THE CONTRIBUTION OF COLLECTIVE MOTION TO THE LIFTING OF *l*-FORBIDDENESS

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The lifetimes of M1 transitions of the type $g_{7/2} \rightarrow d_{5/2}$ have been studied in the spherical nuclei Eu^{147}, Eu^{149}, and Eu^{151}, which just precede the deformation region. The half-lives of the first excited states $(g_{7/2})$ of these three nuclei are equal respectively to $(1.8 \pm 0.2) \times 10^{-10}$, $(3.2 \pm 0.2) \times 10^{-10}$ and $(3.4 \pm 0.2) \times 10^{-9}$ sec, and the M1 delay factors are 115, 78, 47, in contrast to the average value of ~ 300 for other known single-proton M1 transitions which are *l*-forbidden. The small values of the observed delay factors and their monotonic decrease as we approach the deformation region seem to indicate an increasing contribution of the collective motion and a corresponding weakening of the *l*-forbiddenness.

1. INTRODUCTION

In a preceding paper [1] the lifetimes of corresponding $h_{11/2}$ levels in the spherical nuclei Eu^{147}, Eu^{149} and Eu^{151} were studied, and it was shown that the matrix elements for M2 and E3 radiative transitions change smoothly when a pair of neutrons is added. In the present work we have investigated the lifetimes of first excited states of these same nuclei, which in all three cases give rise to protonic M1 transitions of the type $g_{7/2} \rightarrow d_{5/2}$, which are forbidden by the angular momentum selection rule ($\Delta l = 2$).

In all known cases, *l*-forbidden M1 transitions have been observed near closed shells, and the values of the delay factors for proton transitions group very well around the average value $\bar{F} = \tau_{exp}/\tau_{Weissk.} = 300$; at the same time the probabilities for allowed proton transitions ($\Delta l = 0$) agree much better with the single-particle Weisskopf estimates (the F factor is small).

In the literature various types of nucleon interaction have been considered as causing the occurrence of *l*-forbidden transitions: meson-exchange interaction, [2] spin-exchange interaction, [3] spin-exchange coupling, [4] etc. The most successful treatment is that based on the assumption that *l*-forbidden transitions appear because of configuration mixing in the initial or final state of the radiating particle. [5] Since *l*-forbidden transitions are observed in the immediate vicinity of closed shells, it was natural to assume that the collective effects which are treated in the unified model of the nucleus [6] should not play an important part in the lifting of the forbiddenness.

The nuclei studied in the present work lie just before the region of large deformations, where collective motion manifests itself most strongly. One might expect that the influence of collective effects would significantly affect the probabilities of *l*-forbidden transitions even for neutron numbers below the critical value (N = 89), where the equilibrium shape is still spherical.

2. DESCRIPTION OF EXPERIMENTS

The 229.5-keV transition in Eu^{147}. To study the lifetime of the 229.5-keV level in Eu^{147}, we used the gadolinium fraction separated from a tantalum target [1] irradiated for two hours with 660-MeV protons in the Joint Institute synchrocyclotron. During the first few days after irradiation, the 35 hour activity of Gd^{147} predominated, converting to Eu^{147} by electron capture. The measurements were made with a multichannel time analyzer using time to pulse height conversion [7] and a two-crystal scintillation spectrometer with sodium iodide crystals (d = 40 mm, h = 30 mm), and a type FÉU-33 photomultiplier.

The "windows" of the scintillation spectrometer were set on the photopeak of the cascades formed by the 396- and 229.5-keV γ quanta, the exact setting of the windows being determined by a preliminary study of coincidences when one "window" is left fixed and the window in the other channel is varied. To reduce the load on the FÉU photomultiplier, the characteristic x radiation was reduced by a phosphor bronze filter. The lifetime of the level was determined from the shift of the center of gravity of the coincidence curve [8] relative to the reference curve for "prompt" coinci-

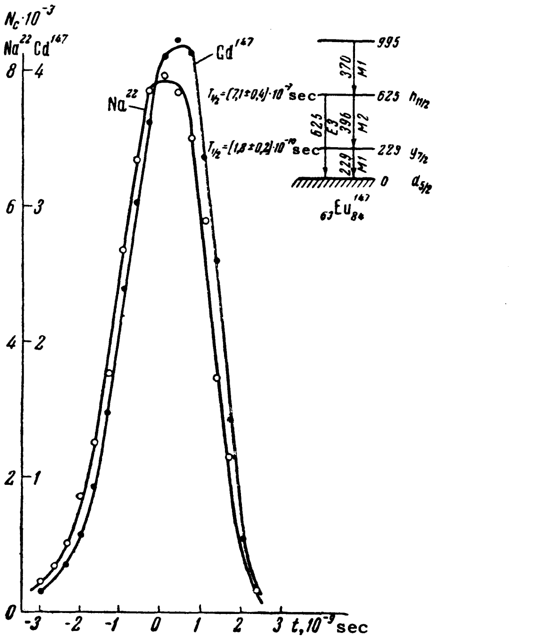

FIG. 1. Coincidence curves (one of six series) for sources of Gd^{147} (decay scheme shown in insert) and Na^{22}, taken with a pair of NaI (Tl) crystals with the same energy intervals.

dences, which was obtained by recording the annihilation quanta from a Na^{22} source (Fig. 1). A correction (~ 5%) was made to the value of the shift for the contribution of "fast" coincidences, which correspond to hard γ transitions in Eu^{147} and Sm^{146}, which give "tails" of their Compton distributions in the region of the photopeaks from the 229.5- and 396-keV γ quanta.

The half-life was found to be

$$T_{1/2} = (1.8 \pm 0.2) \cdot 10^{-10} \text{ sec}.$$

The 150-keV transition in Eu^{149}. Nine to ten days after irradiation, when the Gd^{147} had practically all decayed, we carried out a chromatographic purification of the source of the accumulating Eu^{147} with a period of 24 days and other isotopes of europium. The remaining activity was due mainly to Gd^{149}, which converts to Eu^{149} with a half-life of 9.3 days by electron capture. Since the 150-keV transition has a sizable conversion coefficient (total conversion coefficient $\alpha_{tot} = 0.63$), to improve the time resolution it was convenient to use a thin crystal of stilbene (~ 0.5 mm) for recording the coincidences between the conversion electrons from this transition and the cascade γ rays at 346 keV, which were recorded at their photopeak in a sodium iodide crystal. To obtain a reference curve, $\beta\gamma$ coincidences were taken with a Co^{60} source, and the lifetime of the 150 keV level was determined from the shift of the center of gravity of the coin-

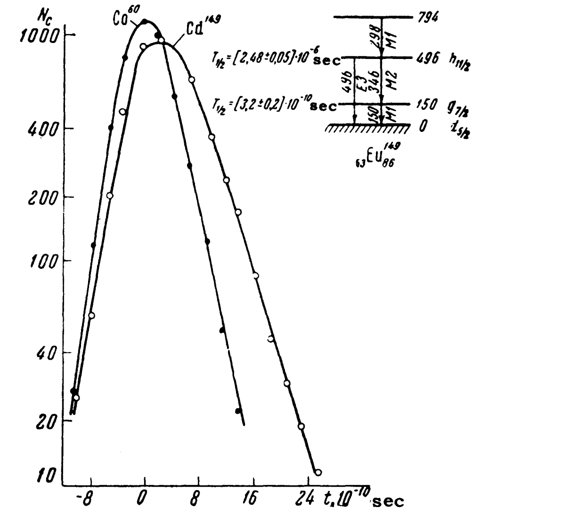

FIG. 2. Coincidence curves (one of five series) for Gd^{149} and Co^{60} sources, taken with a pair of stilbene crystals.

cidence curves obtained with Gd^{149} and Co^{60}. In another variant of the experiment, 346-keV γ rays were recorded using a packaged stilbene crystal (d = 35 mm, h = 20 mm); this permitted an improvement of the time resolution to such an extent ($2\tau_0 \sim 10^{-9}$ sec) that the exponential shape began to be apparent on the right side of the coincidence curve for the Gd^{149} source (Fig. 2). Treating this branch of the curve by least squares gave

$$T_{1/2} = (3.2 \pm 0.2) \cdot 10^{-10} \text{ sec}.$$

This result coincided with the average value from numerous measurements using the center of gravity method.

The 21.7-keV transition in Eu^{151}. The source of Gd^{151}, which decays by electron capture to Eu^{151} with a period of ~ 170 days, was obtained by separation from the terbium fraction (the irradiation time of the tantalum target in the proton beam was ~ 4 hours), 25—30 hours after the irradiation, when most of the Tb^{151} nuclei ($T_{1/2}$ = 20 h) have converted to Gd^{151}, while the Tb^{153}, which decays with a half-life of 60 h to Gd^{153}, has only partially decayed. This improved the ratio of Gd^{151} to Gd^{153} ($T_{1/2}$ = 230 d) in our source in favor of Gd^{151}.

For the measurements we used a two-crystal scintillation coincidence spectrometer with a variable delay line.[9,10] The multichannel time analyzer could not be used in this case because of the limited region of linearity, which prevented us from following the decay curve over several periods.

Coincidences were recorded between the K conversion electrons from the 175-keV transition ($\alpha_K = 2.5$) and the L, M, and N electrons from

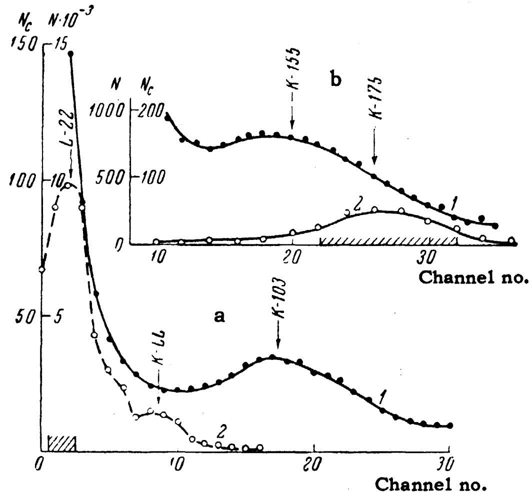

FIG. 3. Spectrum of conversion electrons from a Gd^{151} + Gd^{153} source. a) region of the 21.7-keV transition: 1) singles spectrum, 2) spectrum of electrons coincident with the K line of 175 keV; b) region of the 175-keV transition: 1) singles spectrum, 2) spectrum of electrons coincident with the 21.7 keV L conversion line for a delay of 20 nsec. The cross-hatching on the abscissa shows the position of the "windows" of the pulse analyzers in the time measurements.

the 21.7-keV transition (with energies of 13.5, 19.7, and 21.5 keV, respectively). Thin stilbene crystals were used for detection. The conversion electrons from the 175-keV transition are in coincidence not only with the conversion electrons from the 21.7-keV transition, but also with Auger electrons (which accompany the conversion process). The energy of the most intense component of the Auger electrons, which accompany the K shell conversion of the 175-keV transition (K-LL) is ~ 32 keV. Because of the "softening" in scattering in the source, and also because of insufficient energy resolution of the scintillation spectrometer, these electrons partially fall in the energy region of the conversion electrons. Coincidences with Auger electrons give a fast curve; the contribution of these coincidences in establishing the setting of the "window" of the analyzer (the region of the L electrons) is insignificant (Fig. 3).

Figure 4 shows coincidence curves for the sample and a reference source. The reference curve was obtained by recording $\beta(e + \gamma)$ coincidences from a source of Hg^{203}, for which the half-life of the intermediate level is known: $T_{1/2} = (2.9 \pm 0.3) \times 10^{-10}$ sec. [11]

Analysis of the exponential branch gave the value $T = (3.4 \pm 0.2) \times 10^{-9}$ sec.

From the shift of the center of gravity, after making corrections for the lifetime of the intermediate level of Tl^{203}, we obtain $T_{1/2} = (3.3 \pm 0.2) \times 10^{-9}$ sec.

3. CONCLUSIONS

The results of the measurements are presented in the table. In calculating the half-lives of the radiative transitions, (col. 4) we used the values of the total internal conversion coefficients (col. 3) from the data of Adamchuk, Bashilov, and Preobrazhenskiĭ [12] for Eu^{147} and Eu^{149}, and those of Achor et al [13] for Eu^{151}.

The data given in column 5 show that the delay factors F in all three cases are considerably smaller than the average value for other proton transitions which are l-forbidden ($\overline{F} = 300$). In addition there is a clear smooth decrease of F as we approach the deformation region. The minimum value (47) of the F factor for Eu^{151}, which contains 88 neutrons and is just at the edge of the deformation region, is only a few times greater than the value for proton transitions which are l-allowed.

Groshev and Demidov [14] pointed out that the similar values of the matrix elements for the previously known protonic M1 transitions which are l-forbidden may be related to the fact that they all

Nucleus	E_γ, keV	α_{tot}	$T_{1/2\gamma}$, sec	F
$_{63}Eu^{147}$	229.5	0.195	$2.20 \cdot 10^{-10}$	115
$_{63}Eu^{149}$	150	0.63	$5.20 \cdot 10^{-10}$	78
$_{63}Eu^{151}$	21.7	29.1	$1.02 \cdot 10^{-7}$	47

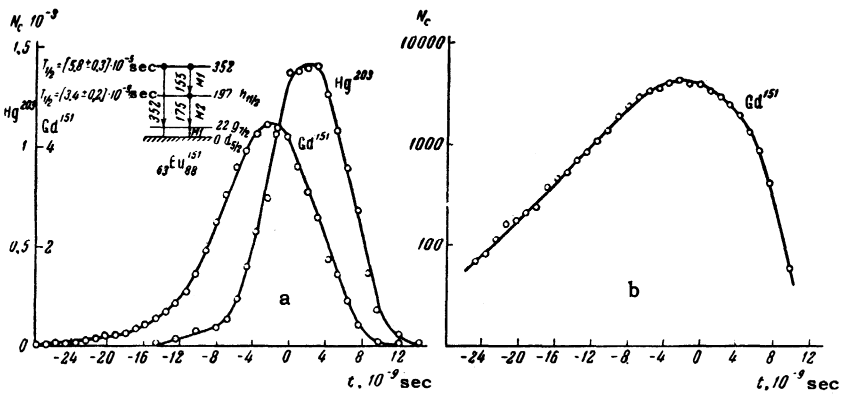

FIG. 4. Coincidence curves for Gd^{151} and Hg^{203} sources, taken with the energy intervals shown in Fig. 3, in ordinary (a) and logarithmic (b) scale. The source was deposited on a 10μ thick aluminum backing, which freely transmits the K conversion electrons of the 175-keV line.

occur between identical configurations: $g_{7/2} \rightleftarrows d_{5/2}$. The assignment of the three transitions which we have studied to the type $g_{7/2} \rightleftarrows d_{5/2}$ follows from the data of Adamchuk et al.[12] and from [1], where this question is discussed in detail.

The conclusion therefore seems justified that the observed small values of the F factors and their smooth decrease as we approach the deformation region reflect the increasing contribution of collective motion to the actual nuclear wave functions of nuclei, which leads to a progressive weakening of the selection rule on l.

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