Revista Brasileira de Fhica, Vol. 16, nº 1, 1986

Gamma-Gamma Directional Correlation Measurements for Transitions in ^{129}Te

MARISTELA QLZON M.D. DE SOUZA* and R.N. SAXENA

Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear, Caixa Postal 11049, São Paulo, 01000, SP, Brasil

Recebido em 18 de novembro de 1985

Abstract The directional correlation of coincident y-transitions in ^{129}Te has been measured following the β decay of ^{129}Sb ($T_{1/2}$=4.4h) using a Ge(Li)-NaI(Tl) gamma spectrometer. The measurements were carried out for 9 gamma cascades resulting in the determination of multipole mixing ratios δ(E2/M1) for 10 y-transitions. The present results suggest a spin assignment of 7/2 for the 760 keV, 1228 keV and 1843 keV levels and confirm several previous assignments to other levels in ^{129}Te.

1. INTRODUCTION

The low lying energy levels of odd mass tellurium isotopes $^{125-129}Te$ are quite similar in many aspects and have received considerable attention through experimental as well as theoretical studies. A number of these levels in ^{125}Te and ^{127}Te have fairly well established spin and parity assignments from previous studies. Similar assignments are, however, less definite in the case of ^{129}Te. A complete review of the experimental work on the ^{129}Te levels is given in referente 1, Results of the directional correlation measurements for a number of gamma cascades in ^{127}Te have been published recently[2] Here we report similar measurements for the gamma cascades in ^{129}Te with a view to provide more definite spin assignments to the excited states of ^{129}Te and to obtain multipole mixing ratios for some of the y-transitions in this nucleus. To our knowledge there are no previous angular correlation measurements reported in this nucleus. The present measurements were carried out for the ^{129}Te gamma rays from the β^- decay of ^{129}Sb($T_{1/2}$ = = 4.4h) using an automatic Ge(Li)-NaI(Tl) spectrometer.

---

*Present address: Departamento de Física, Universidade Federal de São Carlos, São Carlos, 13560 , SP, Brasil

2. EXPERIMENTAL

The radioactive sources of ^{129}Sb were produced by the $^{130}Te(\gamma,p)\ ^{129}Sb$ reaction using a natural target followed by a chemical separation of antimony from tellurium. Approximately 8 g of tellurium metal powder were irradiated for 10 hours with the *bremsstrahlung* from the 30 MeV electron beam of the linear accelerator at the Institute of Physics of the University of São Paulo. Soon after the irradiation, antimony activity was chemically separated from tellurium and purified using a procedure similar to the one described by Abecassis[3]. Finally, the precipitate of Sb_2S_3 was dissolved in two drops of diluted NaOH solution and transferred to the lucite sample holder. The chemical separation took approximately 25 min.

The Y spectrometer consisted of the combination of a 45 cm true co-axial Ge(Li) detector and a 7.6 cm × 7.6 cm NaI(Tl) detector. The automatic spectrometer and the associated electronics used iin the experiments have been described earlier[4]. The measurements were carried out at angles from 90° to 270° in steps of 30°. Angular position of the movable NaI(Tl) detector changed every 20 min. and the counting from a single source was for a period of approximately 10 h after which a new source was prepared, A total of 70 sources were used for the entire experiment.

The single channel analyser (SCA) windows (-50 keV wide) were set to include the photopeaks at 359, 684, (773 + 813), 966 and 1261, keV in the NaI(Tl) detector spectrum. The intensities of the coincident γ rays were measured from the Ge(Li) detector spectra at various angles and these were corrected for the random coincidences and the source decay during measurements. The random coincidences were measured separately for each gate setting, The effects of Compton scattered radiation of higher energy coincident γ rays ineluded in the window settingsare negligible for the 295-359, 523-684, 915-813, 1030-813, 761-966,876-966 and 1261-359 keV cascades (see the detailed decay scheme ref.1). In the case of the 684-545 keV cascade measured from the 684 keV gate and of the 773-545 keV cascade measured from the (773 + 813) keV gate setting, the effects of Compton scattered radiation were determined by setting narrow gates (-20 keV wide) around 725 keV and 820 keV respectively and

measuring the coincidence spectra. These effects were properly taken into consideration in the analysis.

The angular correlation coefficients A_{kk} were determined by a least square fitting procedure in the usual manner and corrected for the finite solid angle effects of the detectors[5,6]. These coefficients were further analysed for the spin assignments to the levels in ^{129}Te and γ-ray mixing ratios δ(E2/M1). The convention of Krane and Steffen[7] has been used throughout this work for the phase of the mixing ratio,

3. RESULTS

The γ-ray spectrum in the decay of ^{129}Sb obtained with the Ge(Li) detector is shown in fig. 1(a). The presence of some of the strong γ-rays from the decay of ^{127}Sb was notices both in the direct as well as in the coincidence spectra, however, they did not interfere in the present measurements. Figure 2(d) shows the γ spectrum from the NaI(Tl) detector with the gate settings indicated. Typical examples ofyspectra observed in coincidence with the photopeaks at 359, 684, (773+813), 966 and 1261 keV are shown in figs. 1(b), 1(c), 2(a), 2(b) and 2(c) respectively. They represent partial measurements, Figure 2(c) is the coincidente spectrum recorded with a 88 cm^3 hyperpure Ge detector which became available at a later stage in the experiment. The directional correlation coefficients A_{kk} corrected for the finite solid angle effects of the detectors are given in table 1. Typical results of some of the directional correlation measurements are shown in fig. 3. The data point at 90^o has been normalized to unity in each case and the solid curve is the least square fit of the experimental data to the function

$$W(\theta) = 1 + A_{22}P_2(\cos\theta) + A_{44}P_4(\cos\theta) .$$

The multipole mixing ratios for the gamma transitions along with the spin sequence found to be most consistent with the observed directional correlation data anú the results of previous studies are presented in table 2. The mixing ratios were determined by the usual χ^2 analysis as a function of δ for the selected spin sequence.

A partial energy level scheme of ^{129}Te taken from ref. 1 and

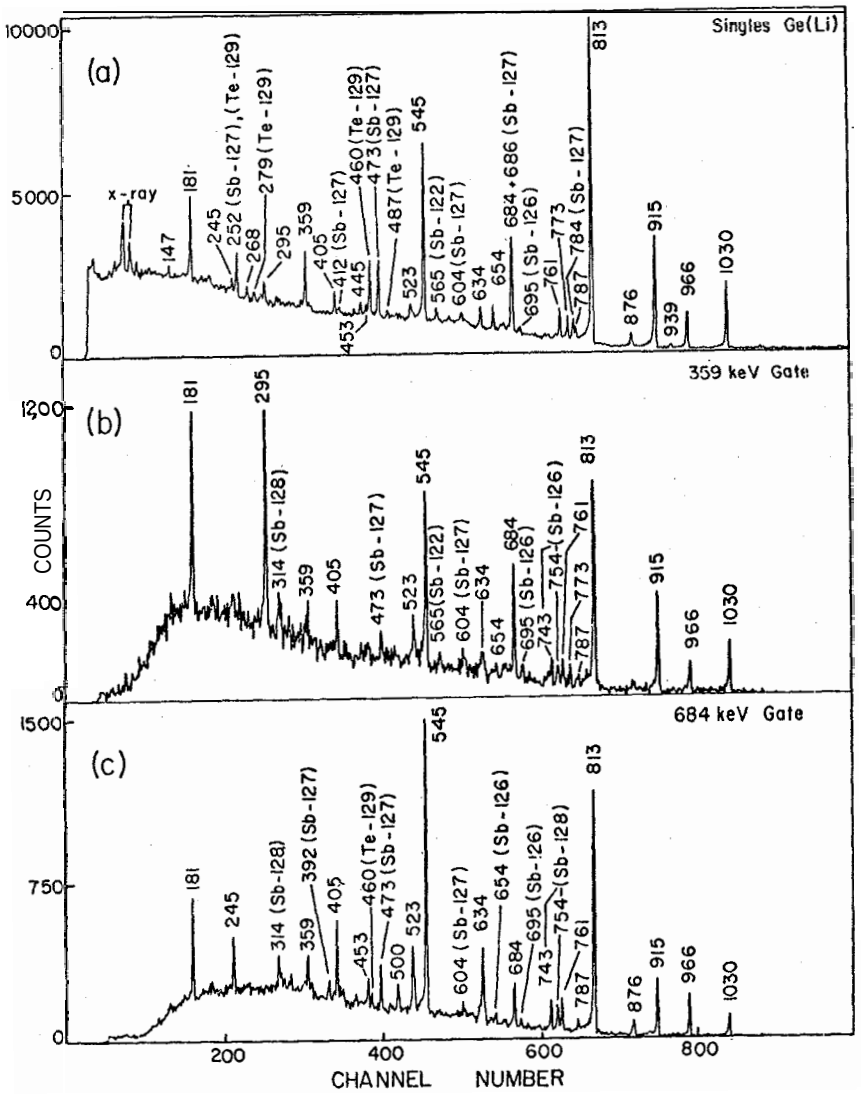

Fig.1 - Direct γ-ray spectrum up to 1.2 MeV in the decay of ^{129}Sb observed with the Ge(Li) detector (a) and the γ-ray spectra in coincidence with the photopeaks at 359 keV (b) and 684 keV (c).

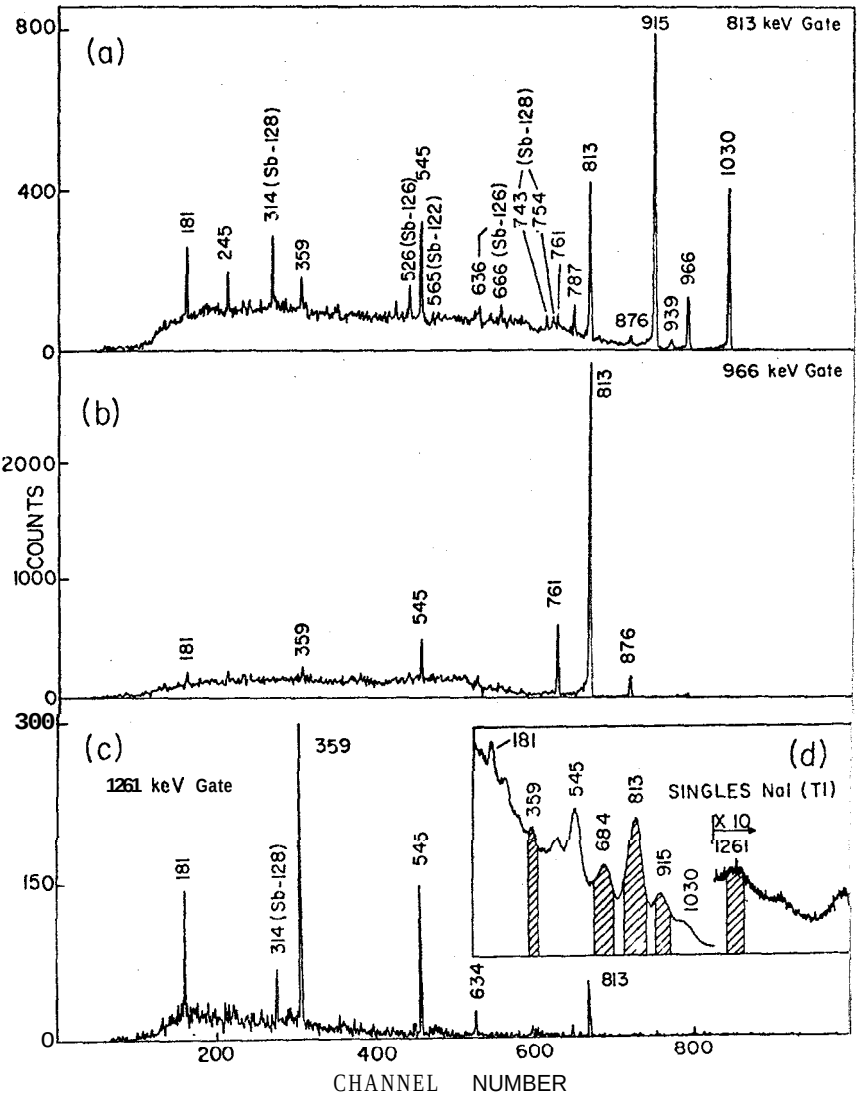

Fig.2 - y-ray spectra observed in coincidence with the photopeaks at 813 + 773 keV (a) 966 keV (b) and 1261 keV (c). In the inset is shown the direct y-ray spectrum observed with the NaI(Tl) detector with the gate positions indicated (d).

Table 1 - Results of Directional Correlation Measurements of Transition in ^{129}Te

Gating Transition (keV)	Gamma Cascade (keV)	A_{22}	A_{44}
359	295-359	0.012 ± 0.031	-0.001 ± 0.050
684	523-684	0.090 ± 0.043	-0.026 ± 0.070
	684-545	0.075 ± 0.018	0.045 ± 0.028
813 + 773	773-545	0.100 ± 0.030	0.048 ± 0.050
	915-813	-0.019 ± 0.013	-0.002 ± 0.021
	1030-813	-0.045 ± 0.020	0.045 ± 0.030
966	761-966	-0.014 ± 0.032	0.013 ± 0.050
	876-966	0.064 ± 0.042	0.029 ± 0.067
1261	1261-359	-0.057 ± 0.046	0.007 ± 0.075

showing only y-transitions relevent to this study is presented in fig. 4. The spin and parity assignments to the levels included in this figure are those consistent with the present results and other available data.

Spins and parities of the ground state, the isomeric stateat 106 keV and the second excited state at 181 keV are quite well established as $3/2^+$, $11/2^-$ and $1/2^+$ respectively from previous studies[1]. The spin and parity of other levels and the results of present directional correlation measurements are discussed below.

The 465 keV level

This level was not observed in nuclear reactions such as (d,p)[8,9] and (t,d)[10] but was assigned as $9/2^-$ in the previous decay studies[11,12]. Odd mass Te systematics strongly support this assignment

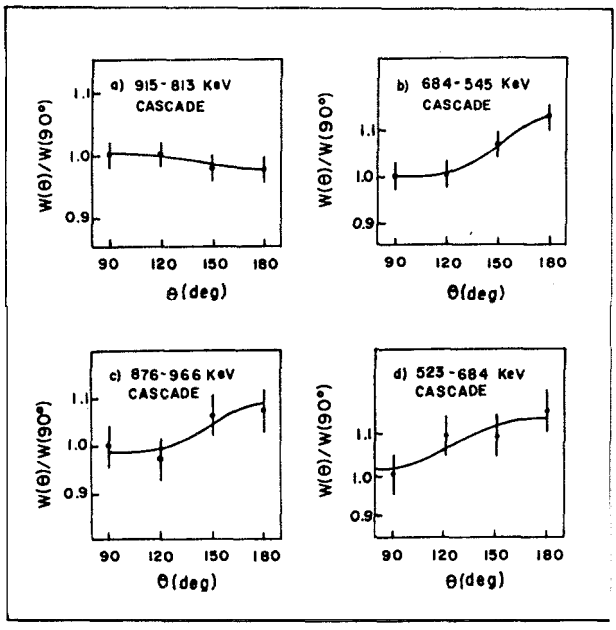

Fig.3 - Directional correlation curves for some gamma cascades typical of intense transitions (a), intermediate intensity transitions (b) and (c), and weak transitions (d). Solid curves are the least square fits to the polynomial $W(\theta) = 1 + A_{22}P_2(\cos\theta) + A_{44}P_4(\cos\theta)$.

as both ^{125}Te and ^{127}Te have well established $9/2^-$ states at 321 keV[13] and 431 keV[2,14] respectively. The angular correlation results of the 1261-359 keV and 295-359 keV cascades are consistent with the above assignment. Furthermore, with the spin and parity of $9/2^+$ for the 1727 keV level[1], the 1261-359 keV cascade has the sequence $9/2^+(1)\ 9/2^-(1,2)\ 11/2^-$. The mixing ratio of the 359 keV transition was determined to be $\delta(359) = -10.8 \pm 0.5$ or -0.02 ± 0.01.

The 545 keV level

The spin and parity of this level is known to be $5/2^+$[1]. Two gamma cascades, 684-545 keV and 773-545 keV, were measured in the pre-

Table 2 - Multipole Mixing Ratios of y Transitions in ^{129}Te

Gamma Cascade (keV)	Spin Sequence	Mixed Transition (keV)	Mixing Ratio δ(E2/M1)
1261-359	9/2(1) 9/2(1,2) 11/2	359	-10.77 ± 0.54
			or - 0.02 ± 0.01
1030-813	7/2(1,2) 7/2(2) 3/2	1030	0.62 ± 0.02
915-813	9/2(1,2) 7/2(2) 3/2	915	0.08 ± 0.02
876-966	7/2(1,2) 5/2(1,2)3/2	876	$-40.30 \pm {}^{29.00}_{\infty}$
			or - 0.18 ± 0.10
761-966	9/2(2) 5/2(1,2) 3/2	966	- 5.93 ± 1.70
			or 0.12 ± 0.04
773-545	a)5/2(1,2) 5/2(1,2)3/2	773	0.73 ± 0.60
		545	- 7.30 ± 1.12
	b)7/2(1,2) 5/2(1,2)3/2	773	- 1.13 ± 0.60
		545	- 7.21 ± 1.20
684-545	7/2(1,2) 5/2(1,2) 3/2	684	- 1.10 ± 0.15
		545	- 7.14 ± 0.60
523-684	5/2(1,2) 7/2(1,2) 5/2	523	- 0.12 ± 0.02
295-395	7/2(1,2) 9/2(1,2)11/2	295	17.50 ± 0.80
			or - 0.11 ± 0.01

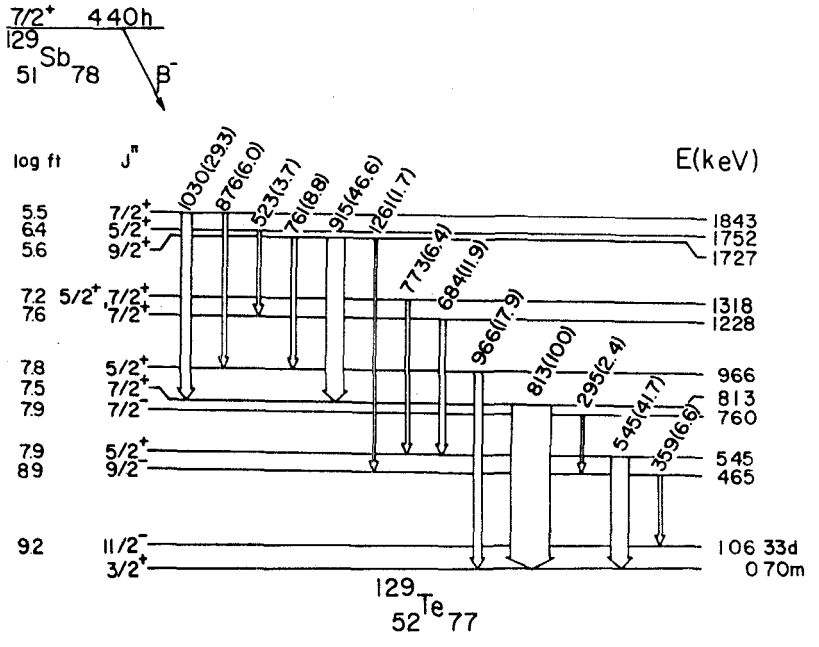

Fig.4 - Partia1 decay scheme of ^{129}Sb to the levels in ^{129}Te.

sent study. Although the three y-transitions involved in these cascades have mixed multipolarities, the mixing ratio of the 545 keV transition should be independent of rhe cascade. The possible spin assignments of the 1228 keV and 1317 keV levels are 7/2 or 9/2[11,12] and 5/2 or 7/2 [1] respectively. These possibilities were tested by comparing the experimental angular correlations of the two cascades with the theoretical predictions in a computer search program, using the usual χ^2 analysis sub-routine. The calculations took into account the spin sequences mentioned above and all possible combinations of the mixing ratios forthe three transitions. It was possible to extract a value of $\delta(545)$ which gave a simultaneous best fit to the experimental data of both cascades as wel1 as the corresponding values of $\delta(684)$ and $\delta(773)$. The analysis of the 684-545 keV cascade further indicated that a spin assignment of

7/2 is preferred over 9/2 for the 1228 keV level. The results are summarized in table 2. As will be seen later a 7/2 spin assignment for the 1228 keV level is also indicated according to the results of the 523-684 keV cascade.

The 760 keV level

A log ft value of 7.9 for the beta decay and the de-exitation to the negative parity levels below limit the spin and parity of this level to $7/2^-$ or $9/2^-$. Results of the gamma cascade 295-359 keV were analysed with the 7/2 and 9/2 spin values for the 760 keV level and the known values of the mixing ratio $\delta(359)$, -10.8 ± 0.5 or -0.02 ± 0.01, determined from the 1261-359 keV cascade results. A much better fit to the data was obtained with the 7/2 value. The existence of similar levels at 525 keV and 631 keV in ^{125}Te and ^{127}Te, respectively, with known spin and parity of $7/2^-$ [13,16] also suggests this assignment for the 760 keV level in ^{129}Te.

The 813 keV level

This level has been previously assigned as $7/2^+$ or $9/2^+$ [1]. The level decays to the ground state $(3/2^+)$ with a strong y-transition and to the 545 keV level $(5/2^+)$ with a much weaker transition[1]. The $9/2^+$ assignment to this level can be ruled out because this would imply that the preferred mode of the level de-exitation is through a M3 rather than an E2 transition, and soch an observation is not consistent with the known systematics. The $7/2^+$ spin assignment is therefore suggested. Levels with similar decay characteristics are observed at 636 and 686 keV in ^{125}Te and ^{127}Te respectively. Two gamma cascades, 915-813 keV and 1030-813 keV, involving this level were measured in this study and served to define the spins of the 1727 keV (9/2) and 1843 keV (7/2) levels as will be discussed later.

The 966 keV level

A spin and parity of $5/2^+$ is known for this level[1]. Two gamma cascades, 761-966 keV and 876-966 keV, were measured involving this

state as the intermediate level, With the 1727 keV level spin as $9/2^{+}$[1], the 761 keV transition is E2. Analysis of the results of the 761-966 keV cascade furnished $\delta(966) = -5.93 \pm 1.70$ or 0.12 ± 0.04. These δ values were used to obtain the *mixing* ratio of the 876 keV transition from the measured A_{kk} values of the 876-966 keV cascade, as given in table 2.

The 1228 keV level

This level has not been observed in nuclear reactions[8-10]; however, decay studies[11,12] limit the spin and parity of this level to $7/2^{+}$ or $9/2^{+}$. The level is initial of the 684-545 keV cascade and intermediate of the 523-684 keV cascade measured in this study. With the already known spin and parity of $5/2^{+}$ for the 1752 keV level[1] results of the 523-684 keV cascade rule out the $9/2^{+}$ assignment for the 1228 keV level (for the $5/2^{+}(2)\ 9/2^{+}(2)\ 5/2^{+}$ sequence, A_{22} (theoretical)=0.2186 whereas A_{22} (experimental) $= 0.090 \pm 0.043$) . Results of the 684-545 keV cascade have already been discussed before and they also indicate a preference for the 7/2 assignment over the 9/2.

The 1318 keV level

The spin of this level has been suggested as 5/2 or 7/2[1] with no indication of parity. The parity of the level is most problably positive as there is no decay to any of the negative parity levels below. The results of the 773-545 keV cascade were unable to better define the spin of the 1318 keV level.

The 1727 keV level

This level has not been observed in nuclear reactions[8-10]; however, based on the decay studies[11,12], a $9/2^{+}$ spin and parity was assigned to it[1]. Although the results of the 1261-359 keV and 761-966 keV cascade are unable to discriminate between the 7/2 or 9/2 spin values for this level, the results of the 915-813 keV cascade favor the 9/2 assignment (figs. 5 and 6). A larger $|\delta|$ value for the 915 keV transition is not compatible with the measured A_{44}.

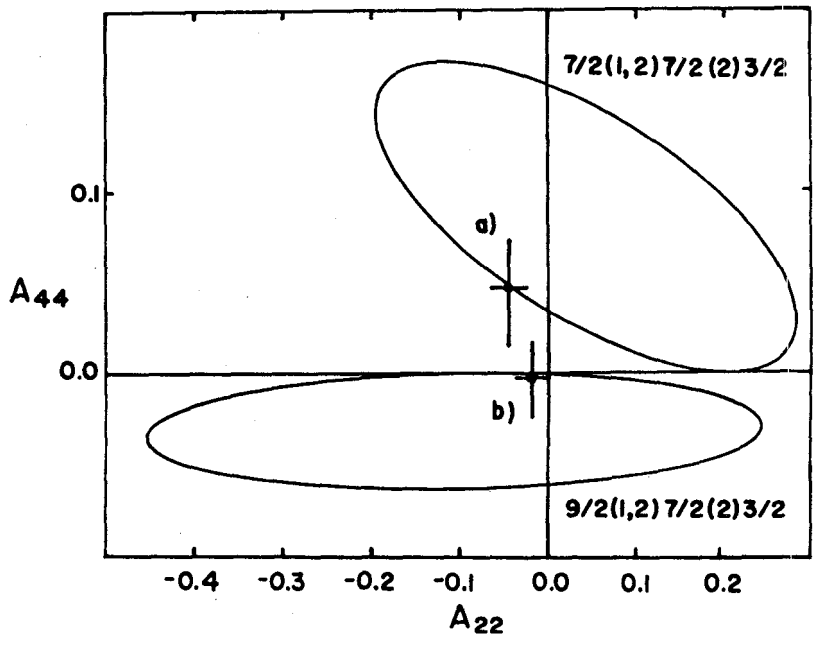

Fig.5 - The parametric plots of A_{22} vs A_{44} as a function of δ for the spin sequences 7/2(1,2) 7/2(2) 3/2 and 9/2(1,2) 7/2(2) 3/2. The experimental (A_{22}, A_{44}) points are shown with error bars (a) 1030-813 keV cascade, b) 915-813 keV cascade.

The 1752 keV level

The spin and parity of this level is $5/2^{+}$ [1], derived both from the (t,d)[10] reaction data and the decay studies[11,12]. The result of the 523-684 keV cascade measured in the present study is not inconsistent with this assignment but in itself cannot rule out other possible spin values. The mixing ratio of the 523 keV transition was calculated using the already known value of $\delta(684)$, namely - 1.10 ± 0.15.

The 1843 keV level

Decay çtudies limit the spin and parity of this level to $7/2^+$ or $9/2^{+11,12}$. Whereas the results of the 876-966 keV gamma cascade are consistent with either of the assignments, the results of the 1030-813 keV cascade have a better agreement with the 7/2 spin value (see figs. 5 and 6). The mixing ratio of the 1030 keV transition was determined as $\delta(1030) = 0.62 \pm 0.02$. The other solution of $|\delta|$ would require a large A_{44}, in disagreement with the measured value and therefore not considered.

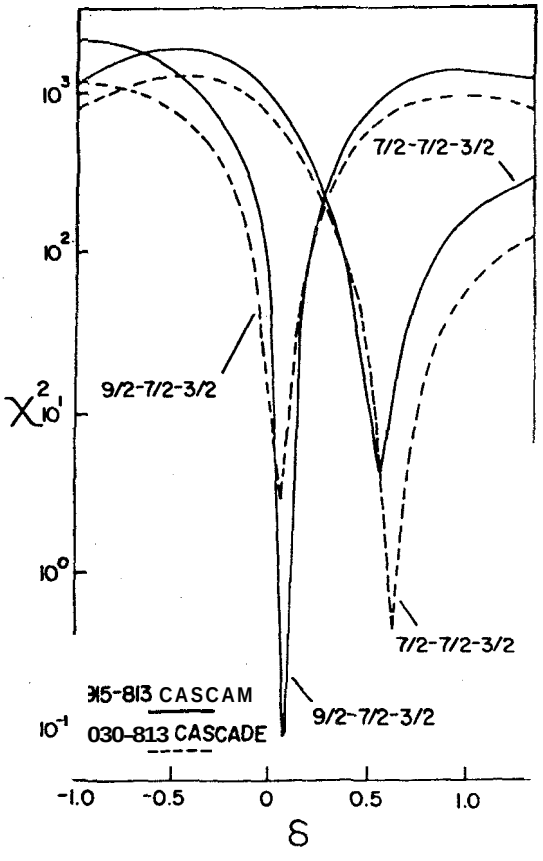

Fig. 6 - Comparison of the experimental and calculated values for the angular correlation of the 1030-813 and 915-813 keV gamma cascades. The curves are for the 7/2 and 9/2 spin values for the 1843 keV and 1727 keV levels.

4. DISCUSSION

As mentioned earlier, remarkable similarities and systematic variations in the levels of both even-and odd-mass Te nuclei have received considerable experimental as well as theoretical attention. This, in part, is due to a large number of stable isotopes of Te available for studies in a variety of nuclear reactions as well as to many types of studies using radioactive parent nuclei which are relatively easily prepared. In addition to this, relative simplicity of calculations for nuclides near a closed shell has also permitted a variety of theoretical studies in Te nuclei. Such studies have revealed a general vibrational description of the even-even nuclides and some evidence that severa1 of the low lying levels of odd-mass isotopes result from the coupling of single particle states to the even-even core.

In a simple shell model treatment the lowest energy orbitals available to the odd neutron in $^{125\text{-}129}$Te nuclei are 2 $d_{3/2}$, 3 $s_{1/2}$ and 1 $h_{11/2}$ in agreement with the experimental observations. Higher energy positive and negative parity levels are thought to result mainly from the quasi-particle phonon coupling such as $2_1^+ \otimes d_{3/2}$, $2^+ \otimes s_{1/2}$ and $2^+ \otimes h_{11/2}$ in addition to the $g_{7/2}$ and $d_{5/2}$ hole states. It might be interesting to compare the levels of ^{129}Te with those observed in ^{125}Te and ^{127}Te; and, as it may be seen from figure 7, there is esseritially a one to one correspondence between the levels up to about 1.2 MeV. Apart from the lowest three rather pure levels there appears to be a general shift of ~100-200 keV towards higher energies in the position of the levels as pairs of neutrons are added successively to ^{125}Te. This may be quite reasonable if these levels contain significant components of phonon in their wave function as the energy of the 2^+ state in the even Te nuclei rises from 603 keV in ^{124}Te to 666 keV in ^{126}Te and to 743 keV in ^{128}Te [15] Furthermore, the lof ft values for the beta feeding of the levels and y-de-exitation are also quite similar[1,13,16]

By considering a pairing plus quadrupole force interaction with the spherical core, Kisslinger and Sorensen[17] were able to obtain the spectra of the excited states of these nuclei in fair agreement with the observed level scheme. A significant failure of their model

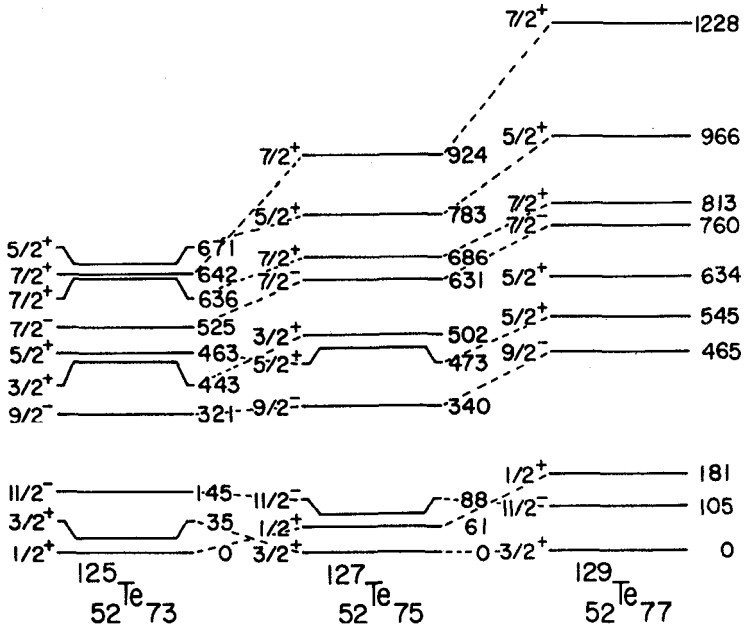

Fig. 7 - Systematics of the low-lying energy levels of $^{125-129}$Te populated in the beta decay of respective Sb isotopes.

was, however, the lack of a predicted $9/2^-$ state which is observed at low energies in these nuclei and has long required a more complex description. Such states have been described as three quasi-particle states $(h_{11/2})^3\ 9/2^-$ by Kisslinger[18] and the measured g-factors as well as the E2/M1 mixing ratios of the $9/2^- \rightarrow 11/2^-$ transitions in ^{125}Te and ^{127}Te are found to agree with such a description[2,19,21].

Although spins and parities of a number of levels in ^{125}Te and ^{127}Te were well established from previous studies, little was known about the ^{129}Te levels. Results of the present investigation suggest that the spins of levels at 760 keV, 1228 keV and 1843 keV are all 7/2 and confirm the previous assignments of several other levels. In addition, the mixing ratios for a number of γ-transitions in ^{129}Te have

been determined. A large E2/M1 mixing ratio for the 359 keV $9/2^- \rightarrow 11/2^-$ transition is consistent with the suggested three quasi-particle nature[18] of the 465 keV level in analogy with similar levels in ^{125}Te and ^{127}Te. With the γ-ray multipole mixing ratios available for a number of transitions in $^{125-129}$Te nuclei, we hope attempts can now be made for theoretical calculations of these quantities in order to further elucidate the level structure of these nuclei.

The authors would like to thank the staff of the linear accelerator laboratory of the University of São Paulo for their very efficient help in the irradiation of samples. One of us (MOMDS) would like to thank the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for the financia1 support. Partial financial support for this work was provided by the Comissão Nacional de Energia Nuclear (CNEN).

REFERENCES

1. Nuclear Data Sheets 39, 593 (1983).
2. Maristela Olzon M.D. de Souza and R.N. Saxena, Phys. Rev. C*31*, 593 (1985).
3. S.M. Abecassis, Radiochim, Acta 2, 103 (1964).
4. R.N. Saxena, N.T.S. Monteiro and Bairrio Nuevo Jr., Instituto de Energia Atômica, São Paulo Report 359, 1974.
5. M.J.L. Yates, *Perturbed Angular Correlation*, edited by E. Carlsson *et al*. (North Holand, Amsterdam, 1964) pp. 453-66.
6. D.C. Camp and A.L. Van Lehn, Nucl. Instrum. Methods 76, 192 (1969).
7. K.S. Krane and R.M. Steffen, Phys, Rev. C2, 724 (1970).
8. R.K. Jolly, Phys. Rev. B*136*, 683 (1964).
9. W.H. Moore, G.K. Schlegel, S.O'Dell, A. Graue and R.J. Lien, Nucl. Phys. A*104*, 327 (1967).
10. A.M. Shahabuddin, J.A. Kuchner and A.A. Pilt, Phys. Rev. C23, 64 (1981).
11. S. Ohya, T. Tamura and S. Kageyama, J. Phys. Soc. Japan 29, 1435 (1970).
12. P.G. Calway and H.D. Sharma, Nucl. Phys. A*156*, 338 (1970).

13. Nuclear Data Sheets 32, 547 (1981).
14. K.S. Krane and W.A. Steyert, Phys. Rev, C6, 2268 (1972).
15. *Table of Isotopes*, edited by C.M. Lederer and V.S. Shirley (John Wiley 1978).
16. Nuclear Data Sheets 35, 233 (1982).
17. L.S. Kisslinger and R.A. Sorensen, Rev. Mod. Phys. 35, 853 (1963).
18. L.S. Kisslinger, Nucl. Phys. 78, 341 (1966).
19. E. Knapec, R. Simon, R.S. Raghavan and H. J. Körner, Phys.Lett.*29* B, 581 (1969).
20, D.W. Cruse, K, Johansson and E. Karlsson, Nucl. Phys.A*154*, 369 (1970),
21. J.C. Soares, P. Herzog and H, Hübel, Nucl. Phys. A*224*, 358 (1974).

Resumo

A correlação angular direcional para transições gama coincidente no núcleo de ^{129}Te foi medido a partir do decaimento β^- do ^{129}Sb ($T_{1/2}$ = 4.4 h) usando espectrômetro de Ge(Li)-NaI(Tl). Foram realizadas medidas para 9 cascatas gamas resultando na determinação de misturas multipolares δ(E2/M1) para 10 transições no ^{129}Te. Os presentes resultados sugerem spin de 7/2 para os níveis a 760 keV, 1228 keV e 1843 keV além de confirmar os valores de spin para outros níveis no ^{129}Te.