Measuring the Half Life of ^{220}Rn with Cloud Chamber

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In this experiment, the half life of ^{220}Rn was measured by counting the numbers of Alpha particles decayed in a cloud chamber. Such Alpha particle decay occur as part of the ^{232}Th decay chain. Alpha particles in cloud chamber was identified as a track of alcohol condensation; by calculating the number of decays in a certain interval and fitting the result to an exponential model, the $t_{1/2}$ half life of ^{220}Rn was acquired. This experiment obtained $t_{1/2} = (55.92 \pm 2.72)$s; uncertainty arises from counting error. The accepted value is 55.6s [1] which is within the measured confidence interval with a discrepancy of 0.58%.

INTRODUCTION

A diffusion cloud chamber was used first to identify the Alpha and Beta decay processes with a ^{210}Bi $\rightarrow$ ^{210}Po $\rightarrow$ ^{206}Pb source and then to measure the half life of ^{220}Rn gas.

Alpha and Beta particles produce different types of tracks in cloud chamber; to distinguish them, a ^{210}Pb source is placed in the cloud chamber. The two decay processes taken place were ^{210}Po $\rightarrow$ ^{206}Pb Alpha decay and ^{210}Bi $\rightarrow$ ^{210}Po Beta decay from the ^{226}Ra decay chain [FIG.1].

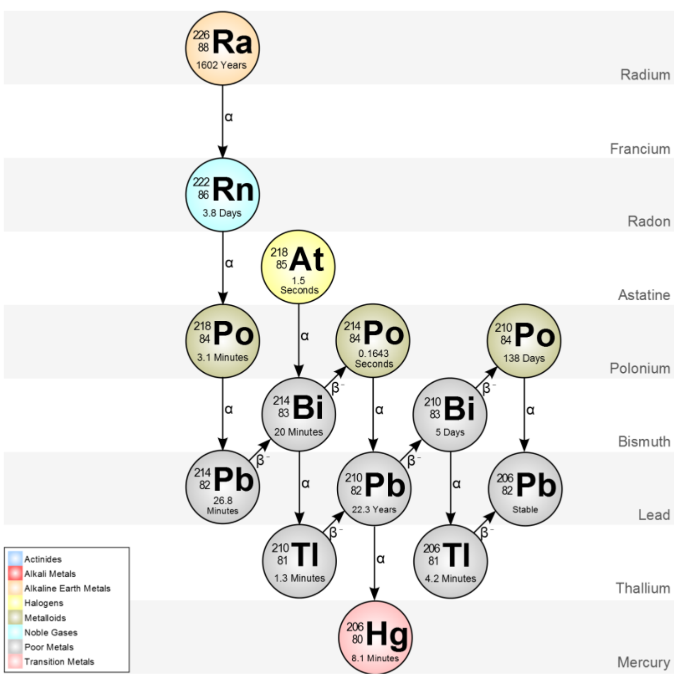

FIG. 1: *Ra-226 decay chain; part of U-238 chain. [2]*

The half life of ^{220}Rn was measured through analyzing the time evolution of Alpha particle count of ^{220}Rn gas. The sequential Alpha decays of ^{220}Rn $\rightarrow$ ^{216}Po $\rightarrow$ ^{212}Pb are part of Thorium decay chain [FIG.2]. Since ^{216}Po has a short half life of 0.14 second, the decay follows the previous ^{220}Rn Alpha decay as if they are simultaneous; hence half of the total Alpha particle count was treated as ^{220}Rn Alpha particle count.

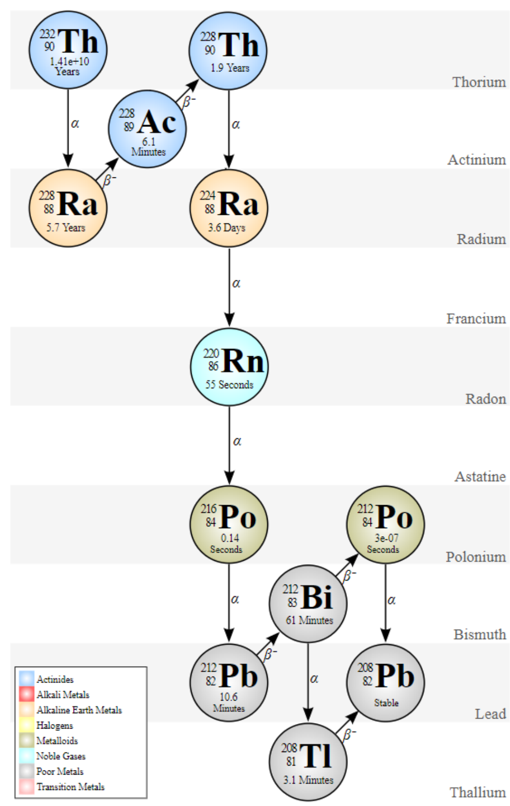

FIG. 2: *Thorium 232 decay chain. [3]*

METHODS

The diffusion cloud chamber used is manufactured by PASCO as shown in [FIG.3]; it includes a main chamber, an AC power adaptor, a high-voltage transformer paired with a jumper wire for applying high voltage across source of interest and chamber bottom, and a rubber tube for cooling fluid circulation.

FIG. 3: *The cloud chamber used in this experiment. [4]*

The main chamber includes a cylindrical vessel with a bottom plate at around -10^{o}C and a side curtain soaked with alcohol. The alcohol evaporates in the upper warm region in the vessel and diffuses to the lower colder region. At the bottom, the alcohol vapour becomes super saturated. When energetic particles pass through, they ionize air molecules causing alcohol vapour to condense onto and producing visible tracks.

A camera was used to record the decaying action in the cloud chamber; the recording was set to 7.61 frames per second with resolution of 800 pixels · 600 pixels.

The experiment consists two parts:

I. Identifying Alpha and Beta particle tracks.

II. Measuring the Half Life of ^{220}Rn.

I. ALPHA AND BETA PARTICLE TRACKS

After cooling the chamber and creating vapour, a needle with ^{210}Pb was placed in the chamber. A voltage of 800V was applied across the needle and chamber bottom to direct particles downward into the ionization region. There were mainly two decay processes taking place: ^{210}Po $\rightarrow$ ^{206}Pb Alpha decay, and ^{210}Bi $\rightarrow$ ^{210}Po Beta decay.

At low energy situations, $E < 3mc^2$, the Bethe formula suggests:

$$dE/dx \propto v^{-2}$$

where c is the speed of light, E is the energy, m is the mass, x is distance traveled by and v is the velocity of the particle. For ^{210}Po $\rightarrow$ ^{206}Pb Alpha decay, the ejected particle has $E \sim 5MeV$; for ^{210}Bi $\rightarrow$ ^{210}Po, a particle has $E \sim 1MeV$.

Since particles have much larger mass than particles, they should have much slower speed and hence would produce brighter and wider tracks with more air molecules ionized along the way. Also, due to the small mass of Beta particle, they are also easily scattered and hence would produce more twisted tracks as shown in [FIG.4].

FIG. 4: *Alpha and Beta particle track comparison. The top-left quadrant shows a Beta particle path with thin, dim, and twisted track. The other three are Alpha particle paths with thick, bright, and straight tracks*

II. HALF LIFE OF RADON-220

Under room temperature and pressure, ^{220}Rn is the only gaseous product in the ^{232}Th decay chain. Using this property, ^{220}Rn gas was prepared by placing ^{232}Th ore inside a sealed injector for about 45 minutes. The ^{220}Rn gas was then injected into the cloud chamber which was set up the same way. A metal pin was placed into the cloud chamber and an 800V voltage was applied across the pin and the chamber bottom to drive particles down to the vapour region.

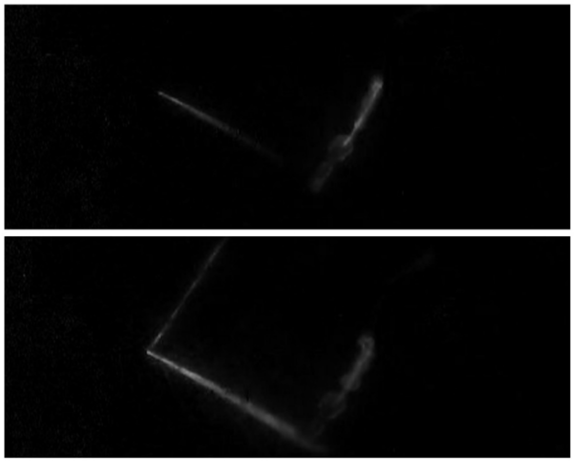

FIG. 5: *The left side of the figure shows coupled tracks with two Alpha particle created by* $^{220}Rn \rightarrow {}^{216}Po$ *and* $^{216}Po \rightarrow {}^{212}Pb$ *subsequently. The right-side track belongs to another alpha decay.*

Video of was taken to count the number of Alpha decays produced. There were mainly two decay processes taking place: ^{220}Rn $\rightarrow$ ^{216}Po Alpha decay and ^{216}Po $\rightarrow$ ^{212}Pb Alpha decay. The first decay is accompanied closely by the second decay, often producing coupled tracks like [FIG.5].

From the video acquired, the total number of Alpha particle tracks was counted for each 20 frames which is about 3 seconds. Due to the proximity of two decays, half of the total Alpha particle counted was treated as number of ^{220}Rn $\rightarrow$ ^{216}Po decays. The counting data was then subtracted from an arbitrary starting number, here 400, to get number of remaining ^{220}Rn particles.

The limitation of the method employed consists mainly two aspects; firstly, the camera allows limited frames per second, here 7.61 fps, which induces systematic uncertainty as the smallest unit of time difference is about 0.15s. Secondly, due to the height of the could chamber, there could exist overlapping Alpha particle track which also contributes to systematic error.

ANALYSIS/RESULTS

The decay formula for ^{220}Rn follows an exponential form of:

$$N(t) = N_0 \cdot e^{-\frac{t}{\tau}}$$

where $N(t)$ is the number of remaining particles at time t, N_0 is the initial number of particles, and τ is the characteristic time of the decay process.

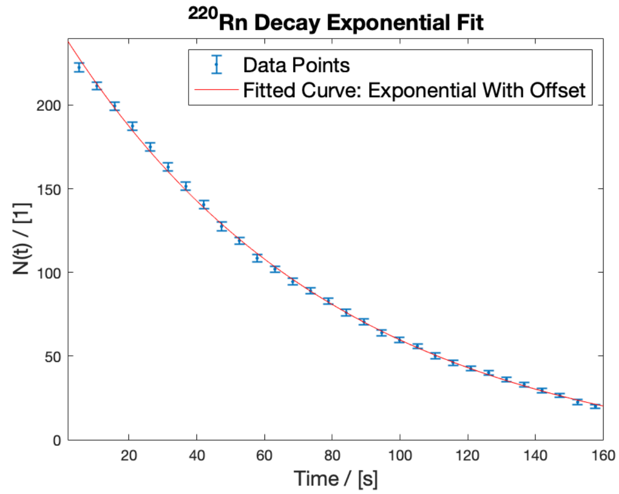

FIG. 6: *The number of remaining* ^{220}Rn *plotted against time with an exponential fit plus constant offset. The fit has* R^2 *of 0.9992 and suggests* $\tau = (80.86 \pm 3.92)$

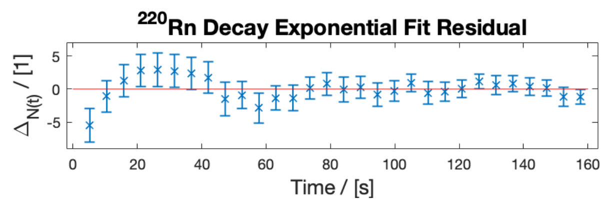

FIG. 7: *The residual of FIG.6 plotted against time. The majority of the data points have error-bars overlapping with the zero line.*

Plotting the acquired data points with an exponential fit [FIG.6], the characteristic time was acquired to be:

$$\tau = (80.86 \pm 3.92)s$$

Hence, the half life of ^{220}Rn was calculated to be:

$$t_{1/2} = \tau \cdot ln(2) = (55.92 \pm 2.72)s$$

DISCUSSION

This experiment reports measurement on the half life of ^{220}Rn to be: $t_{1/2} = (55.92 \pm 2.72)s$; the excepted value is 55.6s. The measurement presents a discrepancy of 0.58% and includes the accepted value within one standard deviation.

The main sources of uncertainty was counting error during the video analysis process; such systematic uncertainty arose from limited frame rate, resolution, and single plane of focus of the video acquired. From the plotting session, a statistical uncertainty was acquired with the exponential fit; it was then propagated and used as overall measurement uncertainty.

Several approaches could be utilized to improve margin of uncertainty. Firstly, to lower systematic error, higher frame rate, higher resolution, and multiple cameras angles could be used to provide better videos and hence more unambiguous counting of Alpha particles. Secondly, to lower statistical error, smaller time intervals of counting could be utilized; for example, instead of using 20-frame intervals, using 5-frame intervals would increase the number of data points for the same data set and hence reduce statistical uncertainty.

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