Determination of the Lifetime of the First-Excited State of Gd^{152}

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The lifetime of the 344-kev level of Gd^{152} was measured by coincidence measurements between the beta spectrum of Eu^{152} and the K conversion line of the 344-kev transition, using a double lens coincidence spectrometer. The time delay between the outcoming coincident pulses was converted to pulse height. From the calibrated shift of the centroids, using the self-comparison method, a mean lifetime of $\tau=(7.6\pm1.3)\times10^{-11}$ sec was obtained. The transition probability is 20 times the single-proton value. Thus, although the level is not "rotational," it has considerable collective character.

INTRODUCTION

MEASUREMENTS of the electromagnetic transition probabilities from the first excited 2+ states in even-even nuclei have been carried out in many cases, through Coulomb excitation or by direct lifetime determinations. A large enhancement of these $E2$ transitions is characteristic for the transitions between the rotational levels of distorted nuclei situated between closed shell, as in the rare earth region. Approaching a closed shell, the equilibrium shape of the nucleus becomes spherical and the first excited states show to a greater extent the characteristics of a vibrational spectrum. The stability of the spherical shape in nuclei which have a few particles outside the closed shell and the rather sharp transition from spherical to deformed nuclei has been recently given a theoretical explanation by Belyaev[1] by treating the effect of pairing correlations on nuclear properties.

This change in the features of the excited levels is strikingly displayed in the nuclei produced by the decay of the Eu^{152} isomers. The excited levels of Sm^{152}, populated by electron capture of Eu^{152} exhibit properties of strongly deformed nuclei; whereas the states of Gd^{152} excited after β decay show the characteristics of vibrational levels. (The decay scheme of Eu^{152} is shown in Fig. 1.) This sudden change in the properties of nuclei, when the neutron number is changed[2] from 90 to 88 is expected also to show up in the transition probabilities of the excited levels in the corresponding nuclei. It is interesting therefore to determine the lifetime of the 2+ first excited state of Gd^{152} and to compare its reduced transition probability with that of the first-excited state of Sm^{152} and with those of other nuclei in this region.

A delayed-coincidence measurement between beta particles from the 13-yr isomer of Eu^{152} and the conversion electron of this transition using the self-comparison method[3] seemed to be the most appropriate for the lifetime measurement of the 344-kev level, provided that the lifetimes of the intermediate levels feeding it are sufficiently short in comparison.

Considering only those transitions which are coincident with β particles of about 300 kev (the energy of the continuous spectrum selected experimentally), then we see that the 344-kev level is populated in more than 90% of the total cases by a direct beta transition and by the 782-kev $E1$ transition from the 1126-kev level, which is itself fed by a lower energy branch. The 3- assignment of the 1126-kev level and the pure $E1$ character of the de-exciting transition was deduced from angular correlation and conversion coefficient measurements.[2,4–6] Owing to the comparatively high energy of the $E1$ transition, the lifetime of the 1126-kev level is very probably short in comparison with the 344-kev level.

The first-excited level is also populated in about 7% of the total cases by the 412-kev $E2$ transition from the 756-kev state. The proposed assignment for this level is 2+ or 4+. Recently Marklund *et al.*[7] have found a 0+ level at 615 kev in Gd^{152} excited by the beta decay of the 9.2-hr isomer of Eu^{152}. It is very probable that the two levels 756 kev and 615 kev are the members of the two-phonon triplet 0+, 2+, 4+ in the limit of harmonic oscillator approximation.[5,7] Owing to the higher energy of the 412-kev transition and its probable collective nature, the lifetime of the 756-kev level is not expected to be longer and is probably considerably shorter than that of the first-excited state. Recalling that in only 7% of the cases the first excited state is populated via the 756-kev level, it would seem that the lifetime measurement of the 344-kev state might be in error at most by only a few percent, on this account.

EXPERIMENTAL ARRANGEMENT

The lifetime of the first-excited state of Gd^{152} was determined by carrying out coincidence measurements between the beta spectrum and K conversion line of the 344-kev transition using a double-lens coincidence beta spectrometer.[8] The transmission and momentum reso-

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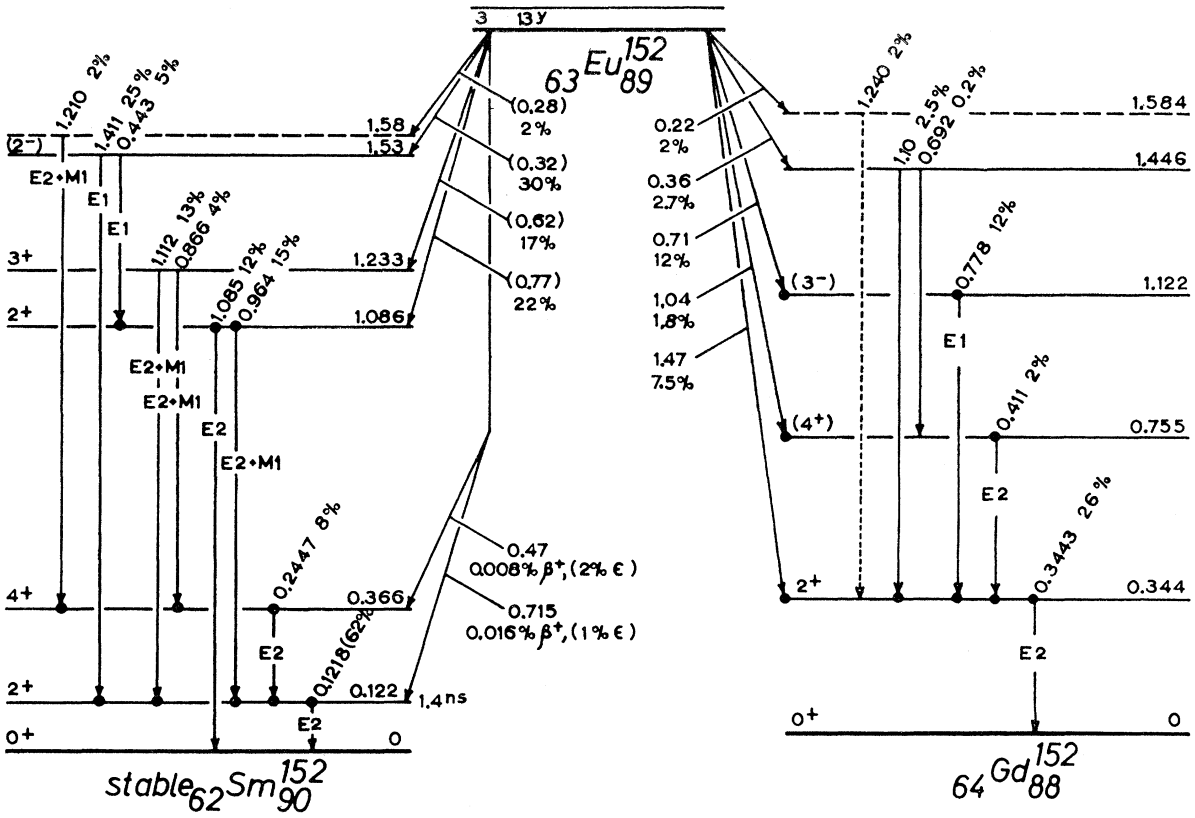

FIG. 1. Decay scheme of the 13-yr isomer of Eu^{152}.

lution in both spectrometers were adjusted to about 5%. A 200-μC source of Eu^{152} in the form of chloride was deposited on a 1-mg/cm^2 Mylar foil covered with an evaporated thin film of gold.

The focused electrons were detected by plastic scintillators coupled to 6810A RCA photomultipliers. The pulses from the collector were fed into a delay-to-pulse-height converter similar to that described by Green and Bell.[9] The pulses from the ninth dynodes were introduced into linear amplifiers, and after discrimination against the noise pulses, passed to a coincidence circuit having a resolving time of 10^{-7} sec. The resolution of the scintillators was about 28% for electrons of 300 kev. A single-channel analyzer transmitted only pulses within a 30% width of the peak voltage. This output of the analyzers together with the output pulses of the fast coincidence circuit were fed into a slow triple coincidence circuit having a resolving time of 2×10^{-6} sec.

The pulses from the time to amplitude converter were fed into an 80-channel pulse-height analyzer gated by the pulses from the fast-slow coincidence circuit. The position of the centroid of the analyzed spectrum, when spectrometer 1 focused the beta spectrum at the lower energetic side of the conversion line and spectrometer 2 focused the conversion electrons, was compared with the position when the role of the spectrometers was inverted by an appropriate increase in energy in both channels.[3] The adjustments of the spectrometers before and after inversion were made in such a way that the average delay between the coincident pulses, due to the small change in energy of the focused electrons and corresponding change in pulse height, was the same. The assumption was made that this delay, to a good approximation, is inversely proportional to the energy of the electrons. The error introduced thus to the lifetime measurement due to the change in the transit time of the electrons in the spectrometers was less than 2×10^{-13} sec.

The shift between the centroids which corresponds to twice the mean lifetime of the excited state[10,11] was calibrated by introducing a 4×10^{-10}-sec delay cable between one of the limiters and the 6BN6 coincidence circuit. To eliminate time-dependent drifts, many sets of measurements of short duration were made. Every set included four measurements of 10 to 15 min each, and consisted of self-comparison measurements carried out for two different lengths of cables.

The experimental set up was checked by the same self-comparison method using the 238-kev transition

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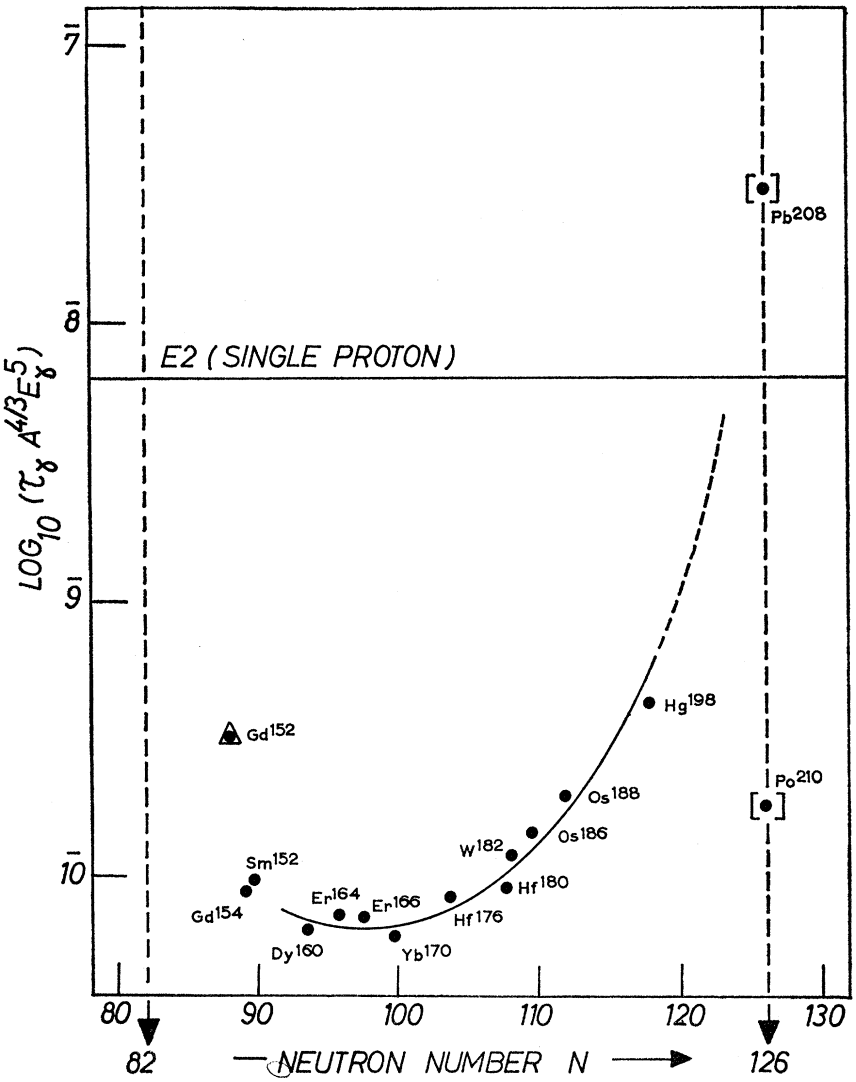

FIG. 2. Comparative lifetime of $E2$ transitions in even-even nuclei against neutron number N, as presented by Sunyar.[12] The present lifetime measurement is added to the plot.

line of Bi^{212} (thorium F line) in coincidence with the β spectrum of Pb^{212}. The counting rate at the peak of the conversion line was about the same as in the case of Eu^{152}. However, in the Pb^{212} source the difference in counting rates, when one spectrometer was set on the line and the second off, was much bigger than in the Eu^{152}. Even under these more stringent conditions, no shift in the centroids was detected within experimental error, as expected for this prompt transition.

RESULTS AND DISCUSSION

The results obtained, by analyzing a total number of 80 000 accumulated coincidences, for the mean lifetime of the 344-kev level of Gd^{152} was $\tau=(7.7\pm2)\times10^{-11}$ sec.

Another set of measurements was carried out utilizing a pile up rejector in addition to the same experimental setup. This arrangement assured that a second pulse from either phototube which came within 3 μsec of a preceding pulse would not be analyzed. The result obtained by analyzing 240 000 coincidences was $\tau=(7.5\pm1.5)\times10^{-11}$ sec. The excellent agreement between the results of the two sets of measurements indicated that the present lifetime measurement was not affected by piling up of pulses. The average value obtained from these two sets of measurements is $\tau=(7.6\pm1.3)\times10^{-11}$ sec.

In deriving the final results, corrections were made for the fact that the spectrometer accepts about 10% of the total intensity of the conversion line when the spectrometer was focused off the line. In estimating the errors the small uncertainty in determining the exact shape of the tail of the conversion line and also the uncertainty arising from the fact that in 7% of the total cases the 344-kev level is populated via the 756-kev level were taken into account.

The total conversion coefficient for the 344-kev level is 0.041 and the mean lifetime of the gamma transition

is therefore $(7.9\pm1.3)\times10^{-11}$ sec. The $E2$ transition probability is thus 20 times the single-proton value.

It is interesting to note that the enhancement of the transition probability from the first excited rotational level of Sm^{152} is three times larger. In Fig. 2 the present measurement is added to a plot of mean life values as presented by Sunyar.[12] Thus, in passing from neutron number 90 to 88 with the decrease in deformation of the nucleus as exhibited in the abrupt change of the sequence of levels and their relative energies, we see a corresponding change in reduced transition probabilities from the first excited states.

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Perlman[13] has recently indicated that a similar case appears in the other region of strongly distorted nuclei, that of the heavy elements where A is greater than 220. For Em^{218}, which is outside the deformed nuclei region as shown by its sequence of levels, the transition probability from its first excited state[14] is correspondingly reduced.

ACKNOWLEDGMENT

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Decay of Cd^{119} and In^{119} Isomers*

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The isomers 9.5-min Cd^{119} and 2.7-min Cd^{119m} are formed in the fission of natural uranium induced by 14-Mev deuterons and fast neutrons, with the latter reaction favoring the production of the low-spin 9.5-min isomer. The decay of 18-min In^{119m}, the daughter of 9.5-min Cd^{119}, is characterized by β rays with a maximum energy of 2.7 Mev and γ rays of 0.024, 0.30, and 0.91 Mev. Some ($\sim$5%) isomeric transition is observed. The decay of 2.0-min In^{119} is characterized by 1.6-Mev β rays and 0.82-Mev γ rays.

INTRODUCTION

IN 1949 Duffield and Knight prepared (17.5 ± 1)-min In^{119} by the reaction $Sn^{120}(\gamma,p)In^{119}$ employing isotopically enriched tin and 23-Mev x rays.[1] Beta rays with a maximum energy of 2.7 ± 0.2 Mev were found to be associated with this nuclide. No γ rays were observed. More recently, Nussis reported 10-min Cd^{119} and a (3.5 ± 0.5)-min Cd isotope.[2,3] The 3.5-min Cd, tentatively assigned mass number 121, was stated to be the parent of two indium daughters, (11 ± 1)-min In associated with 1.2- and 3.8-Mev β-ray groups and 850-kev γ rays, and (32 ± 2)-min In associated with 1.7-Mev β rays and 740- and 520-kev γ rays.

Earlier studies in our laboratory of neutron-rich isotopes of Cd and In formed in fission revealed several short-lived species that could not be ascribed to the known 115, 117, and 118 chains.[4,5] This study is an extension of this work employing similar irradiation and chemical procedures.

EXPERIMENTAL RESULTS

Cadmium produced by the fission of natural uranium (U^{238}) with 14-Mev deuterons, bombarded 1 to 3 min and separated 3 min after irradiation, showed an apparent 3.1-min period for gross β decay and longer periods due mainly to 49-min Cd^{118}, 50-min Cd^{117}, and 3-hr Cd^{117m}. In a series of 11 experiments in which In was separated from the Cd within 3 min after the initial Cd separation β-decay periods of 2.0 ± 0.2 and 18 ± 1 min were apparent when measured on a proportional counter. Extracts of In taken at times greater than 15 min after the initial Cd separation displayed only the 18-min half-life. Analysis of the apparent 3.1-min period showed it to be a composite of the decay of Cd

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