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FINE STRUCTURE OF α-SPECTRA IN RARE EARTH REGION

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1. Introduction

The α - decay of heavy atomic nuclei into excited states (the fine structure of α -spectra) has been known a long time ago. The study of this phenomenon for heavy ($A > 210$) atomic nuclei appeared to be one of the major sources of information about nuclear structure in this region and permitted to obtain a lot of experimental data.

It is natural that the α -decay into atomic nuclei excited states should take place for lighter nuclei too, for instance for rare earth nuclei. However, while α - decay is one of the main modes of disintegration of heavy elements (nuclear decay with α -particle emission occurs in 50-100% of nuclear decays), in the region of rare earths the main mode of decay is β -decay ; α-decay is a part of a percent of all nuclear decays. The decay into nuclear excited states should be weaker since the energy of α -particles is lower.

The small intensity of α -decay forced experimentalists to use high-transmission α -spectrometers; i.e. ionization chambers and semi-conductor α -spectrometers, to study α -decay in the region of light nuclei. These investigations resulted in the observation of α -decay of a number of light nuclei, but because of a poor resolution of these devices and a relatively high background, the phenomenon of fine structure of α -spectra was not observed.

At our laboratory some methods have been developed in order to obtain very high total and specific activity neutron-deficient isotopes of rare earths. This fact enabled us to use a high-resolution magnetic α -spectrograph in investigations of α -decay of rare earths. Previously magnetic spectrographs were not used to study α -decay in this region due to a low activity of the sources.

In the present paper the α -spectra of ^{151}Tb , ^{150}Tb, and ^{149}Tb isotopes are studied.

2. The α-Spectrograph. Preparation of Sources

The α-particle spectra were studied with the help of a magnetic α-spectrograph similar to that described by S.A. Baranov et al.[1]. The main parameters at which the studies were carried out were as follows: resolving power, i.e. the line width at a half-height, is $\approx$ 5 keV ; the used solid angle Ω = 0.04% of 4π ; the source area S = 2.5 x 35 mm^2. The calibration of the spectrograph by energies was made on the α_0-line of Cm^{244} (ref.[2]).

Tb radioactive isotopes were produced by irradiating a tantalum target with 660-MeV protons on the JINR synchrocyclotron. Separation of rare earths was performed using the chromotographic method. The duration of target irradiation was varied in the range 2 to 10 hours. In the case of 2-4 hour irradiation chemical procedures were begun just alter the irradiation. The measurements on α-spectrograph were initiated 3-5 hours after the irradiation. In the case of 10 hour irradiation the separation of terbium was made 7 hours after the irradiation. With three hours passed from the moment of separation of terbium from the target irradiated during 10 hours, it was again separated from dysprosium and gadolinium impurities. In this case the measurements on the α-spectrograph were initiated about 12 hours after the irradiation.

The source for the α-spectrograph was prepared by means of evaporation in vacuum. α-particles were detected with the help of photographic plates type A-2 with emulsion layer 50μm thick.

3. Results of Measurements

The α-spectum was studied in the range 3070 to 3980 keV. The time of exposure was varied in the range 4 to 35 hours. The previously known α-lines were observed at energies 3409 kev (refs. [3,4,5]), 3644 keV (ref.[5]), and 3967 keV (refs.[5,6,7]) attributed in the mentioned references to ^{151}Tb, ^{150}Tb and ^{149}Tb, respectively (see Figs. 1 and 3). The evaluations of the half-lives of the indicated lines were in agreement with the known half-lives of these isotopes. The values of the α-lines energies were in good agreement with the values listed in ref. [5]. Two new lines with energies 3183$\pm$5 keV and 3492$\pm$5 keV were also observed arising from the decay of Tb isotopes. The energies and half-lives of the observed α-lines were determined. The partial half-life of ^{150}Tb decay was estimated. The results of our measurements are presented in table 1.

Now we shall consider the problem of assigning the observed α-lines to Tb isotopes.

<u>^{151}Tb</u> : 3409 keV α-particles were observed in works by Rasmussen et al./3/, Toth et al./4/, Gromov et al./5/. Toth and Rasmussen /4/ attributed the α-activity with an 19 h half-life to ^{151}Tb. We have observed a new weak α-line with an energy 3183$\pm$5 keV (Fig. 1). In studying this line it was determined that at fist its intensity decreases with the half-life about 18 h and then it practically does not vary. The long-lived component of this group should be attributed to the α-decay of ^{148}Gd ($T_{1/2}$ = 84 years) resulting from the β-decay of ^{148}Tb ($T_{1/2}$ = 70 min). The energy of ^{148}Gd α-particles was measured by Silvola/8/ to be 3180 $\pm$10 keV. The portion of ^{148}Gd α-particles in the α-lines of energy 3183 keV was about 20%. The evaluations of half-lives of the rest part of this α-line (16-52 h), make it possible to attribute it to ^{151}Tb, ^{152}Tb or ^{154}Tb. The assumption that the new line belongs to ^{152}Tb does not agree with the latest data concerning the α - β-decay cycle of ^{152}Tb $\longrightarrow$ ^{148}Sm (Fig. 2). It has been calculated from this cycle that the total energy of ^{152}Tb α-decay Q_α is equal to 2940 $\pm$ 110 keV, the energy of ^{152}Tb α-particles being 2844 $\pm$ 110 keV. The energy of α-particles arising from the α-decay of Tb isotopes with $A \geq 153$ should be still lower. Thus we think that the new α-lines should be attributed to the ^{151}Tb decay, being the α-decay into an ^{147}Eu excited state with an energy 232$\pm$5 keV. The 229 keV ^{147}Eu level became known from the studies of the β-decay of ^{147}Gd. Evidently the α-decay of ^{151}Tb populates this particular level.

<u>^{149}Tb and ^{150}Tb</u>. The half-lives of ^{150}Tb and ^{149}Tb are most precisely determined in the work by Toth et al./7/: 3.1 $\pm$ 0.2 h and 4.10 $\pm$ 0.05 h, respectively. We observed the intensity decrease of the α-lines with energies 3492 keV, 3644 keV and 3967 keV for about 24 hours. In order to determine the half-life of the 3644 keV α-line, in one of the experiments a semi-conductor α-detector was used instead of a photoplate. The obtained values of the half-lives enable us to make the following conclusions: a) the 3967 keV α-line appears as a result of the α-decay of ^{149}Tb. The α-decay of ^{149}Tb was observed in works by Toth et al./6,7/ and Gromov et al./5/. The obtained in the present paper value of the energy of ^{149}Tb α-particles agrees, within the experimental errors, with the values listed in references/5,6,7/. The accuracy of determining the energies is twice as high as that in ref./5/. b) The

3644 keV α -line has been originally observed by Gromov et al[5]. Using the approximate value of the half-life ($T_{1/2}$ =3-7 h) and the data about the $\alpha-\beta$ decay cycle of ^{150}Tb , the authors have expressed the assumption that this line belongs to ^{150}Tb.

The measured in the present paper value of the half-life 4.1 ± 0.1 h permits us to state that 3644 keV α -particles arise from the α -decay of ^{149}Tb . This decay results in the excited level of ^{145}Eu with an energy of 331±5 keV (Fig. 3). c) the 3492 keV α -line (Fig. 3) arises from the decay of ^{150}Tb. This assumption is in good agreement with the data about the $\alpha-\beta$ decay cycle of ^{150}Tb into ^{146}Sm (Fig. 4). The lines of the fine structure of ^{150}Tb α -decay have not been observed. Their intensity is less than one tenth of the intensity of the line with E_α = 3492 keV.

4. Conclusions

Thus, the use of the high-resolution alpha-spectrograph has permitted to observe α -lines of very low intensity. For instance, the observed decay of ^{151}Tb into a 229-keV level of ^{147}Eu is about 3×10^{-8} of the total number of ^{151}Tb decays.

Two cases of the α -desay of ^{151}Tb and ^{149}Tb isotopes into the excited levels of daughter nuclei have been observed.

According to the theoretical evaluations using the formulae of Taagepera and Nurmia[14]

$$\log_{10} T = 1,61 [\frac{Zd}{E_\alpha^{1/2}} - Z^{2/3} d] - 28,9$$

the ratio of the intensity of α -decay into ^{147}Eu 229 keV and ^{145}Eu 331 keV levels to the intensity of decay into the ground state of these nuclei are 1.1×10^{-2} and 6.2×10^{-3}, respectively. The obtained experimental ratios are as follows: 1×10^{-3} and 3×10^{-4} (see the table I), i.e. about 10 times less than the calculated ones. The mentioned formula takes into account the dependence of α-decay probability on α -particle energy only. The differences between the experimental and calculated ratios might be caused by a large variation of the spin in α -transitions to excited states.

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T a b l e I

	α -particle energy (keV)	Total half-life (Hours)	Identif.	Partical α-period (years)	Notes
1.	3183$\pm$ 5	25^{+27}_{-9}	α_1 ^{151}Tb		$\frac{I_{\alpha_1}}{I_{\alpha_0}}$ =(0,9–1,2)10^{-3}
2.	3409$\pm$5	18$\pm$ 2	α_0 ^{151}Tb		
3.	3492$\pm$5	3.15 $\pm$0.20	α_0 ^{150}Tb	180^{+300}_{-120} x)	$\frac{I_{\alpha_1}}{I_{\alpha_0}} < 0.1$
4.	3644$\pm$5	4.1 $\pm$0,1	α_1 ^{149}Tb		$\frac{I_{\alpha_1}}{I_{\alpha_0}}$ =(2,5–4.0) 10^{-4}
5.	3967$\pm$ 3	4.10$\pm$0.05	α_0 ^{149}Tb		

x) In evaluating T_α we have used the data from ref./15/ about relative yields of Tb isotopes and the value of ^{151}Tb half-life time of 64$\pm$ 22 years 5).

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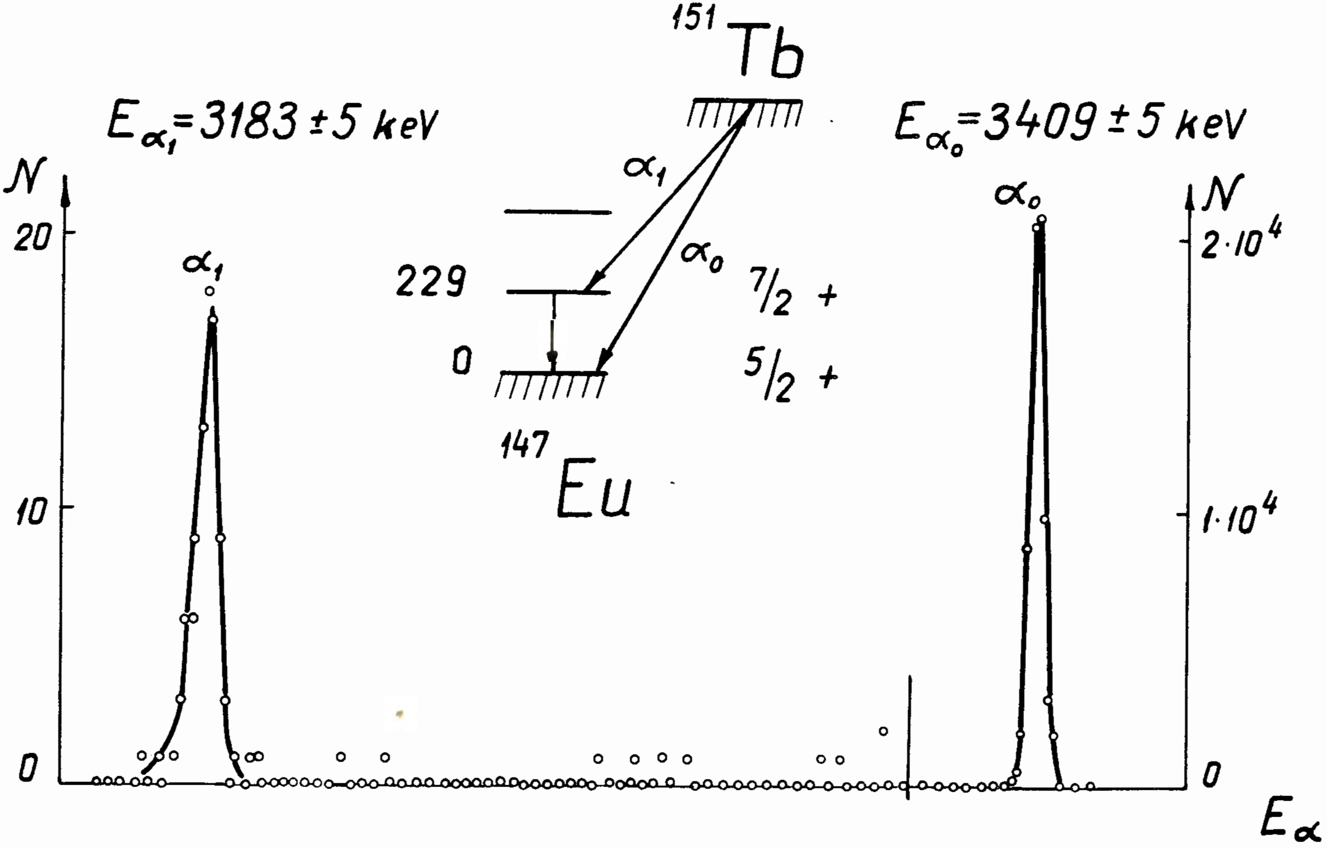

Fig. 1. The α – spectrum and decay scheme of ^{151}Tb. The ordinates give the number of α-tracks counted in the band 2 x 50 mm^2 in area. The exposure duration is 17 hours.

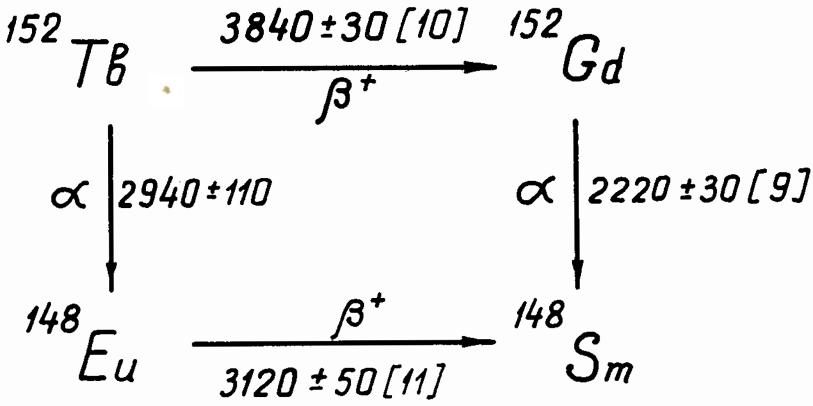

Fig. 2. The α -β - decay cycle for $^{152}Tb \rightarrow {}^{148}Sm$.

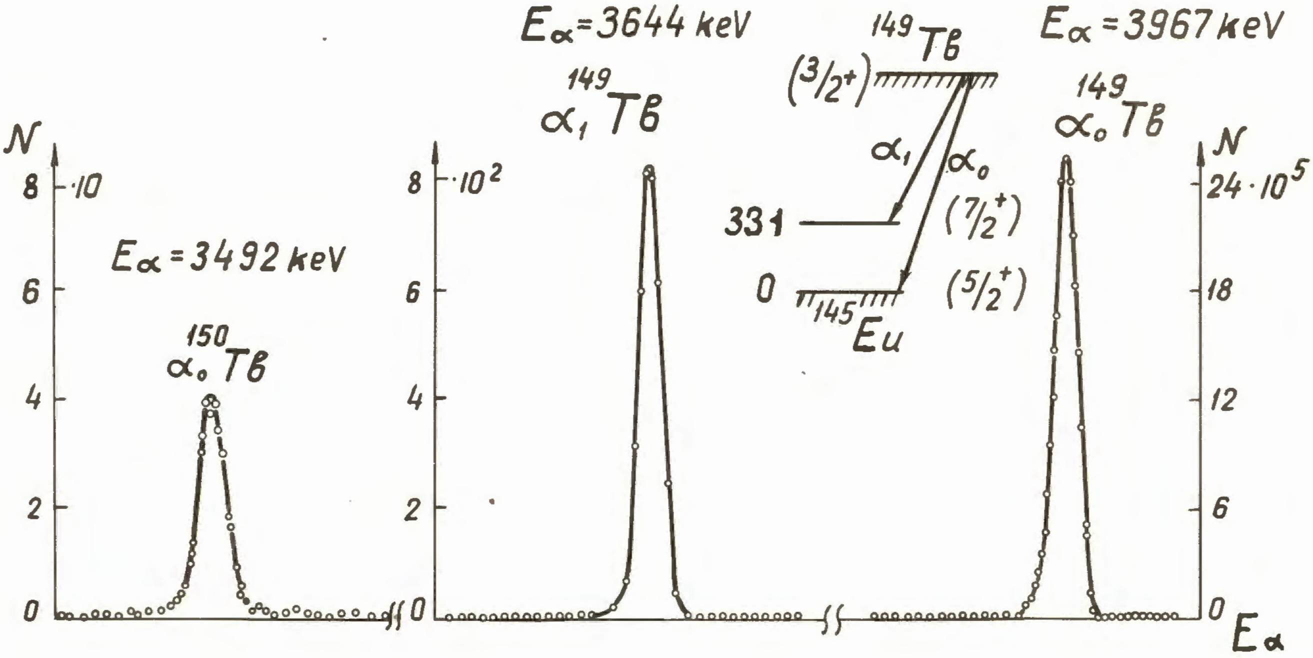

Fig. 3. The α-spectrum of ^{150}Tb and ^{149}Tb. In the right corner the decay scheme for ^{149}Tb is shown. The ordinates give the number of α-tracks counted in the band 0.4 x 50 mm^2 in area. The exposure duration is 12 hours.

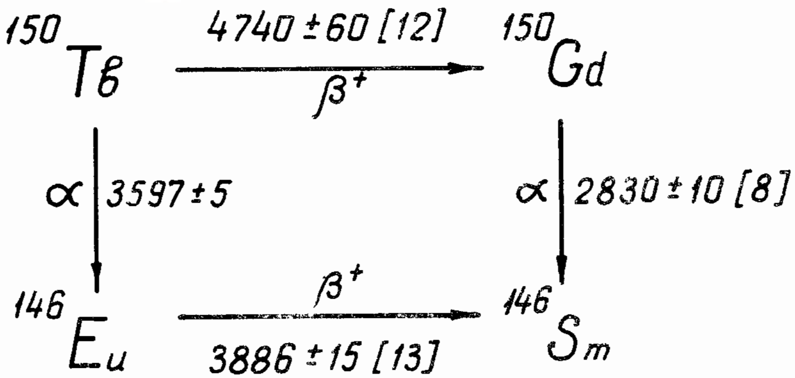

Fig. 4. The $\alpha - \beta$ - decay cycle for $^{150}Tb \rightarrow {}^{146}Sm$.