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Coexisting Structures in the $^{120-124}$Te Nuclei

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Abstract. The level schemes of the mid-shell tellurium nuclei, A=120-124, have been developed utilizing in-beam γ-ray spectrosopy following the (n,n'γ) and (α,2nγ) reactions and Iodine beta decay. Excitation functions, $\gamma-\gamma$ coincidences, and angular distributions were measured. Spectroscopic information is obtained for many new levels below 4.5 MeV excitation. Low-spin states are found to be a mixture of spherical-vibrational, two-particle, and intruder configurations. The emerging intruder band is identified in ^{120}Te. The situation in ^{122}Te and ^{124}Te is not quite as clear.

1. Introduction

Tellurium has a wide range of abundant stable isotopes. The tellurium nuclei have two valence protons with respect to Z = 50 and a range of neutron numbers. Three different types of structure are thought to be active in these nuclei: collective, two-particle, and particle-hole excitations known as intruders. Because there are seven stable even-even Te nuclei, one can study the evolution of these excitation modes over a wide range in neutron number. Emphasis centers on understanding the interplay between single-particle and collective features and on the aspects of the nuclear forces that determine the relative importance.

Tellurium-120 is often used as a textbook example of a quadrupole vibrational nucleus [1]. The two-phonon triplet and three-phonon quintet (spins 0, 2, 3, 4, 6) of states seem readily apparent[2]. The splittings between members of multiplets are reasonably small which suggests that a spherical vibrational model would provide a good description of the nuclear properties. As one moves away from the mid-shell

^{120}Te, anharmonicities should grow as the nucleus becomes more γ-soft. Toward the heavier Te nuclei, the energies of the 2_1^+ $4_1^+$and 2_2^+ states increase as expected and the 0_2^+ state rapidly rises to join the 3_1^+ state. Several observed trends are not expected from γ-soft / O(6) / U(5) nucleus. The 6_1^+ state drops to a fixed excitation instead of maintaining its position near the 3_1^+ and 4_2^+ states. This behavior indicates strong particle-like components in the 6_1^+ state wavefunction.

2. Experimental Methods

At the University of Kentucky Nuclear Structure Laboratory, targets of isotopically enriched ^{122}Te and ^{124}Te samples have been investigated with inelastic neutron scattering techniques. Gamma-ray excitation functions, angular distributions, $\gamma\gamma$-coincidences, and Doppler shifts have been measured.

The nuclei ^{120}Te and ^{124}Te were studied with enriched targets and the Sn(α,2nγ) reactions at the Paul Scherrer Institut. Level schemes were constructed from $\gamma\gamma$-coincidence data. Angular distributions and excitation functions were also measured.

By a combination of the measurements, level schemes are known to near 4.5 MeV excitation energy, and spectroscopic information including level spins and parities, branching and multipole-mixing ratios. Lifetimes were also obtained from the (n,n'γ) data using the Doppler-shift attenuation method.

In this paper we quickly consider those results which impact the global nuclear structure of the mid-shell tellurium nuclei.

3. Discussion

Both IBM-2[3] and Particle-Vibration coupling model[4] calculations are able to reproduce the excitation energy level schemes for the nuclei in question. Particle-core model calculations do a slightly better job with transition rates[5–8].

One can gain information on the nature of the proton orbital structure of Te by examining the spectroscopic factors of Sb levels. Proton transfer measurements[9, 10], Sn(^{3}He,d), indicate that the $5/2_1^+$, $7/2_1^+$ states nearly exhaust the allowed strength of the $d_{5/2}$ and $g_{7/2}$ orbitals. The $h_{11/2}$ strength in the $11/2_1^-$ state is moderately strong. Proton pickup measurements[11], (t,α)Sb indicate that the $9/2_1^+$ state has very strong $g_{9/2}^{-1}$ character.

Rotational bands appear in Sb which are built upon this $g_{9/2}$ hole excitation[12, 13]. In Sn nuclei, the corresponding bands are 2p-2h excitations[14, 15]. Nilsson model calculations have been performed by Heyde[16] which demonstrate that the energy required to produce these p-h pairs is greatly reduced if one allows the nucleus to acquire a slight deformation ($\epsilon \sim 0.1$ - 0.2). For tellurium, the corresponding 4p-2h configurations will occur at low excitation and are refered to as intruder states.

Intruder states in the mid-shell tellurium nuclei have proven to be elusive.

Model calculations by Rikovska[3], utilizing the IBM framework, have demonstrated that at low spin (0-4), the intruder configurations are well-mixed with "normal" collective configurations and that band structure is not apparent. This is distressing given that intruders are so clearly apparent in Sn and Sb.

To identify the intruder bands one must extend the search to the higher spin states where band structures are apparent. We require that the behaviour of a band in Te be the same as in Sn and Sb. A convenient method to make the comparision utilizes plotting the "aligned angular momentum" versus rotational frequency[17]. The candidate band in ^{120}Te is shown in Fig. 1. Bands not shown in the figure have radically different form.

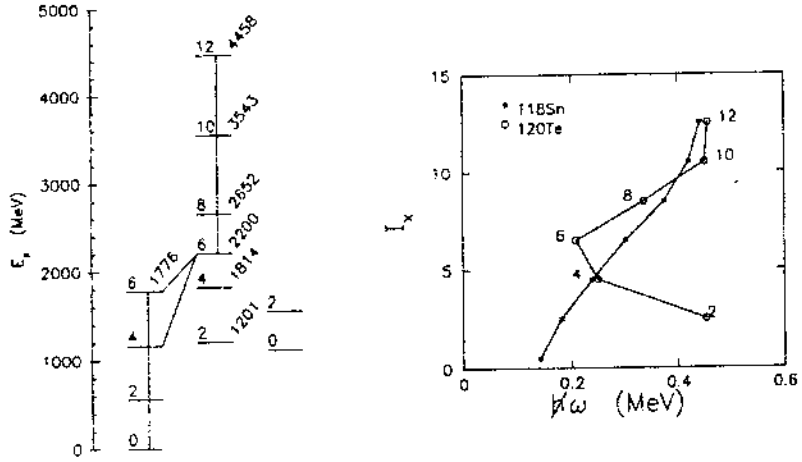

Fig. 1. Fig. 1 Comparison of intruder band candidates in ^{118}Sn and ^{120}Te.

The behavior is very similar for spins greater than 6. The intruder band structure disappears below spin 6 when mixing between the two-particle, 4p-2h, and "normal" collective configurations becomes appreciable.

A similar band has been recently reported in ^{118}Te[18] with nearly identical high spin behavior. From the available data on ^{122}Te[6] and ^{124}Te[7], the corresponding levels in those nuclei do not appear to be clearly related the intruder bands in ^{118}Te and ^{120}Te.

4. Conclusions

Level sequences and transition rates obtained from these measurements are compared to IBM-2 model calculations both with and without intruder-state mixing[3] and to particle-vibrational coupling model calculations[4]. The IBM-2 model calculations with intruder mixing reproduce well the level energies in the mid-shell Te; however, examination of the electromagnetic transition rates reveals that there is no clear improvement in the description of the spin 0-6 states of these nuclei by adding the intruder configurations. To identify the intruder bands one must extend the searchs to higher spin where band structures are apparent. The intruder band in ^{120}Te was identified by comparison to the known deformed band in ^{120}Sn. Identification of any intruder components in ^{122}Te and ^{124}Te will require additional higher spin data ($I > 10$).

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References

1. K.S. Krane *Introductory Nuclear Physics* New York: J.Wiley & Sons (1988) .
2. R.B. Firestone, S.Y.F. Chu, and C.M.Baglin, *Table of Isotopes CD-ROM* Eighth Edition (1998) .
3. J. Rikovska, N.J. Stone, P.M. Walker, W.B. Walters, *Nucl. Phys.* **A505** (1989) 145 .
4. V.Lopac, *Nucl. Phys.* **A155** (1970) 513 .
5. J.R. Vanhoy *et al.*, Talk presented at APS Division of Nuclear Physics Meeting, Asilomar, CA, Oct 21-23 1999.
6. S.F. Hicks *et al.*, Talk presented at APS Division of Nuclear Physics Meeting, Asilomar, CA, Oct 21-23 1999.
7. N.V. Warr *et al.*, *Nucl. Phys.* **A636** (1998) 379.
8. B.C. Champine *et al.*, *Proceedings: Eleventh National Conference on Undergraduate Research 1997*, Ed: R.D. Yearout, Apr 24-26 1997, Asheville: Univ North Carolina at Asheville Press, 1997, p. 1531.
9. T. Ishimatsu *et al. Nucl. Phys.* **A104** (1967) 481.
10. M. Conjeaud, S.Harar, and Y. Cassagnou, *Nucl. Phys.* **A117** (1968) 449 .
11. M. Conjeaud, *et al.*, *Nucl. Phys.* **A215** (1973) 383 .
12. A. Gaigalas, *et al.*, *Phys. Lett.* **35** (1975) 555.
13. R.E. Shroy, *et al.*, *Phys. Rev.* **C19** (1979) 1324 .
14. J. Bron, *et al.*, *Nucl. Phys.* **A318** (1979) 335 .
15. A. Savelius, *et al.*, *Nucl. Phys.* **A637** (1998) 491 .
16. K. Heyde, *et al.*, *Phys. Lett.* **64B** (1976) 135 .
17. R. Bengtsson and R. Frauendorf, *Nucl. Phys.* **A327** (1979) 139 .
18. S. Juutinen, *et al.*, *Phys. Rev.* **C61** (1999) 014312 .