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Decay Scheme of the Isomers of Te^{129}

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The decay of 70-min Te^{129} and 33-day Te^{129m} has been studied using a beta-ray spectrometer, scintillation spectrometers, and coincidence techniques. The 70-min activity, studied in equilibrium with Te^{129m} and also independently, was seen to emit gamma rays of energies 27, 205, 245, 275, 350, 455, 550, 625, 755, 810, 825, 960, 1080, and 1235 keV. From coincidence relationships among these gamma rays, it was concluded that levels at 27, 275, 350 or 755, 482, 550, 810, 1105, and 1235 keV are excited in the decay of the 70-min activity. Te^{129m} was observed to decay by the emission of gamma rays of energies 550, 695, 720, and 830 keV in addition to the 106-keV isomeric transition. These gamma rays were attributed to the excitation of levels at 695, 830, 1385, and 1415 keV. The Fermi plot of the beta spectrum of Te^{129m} studied with a Siegbahn-Slätis spectrometer showed beta groups with end-point energies of 1595, 1452, 976, and 690 keV. From beta-gamma coincidence measurements it was concluded that 1595 keV is the end-point energy of the beta transition from Te^{129m} to the ground state of I^{129} while 1452 keV is the end-point energy of the beta transition from the 70-min activity to the 27-keV level. Comparison of the total intensities of the beta transitions from Te^{129m} and Te^{129} showed that the isomeric transition takes place with a branching ratio of 0.64. The log ft values for the various beta groups were found from their relative intensities and spin assignments to various levels were made on this basis.

I. INTRODUCTION

THE decay of the Te^{129} isomers has been the subject of several investigations[1–4] in the past, the most recent one being reported by Rao *et al.*[5] The energies and intensities of beta and gamma radiations reported by these workers and the decay schemes suggested show considerable disagreements with each other. In particular the earlier work seems to imply that Te^{129m} decays by the isomeric transition with a relative intensity of 95% and by beta transitions with an intensity of only 5%. Moreover no attempts have been made in the earlier work to identify the gamma rays which arise due to beta transitions from Te^{129m} to excited states of I^{129}. Preliminary studies of the decay of Te^{129m} made in this laboratory[6] indicated that the intensity of beta transitions from Te^{129m} was more than 5% and also that there were beta transitions to excited states of I^{129}. Recently, Andersson and Hagebo[7] have shown that the intensity of the isomeric transition is only 68%. In the present work the decay of the Te^{129} isomers has been studied in greater detail to arrive at a consistent decay scheme and to provide more information on the level structure of I^{129}.

II. EXPERIMENTAL PROCEDURE AND RESULTS

1. Source Preparation

The 70-min activity of Te^{129} was obtained by irradiating about 3 mg of enriched Te^{128} (97%) in the Apsara reactor for 3 h at a flux of $\approx 10^{12}$ neutrons/cm^2 sec. The Te^{129m} was produced by irradiating about 10 mg of the enriched Te^{128} in the DIDO reactor at Harwell for a

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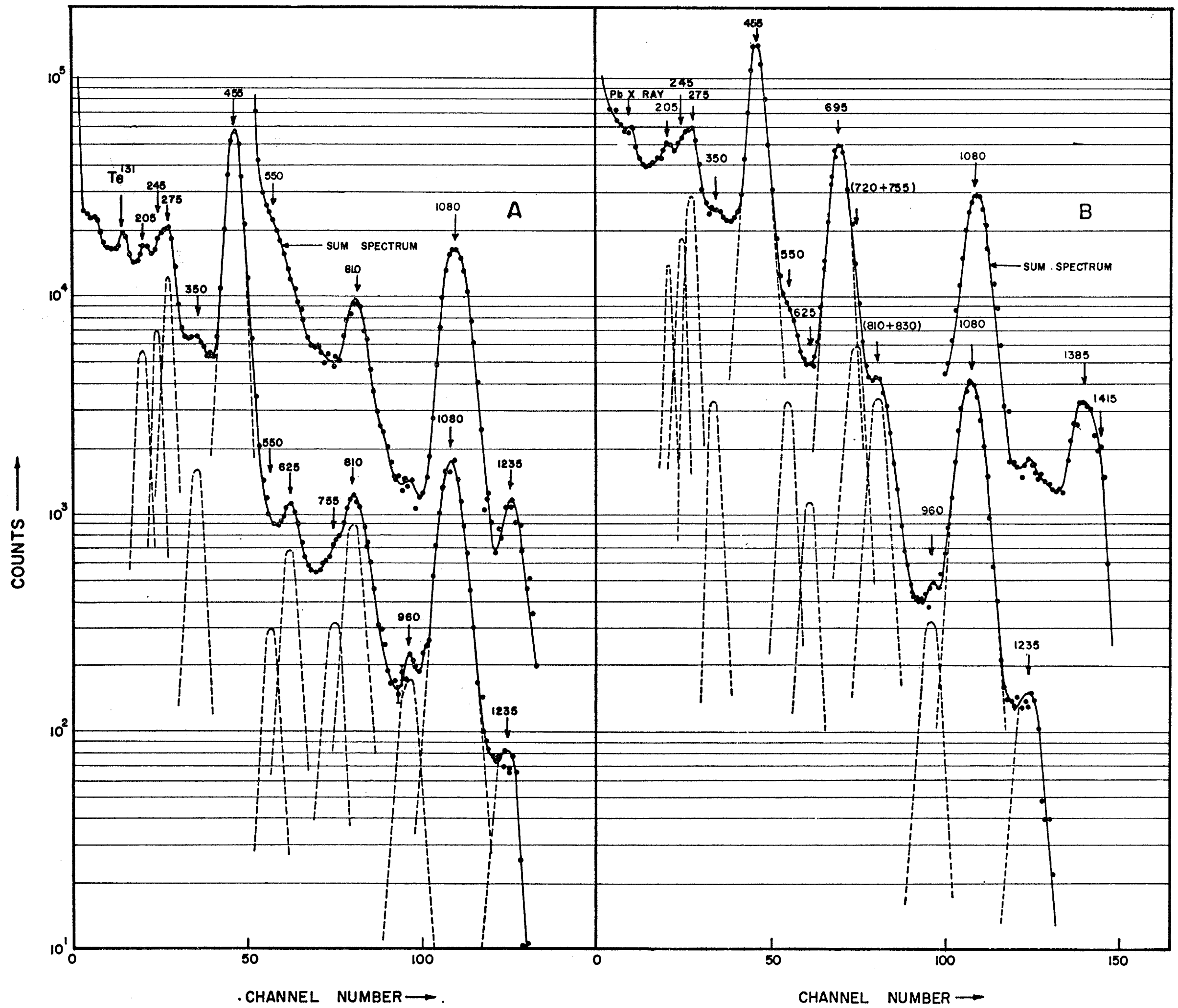

FIG. 1. (A) Gamma spectrum of Te^{129} (70 min). (B) Gamma spectrum of Te^{129m} (33 day). The spectrum taken in 4π geometry is shown above the singles spectrum.

period of $3\frac{1}{2}$ weeks at a flux of 1.2×10^{14} neutrons/cm^2 sec. Te^{129m} was also obtained as a fission product from the Radiochemical Centre, Amersham. All these sources were chemically purified to remove any impurities that might be present. The sources for the study of the gamma spectra and gamma-gamma coincidences were made by depositing the metallic tellurium precipitate on aluminum or Perspex source holders $\frac{1}{16}$ in. thick. The sources for the beta-ray spectrometer and for beta-gamma coincidence with scintillation spectrometers were made by depositing the activity in the form of Telluric acid on a Mylar backing $\simeq$700 μg/cm^2 thick. The thickness of such sources was estimated to be <1 mg/cm^2.

2. Gamma-Ray Spectrum

The scintillation spectrometer used for the study of the gamma-ray spectra consisted of a 3-in.-diam$\times$3-in.-thick NaI(Tl) crystal coupled to a DuMont-6363 photomultiplier. The resolution for the photopeak of the 662-keV gamma ray of Cs^{137} was 8.5%. This scintillation crystal has a well $\frac{1}{4}$ in. diam$\times1\frac{1}{2}$ in. deep which enables the study of total-absorption gamma-ray spectra. The spectra were recorded on a multichannel analyzer. A Perspex absorber $\frac{1}{2}$ in. thick was used for absorbing beta particles, and a source to crystal distance of 15 cm was used. The gamma spectra of Te^{129} and Te^{129m} obtained in this way are shown in Figs. 1(A) and 1(B), respectively. Also shown here are the total-absorption gamma spectra taken in 4π geometry obtained by introducing the source inside the well of the crystal. These spectra were analyzed in the usual manner and the standard line shapes as they were fitted in the analysis are also shown in the figure. It is seen that Te^{129} decays by the emission of gamma rays of energies 27, 205, 245, 275, 350, 455, 550, 625, 755, 810, 825, 960, 1080, and 1235 keV. By following the decay of the intensity of these gamma rays, it was confirmed that they are all due to Te^{129} which decays with a half-life of 70±1 min. Comparison of this spectrum with the total-absorption spectrum showed that the intensities of the photopeaks of 625-, 755-, and 960-keV gamma rays were reduced relative to the intensity of the 455-keV photopeak due to summing in the total-absorption gamma-ray spectrum. On the other hand, the intensities of the 550- and 1235-keV photopeaks were increased relative to the 455-keV photopeak indicating levels at these energies which are fed by beta transitions. As can be seen from Fig. 1(B), all the gamma rays of Te^{129} are also present in the gamma spectrum of Te^{129m} due to the isomeric transition. In addition, there are also gamma rays of energies 695 and 720 keV which must arise from levels which are directly fed by beta transitions from Te^{129m}. The total-absorption gamma

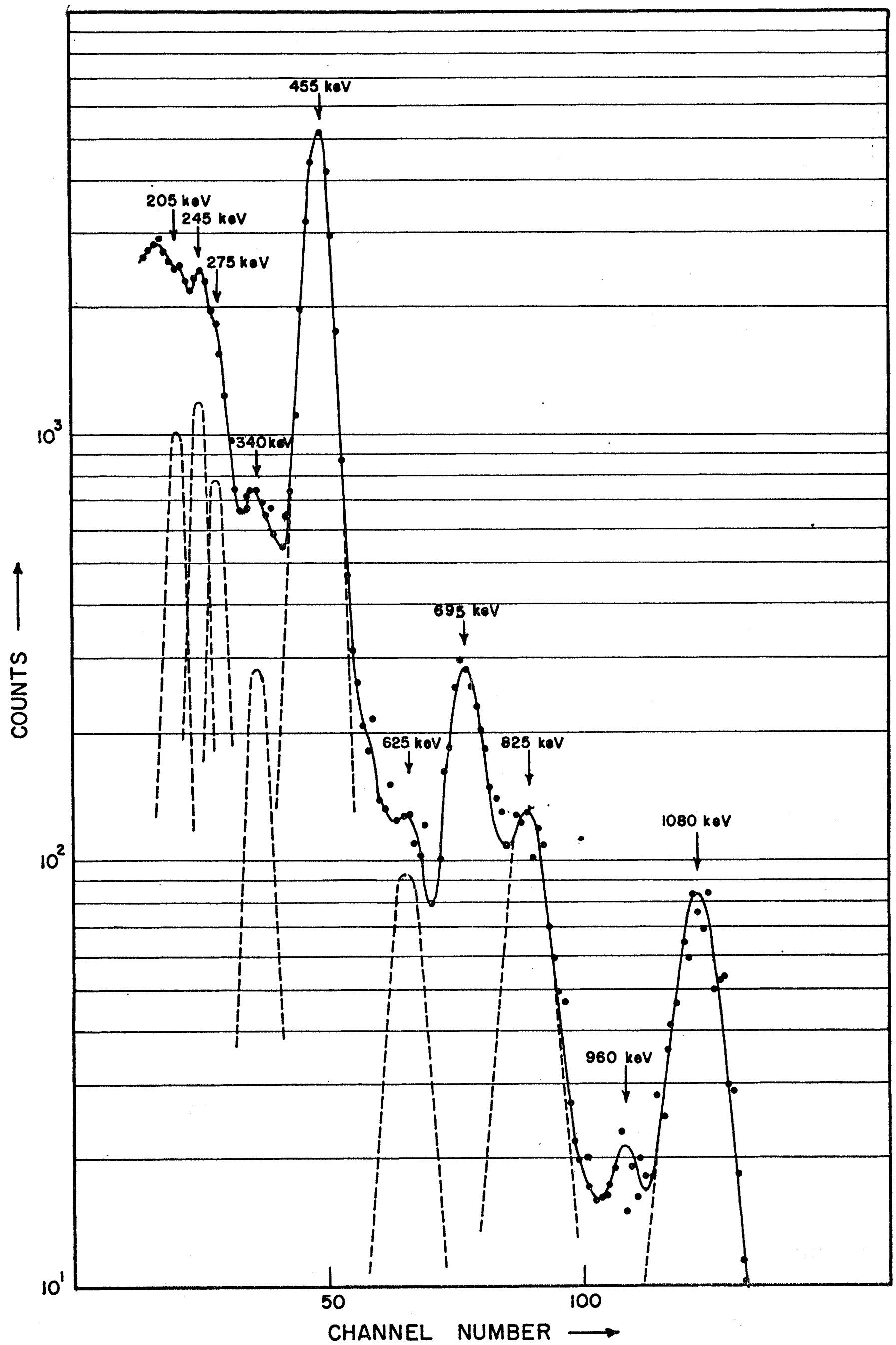

FIG. 2. Gamma spectrum in coincidence with 27-keV photopeak.

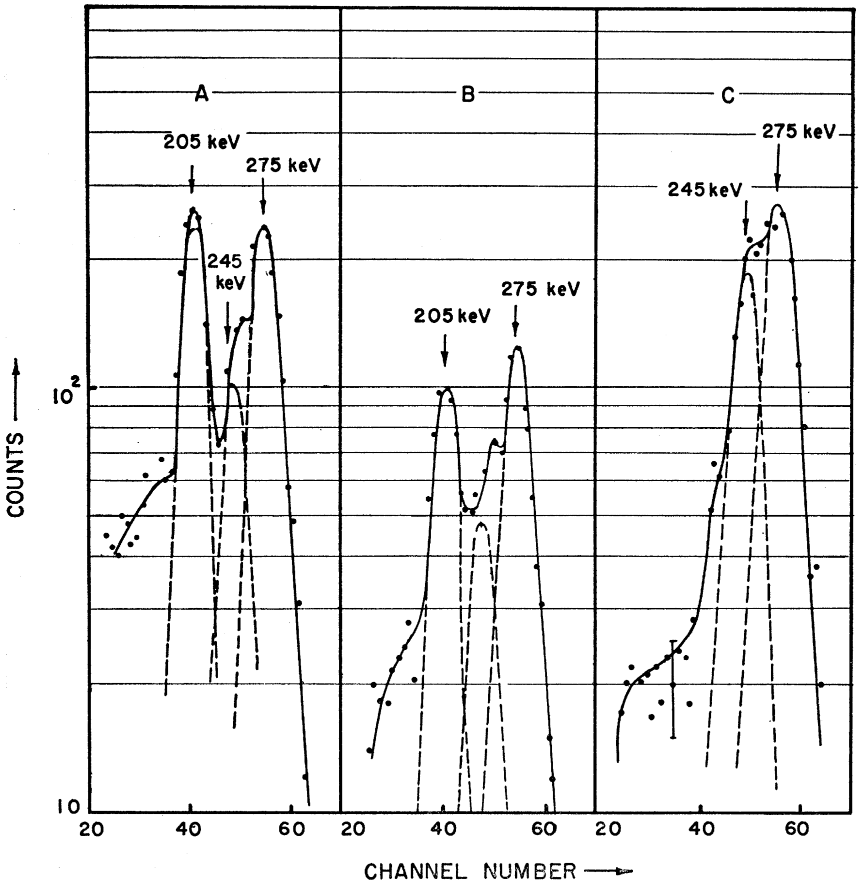

FIG. 3. Spectrum in coincidence with: (A) 275-keV region, (B) 245-keV region, (C) 205-keV region.

TABLE I. Relative intensities of gamma rays for Te^{129} and Te^{129m}.[a]

Energy (keV)	Relative intensity 70-min activity	33-day activity	From combined coincidence data for Te^{129} and Te^{129m}
27	125	d	
205	4.4±1.0	3.8±0.9	
245	5.5±1.4	6.5±1.6	
275[b]	11.0	10.0	3.5
275[c]			7.5
330	1.5	1.7	0.5
350			1.2
455	100	100	
550	0.59	2.9	0.59
555	···		2.3
625	1.6±0.2	1.2±0.3	
695	···	67.0±6.0	
720	···	4.0	2.8
755	1.2		1.2
810			2.4
825	3.0±0.4	5.3	0.56
830			2.3
960	0.8	0.7	
1080	9.3±0.9	10.0±1.0	
1235	0.5±0.05	0.5±0.05	

[a] Wherever errors are not mentioned, the accuracy is ±20%.
[b] 275-keV gamma ray arising from 550-keV level.
[c] 275-keV gamma ray arising from 275-keV level.
[d] Intensity could not be determined because of the K x ray of tellurium due to the isomeric transition.

spectrum shows an additional broad sumpeak at about 1400 keV indicating the presence of a cascade with a total energy of 1400 keV in the decay of Te^{129m}. The relative intensities of the gamma rays corrected for any absorption and summing effects are given in Table I. Gamma-gamma coincidence measurements to be described in the next section revealed that there were pairs and triplets of gamma rays with energies differing only slightly from each other. The relative intensities of such gamma rays as obtained by combining the results of the coincidence measurements with Te^{129} as well as Te^{129m} are also shown in Table I.

3. Gamma-Gamma Coincidence Measurements

The coincidence relationships for the gamma rays were investigated with a fast-slow coincidence circuit of conventional type with a resolving time $2\tau = 0.04$ μsec. The scintillation spectrometers consisted of $1\frac{3}{4}$-in.-diam $\times$2-in.-thick NaI(Tl) crystals mounted on RCA-6810A photomultipliers. The spectra coincident with the photopeaks of various gamma rays were recorded on the multichannel analyzer. Most of the spectra were recorded in a 180° geometry while the spectra coincident with 205-, 245-, and 275-keV regions were taken with the detectors at right angles to each other. In both cases, suitable shielding was used to prevent spurious coincidences due to scattering. The correction for the Compton contribution of high-energy gamma rays was made by recording the coincidence spectra with the gate shifted away from the photopeaks wherever possible When this was not possible, the correction was made by analyzing the gate as well as the coincidence spectra. The gamma spectrum coincident with the 27-keV photopeak, taken with the Te^{129m} source, is shown in Fig. 2. Analysis of the spectrum shows gamma rays of energies 205, 245, 275, 455, 625, 695, 825, and 1080 keV. The 960-keV photopeak was rather weak to be seen clearly in the analysis but it was confirmed by observing the spectrum in coincidence with the 960-keV energy region. The 695-keV photopeak which also is present in the coincidence spectrum was attributed to the inclusion in the gate of bremsstrahlung produced by the beta transition which is in coincidence with the 695-keV gamma ray. This interpretation was verified by taking the 695-keV photopeak in gate and checking that it did not give coincidence with the 27-keV gamma ray. The spectrum coincident with the 27-keV photopeak taken with the shortlived Te^{129} activity was found to be exactly similar except that the 695-keV photopeak was not present, making the 625-keV photopeak more distinct. Since the first excited state of I^{129} is known to be at 27 keV,[4] the fact that the 455-keV gamma ray is in coincidence with the 27-keV transition indicates the possibility of a level at 482 keV which de-excites to the 27-keV level by a 455-keV gamma ray and similarly the 1080–27 keV-coincidence implies the possibility of a level at 1105 keV.

Spectra coincident with 275-, 245-, and 205-keV photopeaks are shown in Fig. 3. Analysis of these spectra shows that 275-keV gamma ray is in coincidence with a gamma ray of the same energy as well as with 205- and 245-keV gamma rays. Similarly, it is seen that 245-keV gamma ray is in coincidence with 205- and 275-keV gamma rays and 205-keV gamma ray is in coincidence with 245- and 275-keV gamma rays. These coincidences show that the 205-keV transition takes place between levels at 482 and 275 keV, and that the latter level de-excites by a 275-keV gamma transition and also by a 245–27-keV cascade to the ground state. The observed 275–275-keV coincidence implies the possibility of a level at 550 keV which de-excites by the 275–275-keV cascade. As has already been pointed out above, the total-absorption spectrum also supports such a level. By analyzing these coincidence spectra and also the spectrum in coincidence with 27 keV, the relative intensities of the upper (i.e., arising from the 550-keV level) and lower (i.e., arising from the 275-keV level) 275-keV gamma rays could be calculated and these are given in Table I. All these three coincidences were exactly similar for Te^{129m} and Te^{129} sources.

Figure 4(A) shows the spectrum in coincidence with 455-keV photopeak. It is seen that the 330- and 625-keV gamma rays are in coincidence with the 455-keV transition. The 625–455-keV coincidence clearly shows that the 625-keV gamma ray corresponds to a transition from the 1105-keV level to the 482-keV level. Similarly the 330–455-keV coincidence indicates a level at 810 keV, which de-excites to the 482-keV level by the emission of the 330-keV gamma ray. In order to confirm the observed coincidence, the 350-keV region was taken in the gate and the coincident spectrum was recorded which is shown in Fig. 4(B). As expected, the 455-keV photopeak is present. In addition, a peak at 755 keV also is present indicating a 755–350-keV cascade from the 1105-keV level. It is thus seen that there are two gamma rays of energies nearly equal to 350 keV, one in coincidence with 455-keV and the other with 755-keV gamma rays. The spectra presented in Fig. 4 were taken with the shortlived Te^{129} activity; but the coincidence spectra taken with Te^{129m} also were similar except for complications due to Compton contribution of coincident gamma rays present only in the decay of Te^{129m}.

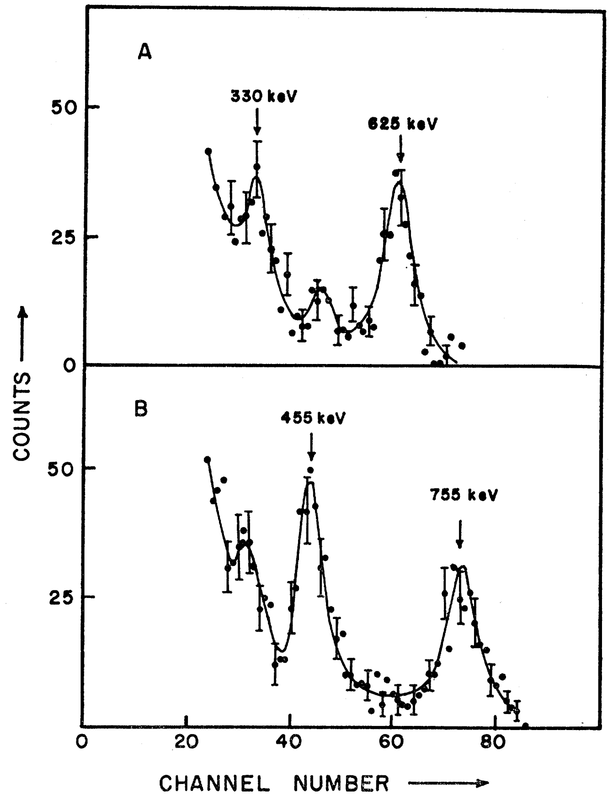

FIG. 4. Spectrum in coincidence with: (A) 455-keV photopeak, (B) 350-keV region.

Gamma spectra in coincidence with 550- and 830-keV regions are shown in Figs. 5(A) and (B), respectively. From this it can be concluded that there is a 555–830-keV cascade indicating a level at 1385 keV. The total absorption gamma spectrum described above also gives indication of levels around this energy. Since this coincidence is observed only in Te^{129m} and not in Te^{129}

decay, it is clear that the level at 1385 keV has a beta feeding only from Te^{129m}. The natural interpretation of this coincidence would be that the 1385-keV level decays to the ground state by a 830–550-keV cascade through the 550-keV level. However, one would then expect that in coincidence with the 830-keV transition there would be 275- and 245-keV gamma rays also which arise from the decay of the 550-keV level. Analysis of the spectrum in coincidence with the 830-keV gamma ray shows that the 245- and 275-keV gamma rays are very much less in intensity than expected from the cascade to cross-over branching ratio for the decay of the 550-keV level. It is, therefore, necessary to postulate a level at 830 keV in order to explain the 555–830-keV coincidence. Thus there are two gamma rays of energy very nearly equal to 550 keV; one from the 550-keV level itself and the other from the 1385-keV level. The relative intensities of these, calculated from the coincidence measurements, are given in Table I. The presence of the 245- and 275-keV gamma rays to a small extent in the spectrum in coincidence with 830 keV is attributed to a 825-keV transition to the 275-keV level from the 1105-keV level. This coincidence has also been observed more clearly with the short lived Te^{129} activity, where the interference from the 830–555-keV cascade is absent. The relative intensities of these 825- and 830-keV gamma rays were also calculated from these coincidence measurements and are included in Table I.

Figure 5(C) refers to the gamma spectrum in coincidence with the 960-keV transition. The 245- and 275-keV gamma rays in coincidence indicate that the 960-keV transition takes place between a level at 1235 keV and the 275-keV level. Evidence for such a level at 1235 keV from the total-absorption spectrum has already been presented above. It may be mentioned here that the intensities of the 245- and 275-keV gamma rays in coincidence with any of the gamma rays landing on the 275-keV level were seen to be consistent with the relative intensities of the 275-keV gamma rays arising from the 550-keV and the 275-keV levels as given in Table I.

Coincidence spectra with 695- and 720-keV regions in gate are shown in Figs. 6(A) and (B). The two gamma rays are clearly in coincidence with each other and not with any other gamma ray. The other photopeaks appearing in the coincidence spectrum were seen to be due to Compton contributions of other gamma rays being included in the gate. The strong 695-keV gamma ray which does not show coincidence with the 27-keV transition also was interpreted as a ground-state transition from a level at 695 keV. The 720-keV transition which is in coincidence with the 695-keV gamma ray must then arise from a level at 1415 keV. As has already been pointed out, the sum peak at about this

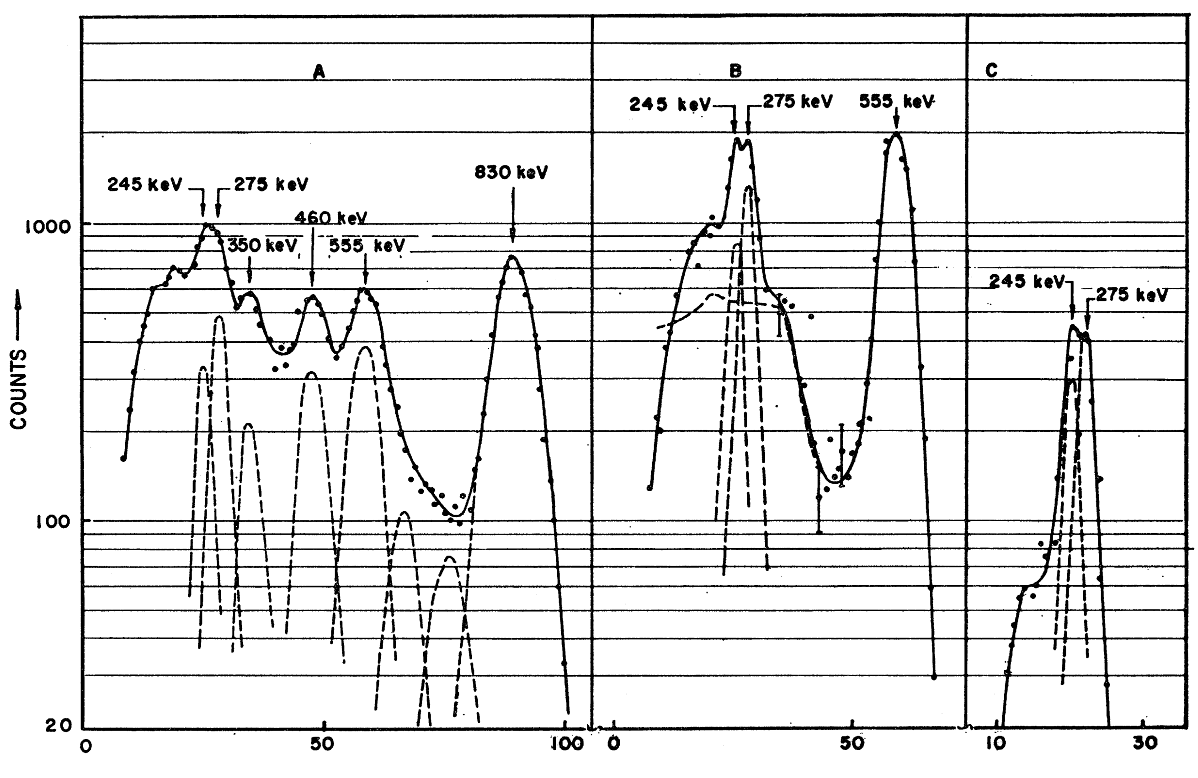

FIG. 5. Spectrum in coincidence with: (A) 550-keV region, (B) 830-keV region, (C) 960-keV region.

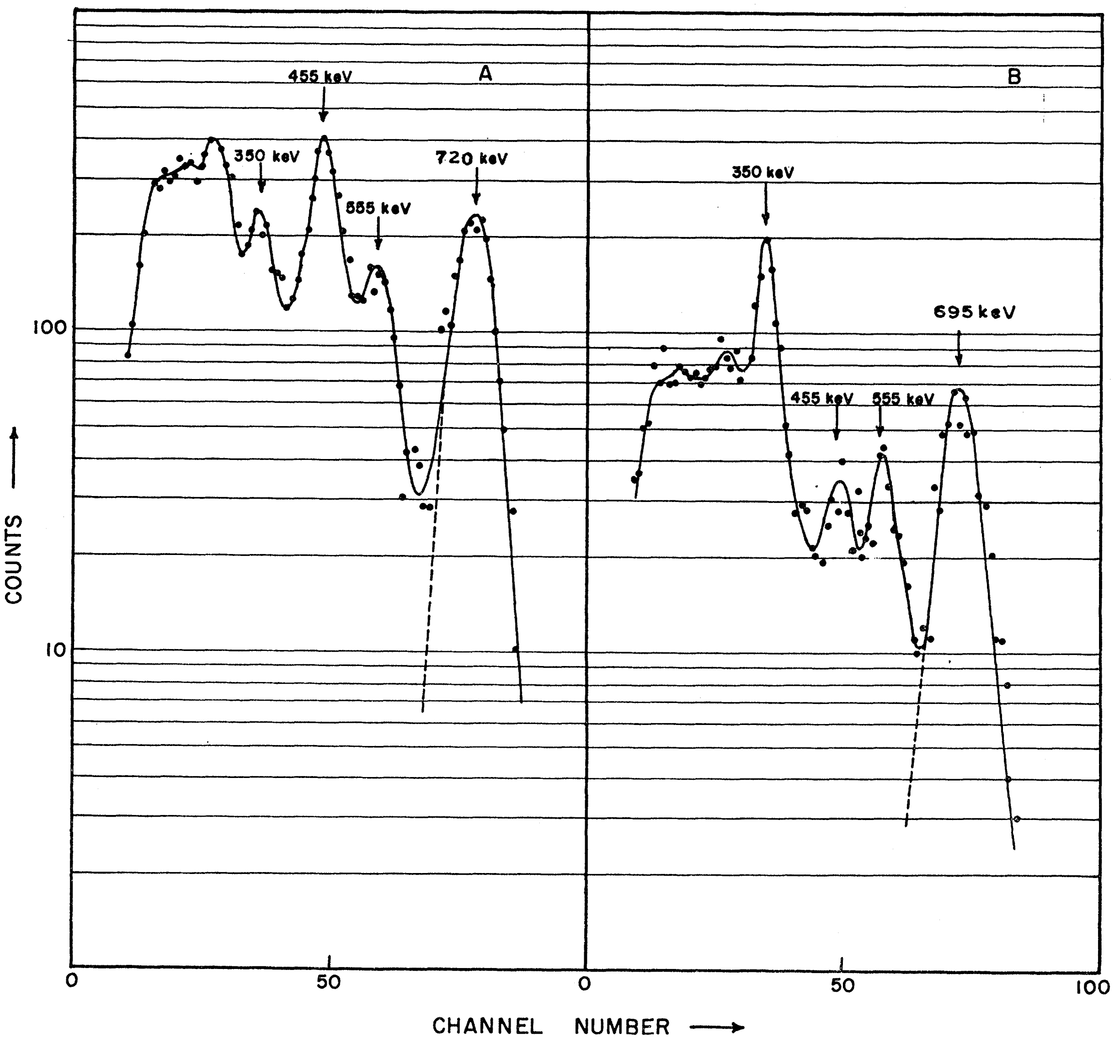

FIG. 6. Spectrum in coincidence with: (A) 695-keV region, (B) 720-keV region.

energy in the total-absorption spectrum also supports such a level. Since the 695–720-keV coincidence does not occur in the case of the short-lived Te^{129} activity, it can be concluded that the 1415-keV level like the 1385-keV level is fed only in the decay of Te^{129m}.

4. Sum-Coincidence Measurements

The conclusions about the various levels and their de-excitation formed on the basis of the coincidence measurements described above were further verified by the sum-coincidence technique.[8,9] The sum-coincidence spectrum with the 1235-keV sum peak in gate is shown in Fig. 7(I). It is clear from this that the 1235-keV level decays by a single 960–275-keV cascade. This was also confirmed by scanning the added spectrum in coincidence with the 960-keV gamma ray which shows a clear sum peak at 1235 keV as shown in the inset of the same figure. Figure 7(II) shows the sum-coincidence spectrum with 1105-keV sum peak in gate. This confirms the conclusion reached from the gamma-gamma coincidence measurements described above, that the 1105-keV level de-excites by a 625–455-keV cascade and to a lesser degree by 825–275- and 350–755-keV cascades. The de-excitation of the 482- and 550-keV levels was studied by recording sum-coincidence spectra with 455-, 480-, and 550-keV regions of the added spectrum, and these are shown in Fig. 7(III). The appearance of only a single peak at 275 keV when 550-keV is taken in gate (part C of the figure) confirms that the 550-keV level decays by a 275–275-keV cascade. When 455-keV region is taken in gate one gets peaks at 205 and 245 keV (part B of the figure) whereas peaks at 205 and 275 keV are present when 480-keV region is taken in gate (part A of the

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[9] S. Jha, H. G. Devare, M. Narayana Rao, and G. C. Pramila, Proc. Indian Acad. Sci. **50**, 303 (1959).

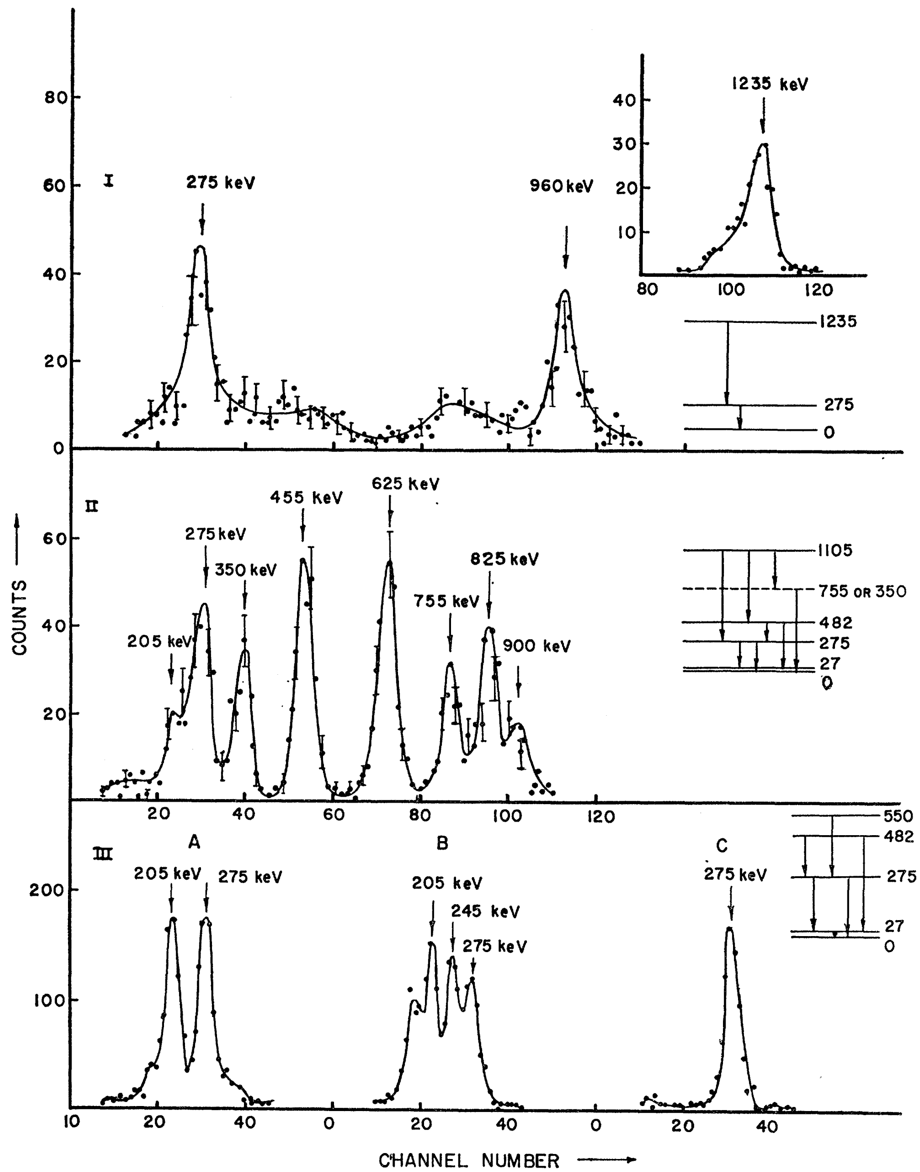

FIG. 7. Sum coincidence spectrum with: (I) 1235-keV sum peak. Inset shows the added spectrum in coincidence with 960-keV gate. (II) 1105-keV sum peak. (III) (A) 480-keV, (B) 455-keV, and (C) 550-keV regions.

figure). This conclusively shows that the 482-keV level decays by a 205-keV transition to the 275-keV level which in turn decays by a 275-keV gamma ray to the ground state or by a 245-keV gamma ray to the 27-keV level. It may be noted here that in all these sum-coincidence spectra, the 27-keV gamma ray cannot have any contribution as the fast coincidence was not adjusted to respond to such a low energy. In all these cases, the proposed decay modes of the various levels being studied are also shown in the figure. In order to verify whether the 1385- and 1415-keV levels really exist and whether they decay by 555–830-keV and 720–695-keV cascades, respectively, as suggested by the gamma-gamma coincidence measurements, sum-coincidence spectra were recorded by taking in the gate 1385- and 1415-keV regions of the final sum peak in the added spectrum. From Fig. 8(IA) one can see that the 1385-keV level indeed decays by the 555–830-keV cascade. As a further confirmation, the 1385-keV sum peak is obtained when the added spectrum is scanned in coincidence with the 830-keV gamma ray and this is shown in Fig. 8(IB). When the 1415-keV region of the sum peak is taken in gate, clear peaks appear at 695 and 720 keV [Fig. 8(IIA)] showing that the 720–695-keV cascade arises from the 1415-keV level. This was also confirmed by scanning the added spectrum in coincidence with the 695-keV gamma ray when one gets a sum peak at 1415 keV [Fig. 8(IIB)]. Since it was not possible to reduce the contribution of the 1385-keV sum peak when 1415-keV region was taken in gate, the

555- and 830-keV peaks also appear in this sum-coincidence spectrum. It is thus seen that the sum-coincidence measurements substantiate the inferences drawn from the gamma-gamma coincidence measurements. In particular, in the sum-coincidence spectrum with 1385-keV sum peak in gate, one does not observe any peak in the 275-keV region, which further strengthens the conclusion that the 555-keV gamma ray of the 555–830-keV cascade does not arise from the 550-keV level.

5. Beta-Spectra and Beta-Gamma Coincidence Measurements

The beta spectrum of Te^{129m} was studied with an intermediate image type Siegbahn-Slätis spectrometer. The baffles were adjusted for 2% resolution at about 1.5% transmission. Fermi analysis of the beta spectrum (Fig. 9) showed four beta groups with end-point energies 1595, 1452, 976, and 690 keV. The beta spectrum of the short-lived activity was studied with a 4π scintillation beta-ray spectrometer using plastic phosphors. The resolution of this scintillation spectrometer was about 15% for the conversion line of the 662-keV gamma ray from Cs^{137}. The energy calibration was achieved with conversion lines from Cs^{137} and Bi^{207} and Compton edges of the gamma rays from Zn^{65} and Na^{22}. The Fermi plot of the beta spectrum of the short-lived activity shows that the highest energy beta group has the end-point energy 1460 keV, while the next group has the end-point energy 1000 keV. From beta-gamma coincidence measurements made with scintillation spectrometers, it was seen that the beta group in coincidence with the 27-keV transition has an end-point energy of 1460 keV. Thus, this beta group feeds the 27-keV level from the 70-min activity of Te^{129}. It is then clear from energy considerations that the beta group with the end-point energy 1595 keV corresponds to a transition from Te^{129m} to the ground state of I^{129}. Figure 10 shows the Fermi plots of beta spectra in coincidence with photopeaks of various gamma rays obtained with the Te^{129m} source. From this it can be concluded that

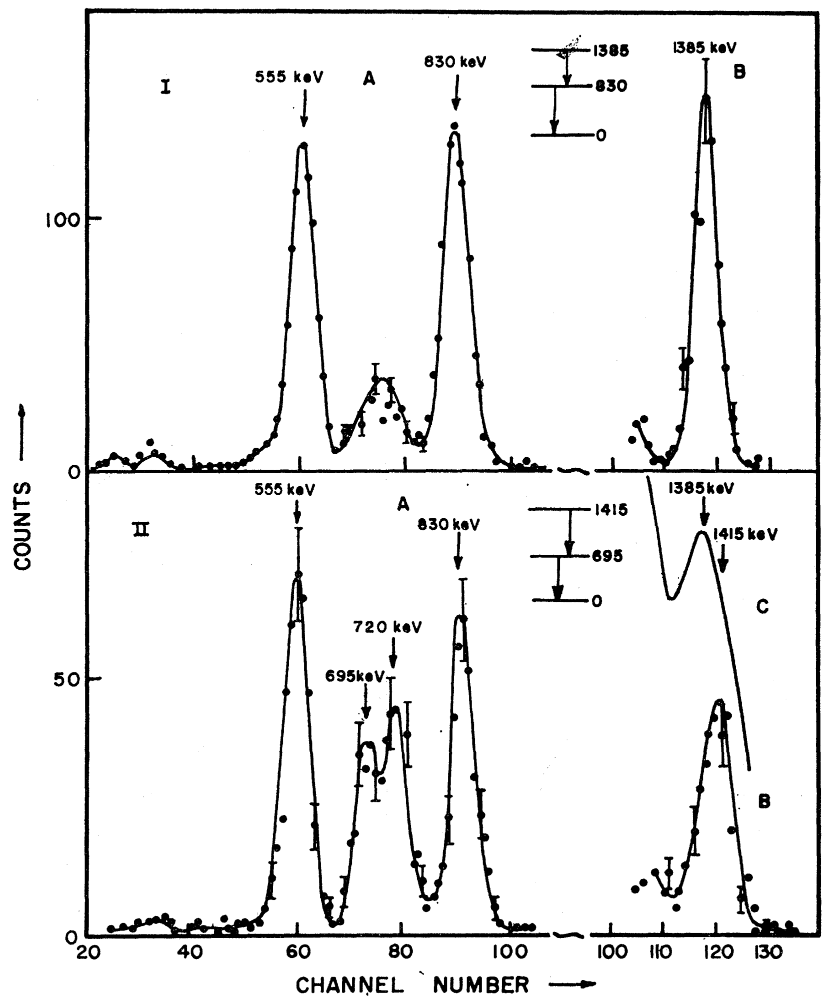

FIG. 8. Sum-coincidence spectrum with: (I) (A) 1385-keV region, (II) (A) 1415-keV region. Added spectrum in coincidence with (I) (B) 830-keV region. (II) (B) 695-keV region. (C) The added spectrum.

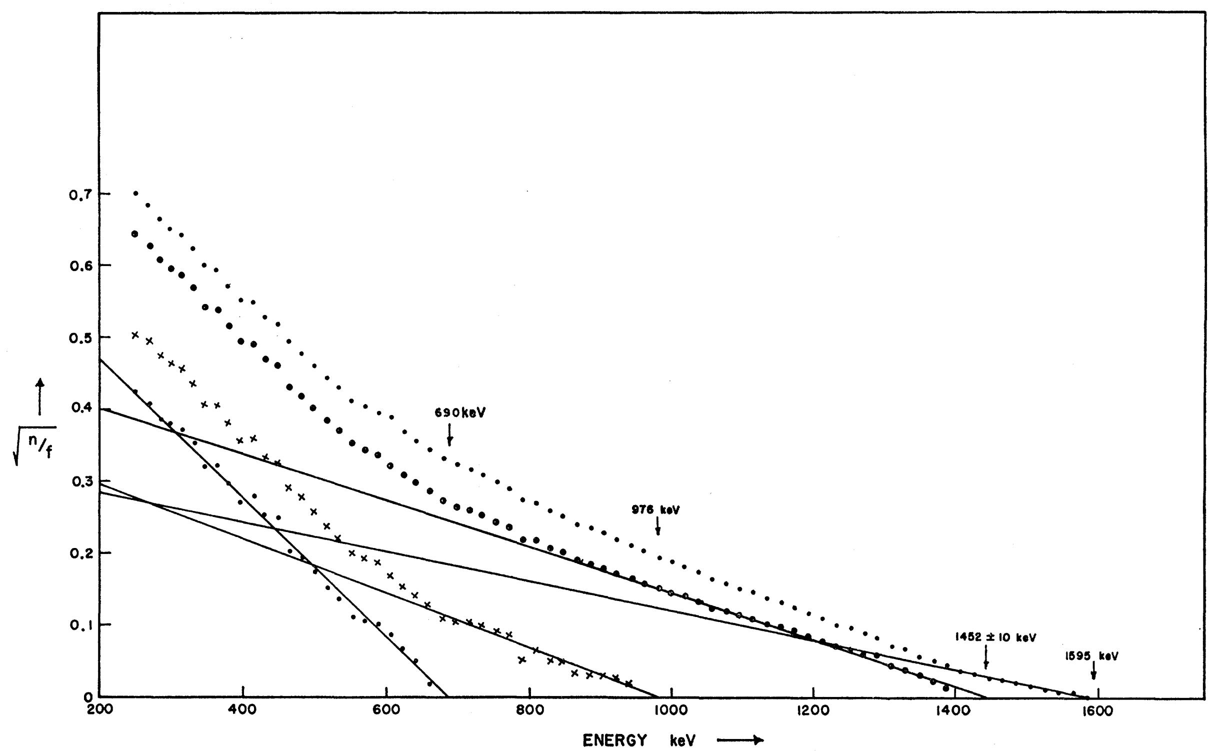

FIG. 9. Fermi plot of the beta spectrum of Te^{129m}.

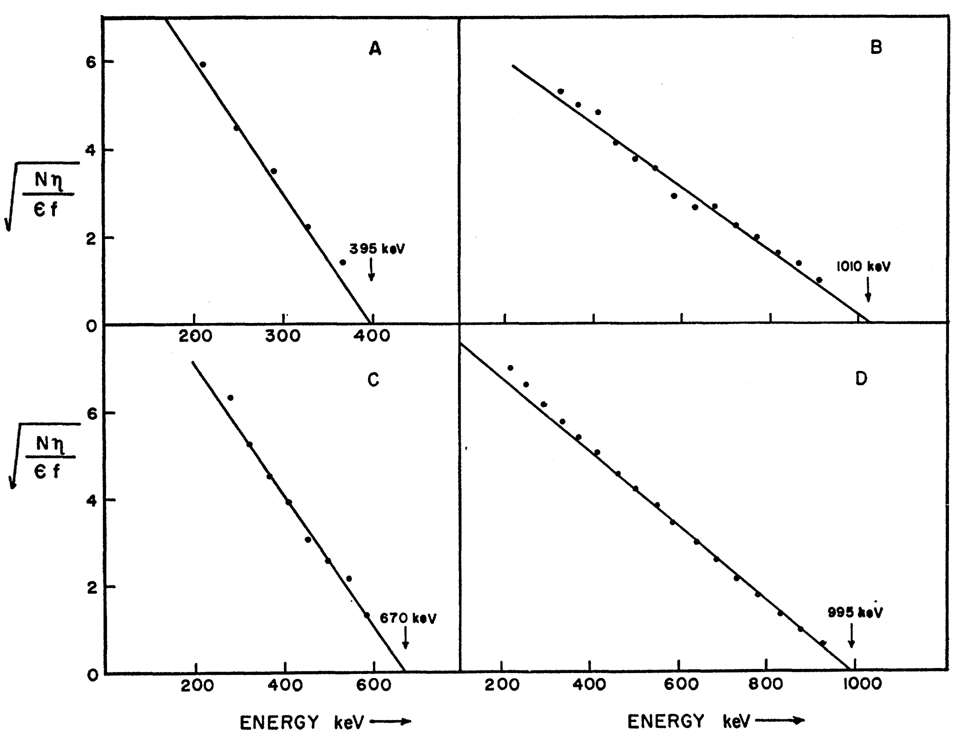

FIG. 10. Fermi plot of the beta spectrum in coincidence with: (A) 1080-keV region, (B) 275-keV region, (C) 810-keV region, (D) 455-keV photopeak.

the 70-min Te^{129} feeds the 482-, 810-, and 1105-keV levels the end points of the respective beta groups being 995, 670, and 395 keV. It is also clear that the 275-keV level has no beta feeding since the beta spectrum in coincidence with the 275-keV transition has almost the same end point as the one in coincidence with 455-keV gamma ray. The Fermi plot of the beta spectrum in coincidence with 695-keV photopeak is shown in Fig. 11 and has the end-point energy 910 keV. This shows that Te^{129m} feeds the 695-keV level as expected from the analysis of the gamma spectrum. Figure 11 also shows the shape correction factor for this spectrum which is discussed later. From the analysis of these beta-gamma coincidence spectra it is seen that there are beta groups with end-point energies 1000 and 910 keV feeding the 482- and 695-keV levels, respectively. It was not possible to resolve these properly in the Fermi analysis of the beta spectrum as shown in Fig. 9, and the beta group with end-point energy 976 keV shown there corresponds to both these beta groups. Moreover, the Te^{129m} source had some impurity of Te^{127m}, which has a strong beta group with $\simeq$700 keV as the end-point energy, and the beta group ending at $\simeq$700 keV seen in Fig. 9, is attributed to this impurity. Thus, the Fermi analysis of the beta spectrum gives the relative intensities of only the two highest energy groups reliably, and the relative intensities of the beta groups feeding the various levels were, therefore, found from the relative intensities of the gamma rays assuming the decay scheme given in Fig. 12. In order to calculate the intensity of the beta group feeding the 27-keV level the total conversion coefficient for the 27-keV transition was assumed to be 5.1, the theoretical value[10] for a pure $M1$ transition. As described later, the experimental value of this conversion coefficient is in good agreement with this theoretical value. The relative intensities of the beta groups and their $\log ft$ values are given in Table II. The combined intensity of the beta groups feeding the 482- and 695-keV levels agrees well with the intensity of the beta group with 976 keV as the

TABLE II. Beta transitions in the decay of Te^{129} and Te^{129m}.

Level fed (keV)	End-point energy (keV)	Relative intensity (%)	$\log ft$
Ground state	1595±10	29.7	9.2
27	1452±10	80.6	5.8
482	997	16.1	5.9
550	929	0.56	7.1
695	900	6.36	9.0
810	669	0.47	6.8
1105	382	1.97	5.4
1235	244	0.21	5.8
1385	210	0.22	8.3
1415	180	0.15	8.3

[10] M. E. Rose, *Tables of Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

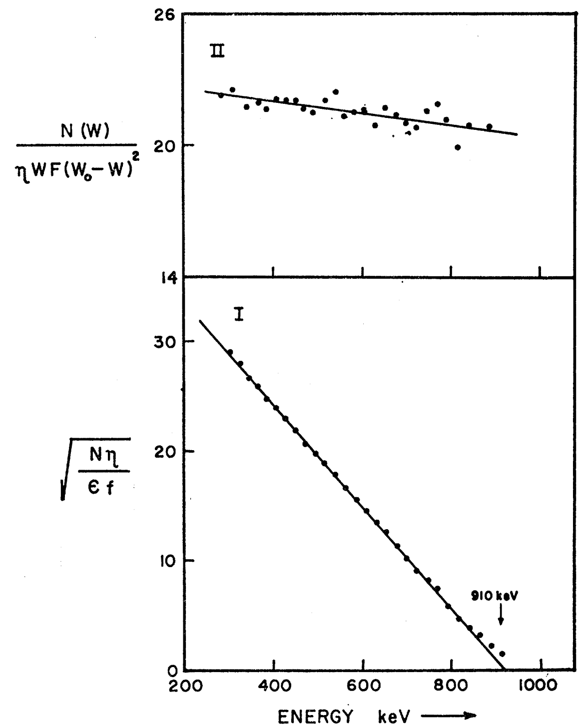

FIG. 11. (I) The Fermi plot of the beta spectrum taken in coincidence with 695-keV photopeak. (II) The shape correction factor for the spectrum I.

end-point energy obtained from Fermi analysis of the beta spectrum (Fig. 9). This confirms the interpretation that this beta group corresponds to the two beta groups feeding the 482- and 695-keV levels, which could not be resolved in the Fermi analysis. By comparing the intensities of the beta groups from Te^{129m} and from Te^{129} in equilibrium with it, the intensity of the isomeric transition was found to be 64±7%. This agrees very well with the value 68±12% obtained by Andersson and Hagebo.[7] It is seen from Table II that the beta transition to the 695-keV level from Te^{129m} has a $\log ft$ value corresponding to a unique first-forbidden transition. In order to check whether this beta transition is really of the unique first-forbidden type, the beta spectrum in coincidence with the 695-keV gamma ray was studied with the 4π beta-ray scintillation spectrometer as has already been described above. The Fermi plot of this spectrum is seen to be linear (Fig. 11) indicating that the transition is not of unique first-forbidden type. The shape correction factor which is also shown in Fig. 11 has only a slight energy dependence and that too in a direction opposite to what is expected for a unique first-forbidden transition. It can be concluded from this that the beta transition to the 695-keV level is a first-forbidden transition having an abnormally high log ft value due to certain peculiar properties of the nuclear matrix elements involved in the transition. It may be mentioned here that the

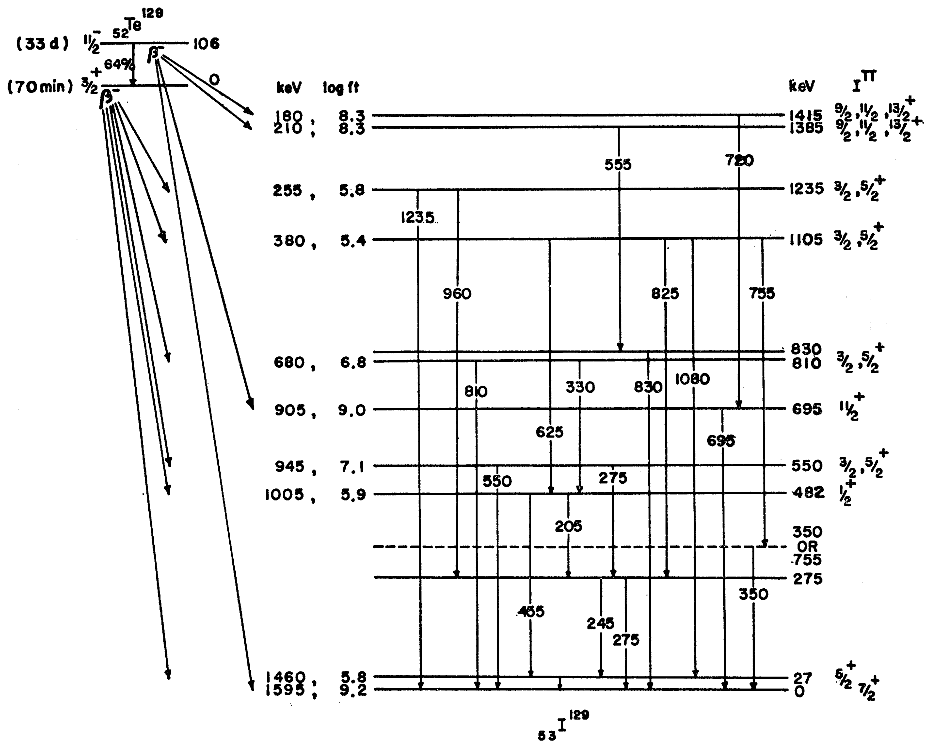

FIG. 12. The proposed decay scheme for Te^{129m} and Te^{129}.

performance of the 4π scintillation spectrometer was checked by studying the shape of the beta spectrum in coincidence with the 930-keV gamma ray from a Cd^{115m} source. This beta transition is known to be of the unique first-forbidden type,[11,12] and the observed shape correction factor had the expected characteristics.

6. Conversion Coefficient of the 27-keV Transition

The total conversion coefficient of the 27-keV transition was determined by taking the 455-keV photopeak in gate and recording the 27-keV photopeak in coincidence on the multichannel analyzer. The gate counting rate was noted and corrected for the Compton contribution due to higher energy gamma rays. Then, knowing the counting rate of the 27-keV photopeak in the coincidence spectrum, the solid angle subtended by the scanner crystal and the photoefficiency for 27 keV, the conversion coefficient of the 27-keV gamma ray could be calculated. In order to minimize the error due to absorption correction, the NaI(Tl) crystal used to detect the 27-keV gamma ray had only 8 mg/cm^2 aluminum on the top and a 5-mm Perspex absorber was used to stop the beta particles. To reduce the uncertainty in the solid-angle measurement the distance of the scanner crystal from the source was kept at 10 cm. Since the lifetime of the 27-keV state is $\simeq 16\times 10^{-9}$ sec,[13,14] the resolving time of the coincidence circuit was made $2\tau = 150\times 10^{-9}$ sec so that the necessary correction due to this effect was also small. The value of the conversion coefficient thus obtained was $\alpha_{\text{total}} = 4.5\pm 0.5$. This is in fairly good agreement with the theoretical value[10] $\alpha_{L+M} = 5.1$ for a pure $M1$ transition. Since this conversion coefficient is very sensitive to any $E2$ mixture, it can be concluded that the 27-keV transition is almost purely $M1$ in character and that any $E2$ admixture must be extremely small.

7. Decay Scheme and Discussion

The decay scheme of the Te^{129} isomers consistent with the results discussed above is presented in Fig. 12. Justification for the various levels proposed here and their decay modes has already been given above when discussing the results of the analysis of the gamma spectrum, gamma-gamma coincidences and sum-coincidence measurements. The position of the level through which the 1105-keV level de-excites by the 755–350-keV cascade cannot be definitely fixed at 755 or 350 keV from our results and so this level is shown by a dashed line. The existence of the 755–350-keV cascade has, however, been established beyond doubt both from gamma-gamma coincidence and sum-coincidence measurements. The beta transitions to most of the levels

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have been confirmed by beta-gamma coincidences, though in a few cases these have been inferred from the relative intensity of the gamma rays. The beta-branching ratios and log *ft* values have also been calculated from the relative intensity of the gamma rays. These relative intensities are consistent with the ones obtained from the Fermi analysis of the beta spectra. The spin and parity assignments have been suggested on the basis of log *ft* values of the beta groups feeding the levels and also the gamma transitions arising from the levels.

The spin and parity assignments for Te^{129m} and Te^{129} are $11/2-$ and $3/2+$, respectively, corresponding to $h_{11/2}$ and $d_{3/2}$ shell-model orbitals. The $M4$ character of the 106-keV isomeric transition[4] confirms these assignments. The ground state of I^{129} is expected to be $g_{7/2}$ from shell-model considerations and the measured value of the spin is[15] 7/2 in conformity with this. The beta transition from Te^{129m} to the ground state of I^{129} should then be of the first-forbidden unique type and the observed value of the log *ft* for this transition agrees with this. On the basis of the shell model, the 27-keV level should be $d_{5/2}$ and the fact that the 27-keV transition is predominantly $M1$ according to the conversion coefficient measurement confirms the $5/2+$ assignment. The allowed value of the log *ft* for the beta transition to this level is also consistent with this assignment. The rather long half-life of the 27-keV level may be attributed to the *l*-forbidden character of the $M1$ transition. The beta transition to the 482-keV level also has an allowed log *ft* value indicating 1/2, 3/2, or 5/2 as the spin of this level. Out of these 3/2 and 5/2 are unlikely since no gamma transition to the ground state is observed from this level and hence the assignment $1/2+$ has been made. On the other hand, the 550-keV level has a gamma transition to the ground state ruling out the possibility of the spin being 1/2 and so the assignment in this case is 3/2 or $5/2+$. The log *ft* value of the beta transition to this level is, however, rather high for an allowed transition. As has already been discussed the beta-transition to the 695-keV level has a log *ft* corresponding to a unique first-forbidden transition though the shape of the beta spectrum does not show any deviation from linearity. The transition is, therefore, interpreted as first forbidden with the large log *ft* value being attributed to some hindrance, which may be due to a cancellation of the nuclear matrix elements. The possible spin values would be 9/2, 11/2, or 13/2. Out of these 9/2 can be excluded since there is no transition to the 27-keV level and 13/2 is not possible because of the transition from this level to the ground state. Thus $11/2+$ seems to be the most plausible spin and parity assignment to this level. The 810-, 1105-, and 1235-keV levels all have been assigned spins 3/2 or 5/2 with positive parity as the beta transitions to these levels are of allowed type. The possibility of the spin being 1/2 has been ruled out because 810- and 1235-keV levels have transitions to the ground state while in the case of the 1105-keV level also such a transition cannot be ruled out. The assignment $9/2+$, $11/2+$, or $13/2+$ to the 1385- and 1415-keV levels has been made by assuming the beta transitions to these levels to be of the first-forbidden type though the log *ft* values are rather high. Concerning the 275-keV level it is rather surprising that it does not have any beta feeding. Nothing definite can be said about the beta feeding of the 830-keV level. In both these cases it is rather difficult to make any spin and parity assignments from the results of the present work.

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The energy levels of I^{129} have been calculated theoretically by Banerjee and Gupta[16] considering a coupling of intermediate strength between the single-particle motion of the odd proton and the collective vibrations of the even-even core. They get a very large number of closely spaced levels out of which some agree very well with the experimentally observed levels. Perhaps a better agreement between experimental and theoretical levels may be possible if the interactions of all the three protons outside the closed shell are taken into account. The excited states of I^{129} may also be interpreted as core multiplets[17,18] resulting from a coupling of the $2+$ one-phonon vibrational state of the even-even core to $g_{7/2}$ and $d_{5/2}$ shell-model states. Levels with spins resulting from such a coupling are present and the center of gravity rule[17] also may be satisfied. However, anything more definite about this can be said only when unambiguous spin assignments and $M1$–$E2$ mixing ratios for the various transitions are available from angular correlation and conversion coefficient measurements.

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