

Radioactive Decay

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A radioactive species is often characterized by its half-life $t_{\frac{1}{2}}$, which is defined as the time it takes for one-half of the nuclei to decay. In this experiment, we are going to calculate half-life of Radon gas.

1. INTRODUCTION

The rate at which a particular radioactive material disintegrates in a given time interval is called the decay constant λ . The decay constant is characteristic of the particular nuclear species and is independent of all external physical and chemical conditions. Radioactive decay is a statistical process as one cannot predict when any individual nucleus will decay. The most that one can know is that the probability that a nucleus will decay in a small time interval dt is λdt .

When a large number of nuclei of a single species are studied, statistics can be used to make definite predictions about the average number of decays that occur in a small time interval. Let $N(t)$ be the total number of undecayed nuclei at time t . If one studied many identically prepared samples, the average number of decays that occur every second $\frac{dN}{dt}$ is given by

$$\frac{dN}{dt} = -\lambda N(t)$$

This can be integrated to give the number of undecayed nuclei at time t

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

Here N_0 is the number of nuclei present at $t = 0$.

Using the equation for $N(t)$ we see that $t_{\frac{1}{2}}$ satisfies

$$\frac{N}{N_0} = \frac{1}{2} = e^{-\lambda t_{\frac{1}{2}}} \implies t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

2. EXPERIMENTAL SETUP

- Wulf's Electroscope
- Thorium Salt
- Ionization Chamber
- HV Power Supply (0-5 kV)
- Stopwatch

3. DATA AND ANALYSIS

In data analysis part, we have S_i and T_i values by using discharge time t_i where:

$$S_i = t_{i+1} - t_i$$

$$T_i = \frac{t_{i+1} + t_i}{2}$$

Squeeze Number	S_i	T_i
6	17.0 sec	8.5 sec
6	34.0 sec	34.0 sec
6	60.0 sec	81.0 sec
8	25.0 sec	12.5 sec
8	47.0 sec	53.5 sec
10	21.0 sec	10.5 sec
10	40.0 sec	42.0 sec
10	87.0 sec	104.5 sec
11	22.0 sec	11.0 sec
11	44.0 sec	44.0 sec
11	84.0 sec	98.0 sec

TABLE I: Values for Voltage 2500 V

Squeeze Number	S_i	T_i
6	10.0 sec	5.0 sec
6	37.0 sec	18.5 sec
6	69.0 sec	81.5 sec
8	20.0 sec	10.0 sec
8	53.0 sec	46.5 sec
8	170.0 sec	158.0 sec
10	13.0 sec	6.5 sec
10	84.0 sec	55.0 sec
10	177.0 sec	185.5 sec
11	11.0 sec	5.5 sec
11	41.0 sec	31.5 sec
11	153.0 sec	128.5 sec

TABLE II: Values for Voltage 3000 V

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Squeeze Number	S_i	T_i
6	5.0 sec	2.5 sec
6	39.0 sec	19.5 sec
6	83.0 sec	85.5 sec
8	12.0 sec	6.0 sec
8	37.0 sec	30.5 sec
8	125.0 sec	112.5 sec
10	6.0 sec	3.0 sec
10	34.0 sec	23.0 sec
10	67.0 sec	73.5 sec
11	4.0 sec	2.0 sec
11	43.0 sec	18.5 sec
11	116.0 sec	81.0 sec

TABLE III: Values for Voltage 3500 V

Squeeze Number	S_i	T_i
6	31.0 sec	16.5 sec
6	61.0 sec	61.5 sec
8	19.0 sec	8.5 sec
8	44.0 sec	41.0 sec
8	106.0 sec	116.0 sec
10	24.0 sec	12.0sec
10	45.0 sec	46.5 sec
10	106.0 sec	122.0 sec
11	15.0 sec	7.5 sec
11	32.0 sec	31.0 sec
11	54.0 sec	74.0 sec

TABLE IV: Values for Voltage 4000 V

And bu using linear fitting for specific voltage and squeeze number, we will have 20 λ and σ_λ . Fitting to

$$\ln S = \ln S_0 + \lambda T$$

where $y = \ln S$ and error propagation for $\sigma_{\ln S}$

$$\sigma_y^2 = \sigma_{\ln S}^2 = \left(\frac{d}{dS} (\ln S) \right)^2 \sigma_S^2 = \frac{2}{S^2}$$

where $\sigma_S = \sqrt{2}$.

After fitting, we have 20 λ and 20 σ_λ . By using these values, weighed values and errors can be calculated as:

$$\lambda_w = \frac{\sum_{i=1}^{20} \frac{\lambda_i}{\sigma_i^2}}{\sum_{i=1}^{20} \frac{1}{\sigma_i^2}}$$

Squeeze Number	S_i	T_i
6	10.0 sec	5.0 sec
6	37.0 sec	18.5 sec
6	117.0 sec	82.0 sec
8	15.0 sec	7.5 sec
8	37.0 sec	36.5 sec
8	97.0 sec	106.5 sec
10	8.0 sec	4.0 sec
10	32.0 sec	24.0 sec
10	52.0 sec	66.0 sec
10	192.0 sec	188.0 sec
11	12.0 sec	6.0 sec
11	34.0 sec	29.0 sec
11	67.0 sec	79.5 sec

TABLE V: Values for Voltage 4500 V

Voltage	Squeeze Number	λ	σ_λ
2500 V	6	0.014	0.00082
3000 V	6	0.011	0.00066
3500 V	6	0.012	0.0006
4000 V	6	0.015	0.00114
4500 V	6	0.019	0.0006
2500 V	8	0.015	0.00156
3000 V	8	0.011	0.00023
3500 V	8	0.012	0.00034
4000 V	8	0.013	0.0004
4500 V	8	0.015	0.00051
2500 V	10	0.014	0.0005
3000 V	10	0.006	0.00014
3500 V	10	0.015	0.0009
4000 V	10	0.012	0.00036
4500 V	10	0.011	0.00018
2500 V	11	0.013	0.00053
3000 V	11	0.016	0.00035
3500 V	11	0.014	0.00056
4000 V	11	0.015	0.00099
4500 V	11	0.016	0.00083

TABLE VI: Fitted λ values where $\sigma_\lambda = \sigma_{a_1}$

and

$$\sigma_{\lambda_w}^2 = \frac{1}{\sum_{i=1}^{20} \frac{1}{\sigma_i^2}}$$

From weighted values of λ , we can measure $t_{\frac{1}{2}}$:

$$t_{\frac{1}{2}} \longrightarrow t_{\frac{1}{2}} = \frac{\ln 2}{\lambda_w}$$

and error of $t_{\frac{1}{2}}$:

$$\sigma_{t_{\frac{1}{2}}}^2 = \left(\frac{d}{d\lambda} \left(t_{\frac{1}{2}} \right) \right)^2 \sigma_{\lambda_w}^2$$

4. RESULTS

$$\begin{aligned}\lambda_w &= 0.0104 \\ \sigma_{\lambda_w} &= 0.0088 \\ t_{\frac{1}{2}} &= 66.12 \text{ sec} \\ \sigma_{t_{\frac{1}{2}}}^2 &= 0.24 \text{ sec}\end{aligned}$$

Error of $t_{\frac{1}{2}}$:

$$\text{Error} = \frac{|66.12 - 55.6|}{0.48} = 21.47 \gg 1\sigma.$$

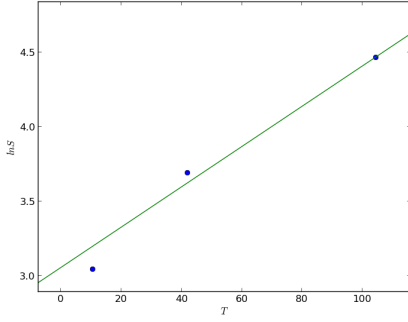


FIG. 1: LSF to straight line

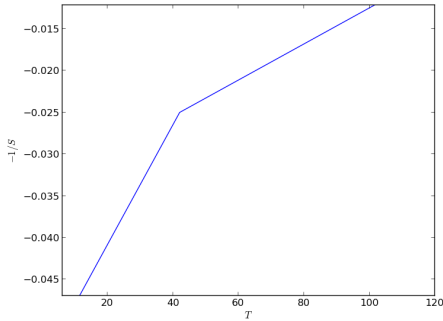


FIG. 2: $-\frac{1}{S}$ versus T

5. CONCLUSIONS

This experiment did not tell much things about radioactive decay since there would be a lot of causes of errors. For example, there were very few sample data to make good estimation and there were an irrelavence between them. My error shows this error explicitly. There is also no bound between numbers of squeezes, voltage value and λ . This experiment showed us sometimes number of sample would be more helpful in making good estimations.

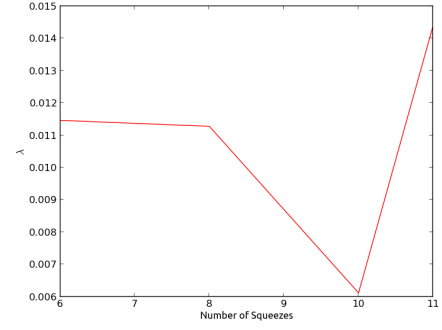


FIG. 3: λ versus number of squeezes at voltage 3000V.

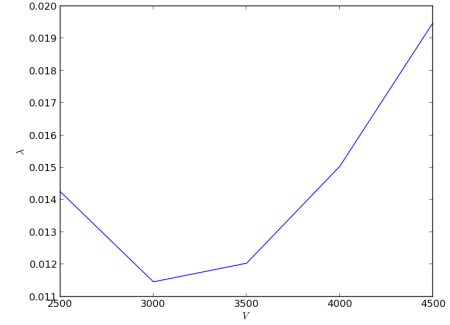


FIG. 4: λ versus V in 6 squeezes.

6. REFERENCES

- E. Gulmez, Advanced Physics Experiment, Istanbul, Bogazici University Publication, 1999
- <http://web.mit.edu/8.13/www/experiments.shtml>

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