# Lifetimes of Some Rotational Levels*

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The lifetimes of a number of rotational nuclear levels have been measured in a pulsed-beam experiment. Gamma rays were counted and timed in a cooled unactivated NaI crystal. The excited states investigated were the first-excited levels in $Gd^{158}$, $Yb^{172,174,176}$, $Hf^{177}$, and $W^{182,184,186}$.

## 1. INTRODUCTION

IN a previous communication from this laboratory,[1] lifetime measurements of $2^+$ levels in some even rotational nuclei were reported. In those measurements pulsed particle beam techniques were employed to time the production of the decaying states and the decay was registered and timed by a plastic phosphor scintillation counter. One of the most serious limitations encountered in those measurements was the lack of energy resolution in the plastic scintillator. In the present measurements a liquid-air cooled unactivated NaI crystal was employed for the detection and timing of gamma rays. These detectors exhibit an energy resolution which is not much inferior to the resolution of ordinary Tl activated NaI crystals, and have considerably shorter light decay times.[2] Another advantage of this type of scintillator over plastic detectors is the high counting efficiency which makes it practical to populate the decaying states in Coulomb excitation with alpha particles. This reaction is less prolific than proton-induced Coulomb excitation (for thick targets and the same particle energy) but produces much cleaner gamma spectra with very little background radiation. The gamma ray spectrum in a $1\frac{1}{2}\times\frac{1}{4}$ in. cooled NaI crystal from a $W^{184}$ target bombarded by 3 Mev alphas is shown in Fig. 1. In Fig. 2 the time distribution of pulses corresponding to the 111-kev radiation is shown compared to "prompt" radiation from the 110-kev transition in a $Tm^{169}$ target bombarded alternatingly with the $W^{184}$ target.

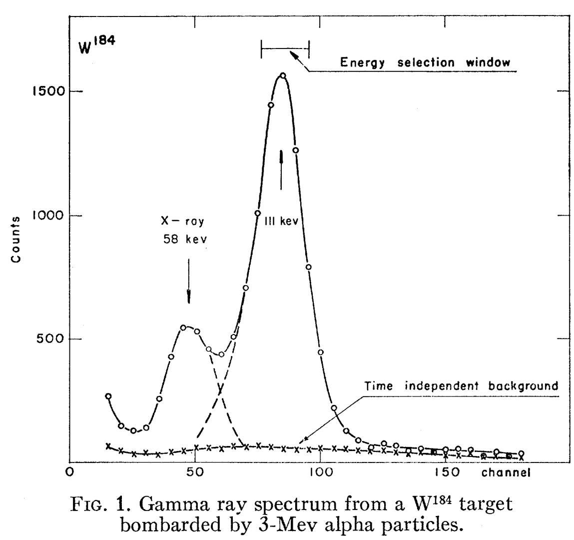


FIG. 1. Gamma ray spectrum from a $W^{184}$ target bombarded by 3-Mev alpha particles.

The over-all time resolution (full width at half-maximum) was found to vary between 2 and 4 nsec, depending on the energy of the radiation and other details. This resolution includes the width of the beam pulse which was in general about one nsec.

## 2. EXPERIMENTAL PROCEDURE

The general experimental arrangement in these measurements was similar to that employed previously.[1] Targets were prepared in oxide form and Coulomb excited by a pulsed beam of either 3-Mev protons or 3-Mev alphas from a Van de Graaff accelerator. Decay gamma radiation was registered in a Harshaw $1\frac{1}{2}$-in.-diam, $\frac{1}{4}$-in.-high liquid-air cooled NaI scintillator and the time difference between the beam pulse, and the counter pulse was converted into pulse amplitude and displayed on a multichannel analyzer.

The time scale was calibrated by changing the length of cable between the counter and the delay-to-pulse-height converter and observing the subsequent shift of the time distribution. The cables were 200 ohm HP-812-52 and the signal velocity in this cable was measured as $(2.746\pm0.006)\times10^{10}$ cm/sec.

A certain distortion of the time distribution may occur if the radiation is strongly anisotropic and if the angular distribution is time-dependent. As the angular distributions for all the transitions considered here are very closely given by $1+A_2P_2(\cos\vartheta)$, such distortions can be avoided if the counter is placed at an angle $\vartheta'$ defined by $P_2(\cos\vartheta')=0$. In the present experiment, an angle $\vartheta=45°$ was chosen for practical reasons. At this angle, $P_2(\cos\vartheta)=\frac{1}{4}$ which is sufficiently small.

## 3. MEASUREMENTS AND EVALUATION OF THE RESULTS

In the case of the first excited states of $W^{182}$, $W^{184}$, $W^{186}$, and $Hf^{177}$ the delayed pulse distributions were each compared with a "prompt" distribution of radiation of approximately the same energy emitted from a short-lived state of some other nucleus. Targets of the

* Supported by a grant from Mr. Harry Scherman, New York.
[1] M. Birk, G. Goldring, and Y. Wolfson, Phys. Rev. **116**, 730 (1959).
[2] L. E. Beghian, G. H. R. Kegel, and R. P. Scharenberg, Rev. Sci. Instr. **29**, 753 (1958).

TABLE I. Summary of the measurements.

| 1<br>Nucleus | 2<br>Bom-barding particle | 3<br>Level spin | 4<br>Transition energy (kev) | 5<br>Comparison target and transition energy (kev) | 6<br>Mean life of comparison radiation (nsec) | 7<br>Fraction of prompt radiation $1-\eta$ | 8<br>Mean life from expo-nential decay (nsec) | 9<br>Mean life from moment analysis (nsec) | 10<br>Mean life, weighted mean from present measurements (nsec) |
|---|---|---|---|---|---|---|---|---|---|
| $Gd^{158}$ | $\alpha$ | $2^+$ | 79.5 | | | | $3.37\pm0.15$ | | $3.37\pm0.15$ |
| $Yb^{172}$ | $\alpha$ | $2^+$ | 78.7 | | | | $2.4\ \pm0.2$ | | $2.4\ \pm0.2$ |
| $Yb^{174}$ | $\alpha$ | $2^+$ | 76.5 | | | | $2.75\pm0.3$ | | $2.75\pm0.3$ |
| $Yb^{176}$ | $\alpha$ | $2^+$ | 82.1 | | | | $2.9\ \pm0.2$ | | $2.9\ \pm0.2$ |
| $Hf^{177}$ | $\alpha$ | $9/2^-$ | 112.9 | $Tm^{169}$ 110 | $0.09^a$ | $0.02\ \pm0.02$ | | $0.80\pm0.08$ | $0.75\pm0.04$ |
| $Hf^{177}$ | $p$ | $9/2^-$ | 112.9 | $Tm^{169}$ 110 | $0.09^a$ | $0.16\ \pm0.02$ | | $0.74\pm0.04$ | |
| $W^{182}$ | $\alpha$ | $2^+$ | 100.0 | $Ho^{165}$ 94.7 | $0.05^b$ | $0.023\pm0.005$ | $2.16\pm0.18$ | $2.05\pm0.06$ | $2.06\pm0.06$ |
| $W^{184}$ | $\alpha$ | $2^+$ | 111.1 | $Tm^{169}$ 110 | $0.09^a$ | $0.007\pm0.001$ | $1.65\pm0.12$ | $1.83\pm0.06$ | $1.79\pm0.05$ |
| $W^{186}$ | $\alpha$ | $2^+$ | 122.5 | $Re^{185}$ 125 | $\leqslant0.02^a$ | $0.023\pm0.003$ | | $1.46\pm0.06$ | $1.46\pm0.06$ |

[a] A. E. Blaugrund, Y. Dar, and G. Goldring, Phys. Rev. **120**, 1328 (1960).
[b] M. Martin, P. Marmier, and J. de Boer, Helv. Phys. Acta **31**, 435 (1958).

nuclei to be compared were placed one above the other, and the beam was alternated between them at about one-second intervals. The mean lives were determined in a first moment analysis of the time distributions. The relative intensity of "delayed" and "prompt" radiation (from background sources) in the energy channel selected could be assessed quite accurately from the energy spectrum, and it was not necessary to carry out a higher moment analysis. In radiation produced by alpha bombardment the relative amount of background or "prompt" radiation, $1-\eta$, was less than 3%.

Since the energy of the comparison radiation was not exactly the same as that of the delayed radiation, a correction was made for the difference in the shape of the two energy pulse distributions within the energy window. The energy dependence of the observed delays which makes this correction necessary was measured by comparing the peak position of time distributions of prompt radiations for different energies.

Mean lives longer than approximately 1.5 nsec could also be determined from the free exponential decay of the radiation. In the two cases ($W^{182}$ and $W^{184}$) where comparison is possible the lifetime derived from the free exponential decay agrees with the lifetime obtained from the first moment analysis.

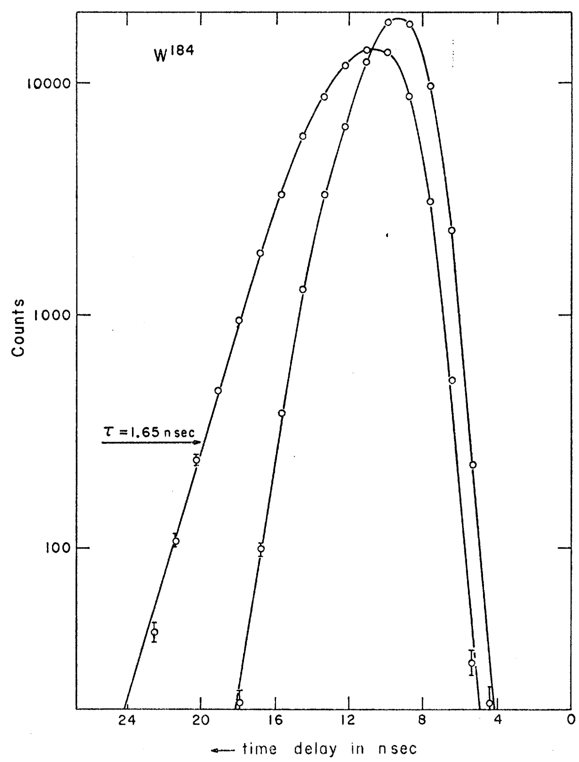


FIG. 2. Time distribution of pulses for the 111-kev radiation from a $W^{184}$ target compared with "prompt" radiation from the 110-kev transition in $Tm^{169}$ normalized to the same number of total counts.

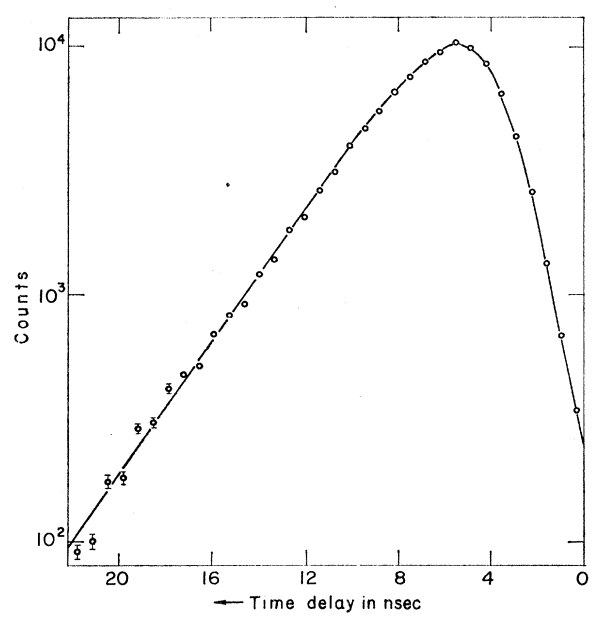


FIG. 3. Time distribution of pulses for the 79.5-kev transition in $Gd^{158}$.

TABLE II. Comparison of the present lifetime measurements with other direct determinations and Coulomb excitation data.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | Mean lives from Coulomb excitation | | | | |
| Nucleus | Transition energy (kev) | $B(E2)_{ex}$ ($e^2\times10^{-48}$ cm$^4$) | Total conversion coefficient[c] | Mean life (nsec) | Mean life from the present measurements (nsec) | Mean life from other recent measurements (nsec) |
| $Gd^{158}$ | 79.5 | $5.44\pm0.25$[a] | 5.92 | $3.39\pm0.16$ | $3.37\pm0.15$ | |
| $Yb^{172}$ | 78.7 | $5.89\pm0.20$[a] | 8.0 | $2.57\pm0.10$ | $2.4\pm0.2$ | |
| $Yb^{174}$ | 76.5 | $5.89\pm0.20$[a] | 10.6 | $2.29\pm0.09$ | $2.75\pm0.3$ | |
| $Yb^{176}$ | 82.1 | $5.78\pm0.20$[a] | 6.86 | $2.37\pm0.09$ | $2.9\pm0.2$ | |
| $Hf^{177}$ | 112.9 | | | | $0.75\pm0.04$ | $0.75\pm0.06$[d], $0.46\pm0.05$[e] |
| $W^{182}$ | 100.0 | $4.00\pm0.20$[b] | 3.84 | $2.05\pm0.11$ | $2.06\pm0.06$ | $1.97\pm0.02$[f] |
| $W^{184}$ | 111.1 | $3.62\pm0.20$[b] | 2.55 | $1.87\pm0.11$ | $1.79\pm0.05$ | $1.84\pm0.12$[g] |
| $W^{186}$ | 122.5 | $3.57\pm0.25$[b] | 1.74 | $1.51\pm0.11$ | $1.46\pm0.06$ | |

[a] See reference 3.
[b] See reference 4.
[c] The total conversion coefficient was calculated by summing $\alpha_k+1.3\alpha_L$. $\alpha_k$ and $\alpha_L$ are Rose's theoretical conversion coefficients given in reference 5.
[d] See reference 6.
[e] See reference 7.
[f] G. H. R. Kegel, thesis, Massachusetts Institute of Technology, 1961 (unpublished).
[g] E. Bodenstedt, E. Matthias, H. J. Korner, E. Gerdan, F. Frisius, and D. Hovestadt, Nuclear Phys. 15, 239 (1960).

Mean lives of the first-excited states in $Gd^{158}$, $Yb^{172}$, $Yb^{174}$, and $Yb^{176}$ were obtained from the free exponential decay only. Figure 3 shows the time distribution of pulses for the 79.5 kev transition in $Gd^{158}$.

The present measurements are summarized in Table I. The mean lives obtained from the free exponential decay are given in column 8. Column 9 contains the lifetimes determined from centroid shifts. In $Hf^{177}$ experiments with protons and alpha particles yield lifetimes which are the same within experimental errors. In column 10 the weighted means of the present measurements are given.

In Table II the present results are compared with other lifetime measurements and with mean lives calculated from $B(E2)$ values,[3,4] and theoretical conversion coefficients.[5]

### 4. CONCLUSIONS

In general there is good agreement between the present results and the mean life values derived from Coulomb excitation cross section measurements and calculated conversion coefficients. This is especially true for the tungsten isotopes for which an accurate moment analysis could be carried out.

In $Hf^{177}$ the 113 kev transition is a mixed $E2$ and $M1$ transition. The percentage of $E2$ radiation can be deduced from the mean life and from the $E2$ excitation cross section measured in Coulomb excitation.[4] With a total conversion coefficient $\alpha=2.3$ the $E2$ fraction derived in this way is found to be $(85\pm7)\%$. This result is made credible by the good agreement in the case of the tungsten isotopes.

The present life time measurement for the 113 kev level in $Hf^{177}$ is in excellent agreement with a delayed coincidence measurement by Hauser et al.[6] (see Table II). However, in a recent publication[7] a value of 0.46 nsec for the mean life of this level is quoted. This value differs appreciably from the values mentioned above and is inconsistent with a lower limit of 0.6 nsec found in an earlier measurement.[8] It is, moreover, inconsistent with recent $B(E2)$ and $E2/M1$ mixing ratio measurements.

### ACKNOWLEDGMENTS

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[3] B. Elbek, M. C. Olesen, and O. Skilbreid, Nuclear Phys. **19**, 523 (1960).
[4] O. Hansen, M. C. Olesen, O. Skilbreid, and B. Elbek, Nuclear Phys. **25**, 634 (1961).
[5] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).
[6] U. Hauser, K. Runge, and G. Knissel (to be published).
[7] H. I. West Jr., L. G. Mann, and R. J. Nagle, Phys. Rev. **124**, 527 (1961).
[8] A. E. Blaugrund, Y. Dar, and G. Goldring, Phys. Rev. **120**, 1328 (1960).