Decay of the 25-min Activity of Te^{131}

S. H. DEVARE, P. N. TANDON, AND H. G. DEVARE
Tata Institute of Fundamental Research, Bombay, India
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The decay of the 25-min activity of Te^{131} has been investigated with scintillation spectrometers and also with an intermediate image beta-ray spectrometer. The energies of the gamma rays which have been observed are 145, 350, 445, 490, 590, 650, 930, 985, 1130, and 1280 keV. On the basis of gamma-gamma coincidence measurements, it is proposed that the 350-, 930-, and 985-keV gamma rays are doublets of gamma rays with energies close to each other. The observed coincidences are explained by proposing levels at 145, 490, 590, 1065, 1130, 1425, and 1480 keV. The total absorption gamma-ray spectrum and sum-coincidence spectra have also been studied to confirm these levels and their decay modes. Spin and parity assignments have been made to these levels on the basis of the log *ft* values of the beta transitions feeding them and also their decay modes.

I. INTRODUCTION

SEVERAL authors have studied Te^{131} with the activity in equilibrium with the 30-h activity of Te^{131m},[1–3] and also independent of the Te^{131m} activity.[4,5] From t he results of these investigations, gamma rays of energies 145, 445, 600, 920, 985, and 1130 keV were assigned to the decay of Te^{131}. On the basis of the coincidence relationships among these gamma rays, it was concluded that levels at 145, 600, 920, and 1130 keV in I^{131} are fed in the beta decay of the 25-min Te^{131}. In all these earlier investigations, ambiguities could arise due to interference from Te^{131m} activity or activities due to other tellurium isotopes. The present work was undertaken in order to study the decay of Te^{131} without any interference from other activities.

II. EXPERIMENTAL PROCEDURE AND RESULTS

A. Source Preparation

The 25-min activity of Te^{131} was obtained by irradiating enriched Te^{130} (96%) in the Apsara Reactor, Trombay, in a flux of $\sim 10^{12}$ neutrons/cm^2 sec for periods ranging from 10 to 30 min. The observations were started within 3 min after the irradiations and it was seen that the I^{131} activity did not grow enough to cause any interference. Chemical separation of I^{131} was, therefore, not necessary. The sources for the study of the gamma spectra were made by sandwiching the irradiated metallic powder of tellurium between two aluminium strips of $\frac{1}{16}$-in. thickness. The sources for beta-gamma coincidence measurements were made by depositing the powder on a $\frac{1}{16}$-in.-thick Perspex holder and covering with 500 μg/cm^2 Mylar film. For the Siegbahn-Slätis magnetic beta-ray spectrometer, the powder was deposited on a 500 μg/cm^2 Mylar backing using a highly diluted adhesive to make it stick. These sources were rather thick, being about 5 mg/cm^2. Since the measurements with the magnetic spectrometer could be started only about an hour after the irradiations, the specific activity was low and it was not possible to use thinner sources.

B. Gamma-Ray Spectrum

The gamma-ray spectrum was studied with a 3-in.-diam×3-in.-thick NaI(Tl) crystal coupled to a DuMont-6363 photomultiplier. This scintillation spectrometer had a resolution of about 8.5% for the photopeak of the 662-keV gamma ray of Cs^{137}. The spectra were recorded on a Nuclear Data 512 channel analyzer. The source-to-crystal distance was 15 cm and a Perspex absorber 1 cm thick was used to absorb the beta particles. The gamma spectrum was analyzed in the usual manner by subtracting out the contributions due to individual gamma rays starting at the high-energy end. The line shapes of the gamma rays from Na^{22}, Zn^{65}, Mn^{54}, Cs^{137}, Au^{198}, and Cr^{51} were used as standards for this purpose. The gamma spectrum is reproduced in Fig. 1 which also shows the line shapes as they were fitted in the analysis. It can be seen that gamma rays of energies 145, 350, 445, 490, 590, 650, 930, 985, 1130, and 1280 keV are present. It was ascertained that all of these are due to Te^{131} by following their decay over

TABLE I. Relative intensities of γ rays corrected for photoefficiency and normalized to 100 for the 145-keV line.

E (keV)	Singles spectrum	Spectra in coincidence with γ rays of energies (keV) 145	490
145±5	100 ±3		
350±15	2.1±0.8	2.28±0.4	0.35±0.06
445±5	28.0±1.5	28.0 ±1.5	
490±10	4.6±0.7		
590±5	7.9±0.8		
650±10	1.3±0.2		1.3 ±0.2
930±15	4.5±0.8	3.12±0.6	1.06±0.2
985±15	7.0±1.4	6.94±1.3	0.83±0.16
1130±10	8.0±1.0		
1280±10	1.2±0.2	1.60±0.2	

[1] A. Badescu, K. P. Mitrofanov, A. A. Sorokin, and V. S. Shpinel, Izv. Akad. Nauk S.S.S.R. Ser. Fiz. **23**, 1434 (1959).
[2] A. Badescu, O. M. Kalinkina, K. P. Mitrofanov, A. A. Sorokin, N. V. Forafontov, and V. S. Shpinel, Zh. Eksperim. i Teor. Fiz. **40**, 91 (1961) [translation: Soviet Phys.—JETP **13**, 65 (1961)].
[3] Elizabeth Hebb, Phys. Rev. **97**, 987 (1955).
[4] C. A. Mallmann, A. H. W. Aten, Jr., D. R. Bess, and C. M. de McMillan, Phys. Rev. **99**, 7 (1955).
[5] J. M. Fergusson and F. M. Tomnovec, Nucl. Phys. **26**, 457 (1961).

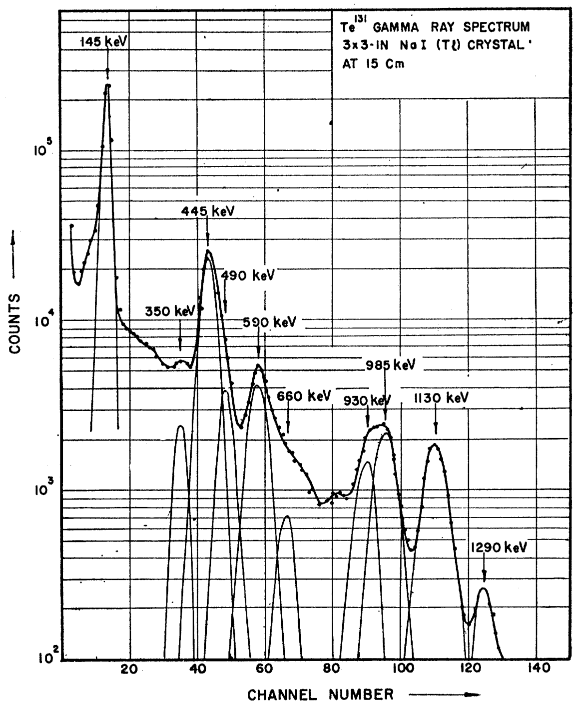

FIG. 1. Gamma spectrum of Te^{131}.

a period of three half-lives. The relative intensities of these gamma rays corrected for the photoefficiency and normalized to a value 100 for the 145-keV gamma rays are given in Table I. The contribution due to genuine or random summing of the gamma rays was seen to be very small and has been taken into account.

C. Gamma-Gamma Coincidence Spectra

The coincidence relationships between the various gamma rays were studied with the help of two scintillation spectrometers consisting of 3-in.-diam×3-in.-thick NaI(Tl) crystals coupled to DuMont-6363 photomultipliers. A fast-slow coincidence set up making use of the crossover pickoff principle[6] in conjunction with double differentiation type linear amplifiers was used. The resolving time was $2\tau = 0.2\ \mu$sec. The crystals were placed face to face with the source in between and a suitable anti-Compton shielding was used to prevent spurious coincidences due to backscattering. The coincidence spectra were recorded on the 512-channel analyzer. The decay of the intensities of the various photopeaks in the coincidence spectra was studied over two half-lives in order to confirm that these were due to Te^{131}. In order to correct for the Compton contributions of the high-energy gamma rays which are included in the gate, the coincidence spectra were recorded with the gate shifted away from the photopeaks. The coincidence spectra were also corrected for chance coincidences which were never more than 10% of the genuine coincidences. The spectrum in coincidence with the 145-keV gamma ray is reproduced in Fig. 2. An analysis of this coincidence gamma spectrum showed that the gamma rays of energies 350, 445, 930, 985, and 1280 keV are in coincidence with the 145-keV transition. Fergusson *et al.*[5] have not observed the 145–930 keV coincidence though they do observe the 145–985 keV coincidence. This may be due to the rather poor statistics in their experiment.

Figure 3 shows the coincidence spectrum with the 490-keV gamma ray in gate. In this case the gate was fixed so as to exclude as far as possible the 445-keV photopeak. It is seen from the analysis of this spectrum that the gamma rays of energies 350, 650, 930, and 985 keV are in coincidence with the 490-keV gamma ray. Coincidence spectra with other gamma rays in the

TABLE II. Te^{131} gamma-gamma coincidence results.

Gate (keV)	Gamma rays in coincidence (keV)
145	350, 445, 930, 985, 1290
350	145, 490, 650, 930, 985, 1130
490	350, 650, 930, 985
650	350, 490
930	145, 350, 490
985	145, 350, 490
1130	350

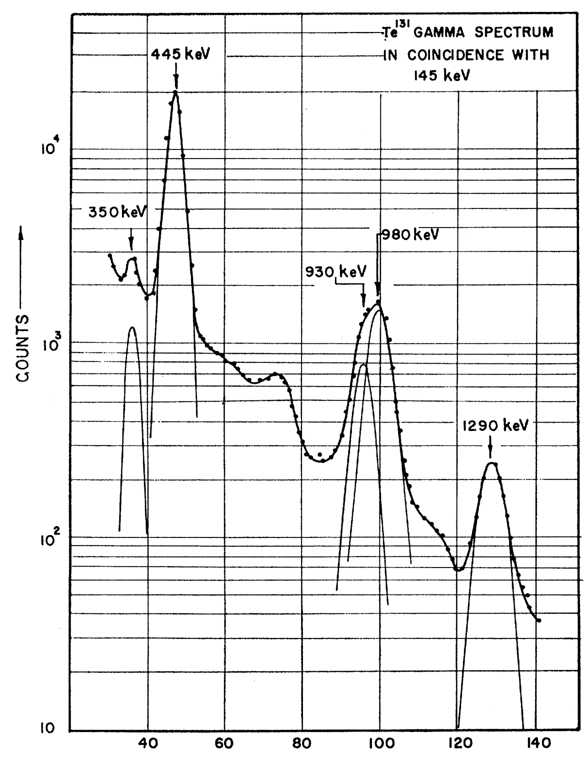

FIG. 2. Gamma spectrum in coincidence with the 145-keV transition.

[6] E. Fairstein, ORNL Report No. 2480, 1958 (unpublished).

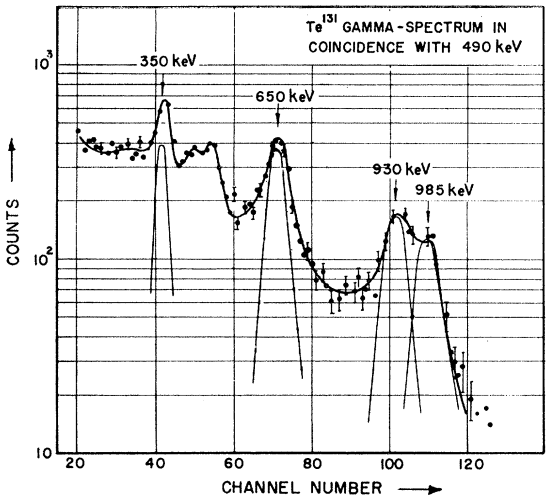

FIG. 3. Gamma spectrum in coincidence with the 490-keV transition.

gate were also studied and the results of all the coincidences are presented in Table II. The fact that 350-, 930-, and 985-keV gamma rays are in coincidence with both the 145- and 490-keV gamma rays which, however, are not in coincidence with each other was interpreted as evidence for each of these to be a doublet of gamma rays of nearly equal energies. All the observed coincidences can then be understood by assuming levels at 145, 490, 590, 1065, 1130, 1425, and 1480 keV. Two gamma rays of energy $\sim$930 keV can arise due to transitions between the 1065- and 145-keV levels and also between the 1425- and 490-keV levels. Similarly, the 985-keV gamma ray is a doublet corresponding to transitions between the 1130- and 145-keV levels and also between the 1480- and 490-keV levels. The 350-keV gamma ray can arise from a transition between the 1425- and 1065-keV levels, as well as between the 1480- and 1130-keV levels. In order to confirm this, it was necessary to find the relative intensities of these gamma rays in coincidence with 145- and 490-keV transitions. This could not be done by the usual method as the solid angles were not known with any accuracy, the source-to-crystal distance being very small. It was noticed, however, that the 445-keV gamma ray is wholly in coincidence with the 145-keV transition and the 650-keV gamma ray is wholly in coincidence with the 490-keV transition. The spectrum in coincidence with the 145-keV transition was analyzed in the usual manner and the relative intensities of the gamma rays in coincidence were determined. The relative intensities in terms of the singles spectrum could then be obtained by using the 445-keV intensity for normalization. Similarly, in the case of the spectrum in coincidence with the 490-keV transition, the intensity of the 650-keV gamma ray was used for normalization. The relative intensities calculated in this way from coincidence spectra are also included in Table I. The agreement between the relative intensities from coincidence measurements and from the singles spectrum seems to be fairly good for the 930- and 985-keV gamma rays. In the case of the 350-keV gamma ray the agreement is poor because of the large errors in the intensity measurement due to several successive subtractions. It is, thus, seen that the coincidence measurements are consistent with new levels proposed at 490, 1065, 1425, and 1480 keV in addition to the previously known levels at 145, 590, and 1130 keV.

D. Total Absorption Gamma Spectrum

In order to confirm the presence of the levels proposed at 1065, 1425, and 1480 keV, the gamma spectrum of Te^{131} was studied in almost 4π geometry by introducing the source in the well of a 3-in.-diam$\times$3-in.-thick NaI(Tl) crystal. The beta particles were absorbed with a copper absorber. In such a spectrum, coincident gamma rays sum up to a large extent giving rise to distinct sum peaks. Levels which have beta feeding can easily be identified from the sum peaks corresponding to them. Figure 4 shows the gamma spectrum of Te^{131} with the source inside the well. The broad peak at the highest energy can be resolved into two peaks as shown, corresponding to levels at 1480 and 1425 keV. It may be remarked here that such sum peaks occur at slightly higher energies due to the nonlinear response of NaI(Tl) and this effect has been taken into account[7] while identifying these with the 1480- and 1425-keV levels. Similarly, the sum peak at 1130 keV is too broad even after taking into account the broadening of the peak due to the simultaneous occurrence of the photopeak of

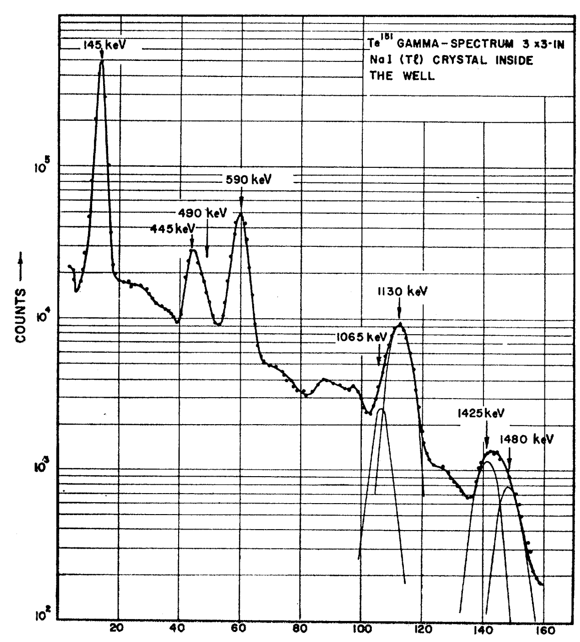

FIG. 4. Total absorption gamma spectrum of Te^{131}.

[7] H. G. Devare and P. N. Tandon, Nucl. Instr. 22, 253 (1963).

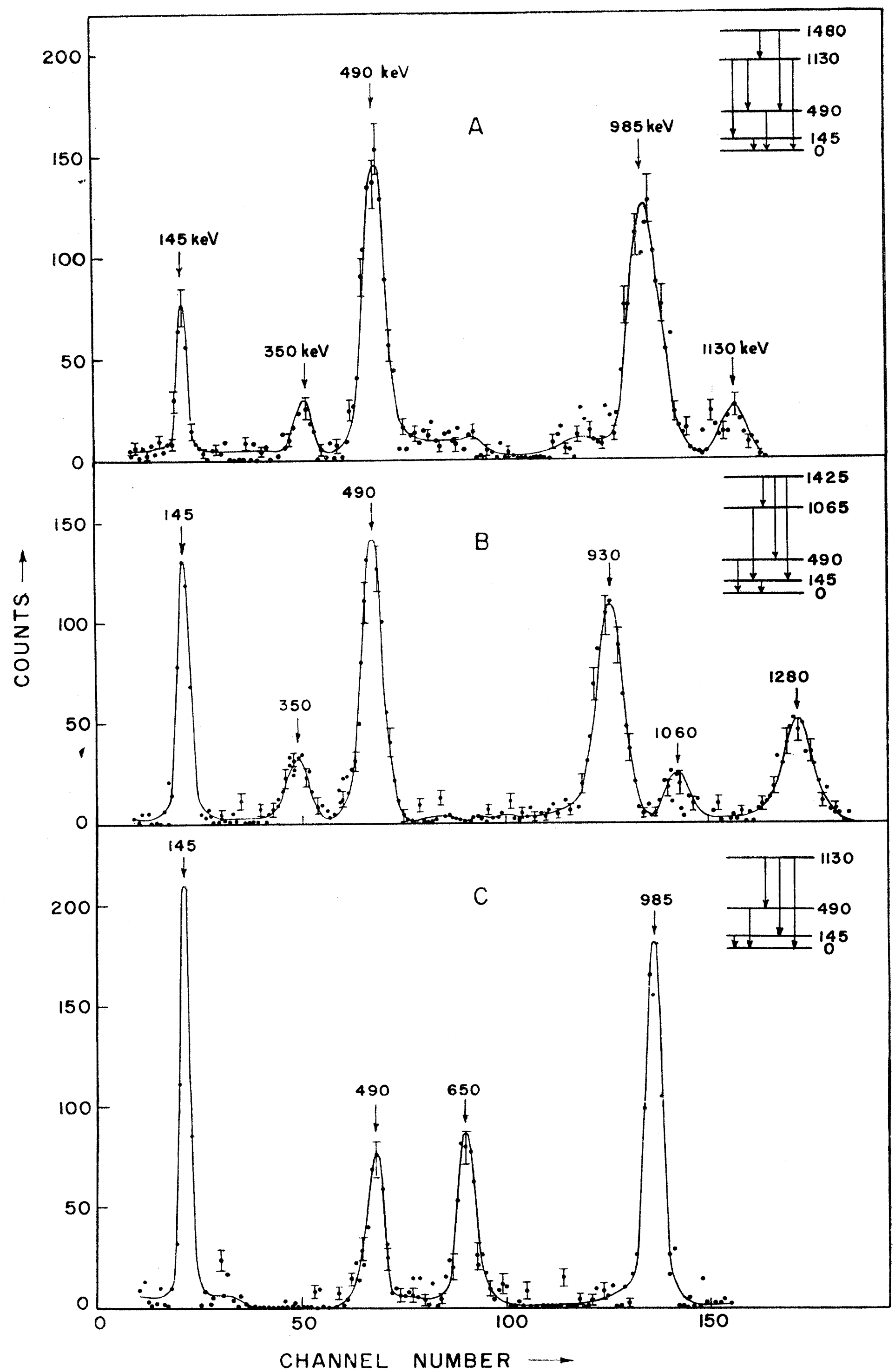

FIG. 5. Sum-coincidence spectra with (A) 1480-keV sum peak in gate, (B) 1425-keV sum peak in gate, and (C) 1130-keV sum peak in gate. In all these cases the final sum peaks have not been shown.

the 1130-keV transition to ground and the slightly shifted sum peak corresponding to the summing of the 985- and 145-keV gamma rays. This also can be resolved into two peaks corresponding to 1130 and 1065 keV as shown in the figure. The intensities of these sum peaks were also seen to be as expected from the relative gamma-ray intensities found from the singles and coincidence gamma spectra. The total absorption gamma spectrum thus substantiates the proposed levels at 1065, 1425, and 1480 keV.

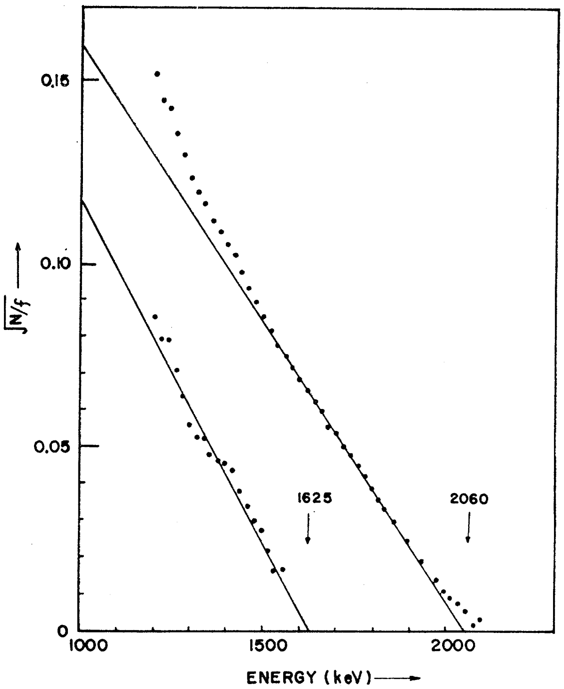

FIG. 6. Fermi plot of the beta spectrum of Te^{131}.

E. Sum-Coincidence Studies

The decay modes of the 1065-, 1130-, 1425-, and 1480-keV levels were also studied with the sum-coincidence technique[8,9] in order to verify further the conclusions reached from the coincidence measurements. The same coincidence setup described in Sec. IIC was used for this purpose. The sum-coincidence spectra with 1480-, 1425-, and 1130-keV sum peaks in gate are reproduced in Fig. 5. The various decay modes of these levels as concluded from the usual gamma-gamma coincidence studies are also shown in each case. It is seen that the 1480-keV level de-excites mainly by the 985–490 keV cascade and to a small extent by 350–1130 and 350–985–145 keV cascades. The intensity of the 350–650–490 keV cascade is relatively smaller and so the peak corresponding to 650 keV is not visible above the background. In the case of the 1425-keV level, the main modes of decay are the 930–490 and 1280–145 keV cascades. Apart from these, de-excitation also takes place to a small extent through the 350–930–145 keV cascade. The peak at ~1065 keV appearing in Fig. 5(B) is due to the summing of the 930- and 145-keV gamma rays and not due to any crossover transition from the 1065-keV level. The sum-coincidence spectrum with 1130 keV in gate shows that this level decays only by 985–145 and 650–490 keV cascades. It may be noted that the widths of the 930- and 985-keV peaks appearing in Figs. 5(A) and 5(B) are more than the width of the 985-keV peak in Fig. 5(C). This is because when the 1480-keV sum peak is taken in gate, a contribution from the 1425-keV sum peak is also present and vice versa. This does not happen in the case of the 1130-keV sum peak where the contribution from 1065-keV sum peak was avoided by choosing a narrow gate. The sum-coincidence spectrum with the 1065-keV gate (not reproduced here) shows peaks at 145 and 930 keV as expected and also other spurious peaks due to summing of Compton contribution with photopeaks. Thus, the sum-coincidence observations also support the proposed levels at 1065, 1130, 1425, and 1480 keV and their decay modes.

TABLE III. Beta-transition data for Te^{131}.

Beta end point (keV)	Level fed (keV)	Relative intensity (%)	log ft
2060±25	145	59	6.2
1625±35	590	25	6.2
1140	1065	1.4	6.8
1075	1130	9.7	5.8
780	1425	2.3	6.0
725	1480	2.2	6.0

F. The Beta-Ray Spectrum

The beta-ray spectrum was studied with a Siegbahn-Slätis intermediate image beta-ray spectrometer. The baffles of the spectrometer were adjusted for a transmission of about 4% and a resolution of $3\frac{1}{2}$%. Because of the low activity and large thickness of the source, only the high-energy part of the spectrum above 1200 keV was studied. The Fermi plot of the beta spectrum corrected for the decay is shown in Fig. 6. The end point of the highest energy beta group is seen to be 2060±25 keV and that of the next group is 1625±35 keV. It was found from beta-gamma coincidence measurements using an anthracene crystal for detecting beta particles that the highest energy beta group feeds the 145-keV level, and the next beta group with end-point energy 1625 keV feeds the 590-keV level. The relative intensities of these two groups as found from the Fermi analysis are 100: 53. However, because of the rather large thickness of the source, the spectrum is expected to be distorted with an excess of low-energy electrons. The relative intensities of the beta groups, therefore, cannot be considered to be reliable. For this reason the relative intensities of the beta groups feeding various levels were obtained from the relative intensities of the gamma rays, assuming the decay scheme shown in Fig. 7 and assuming the total conversion coefficient of 145-keV gamma ray to be 0.25. The beta transition data are summarized in Table III.

III. DECAY SCHEME AND DISCUSSION

The decay scheme proposed on the basis of the present studies is shown in Fig. 7. The levels at 145,

[8] A. M. Hoogenboom, Nucl. Instr. **3**, 57 (1958).
[9] S. Jha, H. G. Devare, M. Narayana Rao, and G. C. Pramila, Proc. Ind. Acad. Sci. **50**, 303 (1959).

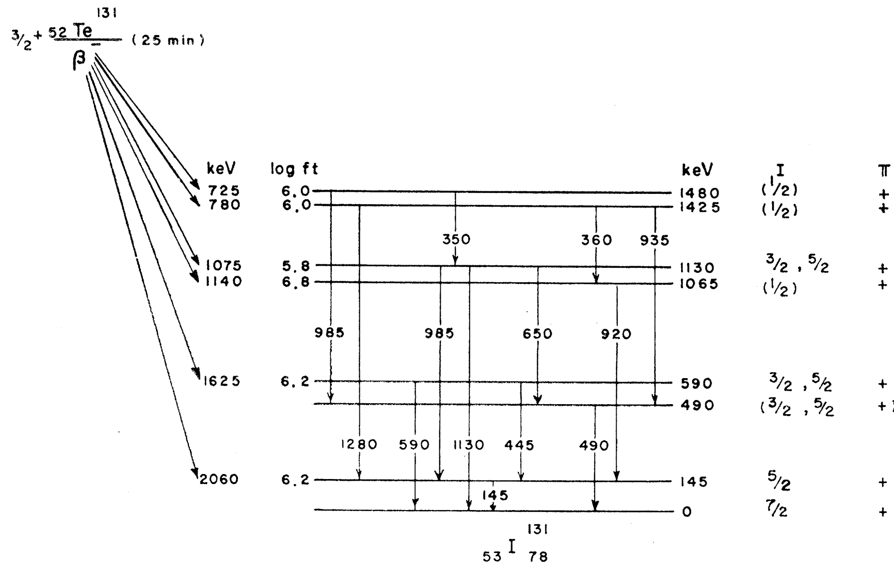

FIG. 7. Decay scheme of Te^{131}.

590, and 1130 keV have been suggested by earlier workers.[1–4] No evidence was found for a level at 930 keV which also had been proposed earlier. The new levels proposed at 490, 1065, 1425, and 1480 keV can satisfactorily explain the occurrence of the 350-, 490-, 650-, and 1280-keV gamma rays, their relative intensities, and also their coincidence relationships. Strong evidence for the 1425- and 1480-keV levels and their proposed decay modes is also obtained from the total absorption gamma-ray spectrum and the sum-coincidence spectra. The possibility of a transition between the 490- and 145-keV levels is not ruled out from the present studies. Such a transition, if present, must be very small compared to the crossover transition to ground. No crossover transitions have been observed from the 1065-, 1425-, and 1480-keV levels. It is also interesting to note that the 590-keV level is not fed from any of the higher levels.

The $\log ft$ values of the beta transitions to all the levels except the 1065-keV one, are around 6 indicating them to be of allowed nature. Now, the ground state of I^{131} has a measured spin and parity of $\frac{7}{2}+$[10] and the beta transition to this from Te^{131m} is known to have a $\Delta J=2$, yes character. This shows that spin and parity of Te^{131m} is $11/2-$, which is also expected from the shell model. The 181-keV isomeric transition has been established to be of $M4$ type from the conversion-coefficient measurements.[3,11] Thus, the spin and parity assignment of Te^{131} should be $\frac{3}{2}+$. The fact that the beta transitions to all the levels except 1065 keV are allowed indicates that all these levels can be characterized as $\frac{1}{2}+$, $\frac{3}{2}+$ or $\frac{5}{2}+$. The $M1$ nature of the 145-keV transition[12] shows that the 145-keV level should have the spin and parity value $\frac{5}{2}+$. The presence of the crossover transition from the 590-keV level rules out the possibility of $\frac{1}{2}+$ as the spin and parity assignment for this level. In the same way the assignment of $\frac{3}{2}+$ or $\frac{5}{2}+$ for the 1130-keV level has been made. The 1480-, 1425-, and 1065-keV levels have been tentatively assigned the spin and parity value $\frac{1}{2}+$ only on the basis of the absence of any crossover transition from these levels to the ground state. This, of course, cannot be considered as a compelling evidence for such an assignment. The assignment of the value $\frac{3}{2}+$ or $\frac{5}{2}+$ to the 490-keV level is consistent with the observed transition to the ground state from this level and also with the transitions to this level from higher levels.

One would normally expect transitions to the 590-keV level from the higher energy levels. Absence of such transitions is rather puzzling and may, perhaps, be due to some of these levels having a predominantly collective character. It is known that such collective excitations can arise in nondeformed odd-A nuclei due to the coupling of the single-particle motion to the quadrupole surface vibrations of the even-even core.[13,14] The energy levels arising due to such a coupling have been calculated in the case of I^{127} and I^{129}.[15] It will be interesting if such calculations are extended to the case of I^{131} also.

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[10] R. Livingston, B. M. Benjamin, J. T. Cox, and W. Gordy, Phys. Rev. **92**, 1271 (1953).
[11] R. D. Hill, Phys. Rev. **76**, 333 (1949).
[12] A. A. Sorokin, Izv. Akad. Nauk S.S.S.R. Ser. Fiz. **23**, 1445 (1959).
[13] D. C. Choudhary, Kgl. Danske Videnskab. Selskab, Mat. Fys. Medd. **28**, No. 4 (1954).
[14] N. K. Glendenning, Phys. Rev. **119**, 213 (1960).
[15] K. K. Gupta and B. Banerji, Nucl. Phys. **30**, 227 (1962).