TWO-CASCADE GAMMA TRANSITIONS IN THE Nd^{144} *NUCLEUS, ACCOMPANYING THE CAPTURE OF THERMAL NEUTRONS*

V. R. BURMISTROV and V. P. RADCHENKO

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The γ radiation accompanying the capture of the thermal neutrons by the Nd^{143} nucleus was investigated by the sum-coincidence method[1] with scintillation counters. Four two-cascade γ transitions have been determined. An energy level scheme that includes the well-known 0.69-Mev level in the Nd^{144} nucleus is proposed. The corresponding states are identified by the relative cascade intensities.

THE γ radiation that accompanies the capture of thermal neutrons by a natural mixture of neodymium isotopes was investigated by the so-called sum-coincidence method.[1] This method consists of feeding the pulses from two counters in parallel to a coincidence circuit and to a linear pulse-adding circuit. If the pulses coincide in time and their sum corresponds to the energy of the nuclear level, from which the investigated two-cascade transition originates, then the pulses from one of the counters are let through for analysis. The scintillation counters used were NaI (Tl) crystals measuring 40 × 40 mm. The apparatus employed was the same as described earlier,[2] except that four crystals pairwise connected in parallel were used.

Neodymium in the form of oxide was placed in an aluminum cartridge weighing 0.26 g. Two targets with 0.74 and 0.42 g of oxide were used. Chemical analysis showed that the investigated substance contained 99.1% of neodymium oxide and 0.2% of oxides of other rare earths.

The greatest contribution to the absorption of thermal neutrons by a natural mixture of neodymium is made by Nd^{143}, and the capture is due to a single resonance with negative energy.[3] The binding energy of the neutron in the Nd^{144} nucleus, equal to 7.8 Mev,[4] is the highest among the binding energies of the other neodymium isotopes, so that the γ transitions are easier to identify.

In the investigation of the γ radiation that arises during the capture, the 'window' of the control channel was set to the binding energy of the neutron in the Nd^{144} nucleus, and the coincidence spectrum was investigated in the analyzed channel. Figure 1 shows a sample of a neodymium γ spectrum, obtained by the sum-coincidence method with the window of the control channel set to 7.8 Mev; the width of the window is 0.55 Mev. A similar spectrum is obtained in a pulse analyzer in a single step. In order to investigate the unresolved region of energies below 1 Mev, the gain of the analyzed channel is increased and additional measurements are made. The spectrum given here is the average of four measurements, each lasting approximately 12 hours. The figure shows also the random-coincidence spectrum, obtained by introducing a delay of 6×10^{-7} sec in one of the channels of the coincidence circuit ($\tau = 0.8 \times 10^{-7}$ sec).

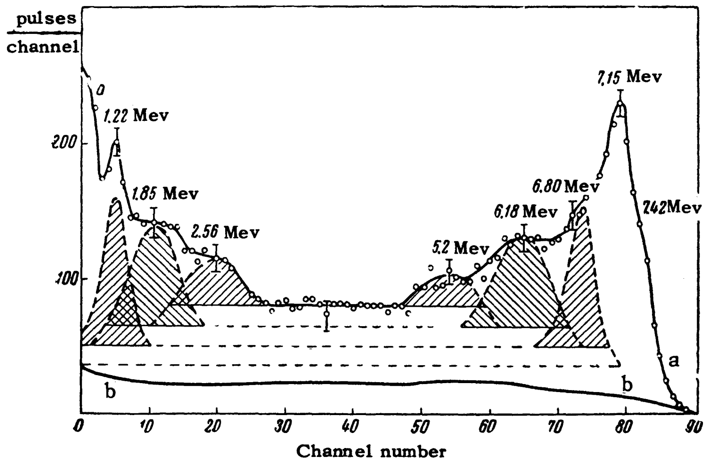

FIG. 1. a – Coincidence spectrum of captured γ radiadiation of Nd^{144}, occurring when the capture is in the energy range 1–8 Mev (rms errors); b – spectrum of random coincidences under the same conditions.

The dotted lines in Fig. 1 shows the resolution of the spectrum into components. In determining the relative intensities, we started out with the shaded areas and used formula (3) of the paper by Hoogenboom.[1] We calculated here the efficiency of registration of γ rays of corresponding energies, as well as the photo contribution of the crysstals, determined experimentally up to 2.76 Mev and extrapolated to higher energies.

In the resolution of the γ spectrum into components, we were guided by the fact that each pair of peaks corresponding to the two-cascade transition is accompanied by a more or less uniform momentum distribution between the peaks. The entire spectrum we obtained consisted essentially of four cascades of approximately equal intensity. Therefore the area under the flat part of the spectrum between 3 and 5 Mev (after subtracting the random coincidences) was cut in four horizontal parts of equal thickness. There is no need for a more exact subdivision in our case. Each of these parts was assumed to be the pulse distribution between a pair of corresponding peaks. Then, starting with the internal pair of peaks at 2.56 and 5.2 Mev, we plotted the distributions of the pulses for all pairs of peaks.

As the result of such an analysis of the γ spectrum, obtained by the coincidence method, we determined the following two-cascade transitions with a total energy of about 7.81 Mev (all the energies are in Mev): $(7.42 \pm 0.07) - (0.48 \pm 0.02)$, $(7.15 \pm 0.10) - (0.69 \pm 0.03)$, $(6.80 \pm 0.10) - (1.22 \pm 0.03)$, $(6.18 \pm 0.15) - (1.85 \pm 0.12)$, and $(5.2 \pm 0.15) - (2.56 \pm 0.15)$. The coincidence spectrum contains also a peak of energy (0.34 ± 0.02) Mev, which should be supplemented by a (7.57 ± 0.18)-Mev peak, which is not observed, however, possibly because of the insufficient resolution of the apparatus. The intensities of the aforementioned γ ray cascades are related as 0.3: 0.8: 1: 1.4: 1.1: 0.1, respectively. The error in the determination of the relative intensities, amounts to 40%.

The 7.42 — 0.48 Mev and 7.57 — 0.34 Mev cascade transitions do not belong to Nd^{144}, for on changing the width of the control channel (i.e., on changing the width of the energy region responsible for the transitions) the relative intensities of these cascades change whereas all other cascades remain constant, within the accuracy limits of the experiment. It is possible that the observed 7.42 — 0.48 Mev cascade is due in fact to the 7.0 — 0.46 Mev cascade of Nd^{146} and appears because the (7.48 ± 0.18) Mev binding energy of the neutron in Nd^{146} (reference 5) is close to the investigated energy (7.81 Mev) of Nd^{144}. The cascade in which the 0.34-Mev γ line participates is possibly due to the γ transitions of Sm^{150} through the 0.337-Mev energy level. The samarium content of the investigated substance was not measured but its presence among the rare-earth oxides is not excluded.

Assuming that in all the observed cascades a high-energy γ quantum, is emitted ahead of a low-energy one, we have constructed a scheme for the γ transitions of Nd^{144}. The proposed scheme of transitions and levels is shown in Fig. 2.

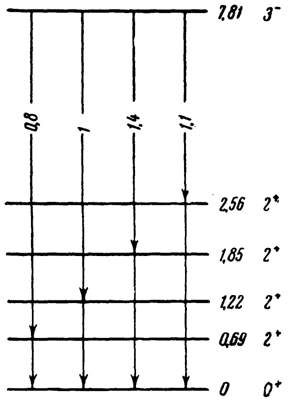

FIG. 2. Proposed scheme of levels and two-cascade γ transitions of Nd^{144}. The numbers on the arrows indicate the relative intensities (the energies of the corresponding levels are in Mev).

Starting with the fact that the relative intensities of the cascades are close to each other, we assume that all the γ-ray cascades have a similar character. The spin and parity of the initial state of Nd^{144}, formed after capture of thermal neutrons, have been determined as 3^- (reference 4), and the characteristics of the 0.69-Mev level are known to be 2^+, so that the transition between these states will be of type E1, while the 0.69-Mev transition to the ground state will be of type E2. Analogously, all the remaining two-cascade transitions from the initial state, shown in the figure, should also be of the E1 → E2 type, so that the states of all the intermediate levels are uniquely determined as 2^+. It is natural to assume that all these levels are identical in nature.

A few words concerning the levels 1.22 and 1.85. Firsov and Bashilov[6] have noted a 1.1 — 1.7 Mev γ-ray cascade accompanying the β decay of Pr^{144}. We have also indicated[2] the possibility of a cascade of γ rays with close energies, namely 1.2 — 1.8 Mev. Searches for these cascades by Porter and Day[7] were not successful. As can be seen from the present investigation, 1.22 and 1.85 Mev levels appear in Nd^{144}, and these may be responsible for the possible 1.2 — 1.8 or 1.8 — 1.2 Mev cascade from the ~3-Mev level in the β decay of Pr^{144}.

Note added in proof (August 4, 1960). It is possible that the 6.8–1.2 Mev cascade is partly due to an impurity of gadolinium in the investigated material, since a similar two-cascade transition was observed in gadolinium, as indicated in a paper by Bartholomew, Campion, and Knowles, presented to the Second All-Union Conference on Nuclear Reactions (Moscow, 1960).

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114