New half-life results on very long-living nuclei

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New half-live measurements for the α-decays of $^{147}$Sm and $^{190}$Pt are given. Improved half-lives and limits of highly forbidden beta decays have been obtained for $^{50}$V and $^{180m}$Ta. Furthermore, new half-life limits for various forms of double electron capture are presented.

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1. New results on $\alpha$-decay half-lives

The study of alpha decays has been important for the understanding of nuclei and their properties for more than a century. Currently these studies still have impact in various areas of nuclear physics, providing information which is valuable and often not accessible otherwise. The half-lives are sensitive to nuclear structure and the half-life region between $10^6$–$10^{10}$ years and beyond is very interesting as several nuclides in this range are used as (cosmo-)chronometers and the limitations on dating precision might be restricted by the accuracy in the known half-life. Furthermore, scanning through the available data there is a reasonable spread in half-life measurements for individual nuclei, which might deserve better precision.

To study $\alpha$-decays experimentally a new Frisch-grid ionisation chamber was built made out of low energy $[\text{MeV}]$ level radioactive materials [1]. This is due to the fact that major interest is in long-living nuclides, of course the chamber can be used for any $\alpha$-decay. Following the Geiger-Nuttall law, long half-lives lead to lower Q-values, typically below 3 MeV. In a background run of 30.8 days it could be shown that the chamber has a background in the region of 1–3 MeV of only one event per 2 days. For more details on the chamber see [1]. In a first attempt a measurement of the $^{147}\text{Sm}$ half-life was envisaged. Even so this is a classical calibration source the measured values over time still show some scattering. In a new measurement with very thin targets more than 60000 events were collected, a fraction of the data is shown in Fig. 1. The half-live obtained is [2]

$$T_{1/2} = (1.0803 \pm 0.0099^{(\text{stat.})} \pm 0.0241^{(\text{sys.})}) \times 10^{11}\text{years}$$

(1.1)

in very good agreement with the most precise value claimed by [3]. In addition, also the half-life into the first excited state of $^{143}\text{Nd}$ has been explored using low background gamma-spectroscopy and results in $T_{1/2} > 3.3 \times 10^{18}\text{yrs} (90\% \text{ CL})$. Such an excited state search was also performed for the $^{146}\text{Nd}$ decay into the first excited state of $^{142}\text{Ce}$. Here, the lower half-live limit obtained was $T_{1/2} > 1.6 \times 10^{18}\text{yrs} (90\% \text{ CL})$ [4].

In a next step the $\alpha$-decay half-live of $^{190}\text{Pt}$ has been explored. Here there is a significant spread between laboratory measurements, cosmochronological results and semi-empirical fitting of $\alpha$ emitters. Previous laboratory measurements have uncertainties of at least 10%, while geological samples are presented with errors less than 1% (for a compilation of results see [5]). The new

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Peak of $^{147}\text{Sm}$ including background. The peak is clearly visible and a high signal to background ratio is achieved.}
\end{figure}
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measurement (Fig. 2) resulted a half life of

\[ T_{1/2} = (4.97 \pm 0.16) \times 10^{11} \text{years} \] (1.2)

with statistical and systematic errors added in quadrature [6]. This is the most precise laboratory measurement and agrees well with the value extracted from cosmochronological data.

![Logarithmic presentation of the peak of $^{190}$Pt including background. The latter can be considered to be very small.](image)

**Figure 2:** Logarithmic presentation of the peak of $^{190}$Pt including background. The latter can be considered to be very small.

2. Study of highly forbidden beta decays

Highly forbidden beta decays ($\Delta I > 2$) are interesting by themselves as the log $ft$-values are well above 10 and the spectral shapes are extremely difficult to calculate. One example is $^{50}$V with its ground state of $6^+$. It has two decay branches into a $2^+$ state of $^{50}$Ti and $^{50}$Cr. These decays are searched for more than 6 decades, with several evidences which were later replaced by more stringent lower limits. Finally, the EC into the Ti-branch has been observed with good statistics to be

\[ T_{1/2} = (2.28 \pm 0.25) \times 10^{17} \text{years} \] (2.1)

while the beta-decay into the Cr-50 branch resulted in a lower limit of $T_{1/2} > 1.5 \times 10^{18}$ years [8]. This triggered some shell model calculations to predict the missing half-life. It turns out that this is expected to be an order of magnitude higher than the current experimental limit [9].

Another example is $^{180m}$Ta, often called nature’s rarest isotope. The isomeric $9^+$ state serves as ground state and can in principle decay into two different $6^+$ states in a similar fashion as the previous nuclide. A new search has been performed using Bayesian statistics and is improving the lower limits of the half-life to $T_{1/2} > 5.8 \times 10^{16}$ years for the beta-decay branch and $T_{1/2} > 2.0 \times 10^{17}$ years for the electron-capture branch respectively [7]. Combining these two values results in an overall half-life limit of $T_{1/2} > 4.5 \times 10^{16}$ years.

3. Very rare event searches- Double electron capture

A very important search is double beta decay, especially the neutrino-less mode. While this is massively investigated there is an alternative process providing additionally information namle
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double positron decay, double electron capture (EC) and the mixed mode. These three different decay modes can be considered:

\[ (Z,A) \rightarrow (Z-2,A) + 2e^+ + (2\nu_e) \quad (\beta^+\beta^+) \quad (3.1) \]
\[ e^- + (Z,A) \rightarrow (Z-2,A) + e^- + (2\nu_e) \quad (\beta^-/EC) \quad (3.2) \]
\[ 2e^- + (Z,A) \rightarrow (Z-2,A) + (2\nu_e) \quad (EC/EC) \quad (3.3) \]

From phase space arguments the double EC should be most likely and its 2 neutrino half-life should be in the same range as for the corresponding double beta decays. Another interesting aspect is neutrino-less double EC. This would violate momentum conservation, hence the easiest way considered to solve this issue is to emit a photon, hence called radiative double EC. Various new measurements have been performed in the past, a few are mentioned here [10, 11, 12, 13]. A half-life limit of \( T_{1/2} > 4.0 \times 10^{21} \) years is given for the \(^{110}\)Pd double beta decay into the first excited state [10]. The radiative double EC of \(^{36}\)Ar is constrained to be larger than \( T_{1/2} > 3.6 \times 10^{21} \) years [13] and the same mode for \(^{58}\)Ni to \( T_{1/2} > 2.1 \times 10^{21} \) years [12].

References

[2] D. Degering et al., submitted
[6] B. Mihaly et al., submitted