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First search for double β decay of dysprosium

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Abstract

A search for double β decay of dysprosium was realized for the first time with the help of an ultra-low background HP Ge γ detector. After 2512 h of data taking with a 322 g sample of dysprosium oxide limits on double beta processes in ^{156}Dy and ^{158}Dy have been established on the level of $T_{1/2} \geqslant 10^{14}$–$10^{16}$ yr. Possible resonant double electron captures in ^{156}Dy and ^{158}Dy were restricted on a similar level. As a by-product of the experiment we have measured the radioactive contamination of the Dy_2O_3 sample and set limits on the α decay of dysprosium isotopes to the excited levels of daughter nuclei as $T_{1/2} \geqslant 10^{15}$–$10^{17}$ yr.

Keywords: RADIOACTIVITY ^{156}Dy(2EC), $(\beta^+ EC)$, (α); ^{158}Dy(2EC), (α); ^{160,161,162}Dy(α); measured E_γ, I_γ; deduced $T_{1/2}$ lower limits for α and various 2β-decay modes. Natural Dy_2O_3 sample of 322 g. Ultra-low background HPGe detector at the Gran Sasso National Laboratory underground facility

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1. Introduction

The double beta (2β) decay experiments are considered to-date as the best way to determine an absolute scale of the neutrino mass and to establish the neutrino mass hierarchy, to clarify the nature of the neutrino (Majorana or Dirac particle), to look for existence of right-handed admixtures in the weak interaction and of hypothetical Nambu–Goldstone bosons (Majorons), and to test some other effects beyond the Standard Model [1]. The developments in the new experimental techniques during the last two decades lead to an impressive improvement of sensitivity to the neutrinoless (0ν) mode of $2\beta^-$ decay up to 10^{23}–10^{25} yr [2]. Allowed in the Standard Model the two neutrino (2ν) double beta decay was detected for 10 nuclides with the half-lives in the range of 10^{18}–10^{24} yr [2,3].

The sensitivity of the experiments to search for the double electron capture (2ε), the electron capture with emission of positron ($\varepsilon\beta^+$), and the double positron ($2\beta^+$) decay is substantially lower: the best counting experiments give only limits on the level of 10^{18}–10^{21} yr [2,4–6].[1] There is a strong motivation to develop experimental technique to search for these processes: study of neutrinoless 2ε and $\varepsilon\beta^+$ decays could clarify the contribution of the right-handed admixtures in weak interactions [8]. Dysprosium contains two potentially 2β active isotopes: ^{156}Dy with one of the largest releases $Q_{2\beta} = (2012 \pm 6)$ keV (therefore both 2ε and $\varepsilon\beta^+$ channels of decay are possible), and ^{158}Dy ($Q_{2\beta} = (284.6 \pm 2.5)$ keV, only double electron capture is energetically allowed) [9]. The decay schemes of the triplets ^{156}Dy–^{156}Tb–^{156}Gd and ^{158}Dy–^{158}Tb–^{158}Gd are presented in Figs. 1 and 2, respectively.

It should be mentioned the possibility of a resonant enhancement of the neutrinoless double electron capture in ^{156}Dy and ^{158}Dy due to energy degeneracy. The resonant double electron capture was discussed in Refs. [12–15], where an enhancement of the decay rate by some orders of magnitude was predicted for the case of coincidence between the released energy and the energy of an excited state. According to [15], high Z atoms are strongly favored to search for resonant 2ε decay. Dysprosium has one of the highest Z among nuclides for which resonant processes could occur.

Resonant captures are possible on a few excited levels of ^{156}Gd and one level of ^{158}Gd. The properties of the excited levels are listed in Table 1. Because transitions with difference in spin more than 2 are strongly suppressed, we consider in this study only the levels of ^{156}Gd with spin $\leqslant 2$. However, we left in the list the level of ^{158}Gd with the spin 4^+ to which the resonant capture is possible.

Unfortunately, the isotopic abundances of both potentially double beta active dysprosium isotopes are rather low: concentrations of ^{156}Dy and ^{158}Dy in the natural dysprosium are 0.056(3)% and 0.095(3)%, respectively [16].

To our knowledge there were no attempts yet to search for double β decays of ^{156}Dy and ^{158}Dy. The aim of the present work was the search for 2β processes in the dysprosium isotopes with the help of ultra-low background high purity (HP) Ge γ spectrometry. As a by-product of the experiment we have estimated the radioactive contamination of the dysprosium oxide sample and set limits on the α decay of the dysprosium isotopes to excited levels of the daughter nuclei.

[1] An indication for $2\beta^+$ decay processes in ^{130}Ba and ^{132}Ba was obtained in geochemical measurements [7]; however, this result has to be confirmed in a direct counting experiment.