Excited States of Iodine-127*

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(Received 2 March 1964; revised manuscript received 14 August 1964)

The lifetime of the 59-keV first excited state of I^{127} has been measured using both xenon and tellurium parents. An average of the two results is 1.8±0.3 nsec. In addition, angular correlation studies have shown the multipolarity of the 59-keV gamma ray to be predominantly magnetic dipole with an electric quadrupole admixture of 0.6±0.6%. Angular correlation studies have also been carried out on two other cascades of I^{127}. One of these, the 175–200-keV cascade, showed an anisotropy of 5±3% when the Xe^{127} source was in the gaseous form; but when the source was adsorbed on charcoal, an anisotropy of 30% was found. The smearing of the angular correlation is attributed to the highly ionized states of the gamma emitters resulting from electron capture. The other, the 356–59-keV cascade, exhibited an anisotropy of 0.498±0.07 after geometric corrections. This permits assignment of the value $\frac{5}{2}$ for the spin of the 415-keV state, while the 356 gamma ray is either 9.3 or 85% electric quadrupole, depending on which of the two possible solutions is selected. The lifetime of the 59-keV state after correction for internal conversion is longer by a factor 67±14 than predicted by the Weisskopf estimate for an allowed magnetic dipole transition. This is consistent with the values observed for other *l*-forbidden *M*1 transitions and with the most recent theoretical estimates.

I. INTRODUCTION

IN the course of a search for the Mössbauer effect in the 59-keV state of I^{127}, it became clear that an independent determination of the lifetime of the state and the multipolarity of the gamma-ray transition would be useful. By delayed-coincidence studies, the mean life of the first excited state of a number of isotopes has been measured. These excited states undergo *l*-forbidden *M*1 transitions, which has a considerable theoretical interest. The multipolarities of a few transitions in I^{127} have been determined by the angular correlation studies. We have found that the anisotropy in the angular correlation of one of the gamma ray cascades in I^{127}, following electron capture in Xe^{127}, is almost completely washed out when the source is gaseous and at a low pressure.

II. SOURCE PREPARATION

The parent sources for the study were Xe^{127} and Te^{127m}. Xe^{127} was formed during a ten minute bombardment of KI^{127} with 120-MeV protons from the Carnegie Tech synchrocyclotron. The reaction induced is

$$I^{127}(p,xn)Xe^{128-x}.$$

For $x=0$, 2, or 4, stable isotopes of xenon are formed. For $x=3$, 5, or 6, isotopes are formed which decay into iodine with half-lives of 18, 2, and 20 h, respectively. Since the desired isotope Xe^{127} has a half-life of 36 days, it is possible, by waiting a period of several days after the bombardment, to separate the gaseous xenon from the solid iodine and thereby obtain a relatively pure sample of Xe^{127}.

The tellurium source was prepared by irradiation of isotopically enriched Te^{126} with neutrons from the Oak Ridge LITR reactor. The source obtained was chemically purified to produce a metallic tellurium source. The half-life of the tellurium source is 104 days as the result of the existence of an 89-keV isomeric state. The partial decay schemes for both isotopes are shown in Fig. 1.

III. LIFETIME MEASUREMENTS

The lifetime measurements were carried out by the delayed-coincidence method, using 404A limiters, a Bell and Green type time to pulse-height converter, and multichannel pulse-height analyzer. The time to pulse-height converter puts out a pulse which is proportional to the time delay between the gamma rays in coincidence. Hence, by inserting a cable corresponding to a known delay time into one side of the coincidence circuit and noting the change in the output pulse, the pulse height was calibrated in terms of time. Two

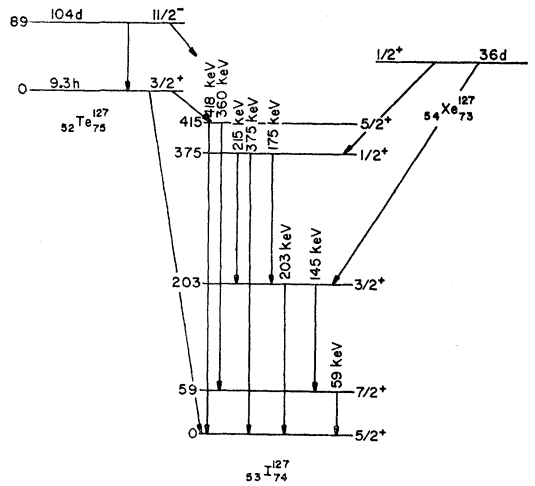

FIG. 1. Partial decay scheme of Te^{127m} and Xe^{127}.

* This work was supported by the U. S. Air Force Office of Scientific Research and the U. S. Office of Naval Research.
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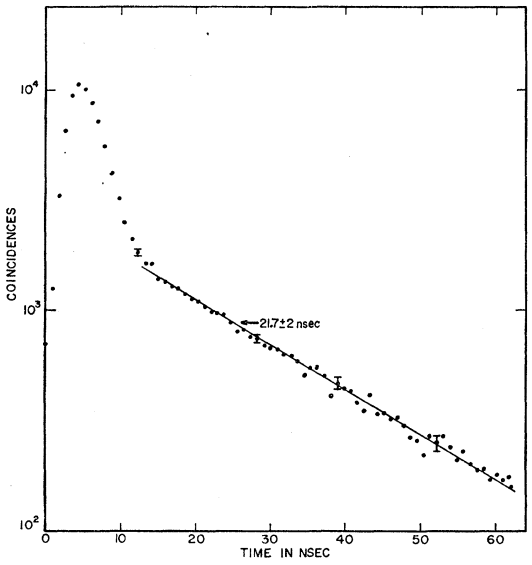

FIG. 2. Delayed-coincidence curve of the 26.8-keV gamma ray in I^{129} (gamma-gamma coincidence).

isomeric lifetimes have previously been measured with this equipment. The first was the lifetime of the 26-keV state in[1] I^{129}. This was achieved using a Te^{129m} source, both by observing gamma-gamma and beta-gamma coincidences. The results of the 454–26-keV gamma-gamma coincidence study are shown in Fig. 2. The slope corresponds to a mean life of 21.7±2 nsec. Figure 3 shows the results obtained using coincidences between the 26-keV gamma and 600–900-keV betas emitted in the decay of the tellurium parent. The weighted mean of two of these measurements is 20.8±1 nsec. In both cases, the 26-keV gamma ray was detected in anthracene

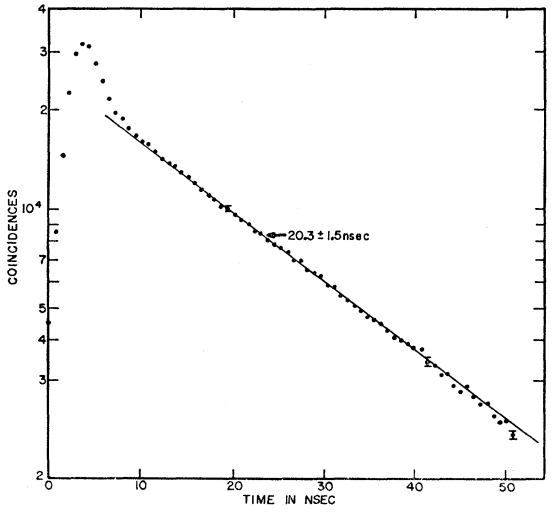

FIG. 3. Delayed-coincidence curve of the 26.8-keV gamma ray in I^{129} (beta-gamma coincidence).

[1] George Lang and R. Leonard, Bull. Am. Phys. Soc. 8, 86 (1963).

crystal and the preceding radiation in Pilot-B plastic scintillant. Other values which have been reported for this lifetime are (26.8±1.6),[2] (22.9±1.9),[3] (20.8±0.7),[4] and 26.9 nsec.[5] The second previously measured lifetime was that of the 22-keV state in Sm^{149}.[6] In the decay of Eu^{149}, the 22-keV state in Sm^{149} is fed by a 328-keV gamma ray from the de-excitation of the 350-keV state. The results of the coincidence studies between the 328- and 22-keV gamma rays, the former detected in a pilot-B crystal and the latter in anthracene, are shown in Fig. 4. The mean life is 10.0±1.0 nsec. This is consistent with the subsequently published value of 10.9 nsec.[7]

In I^{127}, the lifetime of the 59-keV state was measured using both the xenon and tellurium sources. In measurements using the xenon source, coincidences were observed between the 59-keV gamma and the 145-keV

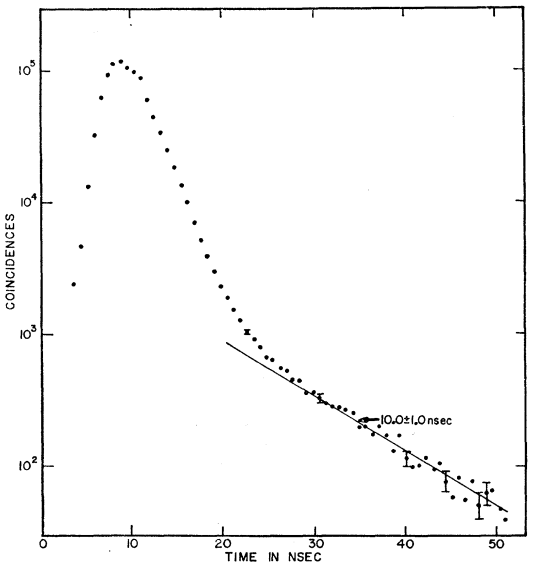

FIG. 4. Delayed-coincidence curve of the 22-keV gamma ray in Sm^{149} (gamma-gamma coincidence).

gamma which precedes it. The results are shown in Fig. 5. Both the radiations were detected in Pilot-B plastic scintillant and selected by comparison with the hump of the 22-keV K x ray of Cd^{109}, 30-keV K x ray of Xe^{127}, the 40-keV K x ray of Sm^{149}, 136-keV gamma ray of Hf^{181}, and 511-keV annihilation radiation. In each case, it was impossible to avoid including in the gate pulses due to higher energy radiation. Conse-

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[5] S. H. Devare and H. G. Devare (private communication).
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quently, the delayed-coincidence spectrum contains a prompt component. For the prompt curve in Fig. 5, coincidences between the 175- and 200-keV gamma rays were examined. The pulses were chosen in the region 70 to 100 keV and 130 to 160 keV to make them as near as possible to those in the delayed cascade. The slope of the tail of the delayed curve corresponds to a mean life of 1.5±0.3 nsec for the 59-keV state.

With the tellurium parent the same lifetime was measured, using coincidences between the 59-keV gamma and the betas emitted in the decay of the parent. Again, both radiations were detected in Pilot B. The result of the measurement is shown in Fig. 6. The slope of the decay curve corresponds to a mean life of 2.1±0.4 nsec, which is not inconsistent with the value obtained using the xenon parent. An average of the two results

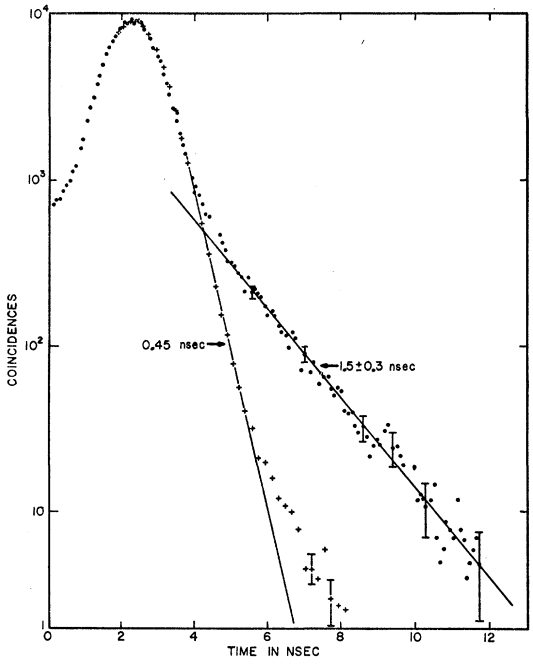

FIG. 5. Delayed-coincidence curve of the 59-keV gamma ray in I^{127} (gamma-gamma coincidence with Xe^{127} source).

is 1.8±0.3 nsec, which is somewhat lower than the value quoted by Geiger.[8] This is also consistent with the Mössbauer effect data of Barros *et al.*,[9] which places a lower limit of 1.25 nsec.

IV. ANGULAR CORRELATION STUDIES

In order to interpret the lifetime measurements, angular correlation studies were undertaken to determine the multipolarity of the 59-keV transition. The same gaseous Xe^{127} source was used, sealed in a cylindrical glass container 1 cm in length and 5 mm in

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[9] F. des Barros, S. Jha, N. Ivantchev, and R. Reddy (to be published).

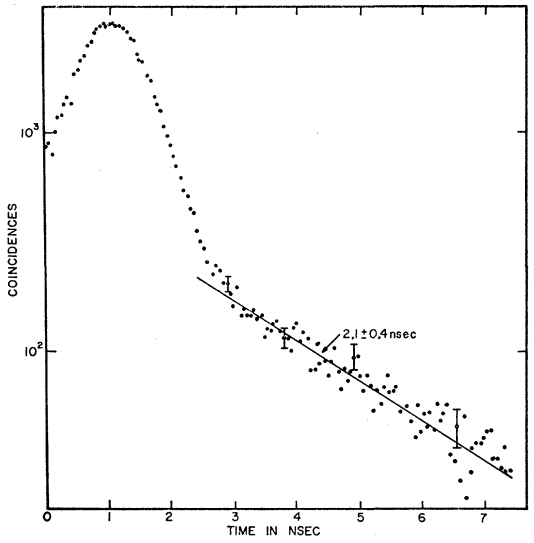

FIG. 6. Delayed-coincidence curve of the 59-keV gamma ray in I^{127} (beta-gamma coincidence with Te^{127m} source).

diameter. The partial gamma-ray spectrum obtained from this source in a $1\frac{3}{4}\times 2$-in. NaI(Tl) crystal is shown in Fig. 7(a). The angular distribution of the 59-keV gamma relative to the 145-keV gamma ray was determined by examining the output of a scintillation counter in a multichannel pulse-height selector set to trigger on the 145-keV radiation. The 59-keV peak as observed in the coincidence with the 145-keV gamma

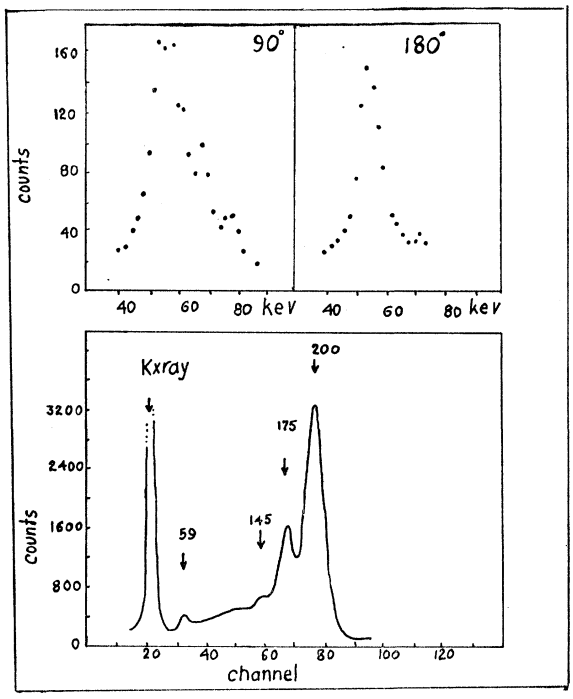

FIG. 7. (a) Partial spectrum of gamma rays from Xe^{127} source. (b) 59-keV peak in coincidence with the 145-keV gamma ray at 90 and 180°.

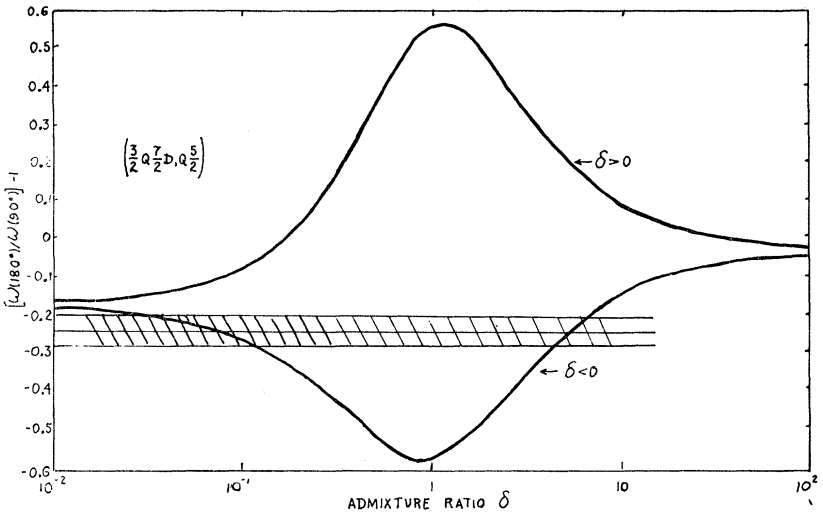

FIG. 8. Expected anisotropy of the 145–59-keV angular correlation as a function of δ, the electric quadrupole admixture in the 59-keV gamma ray (the 145-keV gamma ray has been assumed to be pure $E2$).

ray at 180° and at 90° is shown in Fig. 7(b). The hump which appears on the high-energy side is presumably due to the backscattering. To eliminate its effect, only the lower half of the 59–keV peak was used in determining an angular correlation. The anisotropy observed, $[W(180°)/(W90°)]-1$ was found to be -0.24 ± 0.04. To interpret this result, the spin assignment shown in Fig. 1 was assumed. The 145-keV transition should then be pure quadrupole so that the only parameter to be determined is the $E2/M1$ mixture ratio in the 59-keV transition. Theoretically, the angular distribution will have the form

$$W(0)=1+\delta^2+(-0.127+0.756\delta+0.31\delta^2)P_2(\cos\theta) -0.134\delta^2P_4(\cos\theta)$$

after corrections for finite source and counter size. A graph of the expected anisotropy as a function of δ, the mixture ratio, is shown in Fig. 8. The crosshatched area in Fig. 8 represents the experimental result and its associated error. Two values of δ may be taken from the graph. Either -0.076 ± 0.04 or -5.4 ± 1.0 will fit the experimental data. In view of the predominantly magnetic dipole nature of similar transitions in neighboring odd-Z isotopes, the first solution is selected. This corresponds to an electric quadrupole admixture of $(0.6\pm0.6)\%$.

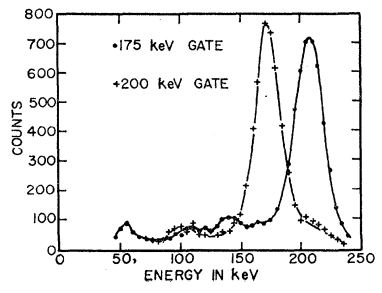

FIG. 9. Coincidence spectra obtained from Xe^{127} source with 200-keV gamma ray as the gate and 175-keV gamma ray as the gate (the source was in the gaseous form, pressure ≈1 mm).

The angular correlation of the 200–175-keV cascade also was studied using a gaseous source of Xe^{127} at a pressure of about 1 mm of mercury. The spectra obtained using the 200-keV gamma-ray pulses and 175-keV gamma-ray pulses in the gate are shown in Fig. 9. The study revealed a very small anisotropy as shown in Fig. 10(a). It was realized that the discrepancy of this result with that of Geiger[8] could be due to the fact that, whereas Geiger used Xe^{127} absorbed in aluminum, the present experiment was carried out with free atoms.[10] The experiment with Xe^{127} adsorbed on charcoal has been carried out with the help of Reddy and Patnaik. The result is shown in Fig. 10(b). This result is consistent with that of Geiger. The anisotropy in the angular correlation of the 146–59-keV cascade, however, is unchanged whether the source is in the gaseous form or adsorbed on charcoal. It could very well be that, within about a nanosecond following the electron capture, the highly ionized I^{127} atom is nearly neutralized so that the 145–59-keV angular correlation is not

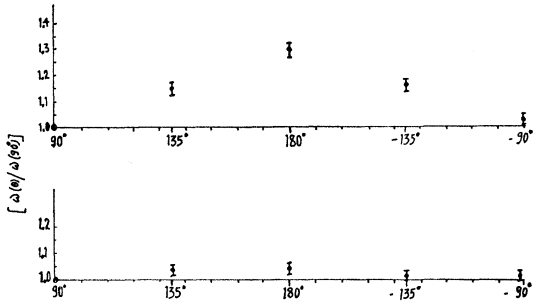

FIG. 10. The angular correlation data of the 175–200-keV cascade from a source of Xe^{127}. (a) The source was in the gaseous form, pressure ≈1 mm. (b) The source was adsorbed on charcoal.

[10] H. Frauenfelder, in *Beta and Gamma Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1955).

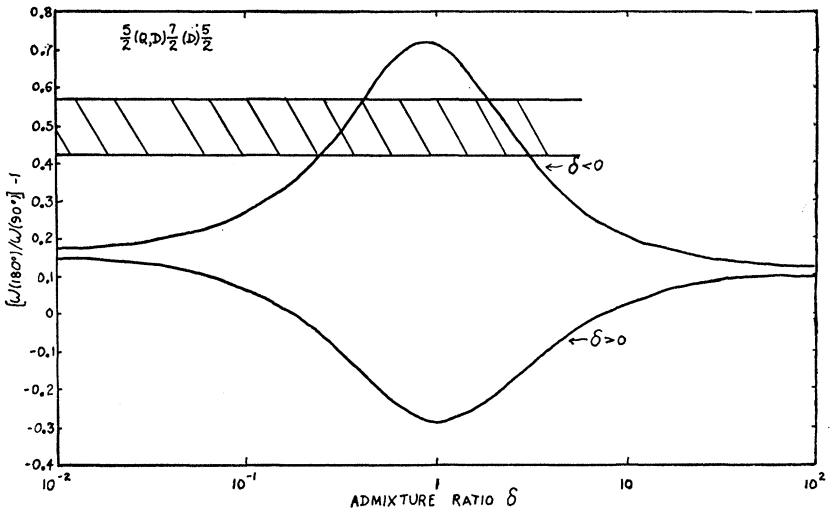

FIG. 11. Expected anisotropy of the 356–59-keV angular correlation as a function of δ, the electric quadrupole admixture in the 59-keV gamma ray.

perturbed. The lifetimes of the 200- and 375-keV states are estimated to be less than about 5×10^{-10} sec.[8] Apparently, in this time interval, the iodine atoms are not fully neutralized and the electric and the magnetic fields at the nucleus produce enough perturbation of the nuclear orientation to seriously attenuate the 175–200-keV angular correlation. If the above view is correct, one should notice pronounced effects with changing the pressure of the gas, and with changes in the medium on which the xenon gas is adsorbed.

Also studied was the angular correlation of the 356–59-keV cascade. This cascade is fed only from the tellurium side. The tellurium source was dissolved in nitric acid and placed in a container of quartz tubing 2 cm in length and 5 mm in diameter. The observed anisotropy $[W(180°)/W(90°)]-1$ was found to be 0.498 ± 0.07 after geometric corrections. Assuming again the spin assignment as shown in Fig. 1 for the ground state and first excited state, and the multipolarity now determined for the 59-keV gamma ray, it is possible to assign the spin of the 415-keV state as well as the multipolarity of the 356-keV photon. The spin of the 415-keV state must be either $\frac{1}{2}$, $\frac{3}{2}$, or $\frac{5}{2}$, since it is fed in the beta decay of the spin-$\frac{3}{2}$ ground state of Te^{127}. The spin-$\frac{1}{2}$ possibility is eliminated since this would require a spin change of three units between the 415- and 59-keV states. The spin-$\frac{3}{2}$ possibility is also eliminated since this would mean that the 356-keV photon would be pure electric quadrupole, and hence would possess the same angular distribution relative to the 59-keV gamma as does the 145-keV gamma ray. This is in disagreement with the experimental result so that the only possible spin assignment is $\frac{5}{2}$. To fit the observed anisotropy, it is then necessary that the 356-keV photon be a mixture of magnetic dipole and electric quadrupole; the admixture, as determined from Fig. 11, being either $(9.3_{-3.0}{}^{+5.7})\%$ or $(85_{-7.0}{}^{+4.5})\%$ depending on which of the two solutions is selected. Without some additional piece of information such as internal conversion coefficients, no choice can be made.

V. DISCUSSION

The angular correlation results indicate that the 59-keV transition is almost entirely magnetic dipole. Since, on the basis of a strict single-particle model, the states involved would be classified as $d_{5/2}$ and $g_{7/2}$, the transition belongs to that group known as l-forbidden

TABLE I. Retardations of l-forbidden magnetic dipole transitions in odd-Z nuclei.

Nucleus	E_γ (keV)	Measured mean life (10^{-10} sec)	Total conversion coefficient	$E2/M1$ ratio	$T_\gamma(M1)$ experimental (10^{-10} sec)	Retardation	Reference
Sb^{123}	160	9.2±0.7	0.17	0	10.8±0.8	216±20	(13)
I^{127}	59	18±3.0	3.8	$(0.6\pm0.6)\times10^{-2}$	86±15	67±14	This paper
I^{129}	26	208±10	4.9	0	1227±60	122±9	This paper
I^{131}	147	11.5±1.4	0.25	0	150±20	300	(14)
Cs^{133}	81	87±6	2.1	0	260±20	670	(14)
Cs^{135}	248	4.1±1.2	0.1	0.4	6.2	470	(14)
La^{137}	10	1280±58	130±65	0	1.6×10^5	760	(15)
La^{139}	163	21±1.5	0.25	0	27±2	360	(14)

$M1$ transitions, first observed by Bell and Graham,[11] and subsequently by many others. The radiative lifetime of the 59-keV state, using a conversion coefficient of 3.8 as extrapolated from the table of Rose,[12] was found to be 8.6 ± 1.0 nsec. This is longer by a factor of 67 ± 14 than predicted by the Weisskopf estimate for an allowed $M1$ transition of this energy. This delay is comparable in magnitude to the retardation observed for other l-forbidden magnetic dipole transitions in odd-Z nuclei shown in Table I.[13–15] In addition, it is in good agreement with the retardation of about 110 predicted by Sorensen[16] who, with Kisslinger,[17] has calculated wave functions for the states involved on the basis of a single-particle model with residual pairing and quadrupole forces. This indicates that the existence of l-forbidden $M1$ transitions is due, in part at least, to a collective nuclear interaction. Sorensen's results differ considerably, however, from many of the observed lifetimes; for instance, in Sb and Cs, indicating that some other effects are slao involved.

ACKNOWLEDGMENT

This work would not have been possible without the help and cooperation of L. George Lang.

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PHYSICAL REVIEW VOLUME 136, NUMBER 6B 21 DECEMBER 1964

Resonance Fluorescence in Ir^{191}†

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(Received 10 August 1964)

Resonance fluorescence from Ir^{191} has been investigated with Pt^{191} as the source of the exciting radiation. The centrifuge technique was used for the compensation of the recoil energy losses. The known level at 539 keV was excited and a mean lifetime of $(1.1_{-0.3}^{+0.7})\times10^{-11}$ sec was determined. A second level excited at (590 ± 15) keV might be identical with that suggested at 584 keV. The limits for the mean lifetime τ are $5\times10^{-13}<\tau<1.5\times10^{-11}$ sec. No resonance fluorescence was observed from the 625-keV level. The small transition probabilities for the γ transitions from the 539- and the 625-keV levels to the ground-state band are not compatible with the previous assignment to Nilsson orbit $(402)\uparrow$. A satisfactory agreement with the Nilsson model was obtained by assuming that these levels belong to the rotational band built on Nilsson state $(411)\uparrow$.

INTRODUCTION

IN the course of a systematic search for resonance fluorescence from odd nuclei in the transition region around mass number 190, the nucleus Ir^{191} has been investigated using the centrifuge technique. A radioactive Pt^{191} source supplied the exciting radiation. The interest was focused on the excitation of the levels at 539 and 625 keV in Ir^{191}. Much information about the properties of these levels is available from recent studies of the radioactive decay of Pt^{191}.[1–3] According to an interpretation in terms of the Nilsson model by Harmatz *et al.*,[1] both levels belong to the rotational band with the asymptotic quantum number $(402)\uparrow$. The ground state of Ir^{191} was assigned to Nilsson state $(402)\downarrow$. Resonance fluorescence experiments in Re^{187} [4] showed that the $(402)\downarrow-(402)\uparrow$ spin-flip transition has a high transition probability. On this basis the 539- and the 625-keV ground-state transitions in Ir^{191} were expected to be very fast. On the other hand, this is in contradiction to the observation of many low-energy γ transitions competing with these ground-state transitions.

EXPERIMENTS AND RESULTS

The experimental procedure and the apparatus for the observation of nuclear resonance scattering using the centrifuge technique has been described elsewhere.[5] A Pt^{191} source was obtained by irradiation of platinum enriched to 0.75% in Pt^{190} in the Oak Ridge research reactor. With a flux of about 2×10^{14} slow neutrons/sec cm^2 and an irradiation time of 3 days, 12 mg of Pt

† Work supported by the National Science Foundation.
* On leave of absence from II. Physikalisches Institut, Goettingen.
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