PHYSICAL REVIEW VOLUME 140, NUMBER 2B 25 OCTOBER 1965

Decay Scheme of 25-Minute Te^{131g}[†]

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(Received 28 May 1965)

The decay of 25-min Te^{131g} produced by Te$^{130}(n,\gamma)$ has been investigated with the use of Ge(Li) and NaI(Tl) γ-ray detectors. Coincidence relationships among the γ rays were determined in γ-γ and sum-peak coincidence experiments. Because of the good resolution of the Ge(Li) detector we have been able to resolve complex γ-ray peaks observed in the ~350- and 950- to 1000-keV regions in previous studies and to observe additional γ rays. The energies (in keV) of observed γ rays and their percentage intensities relative to 150-keV (in parentheses) are: 279 (1), 343 (1.1), 384 (1.1), 453 (24.0), 493 (7.0), 544 (0.4), 603 (5.9), 654 (1.8), 695 (0.5), 727 (0.4), 842 (0.2), 898 (0.3), 933 (1.2), 948 (3.0), 952 (0.6), 997 (5.1), 1007 (1.5), 1098 (0.8), 1147 (9.4), 1295 (1.4). The main changes from previous level schemes for I^{131} are the lowering of the ~350-keV transitions to near the ground state and the addition of levels at 877, 1188, and 1445 keV. Preliminary measurements on the γ rays of 1.2-day Te^{131m} are reported. Trends of the low-lying levels of odd-A iodine isotopes from mass 127 to mass 131 are discussed. The half life of Te^{131g} was determined to be 25.0±0.1 min.

I. INTRODUCTION

THE low-lying levels of even-Z, odd-N nuclides in the neutron-shell region $50 \leq N \leq 82$ have been extensively studied, especially with the use of (d,p) and (d,t) nuclear reactions.[1–4] The results have been compared with nuclear models, particularly the treatment by Kisslinger and Sorensen.[5] Information on the levels of odd-Z, even-N nuclides is in general more difficult to obtain and, consequently, much less information is available. The study of the β and γ decay of odd-mass tellurium isotopes $A=127$ to 133 to levels of the daughter iodine isotopes offers excellent possibilities for study of the trends of 53-proton levels as a function of (even) neutron number 74 to 80. A useful feature of this series is the fact that the β decay of both $\frac{11}{2}-$ and $\frac{3}{2}+$ isomers of the tellurium isotopes can be observed. Thus, a wide variety of spin-parity states are populated and not as many levels are missed as in most radioactive-decay studies.

The work reported here concerns mainly the decay of 25-min Te^{131g}. The decay of Te^{131g} has been studied in several previous works,[6–8] the most definitive being that of Devare, Tandon, and Devare[8] (hereinafter designated DTD). In the latter work, γ-ray spectra taken with NaI(Tl) detectors showed considerable complexity in the region 900 to 1000 keV. In constructing the decay scheme, DTD found it necessary to invoke the existence of γ rays of 920-, 935-, and two of 985-keV energies. The level scheme also included γ rays of 350 and 360 keV, although these were not resolved in the spectra obtained with NaI(Tl). With the use of a Ge(Li) detector, both in "singles" and coincidence experiments, we have been able to eliminate the uncertainties in those regions, to observe additional γ rays, and determine with high accuracy (±1 keV) the energies of all observed transitions. In order to check whether or not weak lines resulted from 1.2-day Te^{131m}, 67-min Te^{129g} [from (n,γ) on Te^{128}], and 8-day I^{131} we have observed singles spectra of those species.

II. EXPERIMENTAL PROCEDURES

Production of Te^{131g}

The Te^{131g} was produced by irradiation of 2-mg samples of tellurium enriched to >99.5% Te^{130} in the M.I.T. reactor. Irradiations lasted for 1 min at a flux of 8×10^{12} n cm^{-2} sec^{-1}. No chemical separation was required and the polyethylene vial containing the irradiated sample was simply opened to release Ar^{41} produced by Ar$^{40}(n,\gamma)$ before counting. The irradiation also produced small amounts of 1.2-day Te^{131m}, but because of its high spin ($\frac{11}{2}-$) and long half-life, the activity was so low that the Te^{131g} could be studied for several half-lives before interference from the isomer was appreciable.

Detectors

The face of the Ge(Li) detector had dimensions 1.5×1.5 cm and the thickness of the intrinsic layer was about 3.5 mm. The detector was mounted in an evacuated portion of a Dewar vessel containing liquid nitrogen. The source was placed just outside the vessel at a position which allowed the γ rays to strike an edge of the detector. The full width at half-maximum of γ-ray peaks in spectra obtained with the detector resulted mainly from noise in the preamplifier and was about 4.9 keV for the γ rays obtained from standard sources of

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[†] This work was supported in part by the U. S. Atomic Energy Commission under contract number AT(30-1)-905.

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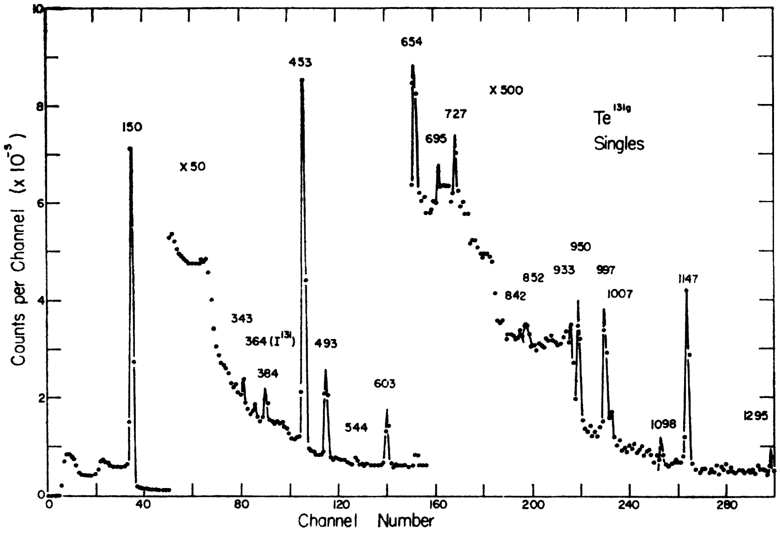

FIG. 1. Gamma-ray spectrum of 25-min Te^{131g} obtained with a Ge(Li) detector.

Co^{57} and Cs^{137}. The NaI(Tl) detectors used were integrally mounted 7.6-×7.6-cm crystals.

Amplifiers and Coincidence Units

Pulses from both types of detectors were passed through preamplifiers and amplifiers. In the case of NaI, the main amplifiers were transistorized DD2 amplifiers. Coincidences were observed with a commercial fast-slow unit operating in the "zero-crossover" mode[9] on the DD2 pulses. The resolving time used for the fast coincidences was generally about 50 nsec, large enough to avoid appreciable loss of coincidences between pulses of very different magnitudes because of differences in zero-crossover time. The main amplifier for the Ge(Li) pulses was of the low-noise *RC* type. For coincidence studies the *RC* pulses were attenuated and fed through a DD2 amplifier before the coincidence unit. Pulses were taken directly from the *RC* amplifier for input to the pulse-height analyzer.

Sum-peak spectra were taken with well-matched 7.6-×7.6-cm NaI(Tl) detectors with amplifiers adjusted to give as nearly as possible the same pulse height for a given energy deposited in either detector. The signals from the two amplifiers were summed in a linear adder. Our sum experiments differ somewhat from others reported in the literature in that we always demanded fast and slow coincidences between the two detectors which were well-shielded against Compton "cross talk." Thus, we eliminated all single γ rays from the spectra. Also, we used low geometry (source-to-crystal distance ~10 cm) so that the probability for observing more than one γ ray per event in each detector was very low. Therefore, essentially all events observed were for one γ ray in each detector.

III. RESULTS

In Fig. 1 we show a typical singles spectrum of 25-min Te^{131g} obtained with the Ge(Li) detector. The γ-ray energies were read from a calibration curve obtained from spectra produced by a number of standard γ-ray sources. For all but the very weak lines and those close to intense lines, the uncertainty of energy is about ± 1 keV. Photopeak areas were determined by subtracting an assumed linear background from the peaks. Relative intensities were obtained from photopeak areas with the use of a calibration curve based on the γ-ray spectra from Bi^{207} and Fe^{59} sources. Intensities of the γ rays emitted from these sources are well known[10] and span the range of γ-ray energies of interest in this work. The resulting curve of total photopeak efficiency (i.e., peak-to-total ratio × total efficiency as used by Heath[11]) versus energy was linear on log-log paper for the energy range covered, in agreement with the relationship observed by Easterday *et al.*[12] In Table I we list the γ-ray energies and their intensities. For comparison, we also list the intensities determined by DTD and by us using NaI detectors. The listed intensities for Ge(Li) were mostly obtained from Fig. 1, but for some lines which do not stand out well in the singles spectra, the intensities were determined from the Ge(Li)-NaI(Tl) coincidence spectra. These cases are discussed in more detail below. The agreement in intensities from the two types of detectors is generally quite good.

In Figs. 2 and 3 are shown the spectra taken with the Ge(Li) detector with the analyzer gated on by pulses

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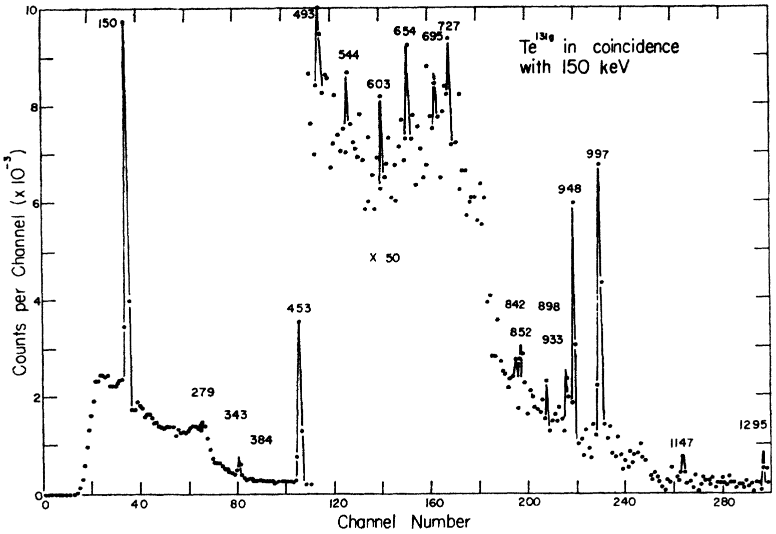

FIG. 2. Spectrum of 25-min Te^{131g} γ rays in coincidence with 150-keV γ rays as obtained with a Ge(Li) detector. A NaI(Tl) crystal was used to detect the 150-keV γ rays.

corresponding to 150 and 453-to-493 keV, respectively, occurring in a NaI(Tl) detector. The great stability of the Ge(Li) detector against count-rate-dependent gain shifts and long-term drifts are particularly useful in this application. Over the course of the Ge(Li) experiments (6 days), the 1.333-MeV peak produced by a Co^{60} standard had a total variation of 0.3 channel (mean position, channel 306). In comparing the positions of the larger peaks of Figs. 1, 2, and 3, we find no detectable change of gain. Thus, we were able to distinguish between a peak at 952-keV coincident with the 453- to 493-keV region and a peak at 948-keV coincident with the 150-keV region, even though these peaks occur only one channel apart and cannot be distinguished in the singles spectrum. In Table I are given the intensities of the γ rays in the coincidence spectra relative to that of the 150-keV line and the ratios of intensities of the various peaks relative to the singles spectrum (the latter designated "coincidence ratios").

In Table II are given the γ-γ coincidences observed in the NaI-NaI experiments. In Fig. 4 is shown the sum-peak spectrum along with the expected intensities of the sum peaks as calculated from the level scheme proposed below.

In Figs. 1, 2, and 3 there is definite evidence for a weak γ ray at 852 keV and in Fig. 3, a weak γ ray at 795 keV, both known to be very strong radiations emitted in the decay of 1.2-day Te^{131m}.[13] In order to check this, several of the samples in which the original Te^{131g} had decayed (although a small amount is present in equilibrium with Te^{131m}) were observed for several hours with the Ge(Li) detector. Although the resulting spectrum, shown in Fig. 5, shows lines which originate in the decay of 8-day I^{131} and 12.9-h Cu^{64} impurity, we

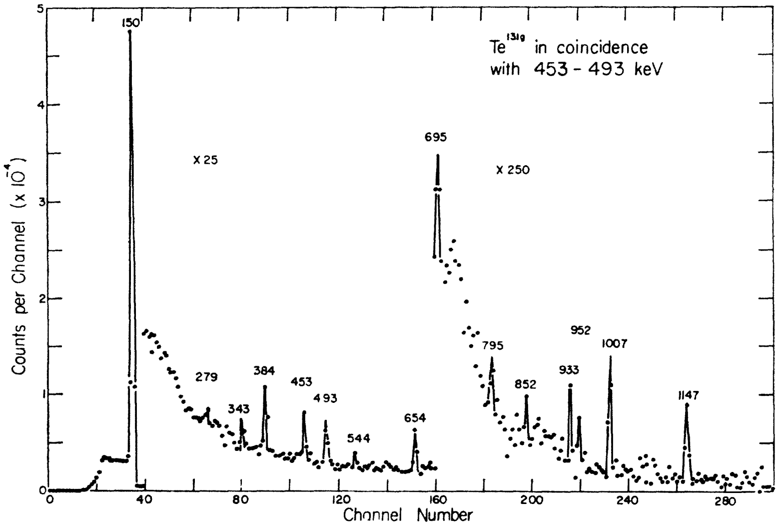

FIG. 3. Spectrum of 25-min Te^{131g} γ rays in coincidence with 453- to 493-keV γ rays as obtained with a Ge(Li) detector. A NaI(Tl) crystal was used to detect the 453- to 493-keV γ rays.

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[13] A. I. Bedescu-Sigureanu, Rev. Phys., Acad. Rep. Populaire Roumaine 7, 173 (1962).

TABLE I. Relative intensities of γ rays following Te^{131g} decay—singles and coincidence spectra.

Gamma-ray energy (keV)	Intensities, percent rel. to 150-keV					Coinc. ratios $I(E_\gamma, \text{coinc.})/I(E_\gamma, \text{singles})$	
	NaI, singles		Ge(Li)				
	DTD[a]	This work	Singles	Coinc./150	Coinc./453-493	Coinc./150	Coinc./453-493
150	(100)	(100)	(100±3)	(100)	(100)	0.011	0.064
279	b	b	1.0+0.2[c]	e	0.10	e	d
343	2.1	1.5	1.1±0.2[c]	3.4	0.11	d	d
384			1.1±0.2	0.7	0.6	0.062	0.29
453	28.0	23.5	24.0±1.5	43.2	0.3	0.205	0.009
493	4.6	6.9	7.0±0.4	0.46	0.33	0.01	0.044
544	b	b	0.4±0.1	0.3	0.08	0.12	0.20
603	7.9	6.5	5.9±0.3	0.3	0.04	0.011	0.009
654	1.3	2.7	1.8±0.2	0.34	0.34	0.05	0.304
695	b	b	0.5±0.1[c]	e	0.09	e	d
727	b	0.9	0.4±0.06	0.21	b	0.16	b
842	b	b	0.2±0.08[c]	0.09	e	d	e
898	b	b	0.3±0.08[c]	0.13	e	d	e
933	4.5	4.5	1.2±0.2[c]	0.01	0.05	d	d
948			3.0±0.4	1.28	b	0.24	b
952			0.6±0.2[c]	b	0.025	b	d
997	7.0	7.2	5.1±0.4	1.70	b	0.18	b
1007			1.5±0.2	b	0.07	b	0.29
1098	b	b	0.8±0.2	b	b	b	b
1147	8.0	7.9	9.4±0.6	0.13	0.07	0.012	0.04
1295	1.2	1.1	1.4±0.2	0.1	b	0.1-0.25	b

[a] Reference 8.
[b] Not seen.
[c] Intensity determined from Ge(Li)-NaI(Tl) coincidence experiments.
[d] Coincidence ratio could not be determined because intensity of peak in singles spectrum was too small.
[e] Peak seen, but not large enough to give a meaningful intensity.

can observe the prominent radiations of Te^{131m}, including the lines at 852 and 795 keV which are the second and third most intense γ rays, respectively, from the decay of Te^{131m}. In successive spectra of Te^{131g}, the 852-keV line appears to decay with a half-life considerably greater than 25 min. Attributing all of the 852-keV intensity in Fig. 1 to the 1.2-day Te^{131m} does not require other Te^{131m} γ rays to be large enough to be clearly observable in the singles spectrum.

IV. CONSTRUCTION OF THE DECAY SCHEME

In Fig. 6 we show the decay scheme of Te^{131g} based on the results presented above, and below we present arguments for the proposed scheme.

The 150-keV γ ray is so intense that it can feed only the ground state. The 453-keV line, known to be coincident with 150, must feed directly the 150-keV level because of its high intensity. The 603-keV line shows coincidences only with the weak 544, 842, and 898 lines (see below); therefore, it must feed the ground state. Within experimental error the level at 603 is the same as that depopulated by 150-453 coincidences. By similar reasoning, a level at 1147 keV is depopulated by an 1147-keV γ ray to the ground state and a 997-keV γ ray to the 150-keV level.

The coincidence ratios from the Ge(Li)-NaI(Tl) experiments listed in Table I are very useful in constructing the decay scheme. Consider the coincidence ratios for the events coincident with 150-keV γ rays. The value for 150-keV γ rays, 0.011, represents random coincidence events. Therefore, the peaks at 493, 603, and 1147 keV are purely random, with no true coincidence with 150-keV γ rays indicated. As we have already established that the 453-keV line feeds the 150-keV level directly, we can take its coincidence ratio, 0.205, as a criterion for γ rays which always lead to the 150-

TABLE II. Coincidences observed in NaI-NaI experiments.[a]

Gate region (keV)	150	279	343	384	453	493	603	654	727	952	997	1147	1295
	γ ray observed in coincidence with gating pulse (keV)												
150			*G,S*		*G,S*	*N*	*N*	*G*	*G,S*	*G,S*	*G,S*	*N*	*G,S*
343	*G,S*			*S*		*N*		*S*		*G,S*		*N*	
384						*G,S*						*N*	
453	*G,S*		*S*									*N*	
493	*N*			*G,S*				*G,S*		*G,S*	*G,S*	*N*	
1147	*N*	*G*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	

[a] Meaning of symbols: *G*, γ-γ coincidence observed; *S*, sum peak observed; *N*, definite absence of coincidence; blank space, no experiment which would prove or disprove coincidence.

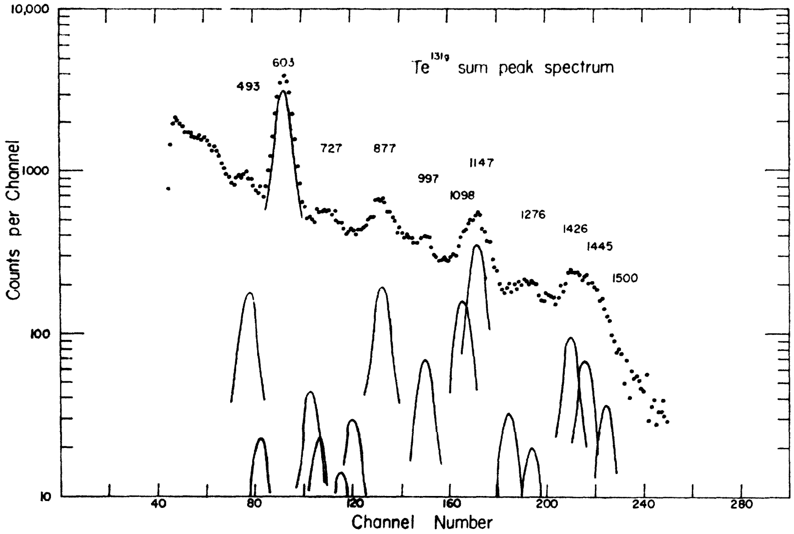

FIG. 4. Gamma-ray sum-peak spectrum of 25-min Te^{131g} obtained with two NaI(Tl) crystals. The points are experimental and the solid curves are the sum peaks calculated on the basis of the proposed decay scheme of Fig. 6. No Compton-Compton or Compton-photopeak background has been added to the calculated sum peaks.

keV level. In this category, we find the γ rays of 343, 727, 948, 997, and 1295 keV. There is considerable statistical uncertainty in the intensity of the 1295-keV line in the coincidence spectrum, but its placement is supported by the data given in Table II. The absence of 453–948 coincidences (see below) and the high intensity of the 948-keV line require that it feed the 150-keV level directly.

This, in addition to a weak γ ray observed only in the singles spectrum at 1098 keV, serves to establish a level at 1098 keV. This corresponds to the level at 1065 keV proposed by DTD.[8]

Very small peaks occur at 842 and 898 keV which may feed either the 150- or 603-keV levels. Their assignments to positions which feed the 603-keV level are based on their observation in coincidence with both the 150-keV peak and the 450- to 493-keV peak area as well as the fact that the levels at 1445 and 1500 keV have been established by other evidence. The intensities of both γ rays are so low that the listed intensities may contain considerable error.

The observation of a 727-keV sum peak, as well as a 727-keV peak in the singles Ge(Li) spectrum, indicates alternate modes of a 727-keV transition, either by a single crossover γ ray or by a 384-343 cascade. From the coincidence ratios of Table I, it appears that the 343- and 727-keV lines feed the 150-keV level directly. The small coincidence ratio for 384 with 150 suggests an alternative mode of decay of the 493-keV level to ground. This is the crossover 493-keV γ ray.

The spectrum in coincidence with the 453- to 493-keV region is more difficult to interpret. Because of the high intensity and proximity of the 453-keV line to that at 493 in the NaI spectrum, it is impossible to gate

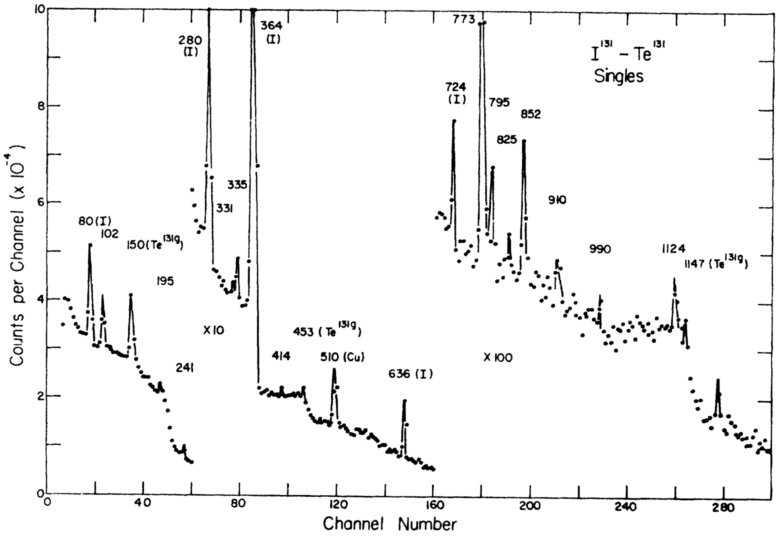

FIG. 5. Gamma-ray spectrum obtained with a Ge(Li) detector on neutron-irradiated Te^{130} samples 15 h after irradiation. Peaks labeled by I, Te^{131g}, or Cu are known to be associated with the decay of 8-day I^{131}, 25-min Te^{131g}, or 12.9-h Cu^{64} impurity, respectively. The other γ rays are presumed to arise in the decay of 1.2-day Te^{131m}.

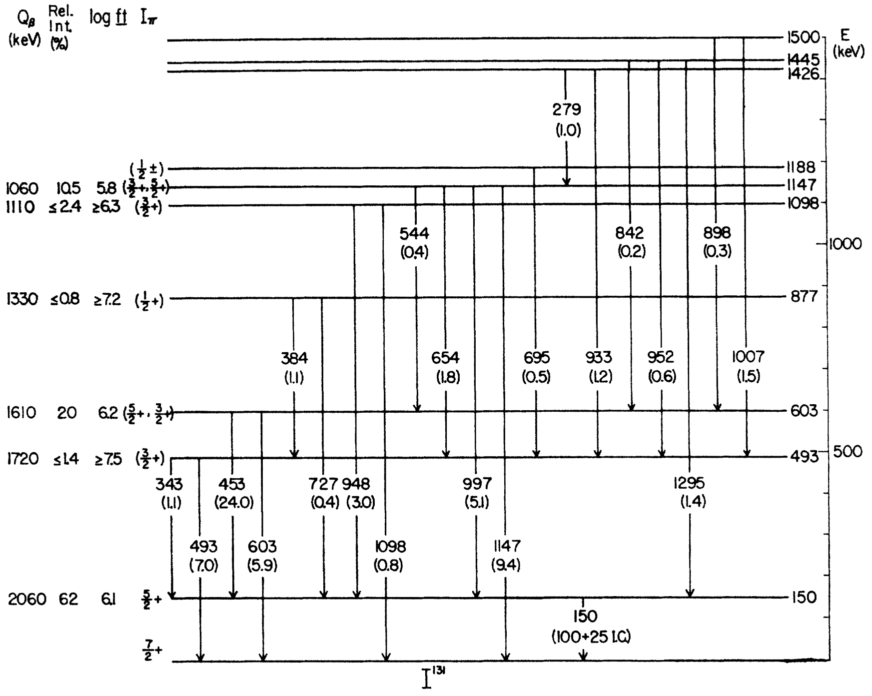

FIG. 6. Decay scheme of 25-min Te^{131g} populating levels of I^{131}. Numbers in parentheses associated with γ rays indicate intensities relative to that of 150-keV γ rays.

on 493-keV events without obtaining a large fraction of gate pulses from the 453-keV events. Also in the gate region there are large Compton tails from higher-energy γ rays. We can eliminate much of the confusion by noting that γ rays coincident with 453 must also be coincident with γ 150. Thus, only the 150-, 544-, 842-, and 898-keV γ rays are coincident with 453. The coincidence ratios (0.009) of 453- and 603-keV lines represent purely random events. The coincidence ratios (0.04) of the 343- and 493-keV lines arise from random events plus coincidences with Compton events in the gate. The ratios (0.3) for the 384-, 654-, and 1007-keV γ rays indicate true coincidences with the 493-keV line and direct feeding of the 493-keV level.

The peak in the vicinity of 950 keV in Figs. 1, 2, and 3 was most puzzling. Since it appears in both coincidence spectra, one might at first suppose that a 950-keV γ ray populates either the 493- or 603-keV level. Thus, it would be coincident with 150 and 453 or 493. But the bulk of the 950-keV line cannot feed the 493-keV level, as this would require the 343-keV line's intensity to be slightly greater than that of 950 in the spectrum coincident with 150. Also, the intensity of the ~950-keV peak in the spectrum coincident with 453- to 493-keV γ rays is too low compared with that of the ~950-keV peak in the singles Ge(Li) spectrum to allow the line to feed entirely the 603-keV level. On the basis of these considerations we propose two different γ rays of about 950-keV energy, the more intense one (948 keV) feeding the 150-keV level, the much weaker one (952 keV) feeding the 493-keV level. As noted above, careful inspection of Figs. 2 and 3 showed an approximately 1-channel shift of this peak, whereas other peaks remained constant.

The small peaks at 695 and 933 keV in the spectrum coincident with 453 to 493 feed the level at 493 keV, as they are not observed in coincidence with the 150-keV peak. The intensities of the 695- and 933-keV transitions were determined from their intensities in the spectrum coincident with the 453 to 493 region relative to that of the 654-keV transition. By gating on the 1147-keV peak and looking at the coincidence spectrum, we found only a very weak 279-keV peak. In Fig. 6 we show it populating the level at 1147 keV.

Above we have presented evidence for all of the features of the γ transitions among the levels in I^{131} populated by the decay of Te^{131g} shown in Fig. 6. An additional check on these results is provided by the sum-peak spectrum of Fig. 4. On the basis of Fig. 6, we have calculated the expected magnitudes of the sum peaks as indicated in Fig. 5, taking into account the assumed[8] total conversion coefficient of 0.25 for the 150-keV transition. Because of the background caused by Compton-Compton and Compton-photopeak summing, it is difficult to "strip" the sum-peak spectrum. However, the agreement appears to be good between the expected and observed magnitudes of the sum peaks.

There is one remaining problem concerning the γ rays. Because of the various arguments presented above, the bulk of the 1147-keV γ line must feed the ground state as indicated in Fig. 6. If this were to account for all of the 1147 intensity, we would expect the coincidence ratio of the 1147-keV γ ray in the spectrum coincident with 453–493-keV radiations (Table I) to be that caused by random events, or about 0.009 as obtained for the 453- and 603-keV lines. Instead, the ratio for 1147 is 0.04, about a factor of 4 too high, well outside of statistical error. We cannot avoid the problem by supposing that we have missed a γ ray of >453-keV energy feeding the level at 1147. If that were to account for the 1147 intensity in the coincident spectrum, the alternate mode of decay, 997-150 cascade, would also have to be high, which it is not. Thus, there is apparently another γ ray in the scheme of about 1147-keV energy, although we have not observed any broadening or shift of the peak in any of the singles and coincidence spectra.

In Fig. 6 we have indicated the intensities of β groups feeding the various levels. These were obtained from the differences between the sum of γ rays feeding and depopulating each level and DTD's observation that no appreciable number of β rays populate the ground state. Account was taken of the approximately 0.25 conversion coefficient of the 150-keV γ ray.[8] The β-ray and log *ft* values for transitions to levels above 1147 keV have not been listed, as both quantities are very sensitive to errors in the intensities of the weak γ lines which depopulate the levels. Beta-ray Q values were determined from the excitation energies of the levels and DTD's measurement of $Q_\beta=2.060$ MeV for the group that populates the first excited state.

We measured the half-life of Te^{131g} by multiscaling the 150-453 coincidence counts produced by a source of Te^{131g} and subjecting the results to a least-squares computer analysis.[14] The resulting half-life is 25.0 ±0.1 min.

V. ASSIGNMENT OF SPINS AND PARITIES

Log *ft* values for the β transitions shown in Fig. 6 were determined with the use of Moszkowski's nomogram.[15] The log *ft* values are in good agreement with those given by DTD in cases where comparison is possible. The β transitions to levels at 150, 603, and 1147 keV are clearly allowed. Although the log *ft* values for transitions to some of the other levels are >7, suggesting forbiddenness, we cannot rule out the possibility that some of them are allowed. As discussed below, the γ transitions suggest strongly that the 493-keV level has spin $\frac{3}{2}$; thus, the β transition to it should be allowed although it has log $ft\geq 7.5$. This apparent hindrance of allowed $\frac{3}{2}+\rightarrow\frac{3}{2}+$ transitions appears to be rather general for the lowest $\frac{3}{2}+$ state of the odd-mass iodine isotopes.

Before applying information on γ-ray branching to the assignment of spins, we should discuss the expected enhancement of $E2$ transition rates and hindrance of $M1$ rates for nuclides in the mass-130 region. From the comparison of experimental and calculated $M1$ rates by Goldhaber and Weneser,[16] it appears that $M1$ transitions in this region are hindered by factors of 10 to 1000 relative to expected single-proton rates. From similar comparisons for $E2$ transitions, it appears that their rates may be enhanced by factors in the range of 20 to 30.[5] More specifically, from the lifetimes of the $M1$ $\frac{5}{2}+-\frac{7}{2}+$ transitions to the ground states of I^{127}, I^{129}, and I^{131}, Jha and Leonard found $M1$ hindrance factors of 67, 122, and 300.[17] From our own calculations on $M1$-$E2$ competition for transitions among the levels of I^{127},[18] we find values for $E2$-enhancement $\times M1$-hindrance in the range 160 to 2000 in agreement with the information given above.

The spins of Te^{131g}, and of the ground state and 150-keV levels of I^{131} are known to be $\frac{3}{2}+$, $\frac{7}{2}+$, and $\frac{5}{2}+$, respectively.[8] Because of the allowed nature of the β groups to the 602- and 1147-keV levels, they must have spins $\frac{1}{2}+$, $\frac{3}{2}+$, or $\frac{5}{2}+$. We can eliminate $\frac{1}{2}+$ for the 603 level because of the strong transition to the ground state. If the spin is $\frac{3}{2}+$, the predicted ratio, $(M1, 603\rightarrow150)/(E2, 603\rightarrow0)$ for single-proton transitions[18] is 4.5×10^3 as compared with the experimental ratio of 4. But as noted above, $E2$ transitions can easily be enhanced relative to $M1$ by a factor of 10^3, so we are unable to rule out spin $\frac{3}{2}+$ for this level. If the spin is $\frac{5}{2}+$ and both transitions are $M1$, the predicted transition ratio is 0.4, within a factor of 10 of the experimental value.

The 493-keV level is very interesting. The β group feeding it has log $ft\geq7.5$, suggesting odd parity or $I\geq\frac{7}{2}$. We rule out odd parity at such a low excitation energy on the basis of systematics of odd-Z nuclides in the mass-130 region. But its spin must be less than $\frac{7}{2}+$ as it is populated by transitions from a number of higher levels whose decay does not feed the ground state. Also, the 493-keV level does not appear to be fed in the β-γ decay of the 1.2-day Te^{131m} $\frac{11}{2}-$ isomer.[13] We can rule out spin $\frac{1}{2}+$ on the basis of the transition to the ground state. Two possibilities remain, $\frac{3}{2}+$ and $\frac{5}{2}+$, as an $E2$ transition to the ground state could be possible with the enhancements noted above.

The 877-keV level must have spin $\leq\frac{3}{2}+$ as no transition to the ground state is observed. If the transitions to the 150- and 493-keV levels were both $M1$ or $E2$, the calculated single-proton ratio of intensities $(877\rightarrow493)/(877\rightarrow150)$ would be 0.13 or 0.04, respectively, compared with the experimental value of 3, which is higher by factors of about 30 and 120, respectively. Since the two ratios simply account for the energy dependence of a given type of radiation, we would not expect the errors to be as large as indicated. Therefore, we conclude that the two transitions must be of different multipolarity, the one to the 493-keV level, $M1$, and the one to the 150-keV level, $E2$. The calculated

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ratio in this case is 100 in agreement with the experimental ratio of 3 when account is taken of $E2$ enhancement. As a result of these considerations, the spin of the 877-keV level is $\frac{1}{2}+$, and that of the 493-keV level is $\frac{3}{2}+$.

The 1147-keV level has spin $\frac{3}{2}+$ or $\frac{5}{2}+$ as γ rays from it feed many levels including those having spins $\frac{3}{2}+$, $\frac{5}{2}+$, and $\frac{7}{2}+$. The level at 1098 keV probably has spin $\frac{3}{2}+$, as γ rays from it feed the ground state and 150-keV level, the latter much more strongly. We would be unable to observe a 604-keV γ ray to the 493-keV level because of the strong 603-keV γ ray present in the spectrum. The level at 1188 keV probably has spin $\frac{1}{2}$ as its decay picks out the lowest spin-$\frac{3}{2}+$ level. A γ ray of 1038 keV to the first excited state should be easily observable if present. At the excitation energy of 1188 keV we do not believe it is safe to assume the parity is even; thus, we assign the level spin $\frac{1}{2}\pm$.

Our information on the higher states is not sufficiently detailed to make further spin assignments. One problem should be noted. It is difficult to understand why the decay of the level at 1426 keV populates the levels at 1147 and 493 keV with comparable probability in spite of the large difference in transition energies.

The most prominent features of our proposed decay scheme agree well with those of the scheme previously proposed by Devare *et al.*[8] When the difference in resolution and accuracy of energy determinations is taken into account, their levels at 145, 490, 590, 1065, 1130, 1425, and 1480 keV correspond well with our levels at 150, 493, 603, 1097, 1147, 1426, and 1500 keV. In addition we have found evidence for levels at 877, 1188, and 1445 keV. With the observation of some additional transitions and the change of placement of the two γ rays of ~360 keV, we have been able to make somewhat more definite spin and parity assignments.

V. INTERPRETATIONS OF LEVELS

In the upper part of Fig. 7, we have summarized information on the low-lying levels of odd-A iodine isotopes $A=127$ to 133 (based on Refs. 10, 13, 17, 19–24 and this work), where we have connected levels in neighboring isotopes that appear to have similar properties. In the region of 53 protons we expect the protons to be filling single-particle levels $g_{7/2}$, $d_{5/2}$, $h_{11/2}$, $d_{3/2}$, and $s_{1/2}$ in approximately that order.

According to the treatment by Kisslinger and Sorensen[5] (hereinafter designated KS), the pure single-quasiparticle levels (before consideration of the long-range force) for odd-A iodine isotopes of mass ~130 are expected to fall at the following energies: $g_{7/2}$, 0; $d_{5/2}$, 0.39; $h_{11/2}$, 1.74; $d_{3/2}$, 2.72; and $s_{1/2}$, 2.91 MeV. Inclusion of the long-range force brings various levels down to the vicinity of the $\frac{5}{2}+$ and $\frac{7}{2}+$ levels and squeezes the $\frac{5}{2}+$ and $\frac{7}{2}+$ levels closer together. These effects can be seen in the lower part of Fig. 7, where we have shown some of the levels predicted by KS, including the effects of the long-range force.

The most apparent trend among the levels shown in Fig. 7 is a general increase of level separations with increasing number of neutrons. The main reason for this effect is that the energy of the 2+ vibrational phonon increases[25] from about 670 keV at Te^{126} to 850 keV at Te^{130} because N approaches the magic number of 82. The KS predictions are in good agreement with this trend among the low-lying levels, although the actual magnitudes of the level energies are in considerable error in some cases.

One of the more interesting questions is the apparent lack of β feeding of the lowest $\frac{3}{2}+$ level in the three isotopes. Although the transition should be allowed, the log *ft* value is high, in the case of $A=131$, ≥ 7.5. In each case, the transition is an example of the KS classification of "odd jumping"; thus, to first order *ft* should be proportional to $(U_{3/2n}U_{3/2p})^{-2}$, where U's are "emptiness" coefficients for the parent $\frac{3}{2}+$ odd-neutron and daughter $\frac{3}{2}+$ odd-proton levels. The value of $U_{3/2n}$ is ~0.7 or greater for the tellurium parent nuclides. As the $d_{3/2}$ proton single-quasiparticle level lies very high relative to $g_{7/2}$ and $d_{5/2}$, it is nearly empty in all cases and $U_{3/2p}\sim 1$. Therefore, the occupancy of levels does not explain the hindrance of the β transitions.

Going to a higher order, one must realize that the lowest $\frac{3}{2}\pm$ proton levels are very heavily phonon mixed. The single-quasiparticle $\frac{3}{2}+$ level lies initially in the vicinity of 2.7 MeV above the ground state. To first order, additional $\frac{3}{2}+$ states can be constructed by adding ~850-keV 2+ phonons to the ground or first-excited states. Thus, the lowest $\frac{3}{2}+$ state is undoubtedly mainly a mixture of $\frac{5}{2}+$ and $\frac{7}{2}+$ single quasiparticles with a 2+ phonon, and probably contains only a very small admixture of pure $\frac{3}{2}+$ single quasiparticle. The KS calculations (reported in Ref. 25) for the corresponding $\frac{3}{2}+$ level (203 keV) in I^{127} predict that the level is only 16% pure $\frac{3}{2}+$ single quasiparticle, with 76 and 7% contributions from $\frac{7}{2}+$–1 phonon and $\frac{5}{2}+$–1 phonon (ph.), respectively. Therefore, to first order the allowed β decay can take place only from the $\frac{3}{2}+$–0-ph. part of the parent state to the similar part of the daughter-state wave function, or from the $\frac{3}{2}+$–1-ph. part of the initial state to the $\frac{5}{2}+$–1-ph. part of the final state. As the $\frac{3}{2}+$ state in Te^{131} is probably nearly pure single quasiparticle (KS predicts 70%), the latter process is also highly hindered. This same reasoning could also explain the apparent hindrance of β transitions to the lowest $\frac{3}{2}+$ states of I^{127} and I^{129}

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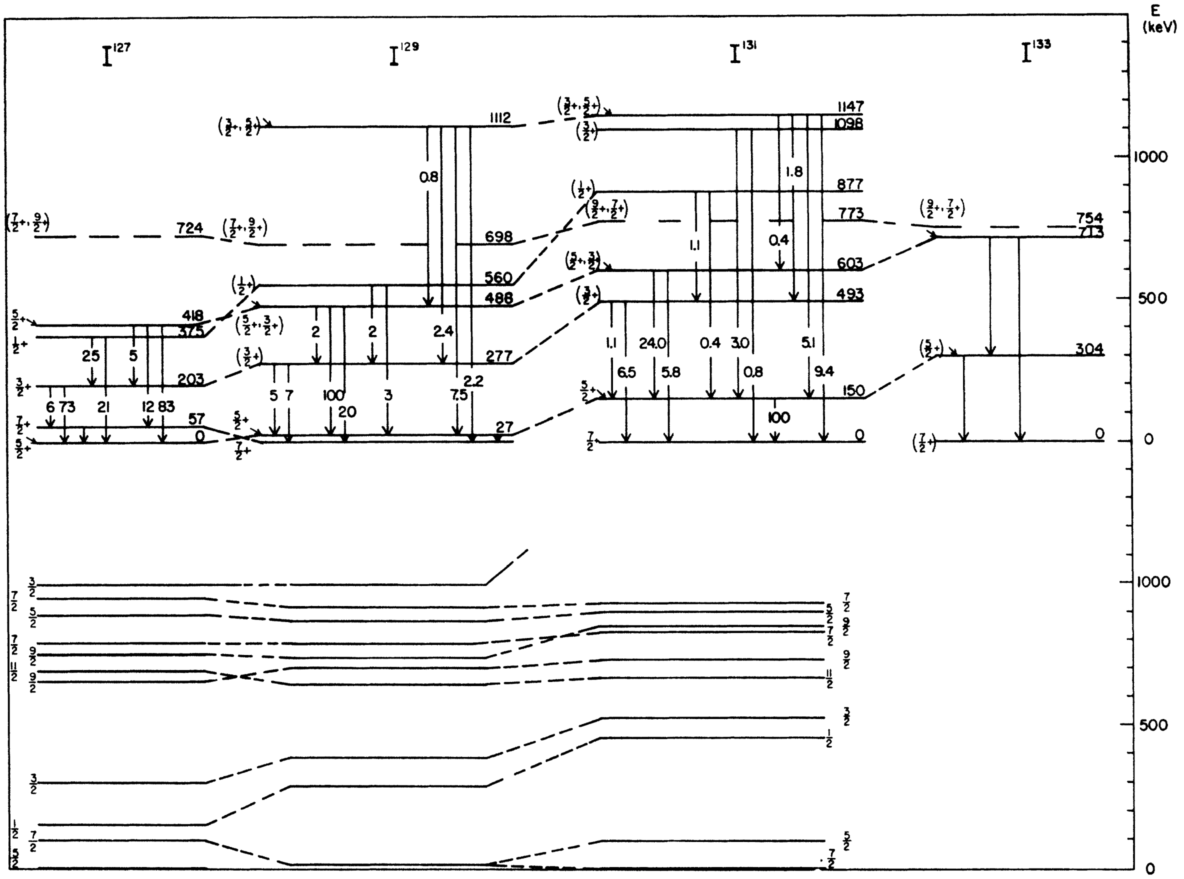

FIG. 7. Upper part: Summary of low-lying levels observed in odd-A iodine isotopes I^{127} through I^{133}. Arrows at the letf of levels denote appreciable β feeding from the $\frac{3}{2}+$ tellurium parent isomer. Dashed levels are seen only in the decay of the $\frac{11}{2}-$ tellurium parent isomer. Numbers associated with γ rays are relative intensities. Lower part: Levels predicted by Kisslinger and Sorensen (Ref. 5).

and the absence of feeding of the lowest $\frac{1}{2}+$ levels in the three members of the series.

If the above explanation is correct we should expect allowed transitions to higher levels which are primarily pure $\frac{1}{2}+$ and $\frac{3}{2}+$ single-quasiparticle levels. The latter could be the 603- or 1147-keV level, both of which are strongly β fed, or one of the levels above 1147 keV. The nearly pure $\frac{1}{2}+$ single-quasiparticle level is probably above 1147 keV. In the case of levels above 1147 keV, even though the *ft* values for some of the transitions may be low, the β feeding would be very small because of the small Q_β values.

It is more likely that the 603-keV level has spin $\frac{5}{2}+$ and is analogous to the 418-keV level of I^{127} and the 483-keV level of I^{129} as suggested in Fig. 7. If so, the strong β feeding of the level presents some difficulty with the KS calculations and the interpretation of hindered β transitions discussed above. The strong β feeding suggests that the wave function for the level should contain a large contribution of pure $\frac{5}{2}+$ single-quasiparticle. However, the KS calculations for the 418-keV level in I^{127} (see Ref. 25) predict only a 1% contribution. From the transition probabilities for γ rays originating from the 418-keV level, Langhoff finds that the $\frac{5}{2}+$-0-ph. contribution should be raised to 4%.[24] A quantitative analysis of the β feeding of the 603-keV level in I^{131} would probably require an even greater contribution. The pure $\frac{5}{2}+$ single-quasiparticle contributions to the second $\frac{5}{2}+$ levels should be larger than those predicted by the KS calculations as, in each member of the series, the upper $\frac{5}{2}+$ lies closer to the lower one than predicted by KS.

In summary, the limited amount of data available on the levels of the odd-A iodine isotopes can be qualitatively well explained with the model of pairing forces plus long-range interactions as treated by Kisslinger and Sorensen.[5]

ACKNOWLEDGMENTS

We wish to thank Dr. H. W. Kraner of the MIT Radioactivity Center and J. A. Sovka of the MIT Nuclear Engineering Department for the use of their Ge(Li) detector and associated equipment. We gratefully acknowledge the helpful suggestions on the work by Professor Charles D. Coryell and Professor R. A. Sorensen. We thank Richard C. Ragaini for his help in the early phases of the experimental work.