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Abstract

Full Text

Physics

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Identification of the Internal-Conversion Spectrum of the Long-Lived Isotopes Eu^{152} and Eu^{154}

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When natural europium, consisting of two isotopes, Eu^{151} (47.77%) and Eu^{153} (52.23%), is irradiated with thermal neutrons, a mixture of the radioisotopes Eu^{152} and Eu^{154} is obtained. The half-life of Eu^{152} is 9.2 hours* and 13 years, and that of Eu^{154} is 16 years ⁽¹⁾. Both isotopes undergo transformations as a result of capture of orbital electrons and β -decay. Their radioactivity has been investigated in works ⁽²⁻⁹⁾; however, up to the present time there is not only no satisfactory decay scheme, but also no satisfactory information on the composition of the γ -radiation. The possibility of contamination of $\text{Eu}^{152,154}$ by other rare-earth radioisotopes and the complex character of the decay of both isotopes make identification of the γ -transitions difficult.

Our investigations were carried out on a double-focusing β -spectrometer. Its main characteristics are: central radius 24.3 cm, luminosity 0.2%, source dimensions $1.5 \times 19.5 \text{ mm}^2$, width of the receiving slit (curved) 2 mm. In iron instruments of this type the resolving power and the profile of the instrumental line depend on the magnitude of the magnetic field and on the prehistory of the magnetic state of the iron. Broadening of the instrumental line lowers the accuracy of measurements. Conditions favorable for operation over a wide range of fields (14-270 oersted, energy of focused electrons 10-1500 keV) were created by a special procedure for preparing the magnet for operation. The spectrum of electrons with energies from 10 to 120 keV was recorded with the magnet preliminarily demagnetized, and that with energies from 100 to 1500 keV with a "trained" magnet. The training consisted in smoothly raising the excitation current from zero to a certain maximum value and lowering it to zero. The procedure was repeated until the residual magnetic field (11.8 oersted) remained constant. The results are illustrated in Fig. 1, where the Eu lines were taken from the corresponding series of measurements. The electron line with energy 1362.5 keV has a half-width of 0.32%. The detector consisted of two Geiger-Müller counters operating in coincidence.

The beta sources were prepared by electrolysis of europium chloride dissolved in ethyl alcohol. The electrolytic bath was a vertical through slit in a Plexiglas disk. On the lower side of the disk the slit had the dimensions of the source. Aluminum foil on a rubber backing served simultaneously as the bottom of the

Figure 1

Figure 1: Figure 1

bath and as the cathode. A platinum wire served as the anode. The duration of electrodeposition was 7-10 min. The mean thickness of the deposit was estimated from the concentration and volume of the solution. The method gives good deposits, is simple and economical. From 1 mg of the initial radioactive europium oxide, about 50 sources of various thicknesses and dimensions were prepared.

The internal-conversion spectrum of $\text{Eu}^{152,154}$ was recorded at a source age of more than 2 years. In the overwhelming majority of cases, both K -,

* The short-lived Eu^{152} was not investigated by us.

as well as L -conversion lines, whose energy is determined with an accuracy better than 0.1%. This made it possible to specify unambiguously the element in which the γ -transition occurs. To avoid energy losses of electrons in the active deposit and in the backing material, the electron spectrum from 10 to 200 keV was recorded with an average deposit thickness of 0.015–0.025 mg/cm², applied to aluminum foil 1.5 μ thick. The harder part of the spectrum was recorded with an average deposit thickness of 0.1–0.2 mg/cm² on 5 μ aluminum foil. The line energies were determined from the standard lines of Th (B + C + C''), Cs¹³⁷, Co⁶⁰ (10). The source holders were standardized, and each source had

Fig. 1. Shape of the instrumental line under different regimes of preparing the magnet for operation.

1 –training; 2 –demagnetization,

a separate holder. The limitation on accuracy in determining the energy associated with the iron of the magnet was eliminated by the fact that, by the method of replacing sources, the standard lines and some Eu lines were recorded as a single spectrum. In subsequent measurements such Eu lines served as reference lines. Interpolation was carried out with the aid of cubic parabolas, each of which requires the assignment of 4 points for its construction. The cubic parabolas were distributed so that portions of the spectrum overlapped by different curves.

Seventy-three internal-conversion lines and 13 Auger-electron lines were observed. The identified γ -transitions are presented in Table 1. In the column "Literature data" all γ -transitions observed in the decay of $\text{Eu}^{152,154}$ are indicated with the corresponding Z (in parentheses). Some transitions have been observed by many authors; only the most accurate values are cited. A discrepancy is noted in the energy values 122 and 123 keV, determined in the present work and by the crystal-diffraction method (9). It seems to us that the data given in (9) are too high.*

After 280 days an additional series of measurements was carried out, making it possible to trace the change in intensity of some lines whose assignment to $\text{Eu}^{152,154}$ is doubtful. It was established that transitions with energies 69.7 and 103.2 keV ($Z = 63$) accompany the decay of Gd^{153} ($T = 236$ days). The lines 583.1 (586.5) and 612.1 (615.5) keV accompany the decay of radioisotopes with a half-life approximately equal to the half-life of $\text{Eu}^{152,154}$ (the low-intensity line 810.6 (813.9) keV was not investigated). The 46.52-keV transition is tentative; the L_I and L_{II} lines may be obscured by the M -lines of samarium Auger electrons. In the β^- -decay of Eu^{155} with $T = 1.7$ years, transitions arise

* V. A. Romanov informed the authors of the results of measurements of the energy of these transitions on a prism β -spectrometer. His data, 121.75 ± 0.03 keV and 123.05 ± 0.03 keV, agree with ours.

in Gd^{155} , whose energies are 18; 84 and 102 keV ⁽¹²⁾. The observed lines 86, 46 and 105.3 keV (18.8 keV was not investigated) did not show a decrease in intensity in comparison with the lines of $\text{Eu}^{152,154}$. It should be assumed,

Table 1

Identification of conversion lines	Energy of γ -transitions, keV $Z = 62$	Energy of γ -transitions, keV $Z = 64$	Literature data
L_I, L_{II}, L_{III}, M	—	18.8	—
(L_{III}, M)	(46.52)	—	—
$K, L_I, L_{II}, L_{III}, M$	—	86.46	—
K, L_I, L_{II}, L_{III}	—	105.3	—
$K, L_I, L_{II}, (L_{III}), M, (N)$	121.77	—	(62) 122.31 ± 0.04 (9)
$K, (L_{II}), L_{III}, (M), N$	—	123.02	(64) 123.54 ± 0.09 (9)
K, L, M	244.66	—	(62) 244.64 ± 0.08 (9)
K, L, M	—	248.04	(64) 247.7 (6)
—	—	—	(64) 336.4 (8)
K, L, M	—	344.32	(64) 344.34 ± 0.23 (9)
K, L	—	411.23	(?) 410 (7)
K, L, M	444.23	—	(64) 448.4 (3)
—	—	—	(62?64) 518.5 (522.0) (8)

Identification of conversion lines	Energy of γ -transitions, keV $Z = 62$	Energy of γ -transitions, keV $Z = 64$	Literature data
K	583.1 or 586.5	—	(62?64) 583.5 (587.0) ⁽³⁾
K	612.1 or 615.5	—	(62?64) 608.3 (611.8) ⁽⁸⁾
—	—	—	(62?64) 655.3 (658.8) ⁽⁸⁾
K	676 or 679	—	—
K, L	689.1	—	(62?64) 687.1 (690.6) ⁽⁸⁾
K, L	—	692.5	—
K, L	720.2	—	(62) 720 ⁽⁷⁾
K, L	723.6	—	—
K	—	757.7	—
K, L	—	779.5	(?) 778 (?)
K	810.6 or 813.9	—	—
K, L	868.5	—	(62?64) 868 (871) ⁽³⁾
K, L	—	873.7	—
K, L	964.8	—	(62) 964 ⁽⁷⁾
K, L	—	996.6	—
K, L	—	1005.4	—
K, L	1086.6	—	(62) 1086 ⁽⁷⁾
K, L	1112.7	—	(62) 1116 ⁽⁷⁾
K, L	1272.7 or 1276.0	—	(?) 1280 ⁽⁸⁾
K, L	1409.4	—	(64) 1415 ⁽⁷⁾
K	$Z = 63$	69.7	(63) 72 ± 8 ⁽¹¹⁾
$K, L_I L_{II}, M$	$Z = 63$	103.2	(63) 100 ± 4 ⁽¹¹⁾

that the indicated lines belong to $\text{Eu}^{152,154}$ or to Eu^{155} , if the lifetime of the latter is comparable with the lifetime of $\text{Eu}^{152,154}$. The identification of four low-intensity conversion lines has not been carried out: 41.19; 43.73; 48.90 and 51.29 keV, with the last two lines belonging to short-lived isotopes.

Fig. 2

Fig. 2 shows some conversion lines of interest. In paper (6) the existence in Gd^{154} of a transition with energy 247.7 keV was indicated. In subsequent studies (7) this transition was ignored. According to our data, the 248.04-keV transition is evident. Its K -line coincides with the K -line of the 244.66-keV transition (see Fig. 1). An analogous situation occurs for the transitions 689.1 and 692.5 keV. The correspondence of the energies of the K - and L -lines, the

absence of a decrease in the relative intensity of the L -lines in an additional series of measurements, and the intensity ratio $\Sigma K/\Sigma L \simeq 7.3$, which does not contradict the theoretical multiplicities,* lead to the conclusion that neither of these two transitions can be ignored. In the case of the 868.5- and 873.7-keV transitions, however, the complexity of the K -line raises no doubts.

In the new nuclear data for 1956 (13), a decay scheme for long-lived Eu^{152} appeared. The following excited levels are indicated: 122; 366; 1085; 1232; 1527; 1576; 1635 keV in ${}_{62}\text{Sm}^{152}$ and 344; 752; 1122; 1444; 1584 keV in ${}_{64}\text{Gd}^{152}$. The exact values of the transition energies obtained in our work may serve as a good check of this system of levels, since it contains cascade and direct transitions. The excited states in Sm^{152} : 121.77; 366.43; 1086.6; 1234.7 and 1531.0 keV, apparently exist. However, one may assume the existence of an additional combination of cascade and direct transitions: 444.23; 244.66 and 689.1 keV; 689.1; 720.2 and 1409.4 keV; 689.1; 121.77 and 810.6 keV; 689.1; 583.1 and 1272.7 keV, which are not explained by the proposed level scheme. The transitions 550 and 1210 keV in Sm^{152} , as well as 1100 and 1240 keV in Gd^{152} , cited in (13), were not observed by us.

Our data make it possible to establish the following excited levels for ${}_{64}\text{Gd}^{154}$: 123.02; 371.06; 996.6 and 1128.6 keV. Here there are cascade and direct transitions: 123.02; 873.7 and 996.6 keV; 248.04, 757.7 and 1005.4 keV.

The pattern of levels of ${}_{62}\text{Sm}_{90}^{152}$ and ${}_{64}\text{Gd}^{154}$ recalls the structure of rotational bands. A careful consideration of this question, however, does not appear possible because of the absence of reliable theoretical coefficients of internal conversion on the L -shell for the given Z and the weak sensitivity of the multipolarity of γ -transitions to the relative intensity of the K - and L -conversion lines.

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* To estimate the ratio of the coefficients of internal conversion on the K - and L -shells, Rose's data (10) were interpolated; $Z = 63$, $K/L \simeq 8.0(E1)$; $6.7(E2)$; $6.7(M1)$; $6.6(M2)$.

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