Experiment 7, Radioactive Decay

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Abstract

In this experiment we found the half life of ^{220}Rn gas via observing the decay of ^{232}Th salt. Decaying of elements is an exponential process . By using this information, we found the half life of the ^{220}Rn from the decaying constant λ.

Theory

Unstable or stable atoms lose energy by emitting γ, α, β and other types of rays in a random process. Stable atoms are atoms that have half life longer than 10 years. Although we may never know when an atom will decay, we can know when high number of atoms will decay to half of its previous quantity. The term half life is meaningful only when we have high number of atoms at hand. Decaying process is, as said earlier in the abstract, an exponential process:

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

Where N_0 is the initial number of atoms in consideration, N(t) is the number of isotops ,^{220}Rn in this case, left at time t. λ is the decaying constant and it is different for different isotops and atoms.

From this relation we can find the half life $t_{\frac{1}{2}}$:

$$\frac{N_0}{2} = N_0.e^{-\lambda t_{\frac{1}{2}}} \tag{2}$$

$$\frac{1}{2} = e^{-\lambda t_{\frac{1}{2}}} \tag{3}$$

$$ln\frac{1}{2} = -\lambda.t_{\frac{1}{2}} \tag{4}$$

$$\frac{ln2}{\lambda} = t_{\frac{1}{2}} \tag{5}$$

To find $t_{\frac{1}{2}}$ all we need to do is to find λ. To find λ,we use Wulf's electroscope. Wulf's electroscope is an intsrument that discharges when it reaches certain and amount of charge and that amount is the same in every discharge (constant Q needed). Then from the relation between the current and the charge ($I = \frac{dq}{dt} = \frac{Q}{s}$) we know that the current is inversely proportional to the elapsed time between the discharges:

$$I \propto \frac{1}{s} \tag{6}$$

where $s = t_{i+1} - t_i$ and t_is are the times we observe discharges.

To find the relation between I and N(t) we look at the derivative of N with respect to t:

$$\frac{dN}{dt} = -\lambda N_0 e^{-\lambda t} = -\lambda N(t) \tag{7}$$

Then $I \propto \frac{dN}{dt} \propto N \propto \frac{1}{s}$ and we find:

$$ln(\frac{1}{s}) = ln(\frac{1}{s_0}) - \lambda.t \tag{8}$$

$$ln(s) = ln(s_0) + \lambda.t \tag{9}$$

So the slope of the t versus ln(s) graph will give us the desired λ!

Other relations that will be useful later in the analysis:

Weighted aritmetic mean:

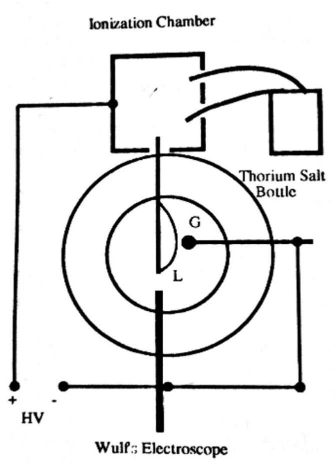
$$\lambda_{wave} = \frac{\sum_i w_i \lambda_i}{\sum_i w_i} \tag{10}$$

where $w_i = \frac{1}{\sigma_i^2}$

Error propagation:

$$\sigma_f = \sqrt{\sum_i^n \left(\frac{\partial f}{\partial x_i}\right)^2 \sigma_{x_i}^2 + \dots} \tag{11}$$

Experimental Procedure and Apparatus



Apparatus	Description
Wulf's Electroscope	Discharges after getting hit so many times by ionized atoms/rays. The amount of charge needed for a discharge is constant.
Thorium Salt	Decays to Radon gas that is pumped into the ionization chamber
Ionization Chamber	Ionizes the gas inside via high voltage so decaying rays hit the Wulf's electroscope
HV Power Supply	Used to give high voltages to ionization chamber.
Stopwatch	Used to measure the time of discharges.

The experimental procedure as follows:

After the circuit is connected like the figure above, we connect the pump consisting thorium salt to the ionization chamber and open the valve on the pump.

We open the HV power supply and set the value voltage to 2500V. We squeeze the gas in the pump consisting the thorium salt 5 times and start our stopwatch. We record the time of the every discharge until we observe couple of discharges. After these, we empty the Radon gas in the ionization chamber and repeat the procedure for 10 and 15 squeezes.

We repeat the same procedure for 3000V,3500V,4000V and 4500V.

Data

$t_{discharge\ number}$ (seconds)	time for 5 squeezes	time for 10 squeezes	time for 15 squeezes
t_1	11.46	9.03	8.38
t_2	27.89	22.81	22.55
t_3	47.94	39.44	39.71
t_4	77.14	60.54	61.42
t_5	122.12	89.69	90.89
t_6	227.67	137.69	138.69

Figure 1: Data for 2500V

$t_{discharge\ number}$ (seconds)	time for 5 squeezes	time for 10 squeezes	time for 15 squeezes
t_1	1.85	1.51	5.23
t_2	16.54	13.10	17.84
t_3	35.02	27.78	33.86
t_4	60.53	45.14	53.30
t_5	97.62	66.20	81.39
t_6	166.86	95.03	122.68
t_7	-	-	208.89

Figure 2: Data for 3000V

$t_{discharge\ number}$ (seconds)	time for 5 squeezes	time for 10 squeezes	time for 15 squeezes
t_1	5.83	10.48	6.28
t_2	20.62	24.45	25.82
t_3	38.93	41.18	52.94
t_4	62.45	62.80	95.58
t_5	97.21	92.48	174.24
t_6	158.92	139.24	-

Figure 3: Data for 3500V

$t_{discharge\ number}$ (seconds)	time for 5 squeezes	time for 10 squeezes	time for 15 squeezes
t_1	8.55	18.28	10.77
t_2	23.13	45.05	24.09
t_3	40.32	87.10	41.95
t_4	62.01	180.22	65.59
t_5	92.46	-	101.10
t_6	141.94	-	170.02

Figure 4: Data for 4000V

$t_{discharge\ number}$ (seconds)	time for 5 squeezes	time for 10 squeezes	time for 15 squeezes
t_1	8.61	2.89	13.41
t_2	22.21	18.86	29.91
t_3	40.75	39.80	50.07
t_4	65.14	62.95	77.15
t_5	99.25	98.29	117.72
t_6	157.75	164.00	204.43

Figure 5: Data for 4500V

Error for every data point is 0.10 second! This is our observational limit.

Analysis

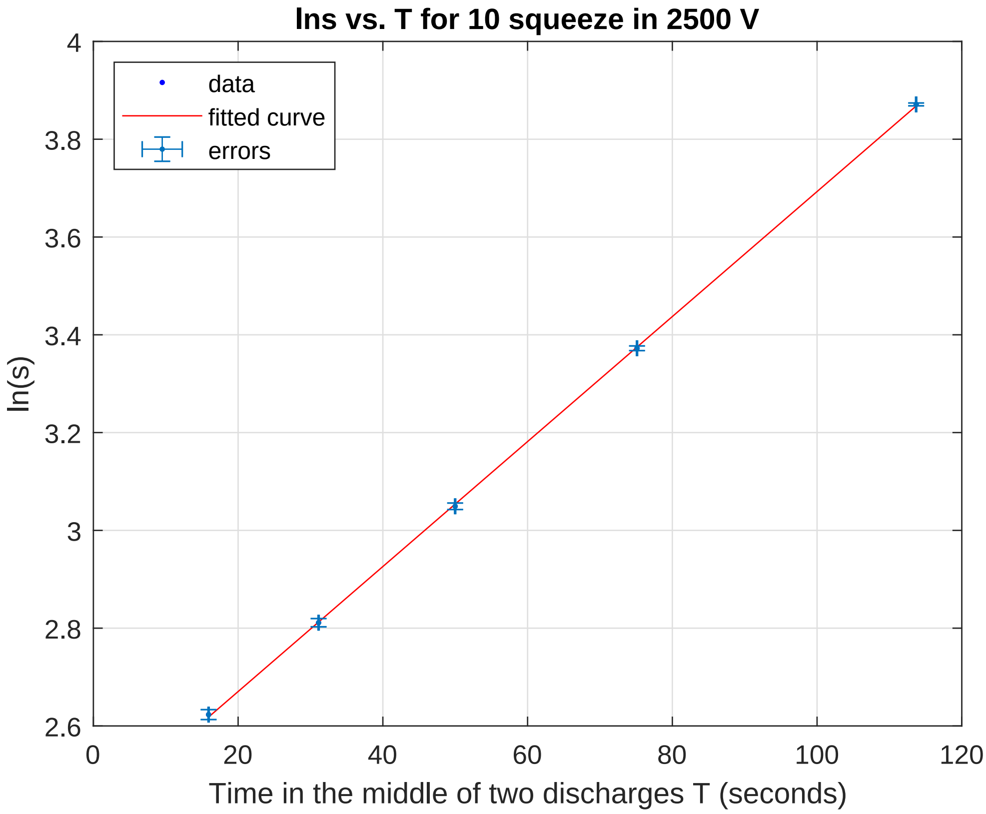


Figure 6: R-square: 0.9999. I use R square instead of chi square because matlab is causing problems in chi-square calculations.As R square gets closer to 1, better the fit. Here, the fit is almost perfect! Also $T = \frac{t_i + t_{i+1}}{2}$

Since errors are too small, error bars seem too small, especially for the horizontal bars!

From the slope of this curve we found : $\lambda_2 = 0.01278 \mp 0.00095$ (1/sec)

Other curves are not graphed but their slopes are given below.
Slope of the 5 squeeze in 2500V: $\lambda_1 = 0.01204 \mp 0.00105$ (1/sec)
Slope of the 15 squeeze in 2500V: $\lambda_3 = 0.01221 \mp 0.00010$ (1/sec)

Slope of the 5 squeeze in 3000V: $\lambda_4 = 0.01255 \mp 0.00054$ (1/sec)
Slope of the 10 squeeze in 3000V: $\lambda_5 = 0.01605 \mp 0.00172$ (1/sec)
Slope of the 15 squeeze in 3000V: $\lambda_6 = 0.01235 \mp 0.00049$ (1/sec)

Slope of the 5 squeeze in 3500V:$\lambda_7 = 0.01247 \mp 0.00023$ (1/sec)
Slope of the 10 squeeze in 3500V:$\lambda_8 = 0.01234 \mp 0.00022$ (1/sec)
Slope of the 15 squeeze in 3500V: $\lambda_9 = 0.01163 \mp 0.00139$ (1/sec)

Slope of the 5 squeeze in 4000V:$\lambda_{10} = 0.01219 \mp 0.00031$ (1/sec)
Slope of the 10 squeeze in 4000V:$\lambda_{11} = 0.01216 \mp 0.00215$ (1/sec)
Slope of the 15 squeeze in 4000V:$\lambda_{12} = 0.01369 \mp 0.00072$ (1/sec)

Slope of the 5 squeeze in 4500V:$\lambda_{13} = 0.01254 \mp 0.00098$ (1/sec)
Slope of the 10 squeeze in 4500V:$\lambda_{14} = 0.01162 \mp 0.00112$ (1/sec)
Slope of the 15 squeeze in 4500V:$\lambda_{15} = 0.01196 \mp 0.00012$ (1/sec)

From these λs we find $\lambda_{w.ave} = 0.0122 \mp 0.0001$ (1/sec)

As said earlier, once we know λ we can find $t_{\frac{1}{2}}$ and by using error propagation we can find its error:

$$t_{\frac{1}{2}} = \frac{ln(2)}{\lambda_{w.ave}} \tag{12}$$

$$t_{\frac{1}{2}} = 56.8 \mp 0.5 sec \tag{13}$$

Conclusion

The real value for half life of radon gas is given to us as 55.6 seconds. Our experimental value is 56.8 seconds and our value is 2.4σ away from the real value. I think being 2.4σ away from the real value is acceptable considering the errors. First of all we should look at the errors caused by us. we might not have squeezed the pump equally in all squeezes. We cannot observe times lower than tenth of a second and we might not observe everything in the edge of our observational limits, thus possibly causing the error to be higher. We might not have emptied the chamber as well etc. Also there are systematic errors. Voltage supply may not work perfectly at all times, Wulf's electroscope is very sensitive and can be charged from rays coming from the space. The list goes on. Maybe we can take data in longer time intervals to reduce errors.

We have seen that half life is independent of number of squeezes and the given voltage since we see that almost all of the λs are very close to each other. This is obviously very reasonable result because we know that the half life of an atom is dependent on the characteristics of the atom not to the environmental effects.

I have used matlab for data analysis and Latex for writing the report. My code and latex files are in the following link:

https://github.com/OnuraySancar/phys442-radioactive.git

References

Advanced Physics Experiments - Gulmez, Prof. Dr. Erhan

Basic Data Analysis for Experiments in the Physical Sciences - Erhan Gulmez

http://www.wikizeroo.net/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUmFkaW9hY3RpdmVfZGVjYXk