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Lifetime of the 321 keV ($9/2^-$) state in ^{125}Te

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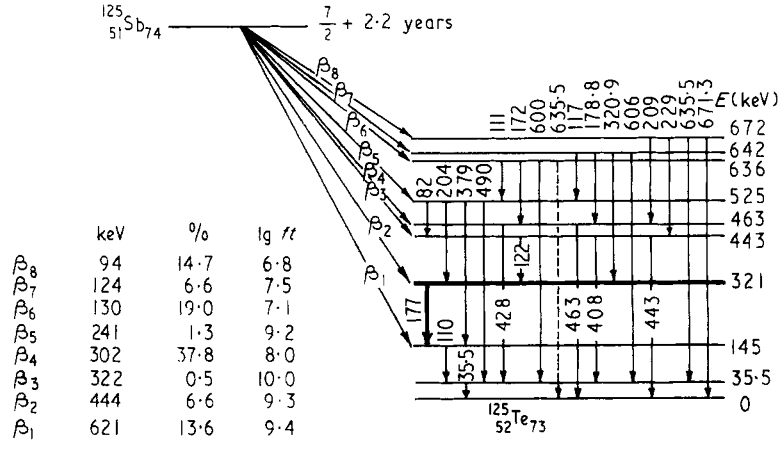
Abstract. The halflife of the 321 keV ($9/2^-$) state in ^{125}Te is measured by the delayed coincidence technique employing a time-to-amplitude converter. On comparing the experimental M1 and E2 transition probabilities with those evaluated by the single particle model, Kisslinger's three-quasiparticle model and the De-Shalit model, it is found that De-Shalit's single particle–core coupling model is applicable in this case.

1. Introduction

The level structure of ^{125}Te is extensively investigated (Inamura 1968) from the studies on beta decay of ^{125}Sb($T_{1/2}$ = 2·2 year) and the main features of the decay of ^{125}Sb are shown in figure 1. The characteristics of the ground, 35·5, 145 and 321 keV states are well established from various spectroscopic studies by Stone *et al* (1968), Graue *et al* (1969) and Dubard *et al* (1966) as $1/2^+$, $3/2^+$, $11/2^-$ and $9/2^-$ respectively. The $11/2^-$ state at 145 keV is an isomeric state ($T_{1/2}$ = 58 day) and considered to be a shell model state which probably corresponds to a configuration $[(g_{7/2})^8(d_{5/2})^6(s_{1/2})^2(d_{3/2})^4(h_{11/2})^3]_{11/2^-}$ for the 23 neutrons in excess of 50 in the fourth major shell. The spin of the 321 keV ($9/2^-$) is not predicted by the single particle model with a spherical potential. Kisslinger and Sorensen (1963) made a generalized study of odd-mass spherical nuclei assuming residual forces of the pairing-plus-quadrupole type. They seem to provide a



	keV	%	lg ft
β8	94	14·7	6·8
β7	124	6·6	7·5
β6	130	19·0	7·1
β5	241	1·3	9·2
β4	302	37·8	8·0
β3	322	0·5	10·0
β2	444	6·6	9·3
β1	621	13·6	9·4

Figure 1. Decay scheme of ^{125}Sb.

fair description of positive parity states in ^{125}Te but could not predict the negative parity states at 321 and 525 keV. Recently Kisslinger (1966) interpreted the 321 keV state as a three-quasiparticle intruder state of the type $(1h_{11/2})^3_{9/2}-$; but it does not seem to explain the transition characteristics of the 176·7 keV transition. In view of the failure of these models, it is proposed to re-investigate the lifetime of the 321 keV state and test the applicable nuclear model for this case.

2. Lifetime of the 321 keV state

The source ^{125}Sb is produced by thermal neutron irradiation of ^{124}Sn in the Apsara Reactor, Bhabha Atomic Research Centre, India. Carrier-free ^{125}Sb is obtained in liquid form as antimony chloride in dilute HCl solution.

The halflife of the 321 keV state is measured by the beta–gamma coincidence method incorporating a time-to-pulse height converter and Na-136 plastic crystals mounted on two well matched RCA 6810A photomultipliers. The beta group of endpoint energy 444 keV feeding the 321 keV state is detected in a plastic phosphor of effective thickness 2 mm while the following 176·7 keV gamma rays are selected in a 1×1 in^2 plastic crystal. The prompt spectrum is recorded with a ^{134}Cs source in position which yielded a halfwidth of $9{\cdot}3 \times 10^{-10}$ s and an intrinsic slope of $1{\cdot}1 \times 10^{-10}$ s. The decay curve of the 321 keV state is shown in figure 2 after subtracting for accidental coincidences. The prompt spectrum (^{134}Cs) is also shown for comparison. The value of the halflife of the 321 keV state thus obtained is $(0{\cdot}704 \pm 0{\cdot}021) \times 10^{-9}$ s. The values of the halflifes of the 321 keV level in ^{125}Te determined in the previous investigations are given in table 1 along with the present experimental result. It can be seen from table 1 that the present value is smaller than that reported by Inamura (1968) but agrees well with the measurements of Kownacki *et al* (1968), Hosangdi *et al* (1969) and Marelius *et al* (1970) within the experimental errors.

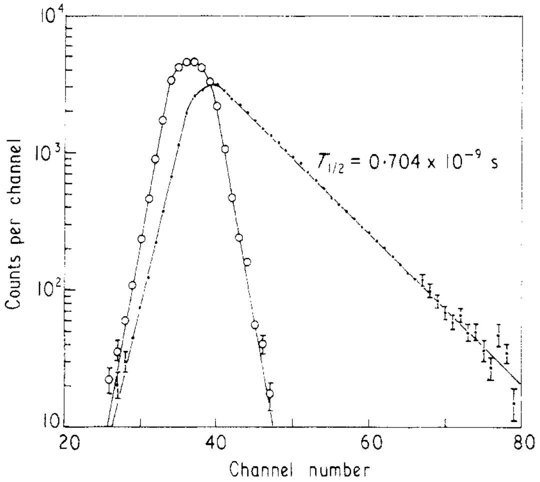


Figure 2. Halflife of the 321 keV state in ^{125}Te. ○ Prompt spectrum obtained with ^{134}Cs; ● experimental time spectrum, calibration $1{\cdot}29 \times 10^{-10}$ s per channel.

Table 1. Halflife of the 321 keV level in ^{125}Te

Sample number	Authors	Halflife ($T_{1/2}$) (ns)
1	Inamura (1968)	$0{\cdot}87 \pm 0{\cdot}08$
2	Kownacki *et al* (1968)	$0{\cdot}695 \pm 0{\cdot}015$
3	Hosangdi *et al* (1969)	$0{\cdot}68 \pm 0{\cdot}03$
4	Marelius *et al* (1970)	$0{\cdot}68 \pm 0{\cdot}03$
5	Satyanarayana *et al* (present work)	$0{\cdot}704 \pm 0{\cdot}021$

3. Transition probabilities of the 176·7 keV transition

The measured halflife of the 321 keV state is employed to estimate the M1 and E2 transition probabilities of the 176·7 keV transition and these are compared with the single particle estimates[†] (Moszkowski 1965 and 1953). The theoretical and experimental transition probabilities of the 176·7 keV transition are given in table 2. The large M1 hindrance and E2 enhancement suggests a collective nature of the 321 keV state. Also the $B(\mathrm{E2})\downarrow$ value of the 176·7 keV transition is comparable in magnitude to the $B(\mathrm{E2})\downarrow$ value of the neighbouring even–even core (^{124}Te and ^{126}Te) (Stelson and Grodzins 1965).

Table 2. Transition probabilities of the 176·7 keV transition

$B(\mathrm{E2})_{\mathrm{exp}}$[†] $e^2 \times 10^{-48}\,\mathrm{cm}^4$	$\dfrac{B(\mathrm{E2})_{\mathrm{exp}}}{B(\mathrm{E2})_{\mathrm{sp}}}$	$\dfrac{B(\mathrm{E2})_{\mathrm{exp}}}{B(\mathrm{E2})_{3-\mathrm{q.p}}}$	$\dfrac{B(\mathrm{E2})_{\mathrm{exp}}}{B(\mathrm{E2})_{\mathrm{De\text{-}Shalit}}}$	$\dfrac{B(\mathrm{M1})_{\mathrm{exp}}\dagger}{3/4\pi(e\hbar/2mc)^2}$	$\dfrac{B(\mathrm{M1})_{\mathrm{sp}}}{B(\mathrm{M1})_{\mathrm{exp}}}$
$0{\cdot}1125 \pm 0{\cdot}009$	427 ± 33	$14{\cdot}5 \pm 1{\cdot}1$	$1{\cdot}08 \pm 0{\cdot}08$	$0{\cdot}0265 \pm 0{\cdot}001$	356 ± 16

[†] Branching ratio $R = 1$ and $\alpha_{\mathrm{total}} = 0{\cdot}156 \pm 0{\cdot}015$ (Inamura 1968); mixing ratio $\delta(\mathrm{E2/M1}) = -0{\cdot}624 \pm 0{\cdot}034$ (Mazets and Sergeenkov 1966).

The configuration of the 145 keV state, according to the shell model, in the fourth shell is $[(g_{7/2})^8(d_{5/2})^6(s_{1/2})^2(d_{3/2})^4(h_{11/2})^3]_{11/2}$, for the 23 neutrons in excess of 50. It is difficult to account for the $9/2^-$ state at such low energies on the basis of shell model. Moreover, this state cannot be explained on the basis of the pairing-plus-quadrupole force model since negative parity states are completely absent above the $11/2^-$ state at 298 keV in Kisslinger and Sorensen's calculation in ^{125}Te. The rotational model was considered by Inamura, but this model is found to predict values of B(E2) and B(M1) which differ significantly from the experimental values.

Recently Kisslinger (1966) tried to interpret the odd parity states in medium and heavy nuclei in the scheme of three-quasiparticles. He considered states derived from coupling three-quasiparticles in the $(h_{11/2})$ level, and showed that one of these, of spin 9/2, may be expected at an energy considerably below the one-quasiparticle plus phonon odd parity levels. This intruder state is characterized by a vanishing M1 transition probability to the one-quasiparticle state, and a nuclear 'g' factor which is just that of $(g_{11/2})$. The theoretical E2 reduced transition probability of the 176·7 keV gamma

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[†] The values of the statistical factors $S(\mathrm{M1}) = 15/11$ and $S(\mathrm{E2}) = 10/143$ have been used in the present calculations.

transition, under the assumption that the 321 keV level is a three-quasiparticle state, is estimated using the expression (Kisslinger 1966) $B(\mathrm{E2})_{3\text{-q.p}} = 17{\cdot}6(2U_jV_j)^2 \times B(\mathrm{E2})_{\mathrm{sp}}$ and compared with the experimental value in table 2. It can be seen from table 2 that Kisslinger's three-quasiparticle model predicts a smaller value of B(E2) although the E2 enhancement is reduced from 427 to 14·5. The agreement observed between the experimental and three-quasiparticle E2 transition rates in the previous calculations (Kownacki *et al* 1968) is due to the neglect of the statistical factor in the single particle estimate. The present $B(\mathrm{E2})_{3\text{-q.p}}$ value agrees with the calculation of Inamura (1968). The experimental value of the mixing ratio $\delta^2 = (\mathrm{E2/M1}) = 0{\cdot}389$ (Mazets and Sergeenkov 1966) for the 176·7 keV transition points to an appreciable fraction of the M1 transition which is also not compatible with the predictions of Kisslinger's model.

In view of the failure of the three-quasiparticle model of Kisslinger (1966) to explain the E2 and M1 transition probabilities of the 176·7 keV transition, the 321 keV state is considered as arising from the coupling of the $\mathrm{h}_{11/2}$ neutron state to the 2^+ phonon of the core. The simplest collective excitation of the type described by De-Shalit (1961) may be used to write down the wavefunctions. The pure De-Shalit model cannot be used since a finite M1 transition probability is observed between $9/2$ and $11/2^-$ states. A finite M1 transition probability is an indication of the impurities in the wavefunctions of the states. Thus $|11/2^-\rangle$ state may contain some $|2\ 11/2\ 11/2\rangle$ part and $|9/2^-\rangle$ state may contain some $|0\ 9/2\ 9/2\rangle$ part. The latter however corresponds to particle excitation. The spin of the 321 keV state being $9/2^-$ (which corresponds to $\mathrm{h}_{9/2}$) it does not seem possible to have this excitation at such a low energy in as much as the $\mathrm{h}_{9/2}$ orbital is contained in the next major shell. Thus the wavefunctions are assumed to be

$$|11/2^-\rangle = A|0\ 11/2\ 11/2\rangle + (1-A^2)^{1/2}|2\ 11/2\ 11/2\rangle$$

$$|9/2^-\rangle = |2\ 11/2\ 9/2\rangle$$

where A is an arbitrary constant. Thus the reduced M1 transition probability B(M1) for the 176·7 keV transition is given by

$$B(\mathrm{M1}) = 3{\cdot}437(1-A^2)(g_{\mathrm{C}}-g_{\mathrm{p}})^2.$$

Here $g_{\mathrm{C}} = Z/A \simeq 0{\cdot}416$ and g_{p} is assumed as $-0{\cdot}194$ from the measured magnetic moments of the $(\mathrm{h}_{11/2})$ states in $^{113\mathrm{m}}$Cd and $^{115\mathrm{m}}$Cd (Fuller and Cohen 1969). Using the present B(M1) value the constants are evaluated as

$$A = 0{\cdot}99 \pm 0{\cdot}05$$

and

$$(1-A^2)^{1/2} = \pm 0{\cdot}14 \pm 0{\cdot}01.$$

The E2 transition probability is estimated with these wavefunctions and the value of A and compared with the experimental value in table 2. It can be seen from table 2 that the E2 transition rate is accurately predicted by these wavefunctions. The magnetic moment of the $|9/2^-\rangle$ state is obtained from this wavefunction as $-1{\cdot}15$ nm which is in good agreement with the value $-(0{\cdot}909 \pm 0{\cdot}072)$ nm determined by Knapek *et al* (1969).

It thus appears that the nature of the 176·7 keV transition could be satisfactorily explained by considering a 2 % admixture of the first phonon contribution in the 145 keV state and viewing the 321 keV state as arising from phonon addition to the $\mathrm{h}_{11/2}$ particle state. The 525 keV state with a possible spin assignment of $11/2^-$ or $7/2^-$ may also form a component arising from such a phonon addition to the $h_{11/2}$ particle state. An accurate experimental determination of the lifetime of the 525 keV state and the multipolarities of the gamma transitions decaying the 525 keV state would yield useful information to further test the applicability of De-Shalit's model for the negative parity states in ^{125}Te. It is also interesting to look for the other negative parity states expected from such a coupling.

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