Determination of half-life of ^{40}K using an innovative approach

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Radioactivity, the process of unstable nuclei undergoing decay to become stable, is a fascinating phenomenon that emits various types of nuclear radiations [1]. The decay is characterized by the half-life, representing the time taken for half of the radioisotope to decay. Determination of the half-life of radioisotopes with relatively short decay times has been achieved through traditional experimental methods. However, for radioisotopes with very long half-lives, the decay rate becomes exceptionally low, posing significant challenges for accurate measurements. Accurate knowledge of the half-life of ^{40}K holds significant practical applications, particularly in geochronology, where it is employed to date rocks and estimate geological ages [2,3]. By refining our understanding of the decay process through precise determination of the half-life, the accuracy and reliability of dating techniques may be enhanced. Moreover, the half-life of ^{40}K plays a crucial role in establishing the chronology of events in Earth's history, contributing to the calibration of geological time scales. Continued advancements in experimental techniques may further improve the accuracy of the determined value and contribute to the ongoing progress in the field of nuclear physics. This work demonstrates the effective use of an innovative experimental approach in studying long-lived radioisotopes contributing to our understanding of radioactive decay processes. In the present work an innovative approach to extract the half-life of the long-lived radioisotope ^{40}K has been employed. Here, a simple experimental setup and detection technique has been used. By overcoming the difficulties associated with measuring long half-lives, this study aims to gain insights into the properties of radioisotopes with extended decay times. The radioisotope ^{40}K, has a very long half-life $\approx 1.251 \times 10^9$ years. The decay of ^{40}K involves three processes: β-emission, electron capture (EC), and gamma emission. About 89.2% of ^{40}K decays result in the production of ^{40}Ca through β^- emission, and around 10.7% lead to the formation of ^{40}Ar via EC, followed by gamma emission. In rare instances (0.001% of events), ^{40}K decays to ^{40}Ar by emitting a positron (β^+) and a neutrino. Natural potassium contains two stable isotopes, ^{39}K (93.3%) and ^{41}K (6.7%), alongwith the radioactive ^{40}K. The ^{40}K is present in trace amounts in most potassium samples, contributing significantly to radioactivity in living organisms, including the human body.

Experimental Details:

The calibration of the gamma-ray spectrometer set-up, has been done by aligning the photopeak of the 1.332 MeV gamma rays of standard ^{60}Co source with the appropriate channel number in the Multi-Channel Analyzer (MCA). This ensures proper calibration and accurate energy measurement of the gamma rays emitted by the KCl sample. The background spectrum is recorded for 15 minutes to account for any ambient radiation, and the total counts over the corresponding channels are extracted. For the actual measurements, known masses of KCl sample (1.0 gm, 2.0 gm, 3.0 gm, 4.0 gm, etc.) are placed on the thin base of a glass beaker and evenly distributed [4]. The sample, arranged horizontally, is positioned on top of the NaI(Tl) detector in a vertical geometry, and the spectrum of γ-rays emitted by the sample is recorded for 15 minutes. A typical recorded spectrum of KCl salt for mass 1.0 gm is shown in Fig.1. The process is repeated for different masses of KCl to obtain a range of data points. The photopeak counts corresponding to the 1.462 MeV gamma line are extracted from each spectrum, and the

background counts are subtracted from the sample counts to determine the net counts for each mass.

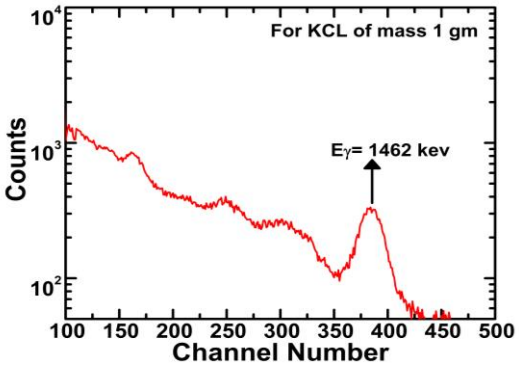

Fig.1: A typical singles spectrum of KCl salt for a mass 1.0 gm recorded for 15 minutes. The 1462 keV γ-ray is marked.

Analysis of data

A plot of Counts/sec/gm as a function of the mass of the KCl sample is generated using the obtained data points is shown in Fig.2. The slope of the line obtained from this graph represents the decay constant (λ) at zero mass thickness, which accounts for the reabsorption of decay products by the sample itself. From the graph, the activity (A) of the KCl sample without any attenuation correction is determined to be approximately A = 0.402 Counts/gm/sec.

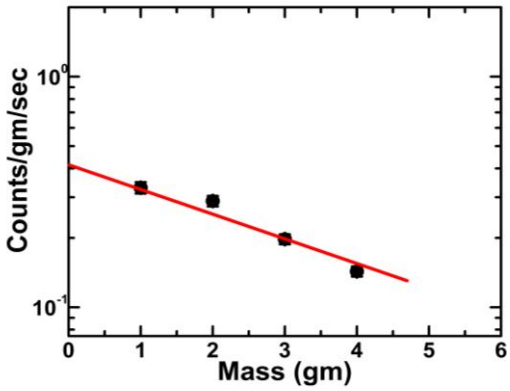

Fig.2: Logarithmic decay plot of ^{40}K. The red line is extrapolated to get the activity (see text for more details).

The number of radioactive ^{40}K atoms in 1gm of natural potassium is estimated to be around 1.8 x 10^{18} atoms. Taking the detector efficiency (20%) into account, the half-life of ^{40}K is calculated using the formula [4];

$$t_{1/2} = \frac{0.693}{A} \text{x } N_0 \text{ . } \varepsilon \text{. } \eta$$

Where, ε being the efficiency of detector while η is the branching ratio of 1462 keV γ-ray.

The deduced half-life of ^{40}K based on the experimental measurements is found to be 1.14 x 10^9 years. This value demonstrates remarkable agreement with the accepted standard value of 1.25 x 10^9 years, with a deviation of approximately 8.8% as a percentage of error. The consistency between the measured and standard values validates the accuracy and reliability of the experimental approach used to determine the half-life of ^{40}K. Further details will be presented.

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