Alpha decay half-life of $^{147}$Sm in metal samarium and Sm$_2$O$_3$


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Abstract. In order to investigate the possible influence of metallic environment on the alpha decay process, we have measured the $^{147}$Sm activities in the hosts of metal samarium and Sm$_2$O$_3$. The $^{147}$Sm half-life was found to be $(1.06\pm0.01)\times10^{11}$ y in metal samarium and $(1.07\pm0.01)\times10^{11}$ y in Sm$_2$O$_3$, respectively. No significant change has been observed within the experimental uncertainty. The absolute half-life presented here is consistent with the recommended value.

1 Introduction

A possible influence of the quasi-free electron cloud in metallic environment on the $\alpha$-decay process has attracted an intense interest in recent years. It was predicted [1, 2] that the $\alpha$-decay rate could be enhanced by a factor greater than two in the metal hosts. Contrary to these predictions, the theoretical calculation with quantum-mechanical tunneling arguments indicated that the change of $\alpha$-decay rate in metals is negligibly small [3]. It was attributed to the fact that the reduction in Coulomb barrier arising from electron screening can be canceled in principle by the decrease in the $\alpha$-decay energy due to the extension of the screened potential into the inner part of the decaying nucleus. On the other hand, a recent study revealed that the electron screening potential in the inner part is smaller than in the external region since it is considered to be related with the energy of the $\alpha$-particle, and the difference leads to a few percent increase of the $\alpha$-decay rate in the metallic environment [4].

For investigating such a conjectural metal host effect, the $\alpha$-decay of $^{221}$Fr has been measured in several materials [5], the result shows that the half-lives of $^{221}$Fr in metals Au/W are slightly shorter by 0.30(17)/0.42(21)% respectively, as compared to that in the insulator Si. We report here an independent measurement of the $^{147}$Sm half-life in metallic environment. $^{147}$Sm is a natural and pure $\alpha$-emitter with relative low $Q_{\alpha}$ (2.31 MeV), and the electron screening potential of the samarium metal for the $D(d,p)T$ reaction was measured to be about 300 eV [1]. Furthermore, the decaying nuclei are homogeneously distributed in the sample, so the doubts related to the ion implantation depth can be obviated spontaneously. For the sake of comparison, we correspondingly performed the measurement for the insulator Sm$_2$O$_3$ sample. The details of the experiment setup and data analysis are described in what follows.

In addition, the $^{147}$Sm-$^{143}$Nd method established by Lugmair [6] plays an important role in the dating of terrestrial, lunar and Martian rocks as well as meteorites. The half-life of $^{147}$Sm was recommended to be $1.06\times10^{11}$ y [7, 8]. It is in fairly good agreement with a measured value of $1.070(9)\times10^{11}$ y in 2009 [9], yet clearly shorter than that of $1.17(2)\times10^{11}$ y reported in 2003 [10]. The new measurements are needful for clarifying the discrepancy of experimental results.

2 Experimental setup and procedure

In order to get good statistics, the $^{147}$Sm-enriched samarium in the form of metal (97.93%) and oxide powder (98.30%) bought from Oak Ridge National Laboratory were adopted to prepare samples. The material was deposited on a high pure quartz glass substrate by vacuum evaporation (metal) and sputtering (oxide), respectively. One metal and one oxide sample have been made, the samples were constrained at the central area of the substrates by a $\varnothing$7 mm diaphragm during the depositing process. The thicknesses of the $^{147}$Sm samples were about 250 $\mu$g/cm$^2$ which was almost 700 atomic layers for metal samarium. Comparing to the ions implantation depth (about 20 atomic layers) in the measurement of $^{221}$Fr $\alpha$-decay half-life [5], our metal sample provided a more reliable metallic environment.

The uniformity of the samples were measured using the CR-39 track detectors. The CR-39 chips clung to the samples and were irradiated for about 100 hours, then were chemically etched in a 6.0 M NaOH solution at 70°C for
Finally, the samples were dissolved into the standard nitric acid, respectively; the residual glass substrates were measured again to determine the background. The α-energy spectra obtained from the samples are shown in fig. 3 together with the corresponding backgrounds.

Monte Carlo simulations were performed for determining the energies of the α-particles emitting into the accepted solid angle, the stopping powers of α-particles in metal samarium and \( \text{Sm}_2\text{O}_3 \) were calculated by the program SRIM [11]. The results agree well with the measured spectra, as shown in fig. 3. Based on the simulations and measurements, the \(^{147}\text{Sm}\) peaks were set to be 1.5 to 2.4 MeV for both samples, the α-particle amounts in the peaks with background subtracted are listed in table 1. The influence of the α-peak range was examined by expanding the range to 1.3–2.6 MeV, the result shows that the increment of the α-particle amount is less than 0.2%.

Assuming that the efficiency of the silicon detector is 100%, the total detection efficiency depends on the solid angle only. Then the activities of \(^{147}\text{Sm}\) in two samples were determined as given in table 1. The α-decay of \(^{148}\text{Sm}\) was ignored because of its long half-life (\(7.0 \times 10^{15}\) y) and low abundance (<1%) in the samples.

For the determination of the \(^{147}\text{Sm}\) number, the samples were dissolved with nitric acid, the solutions were weighed using an analytical balance with a precision of 0.1 mg. The number of \(^{147}\text{Sm}\) in the sample, \(N_{147}\), was determined by

\[
N_{147} = mC_x X_{147},
\]

where \(m\), \(C_x\) and \(X_{147}\) are the mass, samarium atomic concentration and \(^{147}\text{Sm}\) atomic abundance of the sample solution, respectively. In the present work, \(C_x\) was determined via Isotope Dilution Mass Spectrometry (IDMS) recommended by ref. [12]. The sample and \(^{154}\text{Sm}\) spike solutions, each about 3.0 g, were mixed together. The samarium isotopic ratios of the sample, spike and blend solutions were measured by the Multi Collector Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS). The concentration of the sample solution was given by

\[
C_x = C_y \cdot \frac{m_y}{m_x} \cdot \frac{R_y - R_B}{R_B - R_y} \cdot \frac{\sum R_{ix}}{\sum R_{iy}},
\]

where \(C_y\) is the samarium atomic concentration in the spike solution, \(m_y\) and \(m_x\) the masses of sample and spike solutions in the mixture. \(R_y\), \(R_y\) and \(R_B\) are the \(^{154}\text{Sm}/^{147}\text{Sm}\) isotopic ratios in the sample, spike and blend solutions, \(R_{ix}\) and \(R_{iy}\) the \(^{154}\text{Sm}/^{147}\text{Sm}\) isotopic ratios in the sample and spike solutions. \(X_{147}\) was then determined by

\[
X_{147} = \frac{1}{\sum R_{ix}}.
\]