Gamow-Teller β^+ decay properties of A=98 isobars near ^{100}Sn doubly magic core

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Abstract

In this work, we have realized some spectroscopic calculations in the framework of the nuclear shell model, in order to estimate the Gamow-teller (GT) β^+ decay of A=98 proton rich isobars in ^{100}Sn mass region near rp-process path. The calculations are carried out by means of Oxbash nuclear structure code, taking into account the monopole effect in the studied mass region. The obtained results are then compared to the available experimental data.

Key words: *nuclear structure; strontium 100; monopoles; o codes; gamow-teller rules; beta-plus decay.*

Propiedades de la desintegración β^+ de Gamow-Teller de isóbaros con A = 98 cercanos al núcleo ^{100}Sn doblemente mágico

Resumen

En este trabajo hemos realizado algunos cálculos espectroscópicos en el marco de trabajo del modelo nuclear de capas para estimar la desintegración β^+ de Gamow-Teller (GT) de isóbaros ricos en protones con A = 98 en la región de masa ^{100}Sn, cerca del camino del proceso rp. Los cálculos se llevan a cabo mediante el código de estructura nuclear de Oxbash, teniendo en cuenta el efecto monopolo en la región de masa estudiada. Los resultados obtenidos se comparan luego con los datos experimentales disponibles.

Palabras clave: *estructura nuclear; estroncio 100; monopolos; códigos O; reglas de GAMOW-TELLER; desintegración beta positiva*

Introduction

Nuclei in doubly magic regions near drip lines have been subject of both theoretical and experimental studies that aim to well understand the spectroscopic behaviour of nuclear forces in such regions. Therefore, the heaviest N=Z magic core ^{100}Sn situated in the proton drip line and near the rp-process provides important information on nuclear structure and astrophysics [1, 2].

The first excited states of ^{98}Cd were first identified by Gorska et al. (1997). They have proposed its experimental level scheme and associated j^p=8+to the $T_{1/2}$=0.48 μs isomer [3]. In 2004, Blazhev et al. [4] have observed a core excited 12^+ isomer and measured $T_{1/2}$=0.23 μs and 0.17 μs in ^{98}Cd. Huyse et al. (1978) discovered the ^{98}Cd b^+ daughterwith the LISOL facility, following the irradiation of ^{92}Mo with a 110 MeV ^{14}N [5]. The ^{98}Ag b^+ descendent was identified and reported by AtenJr and Vries-Hamerling (1955) [6].

Brown and Rykaczewski (1994) theoretically studied GT b^+ decay properties of nuclei near ^{100}Sn mass region[1]. They have presented their spectroscopic calculations using SNB interaction [1] in fpg space model, for odd-even and odd-odd nuclei in near ^{100}Sn. Covelo et. al. (2006) have performed shell model calculations for nuclei in the vicinity of ^{100}Sn core using an interaction derived from CD-Bonn one in gdsh space model [7]. They obtained good agreement with the experimental data.

In this paper, we have studied the b^+ Gamow-Teller decay properties of A=98 proton rich isobars near the doubly magic tin-100 core by means of shell model calculations using Oxbash nuclear structure code [8].

Theoretical framework

The shell evolution is the result of the interactions between the magic core, and the adding nucleons [9, 10, 11] or the so-called monopole effect described byPoves and Zuker [12] and defined in terms of the two-body interaction. Hence, the consideration of this effect can reproduce the missing nuclear properties of nuclei far from stability. They proposed to express the monopole Hamiltonian of the system in terms°: [13, 14, 15],

$$H_m = \sum_s n_s e_s + \sum_{s \le t} \left(a_{st} n_{st} + b_{st} T_{st} \right)$$

$$V_{st}^{tt'} = \frac{\sum_J (2J+1) V_J (j_s j_t)}{\sum_J (2J+1)}$$

sand/or t denote a proton and/or a neutron orbit. $n_{s,t}$ and $T_{s,t}$ refers, respectively, to the number and the isospin operator defined by A. P. Zuker (2003) [9, 14] as a function of the monopole Hamiltonian diagonal part $V_{st}^{tt'}$ [11], and τ (τ') stands for proton or neutron.

In this work, we have used the recent single particle energies (SPEs), and considered the mass and the monopole effects to introduce some modifications on the two body matrix elements (TBMEs) of the original interaction jj45apn from ^{78}Ni mass region (Jensen [16, 17]). These TBMEs are used in order to calculate the monopole terms:

$$V^{pn}_{1g_{\frac{9}{2}} 2d_{\frac{5}{2}}} \approx -430\ keV,\ V^{pp}_{1g_{\frac{9}{2}} 1g_{\frac{9}{2}}} \approx 112\ keV \text{ and } V^{nn}_{2d_{\frac{5}{2}} 2d_{\frac{5}{2}}} \approx -18\ keV$$

to modify TBMEs chosen basing on the energetic sequence of the single particle space. Using the resulting interaction *jj45m* and the original one, some calculations are carried out in order to reproduce the nuclear and β^+ Gamow-Teller transition properties of A=98 isobars (Figure 1).

The β decay rate, λ_{ij}, of transition from the state *i* to the state *j*, and the allowed $(ft)_{ij}$ values can be estimated using [18]:

$$\lambda_{ij} = \frac{ln\,2}{(ft)_{ij}} f_{ij} \quad \text{and} \quad \frac{1}{(ft)_{ij}} = \frac{1}{(ft)^{GT}_{ij}} + \frac{1}{(ft)^{F}_{ij}}$$

f_{ij} denotes the β decay phase space factor. $(ft)^{GT,\,F}$ are the (*ft*) values for Gamow-Teller (GT) and Fermi (F) transitions, which can be expressed in terms of the matrix elements M_{GT} and M_F used to estimate the GT and F transition probabilities [19],

$$B_{GT} = \frac{g_A^2}{2J_i+1} |M_{GT}|^2, \qquad B_F = \frac{g_V^2}{2J_i+1} |M_F|^2 \qquad \text{with} \qquad \frac{g_V}{g_A} = \frac{1}{1.26}$$

Results and discussion

In this work, we have performed shell model calculations, using the new interaction *jj45*m in $\pi(0f_{5/2}, 1p_{3/2}, 1p_{1/2}$ and $0g_{9/2})^{Z-28}$ and $\nu(0g_{7/2}, 1d_{5/2}, 1d_{3/2}, 2s_{1/2}$ and $1h_{11/2})^{N-50}$ model space using ^{100}Sn as a magic core. The experimental single hole and single particle energies taken, respectively, from ^{99}In for protons and ^{101}Sn for neutrons are used as a starting point to calculate the effective single particle energies [20, 21] using in the interaction.

The calculated configuration changes between the initial and final states indicate that the important values are observed for $\pi g_{9/2}$ and $\nu g_{7/2}$. Which means that the ^{98}Cd and ^{98}Ag protons in the $\pi g_{9/2}$ populate the ^{98}Ag and ^{98}Pd neutrons in $\nu g_{7/2}$ respectively (Figure 2).

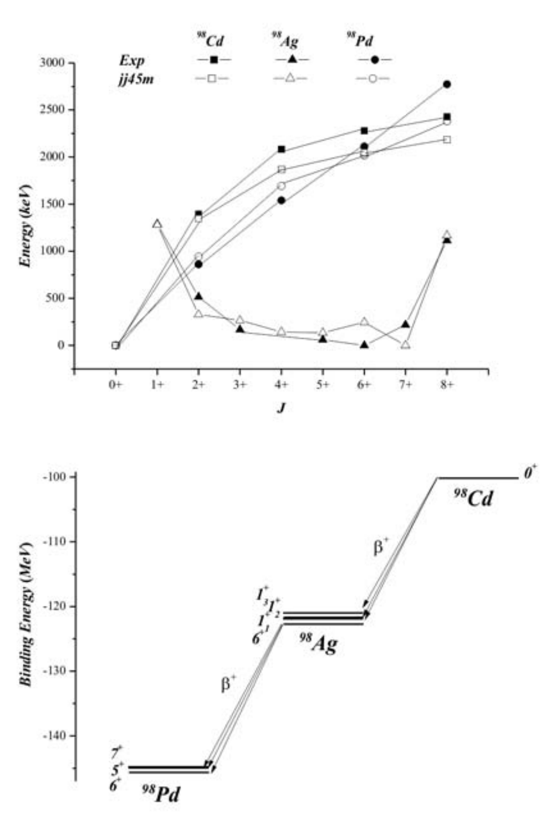

Figure 1. Calculated spectra with jj45pm interaction in comparison with the experimental ones (above) and β^+ decay (below) of A=98 isobars.

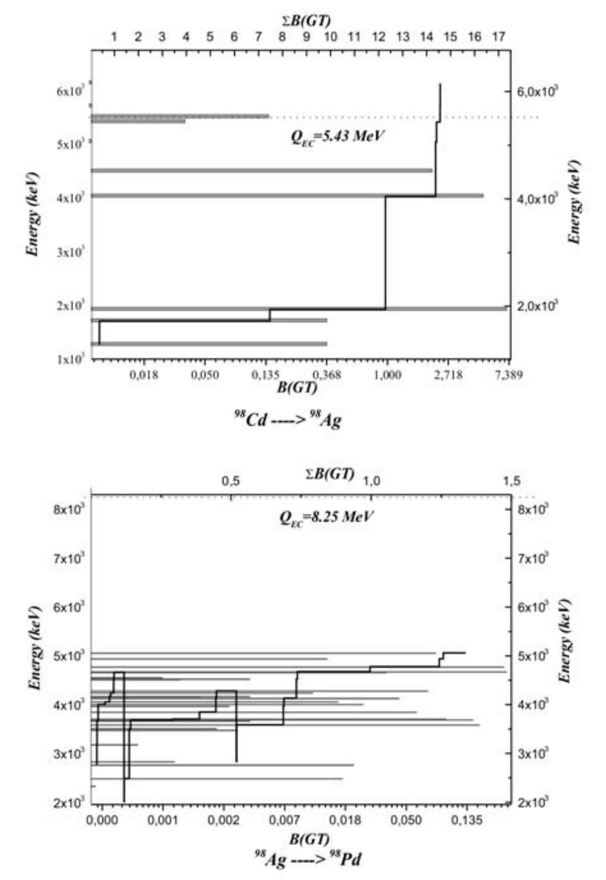

Figure 2. Calculated B(GT) (bars) and ΣB(GT) (vertical steps) of A=98 isobars as a function of excitation energy.

Most of the strength of the ^{98}Cd → ^{98}Ag GT transition, limited by a Q_{EC} value of 5.43 MeV, is located in two peaks concentrated at about 1.5 MeV and 4.5 MeV. For the ^{98}Ag → ^{98}Pd GT transition, limited by a Q_{EC} value of 8.25 MeV, it is located in two peaks concentrated at about 2.5 MeV and 4.5 MeV (Table 1).

Table 1. Experimental and calculated $T_{1/2}$ for ^{98}Cd and ^{98}Ag

	$T_{1/2}$Exp(s)	$T_{1/2}$Cal(s)	$Q_{\beta+}$(MeV)	B(GT)
^{98}Cd	9.2	98.920	4.410	14,566
^{98}Ag	47.5	2.61	7.23	1,337

Conclusion

This study is based on the energetic spectra and Gamow-Teller properties calculations, for odd- odd A=98 isobars, with few hole protons and neutrons in their valence spaces. The calculations are realized in the framework of the nuclear shell model, by means of Oxbash nuclear structure code. Using the jj45apn original interaction of the code, we carried out some modifications based on the proton-neutron monopole interaction to get jj45m interaction. The calculated energetic spectra are in agreement with the experimental data for ^{98}Cd and ^{98}Pd; however, the spin and parity of ^{98}Ag ground state are not reproduced. The ^{98}Cd and ^{98}Ag protons in the $\pi g_{9/2}$ populate the ^{98}Ag and ^{98}Pd in $\nu g_{7/2}$ respectively.

The obtained half lives of the studied transitions have the magnitude of the experimental ones. The studied GT transitions are limited by Q_{EC} values of 5.43 MeV and 8.25 MeV. Most of the strength of the ^{98}Cd → ^{98}Ag GT transition is located in two peaks concentrated at about 1.5 MeV and 4.5 MeV. Most of the strength of the ^{98}Ag → ^{98}Pd GT transition is located in two peaks concentrated at about 2.5 MeV and 4.5 MeV.

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References

[1] BROWN BA, RYKACZEWSKI K. Gamow-Teller strengh in the region of ^{100}Sn.Phy. Rev. C.1994; 50(5): R2270-R2273.

[2] FERRER R, BREE N, COCOLIOS TE, et. al. In-gas-cell laser ionization spectroscopy in the vicinity of ^{100}Sn. Phys. Lett. B. 2014; 728: 191-197.

[3] GÓRSKA M, LIPOGLAVSEK M, GRAWE H, et. al. ^{98}Cd: the two-proton-hole spectrum in ^{100}Sn. Phys. Rev. Lett. 1997; 79(13): 2415-2418.

[4] BLAZHEV A, GÓRSKA M, GRAWE H, et. al. Observation of a core-excited E4 isomer in ^{98}Cd. Phys. Rev. C. 2004; 69: 064304.

[5] HUYSE M, CORNELIS K, DUMONT G, et. al. The decay of neutron deficient ^{97}Ag, ^{98}Ag, and $^{99g,\,m}$Ag. Z. Phys. A. 1978; 288(1): 107-108.

[6] ATEN AWH Jr, de VRIES-HAMERLING T. Formation and properties of neutron-deficient isotopes of rhodium and palladium. Physica. 1955; 21: 597-598.

[7] COVELLO A, CORAGGIO L, GARGANO A,ITACO N. Structure of particle-hole nuclei around ^{100}Sn. Phys. Rev. C. 2004; 70: 034310.

[8] BROWN BA. Oxbash for windows PC. MSU-NSCL Report. 1289. 2004.

[9] SMIRNOVA NA, BALLY B, HEYDE K, et. al. Shell evolution and nuclear forces. Phys. Lett. B. 2010; 686(2-3): 109-113.

[10] SORLINO & PORQUET MG. Nuclear magic numbers: new features far from stability. Prog. Part. Nucl. Phys. 2008; 61(2): 602-673.

[11] UMEYA A, NAGAI S, KANEKO G & MUTO K. Monopole and quadrupole interactions in binding energies of sd-shell nuclei. Phys. Rev. C. 2008; 77: 034318.

[12] POVES A & ZUKER AP. Theoretical spectroscopy and the fp shell. Phys. Rep. 1981; 70(4): 235-314.

[13] ZUKER AP. Monopole, quadrupole and pairing: a shell model view. Phys. Scr. 2000; T88: 157-161.

[14] ZUKER AP. Three-body monopole corrections to the realistic interactions. Phys.Rev.Lett. 2003; 90(4): 042502.

[15] OTSUKA T, SUZUKI T, HOLT JD, et. al. Three-body forces and the limit of oxygen isotopes. Phys. Rev. Lett. 2010; 105: 032501.

[16] JENSEN MH, KUO TTS & OSNES E. Realistic effective interactions for nuclear systems. Phys. Rep. 1995; 261(3-4): 125-270.

[17] REJMUND R, NAVIN A, BHATTACHARYYA S, et. al. Structural changes at large angular momentum in neutron-rich $^{121-123}$Cd. Phys. Rev. C. 2016; 93: 024312.

[18] KAR K, CHAKRAVARTI S & MANFREDI VR. Beta decay rates for nuclei with 115 < A < 140 for r-process nucleosynthesis. Pramana-J Phys. 2006; 67(2): 363-368.

[19] SUHONEN J. From nucleons to nucleus: concepts of microscopic nuclear theory. Series: theoretical and mathematical physics: Berlin Heidelberg: Springer, 2007.

[20] AUDI G, WANG M, WAPSTRA AH, et. al. The AME2012 atomic mass evaluation. Chinese Phys. C. 2012, 36(12): 1603-2014.

[21] GRAWE H, LANGANKE K, MARTINEZ-PINEDO G. Nuclear structure and astrophysics. Rep. Prog. Phys. 2007; 70(9): 1525-1582.

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