NEGATIVE PARITY STATES ANALYSIS FOR ^{125}TE NUCLEUS WITH THE INTERACTING BOSON- FERMION MODEL (IBFM)

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Abstract

The negative parity states of ^{125}Te up to excitation energy of ~ 2.3 MeV were investigated in the framework of the IBFM. One level calculation is more reliable than multilevel calculations. The 1h$_{11/2}$ has been considered as nearly half full. The assignments of some experimental levels have been confirmed. Electromagnetic transition for some low-lying transitions, magnetic moments and the spectroscopic factor were deduced.

Nuclear structure, IBFM, Te- odd nucleus.

تحليل مستويات التماثل السالب لنواة ال ^{125}Te باستخدام نظام تفاعل البوزون – فرميون

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الخلاصة

تم دراسة مستويات التماثل السالب لنواة ال 125Te ولحد مستويات تهيج ~ 2.3 مليون اليكترون فولت باستخدام نظام تفاعل البوزون – فرميون . ثبت بان استخدام مستوى واحد فى التحليل هو اكثر ملائمه . المستوى المستخدم 1h11/2 قد اعتبر بانه نصف مملوء تقريبا . بعض المستويات العمليه تم تأكيد توصيفها . الانتقالات الكهرومغناطيسيه والعزم المغناطيسى والدليل الطيفى لبعض المستويات الواطئه تم حسابها .

Introduction

Information about the experimental nuclear level scheme of ^{125}Te from different reactions, has been reported in several papers[1-9]. They agreed for the assignments of the most positive-parity states, while there are discrepancies in the assignments and the excitation energy of the negative- parity states. These discrepancies were started from the second state at 321 keV and higher including many intruder states. The appearance of intruder states, arising from h$_{11/2}$ orbit, was explained by the most recent experimental and theoretical works[7] using three and more quasiparticle mode.

A revised low-level scheme for ^{125}Te was constructed[10] confirming the existence of 10 well established levels below 700 keV, and introducing three other levels at 402.0, 538.6 and 652.9 keV all with positive parity.

Levels in ^{125}Te were investigated experimentally in the range up to 3.3 MeV excitation energy by the (n,γ), (d,p) and (^{3}He,α) reactions by Honzatko et al[7]. In their study over 160 levels and about 360 γ- transitions were established, most for the first time, as they claimed.

Also, they used unitary treatment when they applied the interacting-boson fermion model (IBFM) for both positive and negative parity states.

The h$_{11/2}$ is the only negative parity orbital embedded in the N=50-82 region which appears as 11/2$^-$ isomer state in all odd-A nuclei located in this range. In QPC model[11], the levels 7/2, 9/2, 11/2, 13/2 and 15/2 have been generated from ($11/2^{-}$ ¤ 2^{+}) and should be located around the 2^{+} phonon energy.

The lowering of I = j-1, j-2 states in the low-lying states, where j is a unique orbital ($h_{11/2}$) was previously explained through cluster model calculations[12] using so-called dressed 3qp and 5qp clusters. Rodland et al.[4] regarded the 3qp and 5qp mode, as ‘ elementary modes’ which breaking the QPC picture.

According to the IBFM, 125Te described as a boson 126Te core coupled with a fermion hole. Honzatko et al.[7] included 1h11/2 plus (2f7/2, 1f5/2, 2p3/2 and 2p1/2) orbital (for stripping strength calculations) and 1h11/2 plus (2f7/2, 3p3/2, 1h9/2 and 3p1/2) orbital (for pick-up strength calculations).

In the present work, the IBFM has been applied for the description of the negative-parity state by using the 1h11/2 orbit only. Hence, the negative parity states in 125Te nucleus described in the IBFM by coupling of single fermion (neutron hole) to the 126Te even-even core composed of five bosons.

Theory :IBFM

In the IBFM, odd-A nuclei are described by the coupling of the odd fermionic quasiparticle to a collective boson core[13]. The total Hamiltonian can be written as the sum of three part

$$H = H_B + H_F + V_{BF} \qquad (1)$$

where HB is the usual IBM-2 Hamiltonian[14] for the even-even core, HF is the fermion Hamiltonian containing only one-body terms.

$$H_F = \sum_{jm} \varepsilon_j \, \hat{a}_{jm} \; a_{jm} \qquad ....(2)$$

where εj are the quasiparticle energies and a+jm , ajm are the creation (annihilation) operators for the quasiparticle in the eigen state ǀjm>.

The boson-fermion interaction, VBF that describes the interaction between the odd quasi-nucleon and the even-even core nucleus, has been shown to be dominated by the following three terms[15]:

$$V_{BF} = \sum A_j \, [\,(\overset{+}{d} \, x \, \tilde{d}\,)^0 \;\; x \; (\overset{+}{a}_j \, x \, \tilde{a}_j \,)^0 \;\;]^0$$

$$+ \sum_{jj'} \Gamma_{jj'} \, [Q^2 \;\, x((\overset{+}{a}_j \, x \, \tilde{a}_j \,)^2 \,]^0_0$$

$$+ \sum_{jj'j''} \Lambda^{j''}_{jj'} \, [(\overset{+}{d} \, x \, \tilde{a}_j \,)^{j''} \, x \, (\overset{+}{a}_j \, x \, \tilde{d}\,)^{jj'} \,]^0_0 \qquad ....(3)$$

where the core boson quadrupole operator

$$Q^2 = (\overset{+}{s} \, x \, \tilde{d} + \overset{+}{d} \, x \, \tilde{d}\,)^2 + \chi \, (\overset{+}{d} \, x \, \tilde{d}\,)^2 \qquad ....(4)$$

and χ is a parameter shown by microscopic theory to lie through $\pm \frac{\sqrt{7}}{2}$, s,d, $\overset{+}{s}$, $\overset{+}{d}$ are boson operators with $\tilde{\mathrm{a}}_{\mathrm{jm}}$ = (-1)j-m aj-m and denotes normal ordering whereby contributions that arise from commuting the operators are neglected. The first term in VBF is a monopole interaction which plays a minor role in actual calculations. The dominant terms are the second and third, which arise from the quadrupole interaction. The third term represents the exchange of the quasiparticle with one of the two fermion forming a boson and has shown[16] that this exchange force is a consequence of the Pauli principle on the quadrupole interaction between protons and neutrons. The remaining parameters in equation (3) can be related to the Bardeen, Cooper and Schrieffer(BCS)[17] occupation probabilities, uj , vj of the single particle orbits.

The Hamiltonian of equation (1) was diagonalised by means of the standard program ODDA[14] in which the IBFM parameters are identified as: A0 = BFM, Γ0 = BFQ and Λ0 = BFE .

The electromagnetic transition operators can be written as the sum of the two terms, the first of which acts only on the boson part of the wave function, and the second acts only on the fermion part in equation (1) .

In the IBFM the E2 operator is

$$T^{(E2)} = e_B \, Q^{(2)} + e_F \sum Q_{jj'} \, (a_j \, x \tilde{a}_{j'} \,)^{\,2} \qquad ....(5)$$

Where eB and eF are the boson and fermion effective charges
The M1 operator is

$$T^{(M1)} = \sqrt{\frac{30}{4\pi}}\, g_B (\overset{+}{d} x \tilde{d})^{(1)}$$

$$-\sum_{jj'} g_{jj'} [j(j+1)(2j+1)4\pi]^{1/2} (a_j x \tilde{a})^{(1)} \quad .....(6)$$

Where gB is the boson g-factor determined by the even-even core, and gjj' is the single particle contribution which depends on gland gs (orbital and spin g-factor) of the odd nucleon.
The transition strengths B(E/Mλ) between levels with spin J and J' are obtained from the operators of equation (5) as

$$B(E/M\lambda; J\rightarrow J') = \frac{\left|\left\langle J' \middle\| T^{(E/M\lambda)} \middle\| J \right\rangle\right|^2}{(2J+1)} \quad ....(7)$$

The magnetic dipole moments (μJ) and the electric quadruple moment(QJ) for a state with spin J can be calculated from M1 and E2 operators respectively. From the matrix elements of T(M1) and T(E2) one can

$$\mu_J = \sqrt{\frac{4\pi}{3}} \sqrt{\frac{J}{(2J+1)(J+1)}} \left\langle J \middle\| T^{(M1)} \middle\| J \right\rangle\Big| \quad ....(8)$$

$$Q_J = \sqrt{\frac{16\pi}{5}} \sqrt{\frac{J(2J-1)}{(2J+1)(J+1)(2J+3)}}$$

$$\left\langle J \middle\| T^{(E2)} \middle\| J \right\rangle\Big| \quad ....(9)$$

Two different IBFM one-particle transfer transition operators can be considered. One deal with reactions where a fermions is added to an even-even core and thus the number of bosons is conserved (pick-up reaction) and can be written as:

$$\overset{+}{\underset{jp}{A}} = [\zeta_j a_j] + \sum [\zeta_{jj'} (\overset{+}{s} x \tilde{d}\ x \underset{j'}{\overset{+}{a}})^{(j)}]_p \quad ....(10)$$

The second operator deals with the reaction where a boson is broken up and one fermions is taken away, leaving the final nucleus with one boson less and one fermions more thus the number of bosons is not conserved (stripping reaction)

$$\overset{+}{\underset{jp}{B}} = [\theta_j a_j] + \sum [\theta_{jj'} (\overset{+}{d}\ x \underset{j'}{\overset{+}{a}})^{(j)}]_p \quad ....(11)$$

The ζ and θ coefficients can be expressed in terms of BCS occupation probabilities of single particle levels with total angular momentum j.
The transfer strengths are then given by

$$S_{\ell j}(J_i \rightarrow J_f) = \frac{1}{(2J_i+1)} \left|\left\langle J_f \middle| \overset{+}{A}_j\right.\right.$$

$$\left.\left. + \overset{+}{B}_j \middle| J_i \right\rangle\right|^2 \quad .... (12)$$

Results and Discussion:

The one level calculations have been used by including the level 1h11/2 only, since it is the only level with negative parity in the region (N=50- 82). The 1h11/2 level has been considered as nearly half full (ϑ2=0.45), and the single- quasiparticle energy, is taken to be equal to 0.144 MeV[3].
Because of the discrepancies between experimental results in both energy levels and their assignments, the IBFM parameters used are those which give the same energy value for the first energy level 11/2-. Hence, a normalization to the level 11/2- at 145 keV was made. The IBFM parameters used are BFQ= - 0.783 MeV, BFE= - 0.139 MeV and BFM= 0.07 MeV.
Figure (1) shows a comparison between the assignments and energy levels suggested experimentally[7] and the IBFM predictions. The average percentage deviation between experimental levels and the IBFM predictions was calculated to be less than 3% only.
The 9/2- level at 321 keV has been predicted by Kisslinger[6] and interpreted as a three-quasiparticle (1h11/2)39/2 intruder state of the type (j)3j-1. Such a complicated state is not observed in (d,p) reaction[3,7]. Several non-IBFM theoretical attempts[3] was made to calculate the 125Te spectrum, and they were not able to produce low-lying negative-parity levels as those observed at 321 keV and 525 keV with any reasonable value for the 1h11/2 single-particle energy. The IBFM prediction agrees with the levels assignment of the most recent experimental work[7]. In the present IBFM calculation, the 9/2- level has 328.0 keV excitation energy.
The 525 keV state is suggested to have spin 9/2- or 11/2- by Stone et al.[2] while Inamura[1] and Hontzatko[7] suggests 7/2-. The IBFM prediction confirms the suggestion of Inamura

and Hontzatko by giving a level at 563.5 keV with 7/2- assignment.

The experimental ambiguity concerning the level 786 keV was explained[4] as a two-step effect. It was assumed to have 7/2- assignment. The most recent experiment[7] solve this ambiguity and gives 7/2- assignment to this level. The IBFM results confirm this assignment suggesting a state at 757.2 keV.

The new level at 1071.65 keV suggested experimentally[7] is established uniquely in the (n,γ) reaction via four de-exciting transitions. From populating and depopulating transitions they[7] suggest 5/2- assignment to this level. The IBFM calculation suggests a level at 1086.4 keV with 5/2- assignment.

Another new level at 1209.73 keV was established uniquely in the (n,γ) reactions[7]. They limit its spin-parity to 5/2- and 7/2+. The IBFM results give a 5/2- assignment to a state at 1127.2 keV.

A close-lying levels at 1319.53 and 1322.42 keV with different angular momenta of l=2 and 4 were observed experimentally[7] assigned unambiguously a 3/2- and 5/2-, 7/2- characteristic respectively. The IBFM results confirm the assignment of 3/2- (1366 keV) while gives 7/2- (1323.8 keV) assignment to the level second level.

Only a very weak primary transition was observed in thermal capture[7] depopulating from the level 1699.93 keV to the 7/2- state. This depopulating transition defines 3/2- assignment to this level. The IBFM results confirm this assignment with 1618.4 keV.

The new experimental[7] level at 1766.45 keV with spin-parity assignment was restricted to 3/2-,5/2- or 7/2 +. However, they[7] prefer the 5/2- assignments while the IBFM results suggest a level at 1783.1 keV with 3/2- assignment.

A new level at 1995 keV observed in (d,p) spectrum, stripping reactions as well as in coincidence spectrum[7] suggesting two different assignment to this level. The deexcitation mode strongly suggest a 3/2- assignment while the depopulating transitions are consistent with the 9/2- assignment. The IBFM results suggest the highest level with 9/2- at 1811.2 keV.

A new level was suggested experimentally[7] at 2076.95 keV they where restricted its spin-parity to 1/2- or 3/2 according to the transition and on three depopulating transitions. The IBFM results confirm the 1/2- assignment with energy 2010.5 keV.

Unresolved triplets(2108.58, 2112.5 and 2126.8 keV) with the ℓ=1+3 transfer were observed in the striping reactions at 2105 keV. Ref.[7] suggests a 2109 keV level with spin-parity assignment 3/2- and 1/2 -. They[7] also established two levels at 2112 and 2126 keV with spin-parity assignments 5/2,7/2 for the first one, and they not sure about the level at 2126 keV. The IBFM result

gives only two states at 2167.5 (3/2-) and 2151.8 (5/2-) keV.

Although, there is no experimental evidence for the level at 2246 keV to have a negative parity, but they suggest a 1/2- or 3/2- assignment to this level according to the intense transition from this level to the 5/2- 1071 keV level[7]. However, the IBFM results suggest a level at 2229.8 with 3/2- assignment.

The highest negative parity state predicted experimentally[7] was at 2521.4 keV with assignment 3/2-. The IBFM cannot give any energy with any assignment higher than nearly 2500 keV.

The energy levels compared are those below 2.5 MeV, since most of the levels at higher energy are not assigned and there are a lot of discrepancies in their excitation energy.

Another step to confirm the IBFM results could be obtained from a comparison of the electromagnetic properties of the levels and their electromagnetic transition rates. Parameters for the electromagnetic transitions analysis using the PBEM program[14] are taken to be the same as for the positive parity states analysis[18]. Table (1) shows a comparison between the IBFM results with the available experimental values for reduced transition probabilities B(E2) and B(M1) reported in ref.[7], and their IBFM prediction for some of the lowest levels. The present IBFM results are more reasonable, and hence the negative parity states of 125Te nucleus can be analyses by including only one level.

Magnetic (Electric) quadruple moments ,μ(Q), for the first three levels 11/2- ,9/2- and 7/2- were deduced theoretically and found to be 0.733 n.m.(-0.538 b.), -0.78 n.m.(-0.033 b.) and -1.022 n.m.(0.185 b.) while the reported weighted average values are[19]

-0.985 (-0.31), -0.92(-0.08) and <0 (-)

respectively. The difference in sign for the level 11/2- probably because of different convention used.

The spectroscopic factor for pick-up reaction was deduced theoretically and found to be 6.7

for the 11/2- (145 keV) state, while the reported experimental and calculated value[7] were 6.2 and 6.81 respectively. As can be seen the deduced value satisfies within the usual experimental uncertainties.

Conclusion

The level energies and decay modes for the negative-parity states of 125Te have been described in the frame work of the IBFM with good accuracy compared with experimental results and other theoretical models. The negative parity states in 125Te nucleus are dominated by the orbit 1h11/2. Hence, analysis with one level (1h11/2) is more reliable than that which includes another orbits from the neighbor regions. Moreover, the 1h11/2 orbit cannot be considered as nearly full, but nearly half full, as seen from the results of the IBFM calculation.
The IBFM successes in describing the negative-parity states of the 125Te nucleus.

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Table 1: M1 and E2 between low-lying states of negative parity in ^{125}Te.

$2(J_i\ \ J_f)^-$	B(M1) ($\mu^2{}_N$)			B(E2) (e^2b^2)		
	Expt.[7]	IBFM[7]	Present	Expt.[7]	IBFM[7]	Present
$9_1\ \ 11_1$	$0.81\text{x}10^{-2}$	$0.142\text{x}10^{-2}$	0.0149	0.123	$0.497\text{x}10^{-1}$	0.124
$7_1\ \ 11_1$				$\geq 0.37\text{x}10^{-1}$	$0.505\text{x}10^{-1}$	0.098
$7_1\ \ 9_1$	$\geq 0.159\text{x}10^{-2}$	$0.654\text{x}10^{-1}$	0.0781	$\geq 0.92\text{x}10^{-1}$	$0.168\text{x}10^{-2}$	0.097
$7_2\ \ 11_1$					$0.220\text{x}10^{-5}$	0.0212
$7_2\ \ 9_1$		$0.296\text{x}10^{-2}$	0.066		$0.652\text{x}10^{-1}$	0.046
$7_2\ \ 7_1$		$0.306\text{x}10^{-3}$	0.0001		$0.906\text{x}10^{-2}$	0.0278
$15_2\ \ 11_2$					$0.494\text{x}10^{-1}$	0.0429
$5_1\ \ 9_1$					$0.212\text{x}10^{-1}$	0.005
$5_1\ \ 7_1$		$0.139\text{x}10^{-2}$	0.0039		$0.541\text{x}10^{-1}$	0.006
$5_1\ \ 7_2$		0.172	0.0001		$0.177\text{x}10^{-3}$	0.144
$3_1\ \ 7_1$					$0.753\text{x}10^{-1}$	0.0146
$3_1\ \ 7_2$					$0.135\text{x}10^{-2}$	0.0003
$3_1\ \ 5_1$		0.233			$0.287\text{x}10^{-1}$	0.063

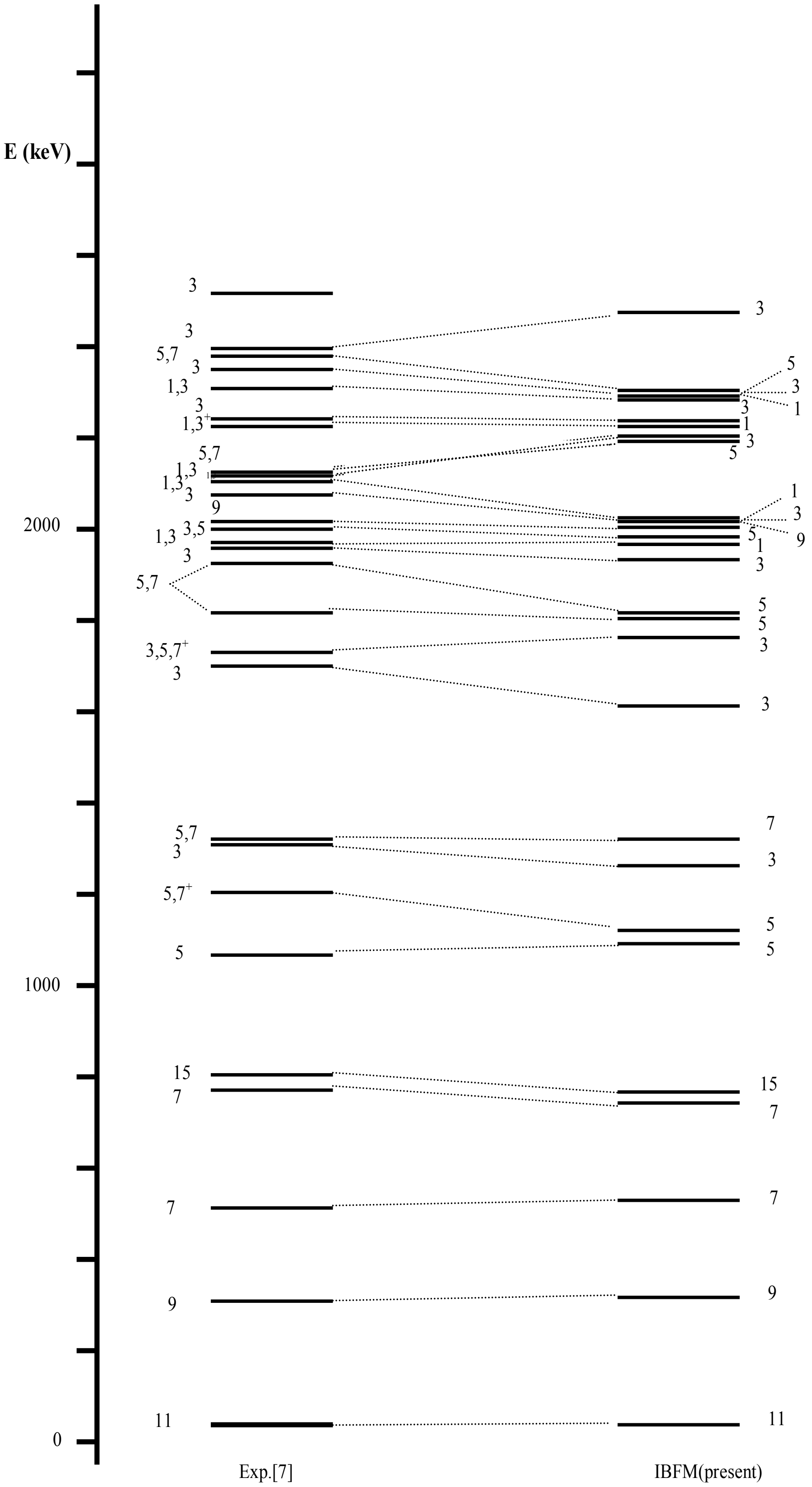

Figure 1: Comparison of the experimental energy levels[7] with the IBFM prediction for negative-parity states in ^{125}Te. All spin values are 2J.