RADIATIONS FROM Eu^{145}, Eu^{146} *AND* Eu^{147}

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The europium and gadolinium fractions separated from Ta irradiated by 680-Mev protons were investigated by means of a magnetic spectrometer and a luminescent γ spectrometer. New γ transitions have been detected. The relative intensities of hard γ rays from Eu^{146} have been determined. More precise values have been determined for the energies as well as intensities of the conversion lines due to previously observed γ transitions in the decay of Eu^{145} ($T_{1/2}$ = 5.6 ± 0.3 days), Eu^{146} ($T_{1/2}$ = 4.6 ± 0.3 days), and Eu^{147} ($T_{1/2}$ = 25 days). The conversion electron spectrum of the europium fraction was measured between ~ 20 and ~ 2600 kev, and the hard γ ray spectrum was investigated up to 3500 kev. The level schemes of Eu^{145}, Eu^{146} and Eu^{147} are discussed.

WE investigated the radiations from the europium and gadolinium fractions, separated from tantalum bombarded with 680-Mev protons, using a Ketron-type[1] magnetic spectrometer ($\Delta H\rho/H\rho \sim 0.5\%$) and a scintillation γ spectrometer (resolving power 7.5% at the 662-kev γ line of Cs^{137}). The new lines were identified by the time variation of their intensity in both the europium and in the gadolinium fractions.

RADIATION FROM THE Eu^{145} NUCLEUS

In addition to observing in the conversion-electron spectrum of the europium fraction the conversion lines belonging to Eu^{146} ($T_{1/2}$ = 4.6 days), Eu^{147} ($T_{1/2}$ = 25 days) and Eu^{149} ($T_{1/2}$ ~ 100 days), which we reported earlier,[2] we observed also the conversion lines due to an europium isotope with a half-life 5.6 ± 0.3 days.[3,4] The energy of the corresponding nuclear transitions and the relative intensities of the conversion lines are listed in Table I.

The lines belonging to the europium with the 5.6-day half life could be distinguished reliably from the Eu^{146} lines ($T_{1/2}$ = 4.6 days). In the gadolinium fraction, the Eu^{146} lines grew stronger; whereas the lines indicated in the table were absent. The gadolinium fraction, containing Gd^{146} ($T_{1/2}$ ~ 45 days), was separated twelve hours after the end of irradiation of the target, and did not contain Gd^{145} ($T_{1/2}$ = 24 min). In addition, we observed that Sm^{145} accumulated in the europium fraction.[4] For these reasons, we ascribed the γ lines listed in Table I to the decay of Eu^{145}. This interpretation agrees with the data of Rasmussen et al.,[5] who assigned a half-life $T_{1/2}$ = 5 days to Eu^{145}. In a recently published paper,[6] only one γ transition of 180 kev energy was observed for Eu^{145}. Grover[7] ascribes the ~ 0.53-, 0.645-, and 0.890-Mev γ transitions to the decay of Eu^{145}, and leaves doubtful the weak 1.30- and 1.65-Mev γ transitions.

Table I. Energy of Transitions and Relative Intensities I of the Conversion Lines of Eu^{145}

E_γ, kev	Observed conversion lines	$100 \cdot I_K/I_K$ (894 kev)	I_K/I_L
110.3±0.5	K, L, M	750±50	6±1
191±1	K	20±5	—
543±2	K	15±3	—
656±3	K, L	13±2	—
766±4	K	6±1	—
894±4	K, L, M	100	5.9±0.5
1663±5	K, L	4.5±0.5	5.8±0.5
1830±8	K	0.4±0.1	—
2001±6	K, L	2.1±0.3	—

We have also made preliminary measurements of the coefficient of internal conversion of the 894-kev γ transition by the method described in reference 8. The coefficient of internal conversion α_K is determined by measuring with a magnetic spectrometer the number of conversion electrons and (by the photoelectrons) the number of γ quanta emitted from one and the same source. The value obtained for α_K is

$$\alpha_K = (2.2 \pm 0.4) \cdot 10^{-3}.$$

This value of α_K, as well as the ratio of the intensities of the K and L lines, make it possible to classify the 894-kev transition as E2.

*Deceased.

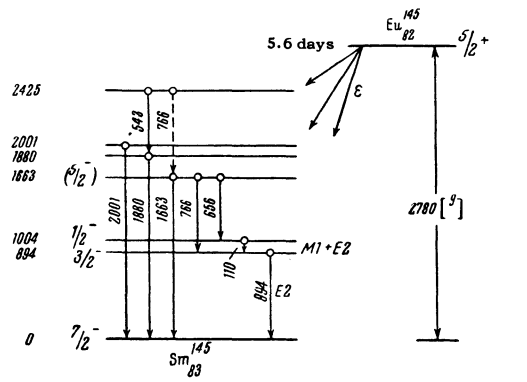

FIG. 1. Proposed scheme of the transitions in Sm^{145}.

Figure 1 shows the proposed scheme of the transitions in Sm^{145}. It is based essentially on energy data. The scheme includes all the transitions which we have observed, except for the transition with energy E_γ = 191 kev. The 766-kev transition is energetically feasible also between the 1663 and 2425 kev levels (shown dotted in the figure).

The nucleus Sm^{145} has only one neutron on top of the filled shell, and apparently fits the Mayer scheme. According to this model, the spin and parity of the ground state should be $7/2^-$ or $9/2^-$. We assume that the spin and parity of the ground state of Sm^{145} is $7/2^-$. The first excited level has an energy 894 kev. The direct transition from this level is of the E2 type (from the measurement of the coefficient of internal conversion). On can therefore assign spin and parity $3/2^-$ to the first excited level. It is apparently necessary to ascribe to the second excited 1004-kev level a spin and parity $1/2^-$. This follows from the multipolarity of the transition with E_γ = 110 kev, found to be M1 + E2 by the I_K/I_L ratio (Table I), and also from the absence of a direct 1004-kev transition to the ground state.

RADIATION OF THE Eu^{146} NUCLEUS

We have observed several new γ lines of Eu^{146}, both by conversion electrons and by γ rays. The lines attributed to Eu^{146}, observed in the gadolinium fraction, first built with a period of approximately 5 days, and then decayed with the half-life of the parent Gd^{146} ($T_{1/2}$ = 45 days). In the europium fractions, the lines constantly decayed with a half life 4.6 ± 0.3 days.

Table II lists the energies of the nuclear transitions, the relative intensities of the conversion lines, and the ratios I_K/I_L for the most intense lines, as well as the relative intensities of the γ rays.

We also measured the relative intensities of the 635- and 748-kev γ rays (by the photoelectrons)

$$I\,(635\,\text{kev})/I(748\,\text{kev}) = 0.7 \pm 0.1.$$

Gold foil ($\sigma \sim 7$ mg/cm^2) and uranium ($\sigma \sim 7$ mg/cm^2) foils were used as emitters.

Table II. Transition Energies and Relative Intensities of Conversion Electrons and γ Rays from Eu^{146}

E_γ, kev	Observed conversion lines	$100\, I_K/I_K$ (748 kev)	I_K/I_L	I_γ/I_γ (748 kev)
188±1	K	50±20	—	—
399±1	K, L	6±1	—	—
413±1	K, L	4±1	—	—
432±1 *	K, L	19±1	5.0±0.5	—
635±3	K, L	75±5	5.5±0.5	75
667±3	K, L	14±2	—	} 24
705±4	K	10±1	—	
748±2	K, L, M	100	5.8±04	100
(900±5)?	K	(<5)	—	(9)
1061±5	K	1,0±0.2	—	7
1154±5	K	0.7±0,2	—	} 7
1180±5	K	0,5±0.1	—	
1298±5	K, L	1,1±0,2	7±1	3
1384±5	K	0,5±0.2	—	2
1412±7	K	0.3±0.1	—	2
1451±7	K	~0,3	—	2
1539±7	K, L	0,6±0.2	6±1	6
1765±8	K	<0,3	—	3
2100	—	—	—	2
2180 ?	—	—	—	1
2300	—	—	—	1
2400	—	—	—	1
2540	—	—	—	~0.7
2670	—	—	—	~0.2
2860	—	—	—	≲0.2
3100	—	—	—	<0.2

*The 423-kev transition was first observed by Zh. Zhelev.[10]

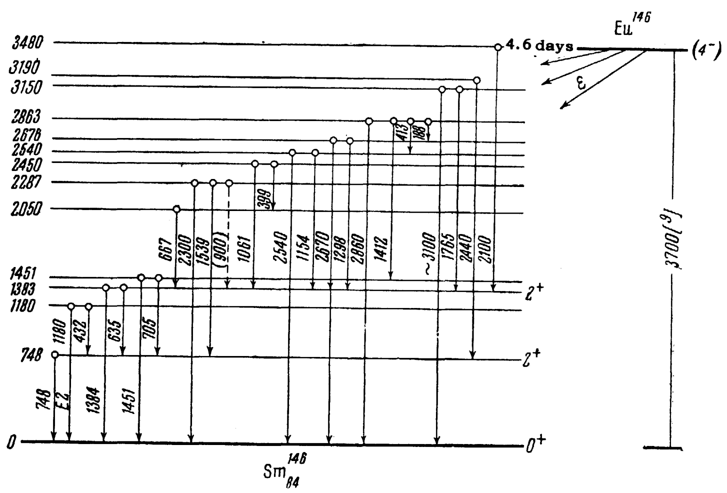

FIG. 2. Proposed scheme of the transitions in Sm^{146}.

Our results do not agree with the data of French workers,[6] who ascribed to Eu^{146} γ rays with energies 125 and 570 kev, but are in agreement with the work Funk et al.[11]

Figure 2 shows the proposed scheme of transitions in Sm^{146}. This scheme includes all the nuclear transitions which we have observed, except the transition with $E_\gamma = 2180$ kev. The decay scheme is based essentially on energy considerations. For most transitions the energy balance holds within 1 — 3 kev. In the construction of the scheme we used the cascade γ transitions, determined by Alexandrov et al.[12] and by Berlovich et al.,[13] namely: 745 — 635 — 667, 745 — 635 — 900, 745 — 635 — 1060, 748 — 635 — 1300, 745 — 635 — 1800, 745 — 1550, 745 — 635 — 2100, and 745 — 2400 kev; the 635-kev γ transition does not agree in time with the 1550- and 2400-kev transitions.

Sm^{146}_{84} is an even-even nucleus and is apparently spherically symmetrical (there are only two neutrons on top of the filled shell). The characteristic of the ground state is 0^+ and the energy of the first excited state of the nucleus is 748 kev. The latter is derived from the following considerations: first, from the intensities of the γ transitions (this is the most intense transition), second from the presence of a coincidence cascade, and third from the systematics of the first excited levels of the even-even nuclei in the region of atomic numbers close to 82.

The characteristic of the first excited state is 2^+. This follows both from the systematics of the even-even nuclei, and from the experimentally determined multipolarity of the 748-kev transition (the ratio $I_K/I_L = 5.8 \pm 0.4$ and the coefficient $\alpha_K = (4.1 \pm 0.6) \times 10^{-3}$ unequivocally point to an E2 transition).

The second excited level of Sm^{146}, with energy 1180 kev, is introduced only on the basis of energy considerations. This level is "de-excited" by two transitions: $E_\gamma = 432$ and $E_\gamma = 1180$ kev.

The 1383-kev level must apparently be assigned spin and parity 2^+. This follows from the presence of a direct transition to the ground state, the multipolarity of which is determined by our data to be E2 or E2 + M1, and also from experiments on correlation,[11] by which the 1384-kev level cannot be assigned a spin 4^+.

RADIATION OF THE Eu^{147} NUCLEUS

We have investigated the radiation of Eu^{147} previously.[2] In the present investigation we observed two additional new γ transitions, with energies 957 and 1080 kev. These transitions were observed both in the europium and in the gadolinium fractions. In the latter fraction, the observed lines first built up with a period ~ 1.5 days, and then decayed with a period of 25 days. Table III lists the transition energies and the relative intensities of the new conversion lines referred to the 187.6-kev line.

Energies of new γ transitions and relative intensities I of the conversion electrons of Eu^{147}

E_γ, kev	Observed conversion lines	$100 \cdot I_K/I_K$ (197.5 kev)	I_K/I_L
197.5±0.5	K,L,M	100	4.0±0.5
957±4	K	0.4±0.1	—
1080±4	K,L	0.6±0.2	3.2±0.6

The scheme of the $Eu^{147} \rightarrow Sm^{147}$ decay was studies by us earlier. We are now able to supplement this scheme with new transitions, with energies 957 and 1080 kev (see Fig. 3).

The spin of the ground state of Sm^{147} was determined experimentally as $7/2$ while the Mayer model predicts for the ground state of Sm^{147} spin

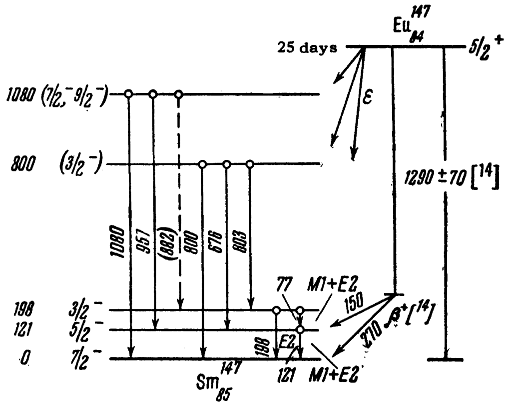

FIG. 3. Decay scheme of Eu^{147}.

and parity values of $7/2^-$ or $9/2^-$.

The spin and parity of the first excited 121-kev level is $5/2^-$, since the E_γ = 121 kev transition is of the M1 + E2 type. The spin and parity of the second excited level is $3/2^-$; this agrees with the multipolarity of the 77- and 198-kev transitions. The 800- and 1080-kev levels can apparently be assigned, with certain reservations, spins and parities of $3/2^-$ and $7/2^-$ or $9/2^-$, respectively.

An analogous placement of the levels is observed in the case of Nd^{147} (reference 15), which differs from Sm^{147} by two protons and two neutrons. The 900-kev transition observed in reference 14 was not observed by us distinctly, and are therefore shown dotted on our scheme.

We have also observed weak conversion lines corresponding to γ transitions with energies 1139, 1167, 1527, and 2050 kev. These lines, present in the gadolinium and europium fractions, have not been identified in view of their low intensity.

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