# *LIFETIMES OF THE EXCITED STATES OF DEFORMED* $Dy^{160}$, $Lu^{175}$, $Hf^{177}$, AND $Ir^{191}$ *NUCLEI*

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Lifetimes of levels of deformed $Dy^{160}$, $Lu^{175}$, $Hf^{177}$, and $Ir^{191}$ nuclei are determined. The half-lives are respectively $(1.7 \pm 0.1) \times 10^{-9}$ sec, $(7.1 \pm 0.9) \times 10^{-11}$ sec, and $\leq 7 \times 10^{-12}$ sec for the 86.5-, 283-, and 966 keV $Dy^{160}$ levels; $(4.2 \pm 0.3) \times 10^{-10}$ sec and $(6.9 \pm 0.3) \times 10^{-10}$ sec for the 113- and 321-keV $Hf^{177}$ levels; $(1.1 \pm 0.1) \times 10^{-10}$ sec and $(3.25 \pm 0.10) \times 10^{-9}$ sec for the 114- and 396-keV $Lu^{175}$ levels; and $(8.1 \pm 1.6) \times 10^{-11}$ sec for the 129.6 keV $Ir^{191}$ level.

The experimental results are compared with predictions of the unified model of the nucleus. The intrinsic quadrupole moments and g-factors of the nuclei are derived. The collective-motion g-factor for the $Ir^{191}$ nucleus located at the upper boundary of the deformation region was found to be much greater than that of the $Hf^{177}$ and $Lu^{175}$ nuclei located in the middle of the deformation region. Retardation factors for single-particle E1 transitions to the ground levels of the $Hf^{177}$ and $Lu^{175}$ nuclei, relative to those computed by the Nielson formula, are $f_H = 650$ and $f_H = 105$ respectively. The probabilities for transition to rotational levels of ground-state bands for these nuclei are close to the theoretical values.

IN the present investigation we measured the lifetimes of the excited states of the deformed nuclei $Dy^{160}$, $Lu^{175}$, $Hf^{177}$, and $Ir^{191}$. We used for our research a time-to-amplitude converter [1], and also a differential time analyzer with variable delay line [2].

## 1. 86.5-, 283-, and 966-keV LEVELS OF $Dy^{160}$

The levels of $Dy^{160}$ (Fig. 1) [3] were investigated on the basis of the successive decay of $Er^{160}$ and $Ho^{160}$

$$Er^{160} \xrightarrow[\varepsilon]{30\,\text{hr}} Ho^{160} \xrightarrow[\beta^+,\varepsilon]{5\,\text{hr}} Dy^{160},$$

the source being the erbium fraction separated from a tantalum target irradiated for several hours in the 660-MeV proton beam of the synchrocyclotron of the Joint Institute for Nuclear Research.

To measure the lifetime of the 86.5-keV ($2^+$) level we used the converter and investigated the coincidences of the $\gamma$ rays, which lead either directly (196.5 keV) or via the upper levels (the lifetimes of which are essentially small) to the excitation of this level, with the K-shell conversion electrons that arise upon de-excitation of the level. The $\gamma$ rays were detected with a wrapped stilbene crystal and the electrons with a thin stilbene plate.

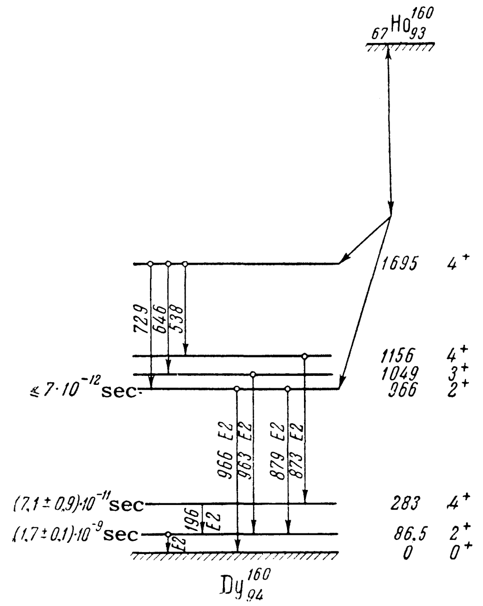


FIG. 1. $Ho^{160} \to Dy^{160}$ transition.

By least-square reduction of the decay curve (Fig. 2) we obtained for the half-life of the 86.5-keV level a value

$$T_{1/2} = (1.7 \pm 0.1) \cdot 10^{-9} \text{ sec.}$$

This value is in good agreement with the $1.8 \times 10^{-9}$ sec obtained by McGowan [4] and by Nathan [5] from

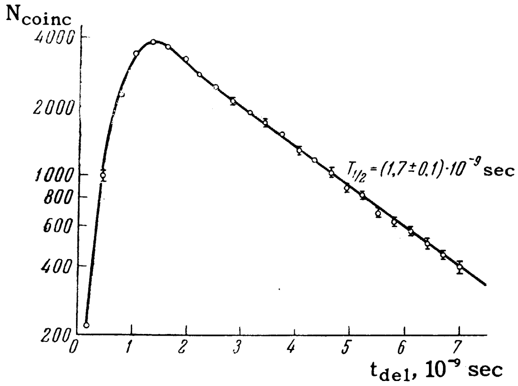


FIG. 2. For the measurement of the lifetime of the 86.5-keV level of $Dy^{160}$.

the $Tb^{160} \xrightarrow[\beta^-]{73\,d} Dy^{160}$ decay by a delayed-coincidence method.

The lifetime of the 283-kev ($4^+$) level was measured with a converter; a thin plate of stilbene was used to detect the conversion electrons of the 196.5-keV transition in the K shell of the dysprosium atom, while a thick wrapped stilbene crystal (h = 120 mm) was used to detect the hard part of the Compton distribution of the $\gamma$ quanta of the weak 873-keV transition. We measured the shift of the center of gravity of the points in this curve relative to the center of gravity of the $\beta\gamma$-coincidence reference curve, obtained with a $Co^{60}$ source: the half-life of the 2500-keV level of $Ni^{60}$, to which the $\beta$ decay leads, amounts to less than $10^{-11}$ sec according to Bay et al,[6] the half-life of the 1330-keV level is $7.6 \times 10^{-13}$ sec according to Metzger[7] and $6.9 \times 10^{-13}$ sec according to Burgov et al.[8] It was essential to prevent in the measurement registration of the 538-keV transition $\gamma$ quanta, which would contribute to the coincidences via the 1156-keV ($4^+$) level. However, since the thin stilbene crystal used to register the K-conversion electrons of the 196.5 keV transition registered to some degree also the quanta from the 729-, 646-, and 538-keV transitions, while the thick crystal registered well the quanta of the 961-, 963-, 879-, and 873-keV electrons, a certain number of "fast" coincidences were observed via the levels of the $\gamma$-vibration band $K = 2^+$ with energies 966 ($2^+$), 1049 ($3^+$), and 1156 ($4^+$) keV. The number of these "fast" coincidences, determined in the individual experiment by filtering out the conversion electrons, was as much as 25% of the total number of coincidences, which decreased the shift of the investigated curve relative to the reference curve (obtained with $Co^{60}$ source). The measured shift (Fig. 3) was corrected for the contribution of the "fast" coincidences. The final result was

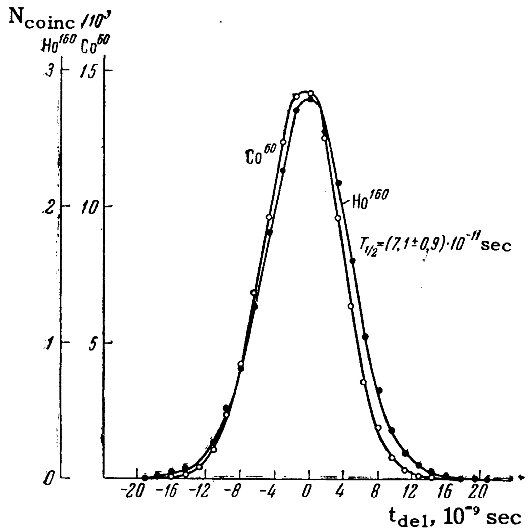


FIG. 3. For the measurement of the lifetime of the 283-keV level of $Dy^{160}$.

$$T_{1/2} = (7.1 \pm 0.9) \cdot 10^{-11} \text{ sec.}$$

Figure 4 shows the results of the measurements of the lifetime of the 966-keV ($2^+$) level, likewise made with a converter using the $\gamma\gamma$ coincidences of the 729- and 966-keV lines, registered with two wrapped stilbene crystals. The window in one of the side channels of the slow part of the coincidence circuit was set in the region of the high-energy portion of the Compton distribution, above the limit for the 729-keV $\gamma$ quanta. In the second channel the window was

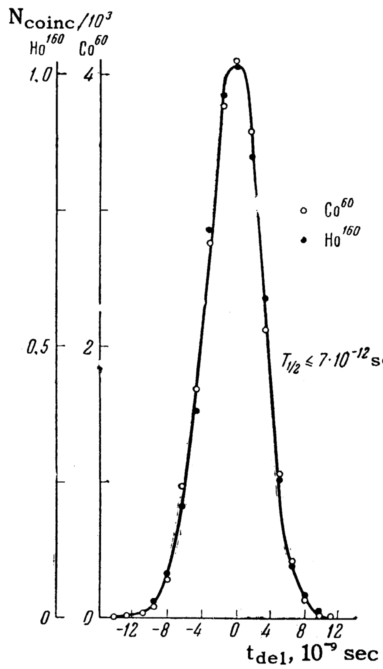


FIG. 4. For the measurement of the lifetime of the 966-keV level of $Dy^{160}$.

set directly above the Compton-distribution limit for the 646-keV $\gamma$ quanta. Within the same working intervals measurements were made of the $\gamma\gamma$ coincidences with a $Co^{60}$ source. Repeated measurements (one series of which is shown in Fig. 4) at a curve width $2\tau_0 \approx 7 \times 10^{-10} - 8 \times 10^{-10}$ sec yielded for the upper limit of the lifetime of the 966-keV level an estimate $\tau \leq 1 \times 10^{-11}$ sec or

$$T_{1/2} \leqslant 7 \cdot 10^{-12} \text{ sec.}$$

An attempt was also made to estimate the lifetime of the 1695-keV ($4^+$) level, which can have a two-quasiparticle nature, being connected with the rupture of two paired nucleons. This level is populated by positron decay of $Ho^{160}$ and an attempt could be made to study the coincidences between the photopeak in the NaI(Tl) crystal due to the annihilation radiation and all the hard $\gamma$ quanta (known to exceed 196.5 keV), assuming the lifetimes of the 1049-($3^+$) and 156-keV ($4^+$) levels, which are de-excited by collective transitions of the E2 type, to be quite small (this is illustrated directly for the 966-keV level above). However, the large contribution of the "fast" coincidences, connected with the fact that the photopeak of the annihilation radiation lies against a strong background of Compton distributions from all the hard $\gamma$ quanta, makes the measurements very difficult. We can therefore draw from our experiments only the rough conclusion that the lifetime of the 1695-keV level can be on the order of $10^{-10}$ sec.

## 2. 113- AND 321-keV LEVELS OF $Hf^{177}$

To investigate the levels of $Hf^{177}$, we used the $Lu^{177} \xrightarrow[\beta^-]{6.8\,d} Hf^{177}$ transition. The source was produced by irradiating enriched $Yb^{176}$ with slow neutrons in the reactor of the Physico-technical Institute. The $Yb^{177}$ produced is converted into $Lu^{177}$ with a half-life of 1.88 hours.

The half-life of the 113-keV state, which we have determined previously [9] with the aid of a time analyzer with variable delay line, turned out to be $T_{1/2} = (4.2 \pm 0.6) \times 10^{-10}$ sec. This measurement could be made more reliably with a converter, both because of the higher measurement speed and as a result of the better time resolution afforded by the converter.

The coincidences of the three-percent 384-keV component of the $\beta$ spectrum with the L-shell conversion electrons of the 113-keV transition were investigated. The detectors were thin plates of stilbene. The window of the differential pulse-height analyzer in the $\beta$-spectrum channel was set somewhat above the limit of the soft component of the spectrum (176 keV). The selection of coincidences with L electrons only was due to the advantage of their having the higher energy (compared with the K electrons), which made it possible to improve the time resolution to about 1 msec and to determine the lifetime from the exponential fall-off of the coincidence curve (Fig. 5). The results of the least-square reduction of several series analogous to that shown in Fig. 5 yield

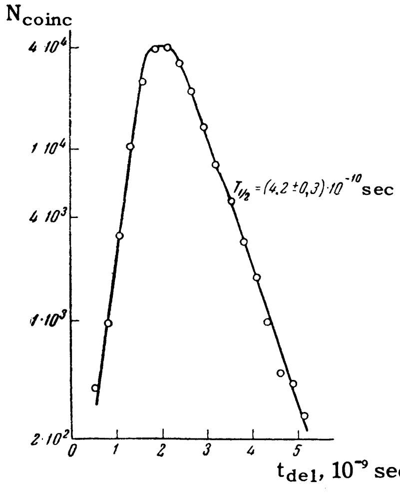


FIG. 5. For the measurement of the lifetime of the 113-keV level of $Hf^{177}$.

$$T_{1/2} = (4{,}2 \pm 0{,}3) \cdot 10^{-10} \text{ sec}$$

which is in splendid agreement with our earlier result [9].

The lifetime of the 321-keV level was measured with a converter using the coincidences of the $\beta$ spectrum with 176 keV end-point energy with the intense 208-keV $\gamma$ transition from this level. The $\beta$-ray detector (thin stilbene slab) registered also a certain number of conversion electrons of the 113-keV transition in the L and M shells. However, on the curve of coincidences with the 208-keV $\gamma$ rays (registered with a wrapped stilbene crystal), the $e\gamma$ coincidences corresponded to the left branch of the curve, whereas the lifetimes of the 321-keV level which were of interest to us in this experiment were determined by the right-hand branch of the coincidence curve (Fig. 6). From a series of curves analogous to that shown in Fig. 6 we obtained

$$T_{1/2} = (6{,}9 \pm 0{,}3) \cdot 10^{-10} \text{ sec.}$$

Measurements made by Vartapetyan [10] with a fast-slow coincidence circuit (with resolution $2\tau_0 \approx 6 \times 10^{-9}$ sec) yielded

$$T_{1/2} = (5 \pm 1{,}5) \cdot 10^{-10} \text{ sec.}$$

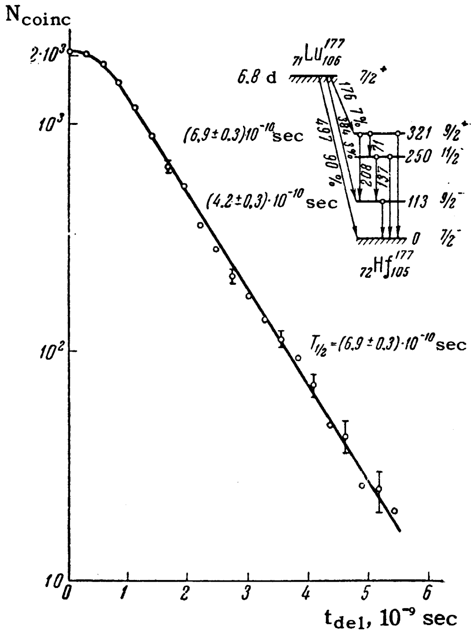


FIG. 6. For the measurement of the lifetime of the 321-keV level of $Hf^{177}$.

## 3. THE 114- AND 396-keV LEVELS OF $Lu^{175}$

The literature data on the lifetime of the 114-keV level of $Lu^{175}$ are contradictory. Thus, according to the estimate we obtained with the aid of a time analyzer with variable delay line, $T_{1/2} \leq 1.4 \times 10^{-10}$ sec [11]. Bozhko et al [12] obtained with a time converter a value $T_{1/2} = (3.6 \pm 0.6) \times 10^{-10}$ sec. Finally, measurements with the aid of a microwave method yielded

$$T_{1/2} = (10.1 \pm 0.7) \cdot 10^{-11} \text{ sec [13]}.$$

In addition to the various effects associated with the method, the role of which is appreciable in measurement of times in the range $10^{-10}$—$10^{-11}$ sec [1,9,14], one of the possible causes of the observed discrepancies may be the influence of the impurities in the ytterbium compound, used in these measurements (the $Yb^{175} \rightarrow Lu^{175}$ transition). First among these is $Yb^{169}$, which turns into $Tu^{169}$ with a half-life of 30.6 days and has in its spectrum the lines 110, 118, and 130 keV (which are close in energy to the investigated 114-keV line); the activity of $Yb^{169}$ may reach 17% directly after the irradiation. These lines are in cascade with the harder lines 177, 198, 240, and 260 keV, and the lifetimes of the 118- and 139-keV intermediate levels are $6.2 \times 10^{-11}$ and $2.9 \times 10^{-10}$ sec respectively [13,15]. Another impurity in the ytterbium activity is usually (up to 2.5%) $Lu^{177}$ (with a half life of 6.9 days), which has a very similar decay scheme (cf. Figs. 6 and 8) and 113-keV $\gamma$ line of practically the same energy as in the case of the investigated 114-keV transition in the $Yb^{175}$ decay, with the half-life of the 113-keV level in the $Hf^{177}$ nucleus, as shown above, amounting to $4.2 \times 10^{-10}$ sec.

In the course of time the influence of both impurities increases because $Yb^{175}$ has a smaller half-life ($T_{1/2} = 4.2$ days).

To eliminate the influence of these impurities, we irradiated an enriched ytterbium compound with 74% $Yb^{174}$ (in lieu of the 32% in the natural isotope mixture). The $Yb^{176}$ content was 0.1%. We investigated (with the aid of the converter) the coincidences of the five-percent component of the $\beta$ spectrum ($E_{lim} = 355$ keV) with characteristic x-radiation accompanying the internal conversion in the K shell in the 114-keV transition. The window of the differential pulse-height analyzer in the channel registering the $\beta$-particle pulses (the detector was a thin stilbene plate) was set above the energy of the hardest conversion electrons (260-keV transition) emitted by the $Yb^{169}$ impurity.

The half-life of the 114-keV level measured by the center-of-gravity method (one measurement series is shown in Fig. 7) was

$$T_{1/2} = (1.1 \pm 0.1) \cdot 10^{-10} \text{ sec}.$$

The lifetime of the 396-keV level was measured with the aid of an analyzer with a variable delay line, using the coincidences of the soft (72 keV) component of the $\beta$ spectrum and the hardest (396 keV) component of the $\gamma$ spectrum.

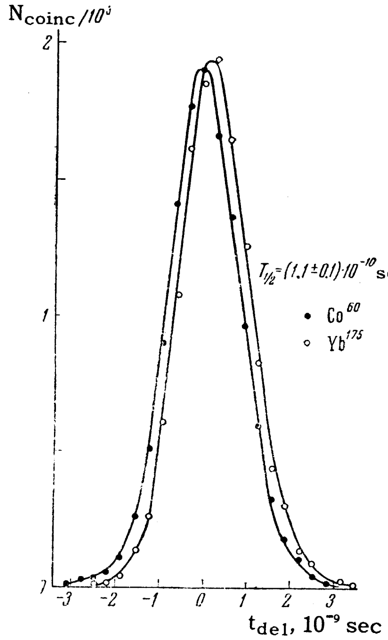


FIG. 7. For the measurement of the lifetime of the 114-keV level of $Lu^{175}$.

Figure 8 shows the resultant decay curve of the 396-keV level, the reduction of which yields

$$T_{1/2} = (3.25 \pm 0.10) \cdot 10^{-9} \text{ sec.}$$

This is close to the value $T_{1/2} = (3.4 \pm 0.3) \times 10^{-9}$ sec obtained by Vartapetyan [16].

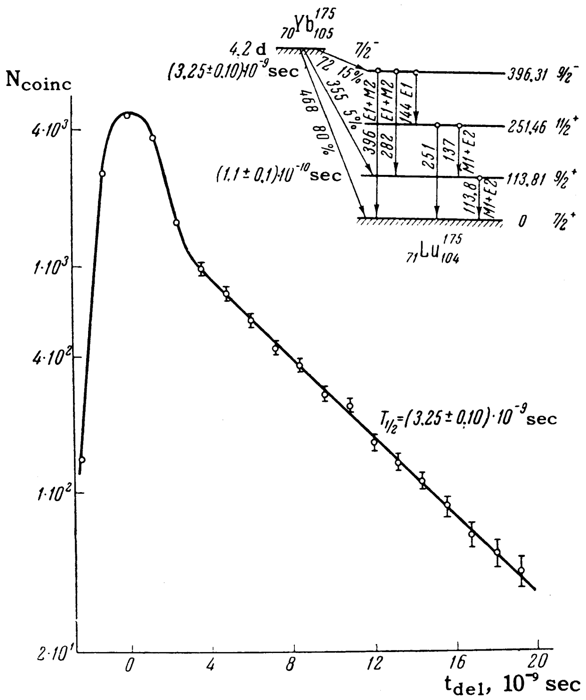


FIG. 8. For the measurement of the lifetime of the 396-keV level of $Lu^{175}$.

## 4. THE 129.6-keV LEVEL OF $Ir^{191}$

The lifetime of the 129.6-keV level of the $Ir^{191}$ nucleus was determined before from the $\gamma$-ray resonant scattering in the Mössbauer effect [17-20]. The various measurements yielded for the half-life values ranging between $6.9 \times 10^{-11}$ and $9.7 \times 10^{-11}$ sec. Since the $Ir^{191}$ nucleus, which has 114 neutrons, is apparently on the very border of the deformation region and it is important to determine the g factor of the collective motion for such a case, we have measured the lifetimes of the level with the aid of the converter.

The source used was an osmium compound irradiated in the reactor for a week. The levels of the $Ir^{191}$ nucleus were excited by $\beta$ decay of $Os^{191}$ ($T_{1/2}$ = 15 days), and the coincidences of the conversion electrons of the 417-keV E3 transition with the $\gamma$ rays of the investigated transition were studied. The reference curve was obtained by measuring the $\beta\gamma$ coincidences in the decay of $Hg^{203}$, for which the lifetime of the intermediate 297-keV level of $Tl^{203}$ is well known. The weighted average of the half-life for this level, determined from all the data known in the literature (see the review [21] and also [22,23]) turned out to be $T_{1/2} = (2.88 \pm 0.09) \times 10^{-10}$ sec. In determining this quantity we have eliminated the value $T_{1/2} = (1.2 \pm 0.3) \times 10^{-10}$ sec, obtained by de Waard and Gerholm [24] and not confirmed by all subsequent measurements (see the review [21]), and also the value $T_{1/2} = (2.41 \pm 0.10) \times 10^{-10}$ sec, obtained by Pederson and Bell [25], which also deviates sharply from a whole series of the well-converging values obtained from both the exponential decrease and from the shift of the centers of gravity.

The results of the measurements yield for the investigated level (Fig. 9)

$$T_{1/2} = (8.1 \pm 1.6) \cdot 10^{-11} \text{ sec}$$

which agrees with the data obtained by the Mössbauer effect.

## 5. DISCUSSION OF THE RESULTS

Knowledge of the lifetime of two rotational levels of one band enables us to check whether the values of the internal quadrupole moment $T_0$ of the band, calculated from the two lifetimes, are the same as would follow from the unified model [26]. In principle, the interaction between levels of like spin and parity but from different rotational bands can change the quadrupole moment of the nucleus in

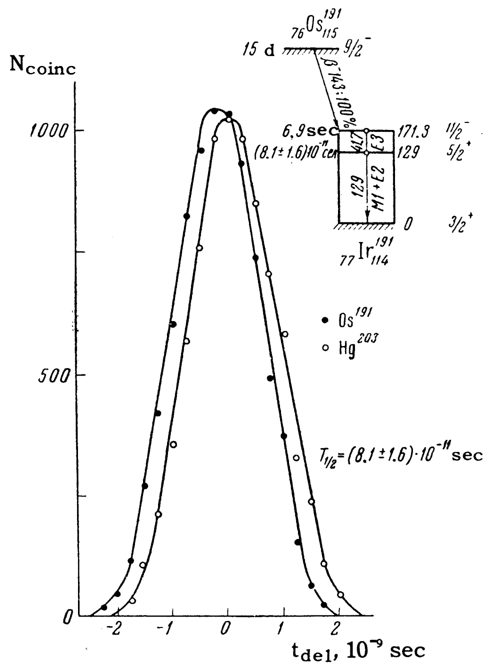


FIG. 9. For the measurement of the lifetime of the 129.6-keV level of $Ir^{191}$.

the rotational state. The effect should be extremely small, however, and in order to detect it the accuracy with which the lifetimes and the conversion coefficients are measured should be raised by a factor of many times.

The values of the internal quadrupole moments, determined from the lifetimes of the first and second rotational levels of the $Dy^{160}$ nucleus, turned out to be, respectively,

$$Q_0 = (8.0 \pm 0.5) \cdot 10^{-24}\ \text{cm}^2,$$
$$Q_0 = (8.5 \pm 1.1) \cdot 10^{-24}\ \text{cm}^2$$

and agree with each other within the limits of experimental error.

In addition, the lifetimes of the two rotational states afford a check on the ratio of the reduced probabilities of the transitions $4^+ \to 2^+$ and $2^+ \to 0^+$, which ratio follows from the expression given by the unified model

$$B(E2) = \frac{5e^2}{16\pi} Q_0^2 \left[ C_{I_i K 20}^{I_f K} \right], \tag{1}$$

where the square brackets contain the Clebsch-Gordan coefficient. From our measurements we get

$$B(E2;\ 4 \to 2) / B(E2;\ 2 \to 0) = 1.68 \pm 0.27,$$

which agrees within the limits of error with the value 1.43 given by (1). The theory of the nonaxial rotator yields for the ratio under consideration practically the same value as the unified model, for all values of the nonaxiality parameter $\gamma$ [27].

The enhancement factors of the E2 transitions, relative to the single-particle estimate of Weisskopf [28] for the 86.5- and 197-keV transitions, are 243 and 410 respectively.

The upper limit of the half-life of the 962-keV $\gamma$-vibrational level of $Dy^{160}$, which amounts to $T_{1/2} \leq 7 \times 10^{-12}$ sec, agrees with the fact that the E2 collective transitions from this level (962 and 879 keV) should be enhanced relative to the single-particle estimate, which yields, say for the $2^+ \to 0^+$ (962 keV) transition, a value $1.3 \times 10^{-11}$ sec. As regards the transitions from the 1694-keV $(4^+)$ level with energies 728, 646, and 538 keV, which are allowed by the selection rules relative to the K projections of the total angular momentum on the deformation axis, it can be stated that the half life of the level, calculated by the Weisskopf formula relative to the most intense of these transitions (728-keV) amounts to $5 \times 10^{-11}$ sec. Were these transitions to have a collective nature, they should be enhanced and have a half-life on the order of $10^{-11}$ sec or less. Our crude estimate of the lifetime of the 1694-keV level ($\sim 10^{-10}$ sec) contradicts the assumption that it has a collective nature.

We have shown earlier [29] that in the $Yb^{173}$ nucleus the single-particle 351-keV type-E1 transition from the $7/2^+$ level to the ground level $5/2^-$ is hindered by three orders of magnitude, compared with the result of calculations by the Nilsson formula [30] for the probabilities of the single-particle transitions in deformed nuclei; at the same time, transitions to the first and second rotational levels show relatively good agreement with Nilsson's formula. It was also noted, on the basis of the data of Vartapetyan [10] and Gnedin [31], that a similar anomaly takes place for E1 transitions to the ground level in $Hf^{177}$ and $Lu^{175}$. Our measurements of the half lives of the 321-keV $(9/2^+)$ and the 396-keV $(5/2^+)$ levels yield more exact data in this respect.

We calculated the experimental probabilities of the radiative transitions from the 321-keV level in the $Hf^{177}$ nucleus using our value of the half life of the level, equal to $(6.9 \pm 0.3) \times 10^{-10}$ sec, and the intensity ratio of the 321-, 308-, and 72-keV $\gamma$ rays obtained by Ofer [32], namely 10:150:1. According to Harmatz et al [33] the coefficient for the 321-keV transition is $\alpha_K = 0.3$ (which corresponds to a ratio E1/M2 = 0.82), while $\alpha_K/\alpha_L = 6.6$; for the 208-keV transition $\alpha_K = 0.06$ and the M2 admixture amounts to not more than 0.9%. According to Ofer [32] and Klema [34] the 72-keV transition is practically pure E1. $\alpha_L$ for the 208-keV transition and also $\alpha_K$ and $\alpha_L$ for the 72-keV transition were taken from the tables of Sliv and Band [35]; it was assumed that $\alpha_{M+N} \approx 0.3\,\alpha_L$. Calculations yield the following transition probabilities:

$$W_{\gamma 321} = 2.6 \cdot 10^7\ \text{sec}^{-1}, \qquad W_{\gamma 208} = 8.5 \cdot 10^8\ \text{sec}^{-1},$$
$$W_{\gamma 72} = 5.7 \cdot 10^7\ \text{sec}^{-1}.$$

The theoretical values of the probabilities, calculated by the Nilsson formulas [30], are

$$W_{H321} = 1.67 \cdot 10^{10}, \qquad W_{H208} = 1.04 \cdot 10^9,$$
$$W_{H72} = 1.15 \cdot 10^7.$$

We thus obtain for the hindrance factors $f_H = W_H / W_{\gamma\,\text{exp}}$

$$f_{H321} = 650, \qquad f_{H208} = 1.13, \qquad f_{H72} = 1.54.$$

In calculating the experimental probabilities of the radiative E1 transitions in the $Lu^{175}$ nucleus we used our value of the half life of the 396-keV level, equal to $(3.25 \pm 0.10) \times 10^{-9}$ sec, the ratio of the 396-, 282-, and 145-keV $\gamma$-ray intensities

| | $E_\gamma$, keV | $\delta^2 = \frac{E2}{M1}$ | $Q_0$, $10^{-24}$ cm$^2$ | $\mu$ nuc. mag. | $B(M1)$, $(e\hbar/2Mc)^2$ | $g_R$ | $g_K$ |
|---|---|---|---|---|---|---|---|
| $Hf^{177}$ | 113 | 34 | 7.76 | +0.61 | $5.2\cdot10^{-4}$ | 0.20 | +0.17 |
| $Lu^{175}$ | 113.83 | 0.25 | 7.45 | +2.0 | $6.67\cdot10^{-2}$ | 0.29 | +0.65 |
| $Ir^{191}$ | 129.6 | 0.14 | 4.25 | +0.17 | $4.8\cdot10^{-2}$ | 0.46 | −0.12 |

taken from [36,37], namely 23:10:1.36, and the mixture ratios E1/M2 = 2 and E1/M2 = 33 for the 396- and 282-keV transitions, respectively. The 145-keV transition was assumed to be pure electric dipole. The following values were then obtained for the experimental transition probabilities:

$$W_{\gamma 396} = 1.2\cdot10^8, \qquad W_{\gamma 208} = 5.7\cdot10^9,$$
$$W_{\gamma 145} = 8\cdot10^6,$$

whereas the theoretical values are

$$W_{H396} = 1.18\cdot10^{10}, \qquad W_{H282} = 9.76\cdot10^8,$$
$$W_{H145} = 1.32\cdot10^7.$$

This leads to the following hindrance factors:

$$f_{H396} = 105, \qquad f_{H282} = 17, \qquad f_{H145} = 1.6.$$

In addition to $Yb^{173}$, $Hf^{177}$, and $Lu^{175}$, similar strongly hindered E1 transitions are observed in a few other deformed nuclei, namely the 174-keV transition in $Lu^{177}$, for which $f_H = 250$ [38], the 74-keV transition in $Dy^{161}$ with $f_H = 40$ [38], and also the 307-keV transition from the 364-keV level of $Tb^{159}$. The lifetime of the 364-keV level was measured by Vartapetyan and his co-workers [38]. Unlike the above cases, the highly hindered 307-keV transition ($f_H = 300$) in the $Tb^{159}$ nucleus is not to the ground level but to the first excited one.

From the measured lifetimes of the first rotational levels of the odd nuclei $Hf^{177}$, $Lu^{175}$, and $Ir^{191}$ we calculated the internal quadrupole moments $Q_0$ and the g factors of the collective ($g_R$) and internal ($g_K$) motions. The results of the calculations are listed in the table.

The data for $Hf^{177}$ and $Lu^{175}$ agree with the results obtained earlier [9,11,13,15]. The internal quadrupole moment $Ir^{191}$ was previously determined by the Coulomb excitation method [39]. The g factors of this nucleus were obtained here for the first time.

The $Ir^{191}$ nucleus, with 77 protons and 114 neutrons, is on the upper limit of the deformation region. The rotational structure of the levels of this nucleus is not sharply pronounced: if the $5/2^+$ level (129.6 keV) is the first rotational level of the ground-state band with $K = 3/2^+$, then the 352-keV level, which apparently has a characteristic $7/2^+$, [40] is probably not a pure second rotational level, since the energy ratio of the two levels is 2.72 in place of the 2.4 expected from the unified-model formula [26]. The internal quadrupole moment of $Ir^{191}$ also deviates greatly from the value at the middle of the deformed-nucleus region, amounting to merely $Q_0 = 4.5 \times 10^{-24}$ cm$^2$ (deformation parameter $\Delta R/R = 0.14$).

*In calculating $Q_0$ and the g factors of $Ir^{191}$ we used for the 129.6-keV transition the value $\delta^2 = E2/M1 \approx 143$, from the unpublished work of E. P. Mazets, graciously furnished by the author prior to publication. This value was obtained with the aid of a prism spectrometer [41] with a resolution $\Delta H\rho/H\rho = 0.1\%$, from the intensity ratio of the conversion lines on the $L_1$, $L_2$, and $L_3$ subshells, and is unconditionally the most reliable. The other values known in the literature fluctuate rather widely, from 0.07 to 1.2 [17].

The gyromagnetic ratio of collective motion in $Ir^{191}$ ($g_R = 0.46$) turned out to be much larger than for the strongly deformed nuclei $Hf^{177}$ and $Lu^{175}$, and close to the crude estimate of the unified model $g_R = Z_A = 0.4$. One of the authors has already noted [21] that among the most accurate values of $g_R$, obtained by measuring the lifetimes of the first rotational levels, a tendency is observed towards increasing $g_R$ near both limits of the deformed-nucleus region. Such an increase in the collective g-factor agrees with the theoretical calculations based on an account of pair correlation [42].

Note added in proof (October 16, 1962). The value obtained in [43] for the half-life of the 283-keV level of $Dy^{160}$ is $T_{1/2} = (7.6 \pm 0.8) \times 10^{-11}$ sec, which agrees with our result. A value $T_{1/2} = (5.2 \pm 0.4) \times 10^{-10}$ sec, which is somewhat larger than the value we obtained, was obtained in [44] for the 113-keV level of $Hf^{177}$.


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