Radiactive Decay Experiment

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***Abstract*—In this experiment we have measured time intervals and then calculated the half life of ^{220}Rn. We used Thorium salt to produce this element which appears during the decay process of ^{232}Th. The amount of decay is measured via taking the time intervals that electroscope discharges in between after reaching some specific charge state. We have calculated the half-life of the ^{220}Rn as 68.56s, compared to the true value 55.6s. Our result is 324.6 sigmas away from the theoretical value.**

I. Theory

In 1896, Henri Becquerel has been studying the properties of xrays which is discovered by Wilhelm Rontgen one year ago in 1895. The radiation coming from potassium uranyl sulfate is shown to be bent by the presence of a magnetic field which means that the radiation is charged so that it is different from xrays. However, different radioactive materials may emit radioation in a different manner: negative, neutral or positive. The term radioactivity was actually first coined by Marie Curie who studies on the subject Becquerel recently discovered. The so called alpha and beta particles, and gamma rays emerging in the radioactive decay of the particles were first named by Rutherford who has made great contributions to the discovery of the properties of radioactive decay. This classification is made according to their ability to penetrate. Alpha particles can interact with matter more easily than the other two.[1]

Radioactive decay is the emission of the energy in the form of ionizing radiation. As stated above, alpha or beta particles or gamma rays can be released during this process. The decay chain of Thorium(232) ends at ^{208}Pb because it is stable. Although there are also beta particles released in the decay process, the vast majority consists of alpha particles which are positively charged. Many of the elements in this chain do not have half-life values to be measured in an ordinary experimental set-up because some of them take years or months. For example, ^{228}Th has a lifetime of 1.9116 years, which not only makes it inefficient for such an experiment, this also helps us to ignore other elements' effect on the electroscope.[2]

Regardless of its type, all radioactive decays obey the same rule[3]:

$$N(t) = N_0 e^{-\gamma t} \tag{1}$$

where γ is the decay constant. N_0 is the initial number of unstable isotope of nuclei.

The half-life can be calculated by using the decay constant via the following formula:

$$t_{1/2} = \frac{ln2}{\gamma} \tag{2}$$

II. Method

In this experiement, we first release Thorium salt by squeezing into the tube where we apply high voltages. Eq(1) implies that number of unstable nuclei is going to decrease with time. Therefore, we conclude that there happens to be radioactive reactions giving rise to positively charged alpha particles which ionized the air. Due to the high voltages applied, this ionized air results in current. However, detecting this current is a hard job so we measured it indirectly by looking at the charge produced. Each time electroscope get some certain amount of charge, it touches the leg that discharges it immediately. The relation between this charge and current is the following:

$$Q = Is- > I \propto \frac{1}{s} \tag{3}$$

So by measuring the time intervals between the instant of the touch between the legs inside the electroscope enabled us to calculate the relationship. We used our computer to measure each successive discharge, which has the precision up to 0.001 seconds. On the other hand, the scientific studies investigating the human eye-hand reaction time indicates that a human's reaction time is approximately 0.2 to 0.3 seconds.[4] We take the long duration of the experiment and the fact that only one person measures each interval during our experiment into account, we increase this error to 0.5 seconds in our measurements of time for the analysis.

1) Torium salt is released
2) High voltage is applied
3) Alpha particles caused the air to ionize
4) Ionized air creates current
5) Accumulated charges causes electroscope to open
6) Electroscope discharges after a certain amount
7) time value is taken for each discharge

III. The Experimental Setup

The materials we used during the experiment are the following:

- Wulf's Electroscope
- HV Power Supply
- Thorium Salt
- Ionization Chamber
- Computer for measuring time differences

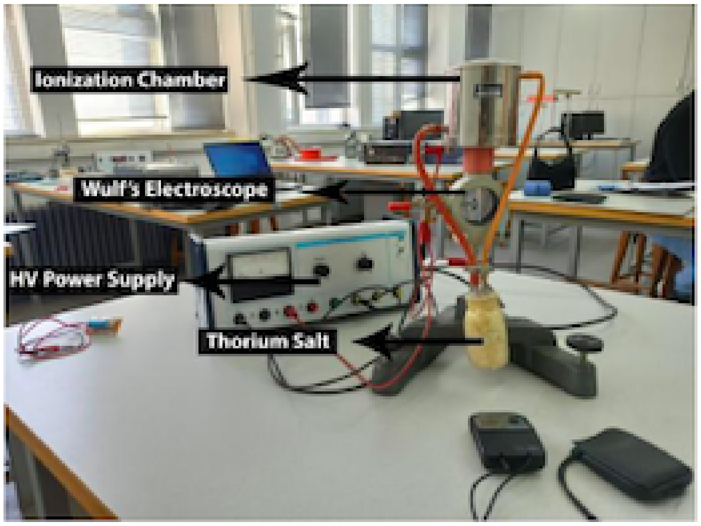

Fig. 1. apparatus

IV. The Data

TABLE I
TIME TABLE FOR 3.0 KV AND 2 SQUEEZES

Elapsed time (s)	
4.0	±0.5
8.0	±0.5
10.0	±0.5
14.0	±0.5
17.0	±0.5
20.0	±0.5
24.0	±0.5
28.0	±0.5
32.0	±0.5
35.0	±0.5
41.0	±0.5
44.0	±0.5
51.0	±0.5
55.0	±0.5
60.0	±0.5
68.0	±0.5
74.0	±0.5
81.0	±0.5
88.0	±0.5
98.0	±0.5
106.0	±0.5
119.0	±0.5
129.0	±0.5
148.0	±0.5
164.0	±0.5
185.0	±0.5
225.0	±0.5
270.0	±0.5
383.0	±0.5

TABLE II
TIME TABLE FOR 3.0 KV AND 3 SQUEEZES

Elapsed time (s)	
2.5	±0.5
4.5	±0.5
7.0	±0.5
9.5	±0.5
12.0	±0.5
15.5	±0.5
18.0	±0.5
21.5	±0.5
24.0	±0.5
28.5	±0.5
31.5	±0.5
35.0	±0.5
38.0	±0.5
43.0	±0.5
45.5	±0.5
52.0	±0.5
55.0	±0.5
61.5	±0.5
65.0	±0.5
72.5	±0.5
77.0	±0.5
83.5	±0.5
89.5	±0.5
98.5	±0.5
106.0	±0.5
116.5	±0.5
125.5	±0.5
139.0	±0.5
151.0	±0.5
165.5	±0.5
189.0	±0.5
217.0	±0.5
251.5	±0.5
337.0	±0.5

TABLE III
TIME TABLE FOR 3.0 KV AND 4 SQUEEZES

Elapsed time (s)	
3.0	±0.5
5.0	±0.5
8.0	±0.5
10.0	±0.5
12.0	±0.5
16.0	±0.5
18.0	±0.5
21.0	±0.5
23.0	±0.5
27.0	±0.5
30.0	±0.5
34.0	±0.5
37.0	±0.5
40.0	±0.5
45.0	±0.5
49.0	±0.5
53.0	±0.5
57.0	±0.5
63.0	±0.5
67.0	±0.5
73.0	±0.5
78.0	±0.5
85.0	±0.5
91.0	±0.5
99.0	±0.5
106.0	±0.5
116.0	±0.5
125.0	±0.5
139.0	±0.5
149.0	±0.5
164.0	±0.5
186.0	±0.5
212.0	±0.5
242.0	±0.5
321.0	±0.5

TABLE IV
TIME TABLE FOR 3.0 KV AND 5 SQUEEZES

Elapsed time (s)	
4.0	±0.5
6.0	±0.5
9.0	±0.5
12.0	±0.5
14.0	±0.5
18.0	±0.5
20.0	±0.5
23.0	±0.5
26.0	±0.5
29.0	±0.5
32.0	±0.5
37.0	±0.5
40.0	±0.5
44.0	±0.5
47.0	±0.5
53.0	±0.5
56.0	±0.5
63.0	±0.5
66.0	±0.5
73.0	±0.5
79.0	±0.5
84.0	±0.5
91.0	±0.5
107.0	±0.5
115.0	±0.5
127.0	±0.5
136.0	±0.5
156.0	±0.5
167.0	±0.5
190.0	±0.5
215.0	±0.5
256.0	±0.5
313.0	±0.5

TABLE V
TIME TABLE FOR 3.5 KV AND 3 SQUEEZES

Elapsed time (s)	
2.0	±0.5
5.0	±0.5
7.0	±0.5
9.0	±0.5
13.0	±0.5
16.0	±0.5
19.0	±0.5
22.0	±0.5
26.0	±0.5
29.0	±0.5
33.0	±0.5
37.0	±0.5
41.0	±0.5
45.0	±0.5
51.0	±0.5
54.0	±0.5
61.0	±0.5
66.0	±0.5
72.0	±0.5
79.0	±0.5
86.0	±0.5
92.0	±0.5
103.0	±0.5
109.0	±0.5
124.0	±0.5
130.0	±0.5
151.0	±0.5
159.0	±0.5
193.0	±0.5
208.0	±0.5
275.0	±0.5
312.0	±0.5

TABLE VI
TIME TABLE FOR 3.5 KV AND 4 SQUEEZES

Elapsed time (s)	
2.0	±0.5
6.0	±0.5
8.0	±0.5
11.0	±0.5
13.5	±0.5
16.5	±0.5
19.0	±0.5
22.5	±0.5
25.0	±0.5
29.5	±0.5
32.0	±0.5
36.0	±0.5
40.0	±0.5
44.0	±0.5
48.0	±0.5
53.0	±0.5
57.5	±0.5
62.5	±0.5
68.5	±0.5
73.5	±0.5
80.5	±0.5
85.0	±0.5
95.5	±0.5
102.0	±0.5
111.0	±0.5
119.5	±0.5
135.0	±0.5
146.5	±0.5
160.0	±0.5
186.5	±0.5
210.0	±0.5
249.5	±0.5
305.5	±0.5

TABLE VII
TIME TABLE FOR 3.5 KV AND 5 SQUEEZES

Elapsed time (s)	
3.5	±0.5
5.5	±0.5
8.0	±0.5
11.0	±0.5
13.0	±0.5
17.0	±0.5
19.0	±0.5
22.0	±0.5
25.0	±0.5
27.5	±0.5
32.0	±0.5
35.0	±0.5
38.5	±0.5
42.5	±0.5
47.0	±0.5
51.0	±0.5
55.0	±0.5
60.0	±0.5
65.0	±0.5
70.0	±0.5
76.5	±0.5
82.0	±0.5
87.5	±0.5
97.0	±0.5
103.5	±0.5
112.5	±0.5
122.0	±0.5
131.5	±0.5
146.0	±0.5
159.0	±0.5
181.5	±0.5
200.5	±0.5
224.0	±0.5
279.0	±0.5
327.0	±0.5

TABLE VIII
TIME TABLE FOR 4.0 KV AND 2 SQUEEZES

Elapsed time (s)	
13.0	±0.5
17.0	±0.5
20.0	±0.5
24.5	±0.5
28.0	±0.5
31.5	±0.5
36.5	±0.5
39.5	±0.5
46.0	±0.5
49.0	±0.5
54.5	±0.5
61.0	±0.5
66.5	±0.5
72.5	±0.5
81.5	±0.5
88.0	±0.5
95.0	±0.5
104.5	±0.5
107.0	±0.5
123.5	±0.5
136.0	±0.5
145.5	±0.5
164.5	±0.5
184.0	±0.5
197.5	±0.5
233.5	±0.5
258.0	±0.5
311.5	±0.5
413.5	±0.5

TABLE IX
TIME TABLE FOR 4.0 KV AND 3 SQUEEZES

Elapsed time (s)	
2.0	±0.5
4.5	±0.5
8.0	±0.5
11.5	±0.5
14.5	±0.5
17.5	±0.5
21.5	±0.5
25.0	±0.5
28.5	±0.5
33.0	±0.5
36.5	±0.5
41.5	±0.5
45.5	±0.5
50.5	±0.5
55.5	±0.5
61.0	±0.5
67.5	±0.5
73.5	±0.5
80.5	±0.5
89.5	±0.5
94.5	±0.5
107.0	±0.5
115.0	±0.5
130.5	±0.5
142.5	±0.5
161.0	±0.5
182.5	±0.5
215.0	±0.5
256.0	±0.5
353.5	±0.5

TABLE X
TIME TABLE FOR 4.0 KV AND 4 SQUEEZES

Elapsed time (s)	
2.5	±0.5
6.0	±0.5
9.0	±0.5
12.5	±0.5
14.5	±0.5
17.0	±0.5
20.5	±0.5
25.5	±0.5
30.0	±0.5
34.0	±0.5
39.0	±0.5
42.5	±0.5
47.5	±0.5
52.5	±0.5
58.5	±0.5
63.5	±0.5
69.5	±0.5
77.0	±0.5
85.0	±0.5
93.5	±0.5
102.5	±0.5
112.5	±0.5
124.5	±0.5
138.5	±0.5
157.5	±0.5
185.5	±0.5
218.5	±0.5
274.5	±0.5

TABLE XI
TIME TABLE FOR 4.0 KV AND 5 SQUEEZES

Elapsed time (s)	
2.5	±0.5
5.5	±0.5
7.5	±0.5
9.5	±0.5
13.0	±0.5
15.5	±0.5
19.5	±0.5
21.5	±0.5
24.5	±0.5
27.5	±0.5
31.0	±0.5
35.0	±0.5
38.0	±0.5
41.5	±0.5
46.5	±0.5
51.0	±0.5
57.0	±0.5
60.5	±0.5
65.0	±0.5
71.5	±0.5
78.0	±0.5
85.0	±0.5
89.0	±0.5
104.0	±0.5
108.5	±0.5
115.0	±0.5
126.0	±0.5
135.5	±0.5
148.0	±0.5
163.0	±0.5
174.5	±0.5
189.5	±0.5
219.0	±0.5
253.5	±0.5
310.5	±0.5
383.5	±0.5

TABLE XII
TIME TABLE FOR 4.5 KV AND 2 SQUEEZES

Elapsed time (s)	
5.0	±0.5
7.5	±0.5
10.0	±0.5
13.5	±0.5
16.5	±0.5
19.0	±0.5
23.0	±0.5
26.5	±0.5
30.0	±0.5
33.0	±0.5
37.5	±0.5
42.5	±0.5
51.0	±0.5
54.5	±0.5
61.5	±0.5
67.0	±0.5
74.5	±0.5
80.0	±0.5
87.5	±0.5
94.0	±0.5
101.5	±0.5
113.5	±0.5
122.0	±0.5
135.5	±0.5
149.0	±0.5
168.0	±0.5
189.0	±0.5
228.5	±0.5
277.0	±0.5
383.0	±0.5

TABLE XIII
TIME TABLE FOR 4.5 KV AND 3 SQUEEZES

Elapsed time (s)	
2.0	±0.5
3.5	±0.5
6.0	±0.5
8.5	±0.5
11.0	±0.5
13.5	±0.5
16.0	±0.5
19.0	±0.5
21.5	±0.5
25.5	±0.5
28.0	±0.5
31.5	±0.5
34.5	±0.5
38.5	±0.5
42.5	±0.5
45.5	±0.5
50.5	±0.5
54.5	±0.5
59.0	±0.5
64.0	±0.5
69.0	±0.5
73.5	±0.5
81.5	±0.5
87.0	±0.5
95.5	±0.5
101.5	±0.5
110.5	±0.5
119.0	±0.5
132.5	±0.5
143.5	±0.5
158.5	±0.5
174.0	±0.5
198.0	±0.5
229.5	±0.5
275.0	±0.5
368.5	±0.5

TABLE XIV
TIME TABLE FOR 4.5 KV AND 4 SQUEEZES

Elapsed time (s)	
3.5	±0.5
6.0	±0.5
9.5	±0.5
12.5	±0.5
16.0	±0.5
18.0	±0.5
22.5	±0.5
24.0	±0.5
29.5	±0.5
37.5	±0.5
46.5	±0.5
49.0	±0.5
56.5	±0.5
59.5	±0.5
68.0	±0.5
72.0	±0.5
81.5	±0.5
85.5	±0.5
96.5	±0.5
102.0	±0.5
118.0	±0.5
126.0	±0.5
141.0	±0.5
156.5	±0.5
177.5	±0.5
197.5	±0.5
237.0	±0.5
295.5	±0.5
320.0	±0.5

TABLE XV
TIME TABLE FOR 4.5 KV AND 5 SQUEEZES

Elapsed time (s)	
3.5	±0.5
5.5	±0.5
8.5	±0.5
10.5	±0.5
13.5	±0.5
15.5	±0.5
19.0	±0.5
21.5	±0.5
24.0	±0.5
27.5	±0.5
30.5	±0.5
34.0	±0.5
37.5	±0.5
41.5	±0.5
44.5	±0.5
49.0	±0.5
53.0	±0.5
57.5	±0.5
61.0	±0.5
68.0	±0.5
71.5	±0.5
78.5	±0.5
83.5	±0.5
90.5	±0.5
97.5	±0.5
105.5	±0.5
114.0	±0.5
122.5	±0.5
135.0	±0.5
146.5	±0.5
162.5	±0.5
178.5	±0.5
204.0	±0.5
235.0	±0.5
288.0	±0.5
392.0	±0.5

V. THE ANALYSIS

For different applied high voltages inside the tube and different number of the squeezes, we have calculated the decay constant for each case. Here our decay constant values for each measurement:

TABLE XVI
TIME TABLE FOR 3.0 KV AND 2 SQUEEZES

Decay Constant	Volt(V)	Squeezes
0.01010±7.9 x 10^-5	3000±100	2
0.01173±9.9 x 10^-5	3000±100	3
0.0125± 1. x 10^-5	3000±100	4
0.0086± 1.3 x 10^-4	3000±100	5
0.0110± 2. x 10^-4	3500±100	3
0.00969± 1.5 x 10^-4	3500±100	4
0.00988± 1.8 x 10^-4	3500±100	5
0.00831± 7.1 x 10^-5	4000±100	2
0.01103± 9. x 10^-5	4000±100	3
0.01158± 2. x 10^-5	4000±100	4
0.00759± 1.1 x 10^-5	4000±100	5
0.00976± 8.3 x 10^-5	4500±100	2
0.01065± 9.2 x 10^-5	4500±100	3
0.00914± 1.2 x 10^-5	4500±100	4
0.01015± 8.6 x 10^-5	4500±100	5

we have found the weighted means of the decay constant as 0.01011 ± 5.89 x 10^-6. The half life of the ^{220}Rn is calculated as follows:

$$t_{1/2} = \frac{ln2}{0.01011} = 68.56 \quad (4)$$

the standard deviation of the half life is given by: $\Delta T_{1/2} = \left| -\frac{\ln(2)}{\lambda^2} \right| \cdot \Delta\lambda = 0.0399$
here are the plots and fits for each voltage and squeeze values

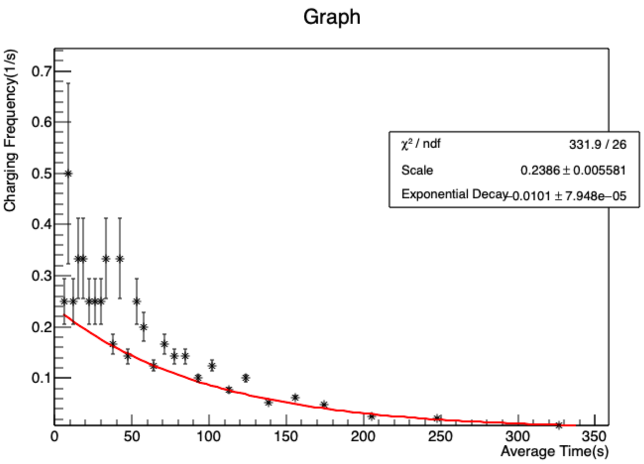

Fig. 2. 3000 volt and 2 squeezes

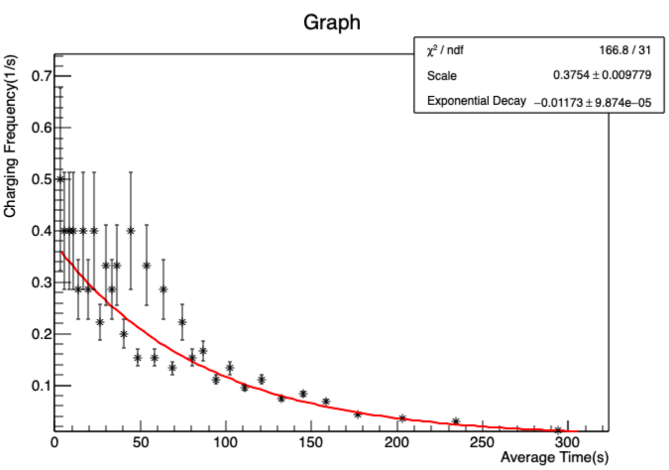

Fig. 3. 3000 volt and 3 squeezes

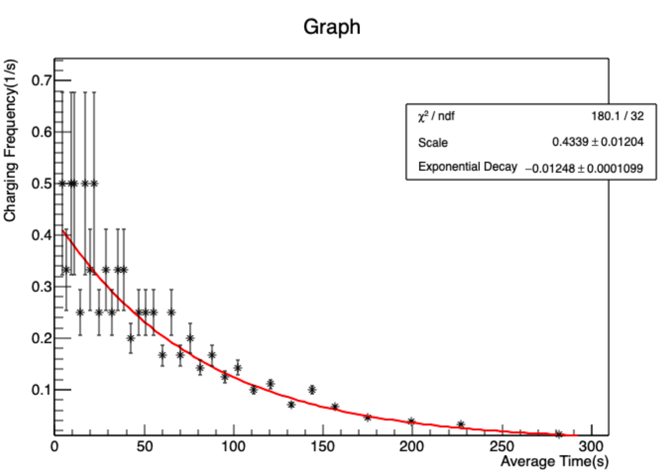

Fig. 4. 3000 volt and 4 squeezes

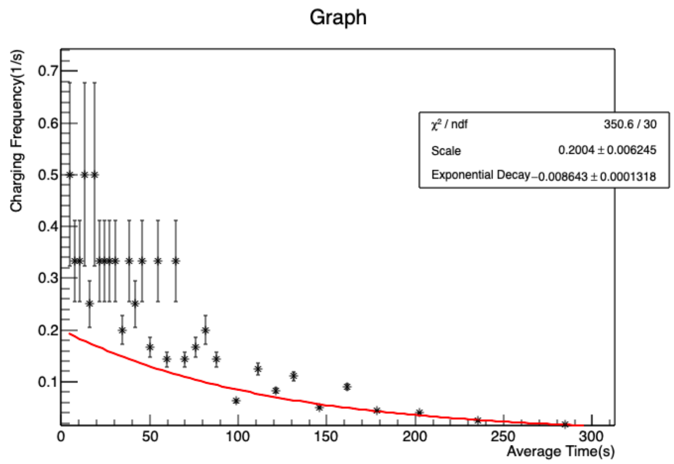

Fig. 5. 3000 volt and 5 squeezes

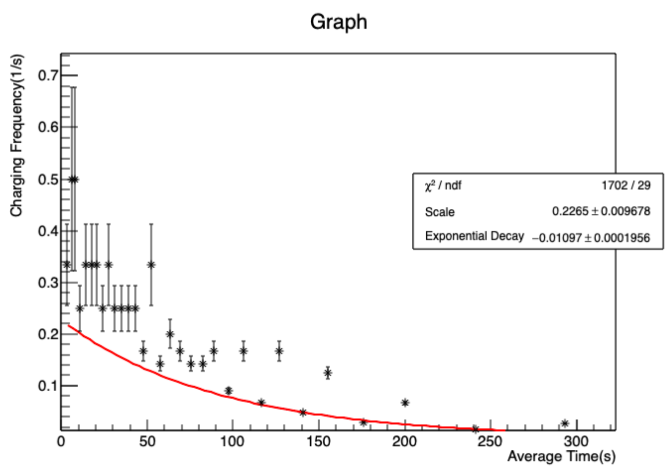

Fig. 6. 3500 volt and 3 squeezes

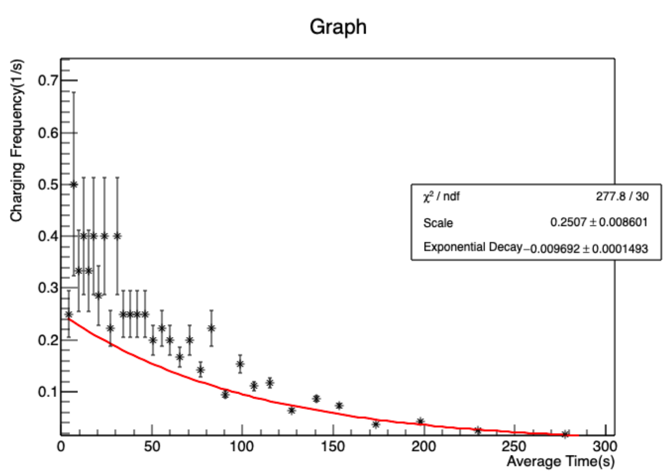

Fig. 7. 3500 volt and 4 squeezes

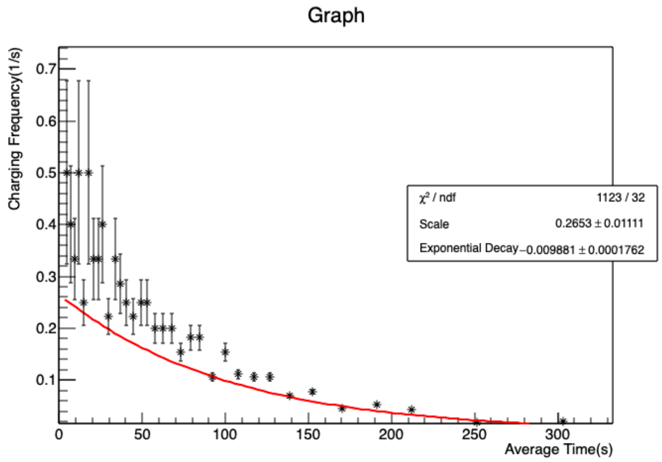

Fig. 8. 3500 volt and 5 squeezes

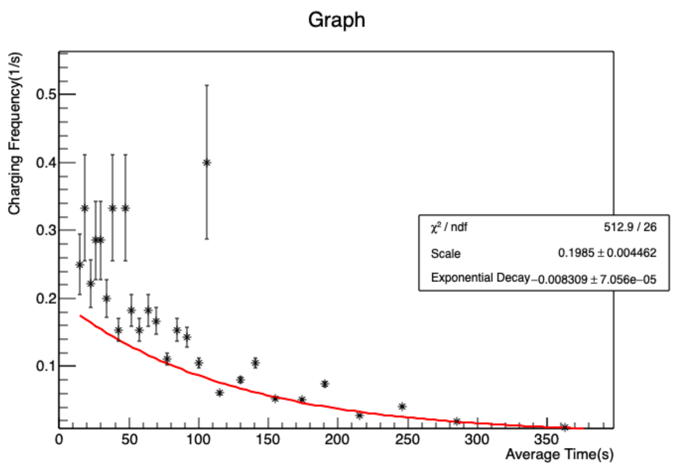

Fig. 9. 4000 volt and 2 squeezes

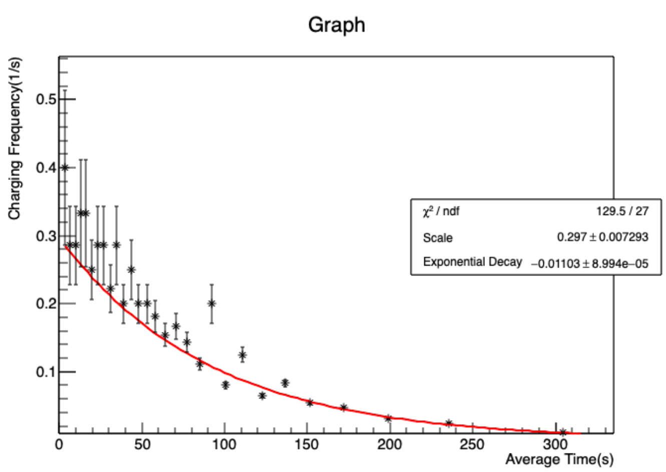

Fig. 10. 4000 volt and 3 squeezes

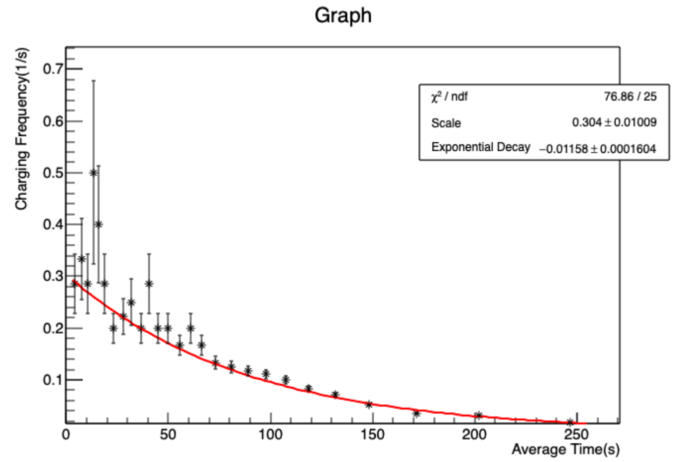

Fig. 11. 4000 volt and 4 squeezes

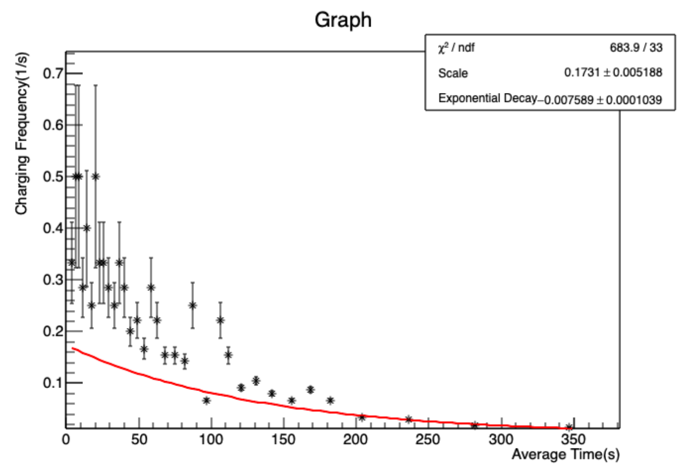

Fig. 12. 4000 volt and 5 squeezes

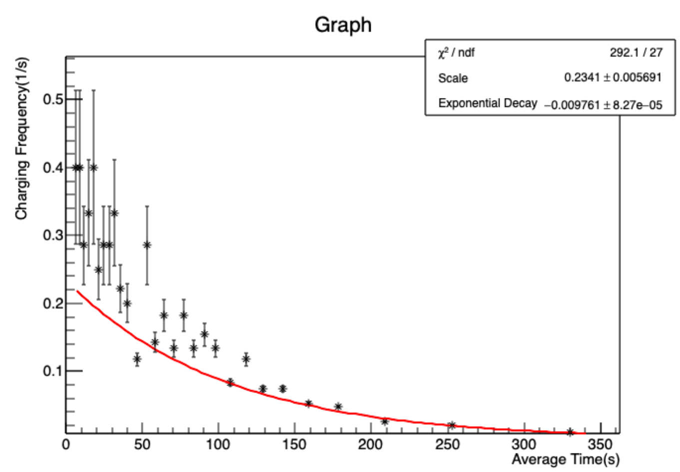

Fig. 13. 4500 volt and 2 squeezes

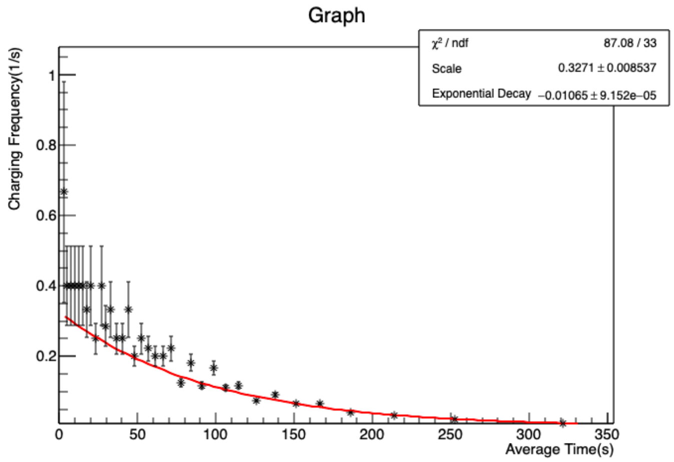

Fig. 14. 4500 volt and 3 squeezes

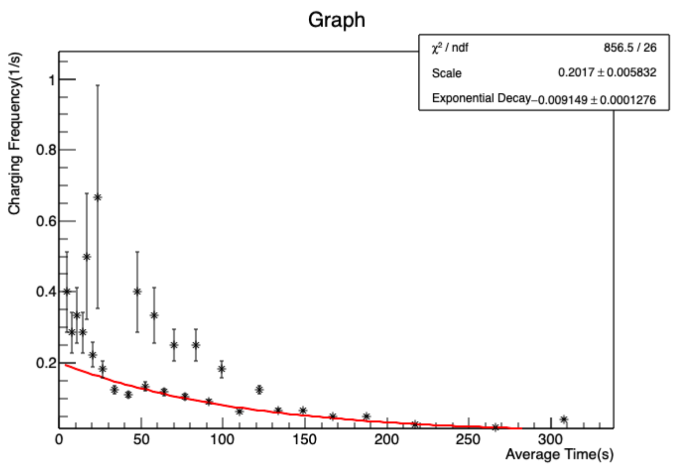

Fig. 15. 4500 volt and 4 squeezes

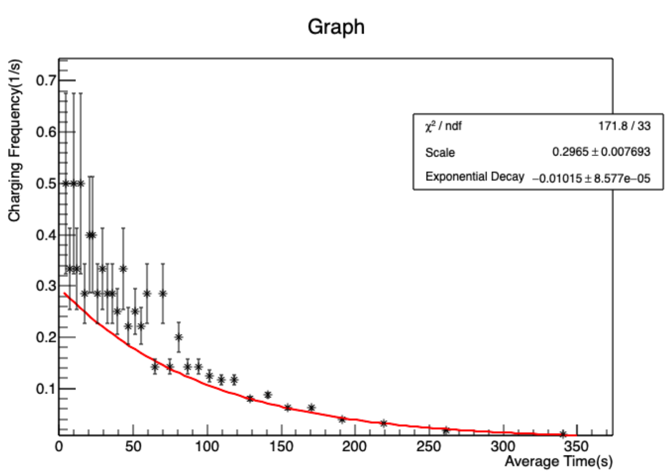

Fig. 16. 4500 volt and 5 squeezes

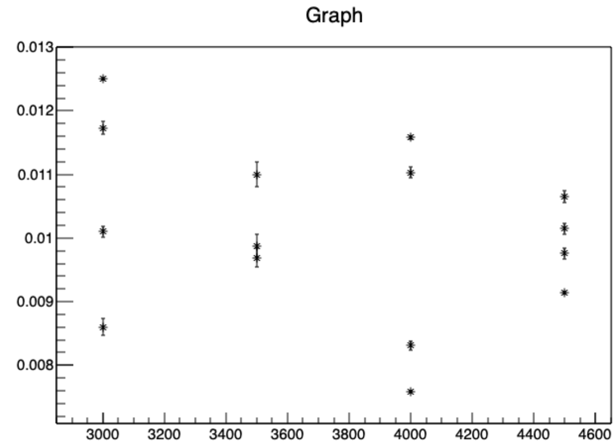

Fig. 17. decay constants vs voltages

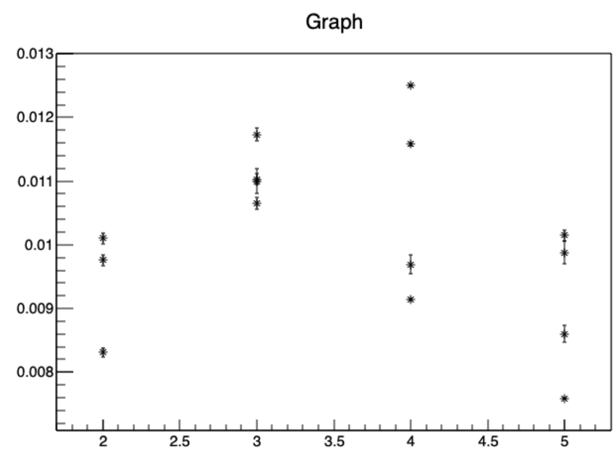

Fig. 18. decas constants vs squeezes

VI. The Result

We have founded the half life of ^{220}Rn to be 68.56 $\pm$ 0.0399 which is 324.6 σ's away from the true value of 55.6 seconds. It seems like our experiment is a failure.

VII. The Conclusion

Our final value for the half-life is far away from the theoretical value that we should be close to. What is more, the error seems to be bigger when we regard our uncertainties. One of the problems is that due to long duration of the experiment, we decided to have a bigger uncertainty for time measurements. In some measurements, we were not able to get the final data that is higher than 60 seconds, which directly affects our fits in a radical way because we made an exponential fit for our data and the last time measurement that we were supposed to take was not there. Finally, there were some problems regarding the equipment such as sometimes electroscope oscillates in a way that it is not possible to take any value when we applied a high voltage. We may sometimes fail to ensure that the gas in the tube was fully gone because of the time limitation. Overall, we tried to take our data as clearly and consistently as possible but the result was not satisfactory at all.

VIII. Acknowledgement

Optional part that you may use to thank anyone who has contributed.

References

[1] *history*. URL: https://www2.lbl.gov/abc/wallchart/chapters/03/4.html (visited on 04/05/2024).

[2] *Thorium Decay Chain*. URL: https://en.wikipedia.org/wiki/Thorium-232 (visited on 04/05/2024).

[3] E. Gülmez. *Advanced Physics Experiments*. 1st. Boğaziçi University Publications, 1999.

[4] *reaction*. URL: https://link.springer.com/article/10.1007/BF00355600 (visited on 04/05/2024).

IX. Appendix

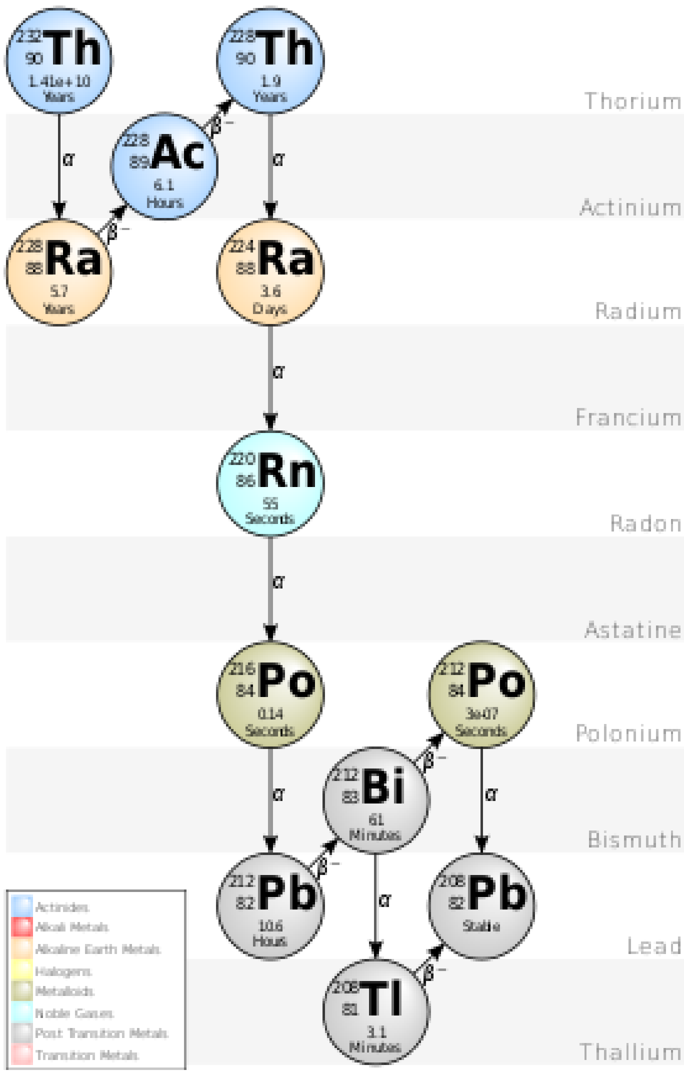

Fig. 19. [2]

We used roo built-in function to get an exponential fit. I have written only for 3.0 kv and 2 squeezes plot's code and squeezes vs decay constants' code because all the other plots were obtained by exactly the same code, the only difference was that I changed the initial arrays that include the data we take. Therefore, I gave only those two in the appendix so that if one is to test them, s/he is going to be able to replicate all the other by simply replacing the initial array with the other data sets that are given in the table in the data section.

```
{
   gStyle->SetOptFit(1);
   const int ndata = 29;
   float times[ndata] = {4.0, 8.0, 10.0, 14.0,
       17.0, 20.0, 24.0, 28.0, 32.0, 35.0,
       41.0, 44.0, 51.0, 55.0, 60.0, 68.0,
       74.0, 81.0, 88.0, 98.0, 106.0, 119.0,
       129.0, 148.0, 164.0, 185.0, 225.0,
       270.0, 383.0};



   x= new float[ndata - 1];
   y = new float[ndata - 1];
   sx = new float[ndata - 1];
   sy = new float [ndata -1];

   float del_time = 0.5;
   for (int i=0; i<ndata - 1; ++i){
      x[i] = (times[i+1]+times[i])/2;
      y[i] = 1/(times[i+1]-times[i]);
      sx[i] = sqrt(2*((1/4)*(1/4)));
      sy[i] =
          y[i]*y[i]*sqrt(2*(del_time*del_time));
   }

   TGraphErrors *mygraph = new
       TGraphErrors(ndata-1,x,y,sx,sy);
   mygraph->Draw("A*");

   mygraph->GetXaxis()->SetTitle("Average
       Time(s)");
   mygraph->GetYaxis()->SetTitle("Charging
       Frequency(1/s)");


   TF1 *expo_fit = new
       TF1("expo_fit","[0]*exp([1]*x)",4,400);
   float par_0 = 0.2;
   float par_1 = -TMath::Log(2)/55;
   expo_fit->SetParameters(par_0,par_1);
   expo_fit->SetParNames("Scale","Exponential
       Decay");
   expo_fit->SetLineColor(kRed);
   expo_fit->SetLineWidth(2);
   mygraph->Fit("expo_fit","R");
   double lambda_error =
       expo_fit->GetParError(1);
   double scale = expo_fit->GetParameter(0);
   double lambda = expo_fit->GetParameter(1);
   cout << "Scale = " << scale << "\n";
   cout << "Lambda = "<< lambda <<"+-" <<
       lambda_error <<"\n";
}


{
   gStyle->SetOptFit(1);
   const int ndata = 15;
   float squeezes[ndata] =
```

```
    {2,3,4,5,3,4,5,2,3,4,5,2,3,4,5};
  float decayconstant[ndata] =
    {0.0101,0.01173,0.0125,0.0086,0.011,0.00969,0.00988,0.00831,0.01103,0.01158,0.00759,0.00976,0.0106
  float sigmas[ndata] =
    {7.9e-05,9.9e-05,1.0e-05,1.3e-04,2.0e-04,1.5e-04,1.8e-04,7.1e-05,9.0e-05,2.0e-05,1.1e-05,8.3e-05,9


  x= new float[ndata];
  y = new float[ndata];
  sy = new float [ndata];

  for (int i=0; i<ndata; ++i){
    x[i] = squeezes[i];
    y[i] = decayconstant[i];
    sy[i] = sigmas[i];

  }
  TGraphErrors *mygraph = new
    TGraphErrors(ndata,x,y,0,sy);
  mygraph->Draw("A*");




}
```