.675 g/cm^2

$$E_0 = \frac{R(g/cm^2) + 0.160}{0.543} = 3.38MeV$$

$$\mu_m = -slope = 0.00403\ cm^2/g$$


N vs σ
y = 8107.4e-0.004x
N
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
σ (mg/cm2)
0
200
400
600
800
1000
1200
1400
1600
1800


ln(N) vs σ
y = -0.004x + 9.0005
ln(N)
0.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
0
200
400
600
800
1000
1200
1400
1600
1800
σ (mg/cm²)

PART III:

$$\bar{n} = \frac{\sum_{i=1}^{100} n_i}{100} = 80.93$$

$$\sigma = \sqrt{\bar{n}} = \sqrt{80.93} = 8.996$$

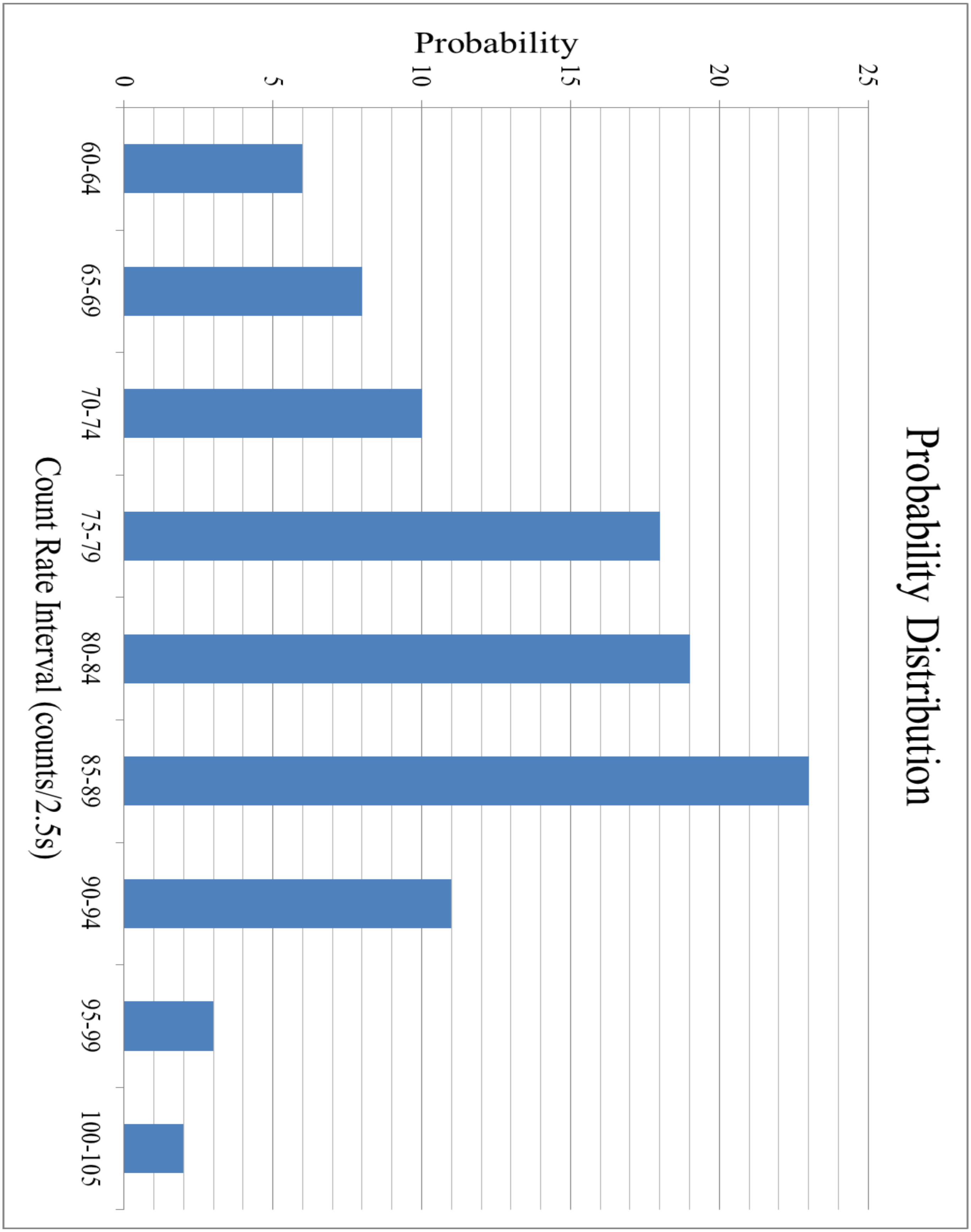
$$A = \sqrt{2\pi\sigma^2} = \sqrt{2\pi(8.996)^2} = 22.56$$

Count Rate Interval (counts/2.5s)	Probability (F_i)	$A_i = \frac{F_i \Delta n}{\sqrt{2\pi\sigma^2}}; \Delta n = 5$
60-64	6	1.330
65-69	8	1.774
70-74	10	2.217
75-79	18	3.991
80-84	19	4.213
85-89	23	5.100
90-94	11	2.439
95-99	3	0.665
100-105	2	0.443

$$A = \sum_i A_i = 22.17$$

or

$$A = \frac{F\Delta n}{\sqrt{2\pi\sigma^2}} = \frac{100 \times 5}{22.56} = 22.17$$


Probability Distribution
Probability
0
5
10
15
20
25
60-64
65-69
70-74
75-79
80-84
85-89
90-94
95-99
100-105
Count Rate Interval (counts/2.5s)

PART IV:

Source	Count Rate (counts/2.5s)	Count Rate (counts/s)
St-Co	43	17.2
St	82	32.8
Co	3	1.2

$R'_{12} = 17.0\ counts/s$

$R'_{1} = 32.8\ counts/s$

$R'_{2} = 1.2\ counts/s$

$$\tau_d = \frac{R'_1 + R'_2 - R'_{12}}{2R'_1 R'_2} = 0.0854s$$

– Results:

$R \approx 1.675\ g/cm^2$

$E_0 = 3.38 MeV$

$\mu_m = 0.00403\ cm^2/g$

$A_1 = 22.56$

$A_2 = 22.17$

$\tau_d = 0.0854 s$

– Discussion:

From PART I, the operation voltage in this experiment was 400V. G-M region about 300-400V. The count rate would increase as the voltage increase.

From PART II, the count rate would increase as the thickness of Aluminum sheets increase. The background intensity about 27 counts/120s, and after putting an 1675mg/cm^2 plate sheet the count rate reached 29 counts/120s. Therefore, the range value ≈ 1675 mg/cm^2 = 1.675 g/cm^2. Knowing this information, we can calculate the kinetic energy of β-particles by using Feather's formula $E_0 = 3.38 MeV$. From the graph ln(N) vs σ, the slope is the mass absorption coefficient which was $\mu_m = 0.00403\ cm^2/g$.

From PART III, the value of $A_1 = 22.56$, and from the data $A_2 = 22.17$. Both values are close to each other. Therefore, this result is accepted. The probability distribution curve tends to Gaussian distribution. Therefore, this result is accepted.

From PART IV, The dead time of G-M tube was $\tau_d = 0.0854s$. The radioactivity for $\left({}^{88}_{38}St\right)$ was $R_1' = 32.8\ counts/s$, but for $\left({}^{59}_{27}Co\right)$ was $R_2' = 1.2\ counts/s$. This means that $\left({}^{88}_{38}St\right)$ is more activity than $\left({}^{59}_{27}Co\right)$.

There are some random errors from the background confusion. Since count due to background = 27 counts/120s. Moreover, the random emission of β-particles can't be detected. There are some systematic errors from the equipment.

– References:

1. H. Abusara, & A. Shawabkeh (2016, November). *Laboratory Manual: Modern Physics Lab* (Second Edition). *Radioactivity* (pp. 59-72). Birzeit University: Faculty of Science.