HIGH SPIN SPECTROSCOPY OF ^{104}Sn*

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High spin states in ^{104}Sn were identified in the reaction ^{58}Ni(^{50}Cr, $2p2n$) at 200 MeV and 205 MeV beam energies. The γ-ray energies, intensities, multipolarities and lifetimes of high spin states were measured with the GASP spectrometer array in combination with a plunger apparatus by means of the recoil distance Doppler shift method. The deduced level scheme and transition probabilities are compared to large scale shell model calculations. The agreement of the level energies is satisfactory, except for a cascade of dipole transitions at high spins. The general good agreement found for $E2$ transition strengths implies a large effective neutron polarization charge. The measured enhanced $E3$ transitions cannot be accounted for, which indicates an admixture of a core excited octupole phonon.

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1. Introduction

Besides single particle structure and the residual interaction, core excitations of $E2$ and $E3$ type are the most interesting features of a doubly magic nucleus. Until recently little was known in this respect on the $N = Z = 50$ shell closure at ^{100}Sn. With the first results on low lying excited levels and $E2$ transitions in the $T_z = 1$ neighbours ^{98}Cd [1] and ^{102}Sn [2], the $T_z = \frac{3}{2}$ nucleus ^{99}Cd [3] and the $T_z = 2$ nucleus ^{104}Sn [4] controversial evidence on the $E2$ polarization charges for protons and neutrons became available. From the single particle structure a large similarity to ^{56}Ni is expected, which due to the LS-open core is subject to strong $E2$ type core excitations [5]. This is corroborated by the systematics of $I^\pi = 2^+$ states, which imply the existence of a low-lying 2^+ state in ^{100}Sn [6]. Also in light Sn isotopes collective bands of "shears" character (magnetic rotation) were identified [7], which raises the question, how little deformation is needed to enable this new collective phenomenon. Therefore an experiment was designed to study the high spin structure of ^{104}Sn, which can be reached with reasonable production cross section, and to measure electromagnetic transition rates in this nucleus.

2. Experiment and results

The experiment was performed at the INFN Laboratory in Legnaro aiming at the measurement of short lifetimes in the range of 1 ps to 0.5 ns by means of the Recoil Distance Method (RDM). The Cologne plunger in combination with a 1.2 mg/cm^2 thick target of ^{58}Ni and a Au stopper of 12.3 mg/cm^2 thickness and the ^{50}Cr beam at 200 MeV energy was used for this purpose. A target of 0.45 mg/cm^2 thick ^{58}Ni foil on a backing made of 50 mg/cm^2 Au and a beam of ^{50}Cr at 200 MeV energy was taken for an experiment to extend the ^{104}Sn level scheme. The γ radiation was measured with the GASP spectrometer [8] with a photopeak efficiency of $\sim$5%. The data from the prompt γ-ray experiment was sorted into nonsymmetric energy γ-γ matrices and a symmetrized γ-γ-γ cube. Further details on the experiment and data analysis are given in Ref. [9].

In the present work the known [4] level scheme could be extended up to almost 10 MeV excitation energy, as seen in Fig. 1. The five gamma rays depopulating the 10^+ state were found to be stretched quadrupole transitions and are assumed to be of E2 character. The γ-ray flux above the 10^+ state is highly fragmented into many branches. Three high energy dipole transitions at energies 1858 keV, 2053 keV and 2104 keV are of E1 character. In addition the 1858 keV and 2053 keV dipole transitions form two cascades with the low energy 594 keV and 436 keV E2 transitions, with cross over E3 transitions at 2452 keV and 2489 keV, respectively (see Fig. 1).

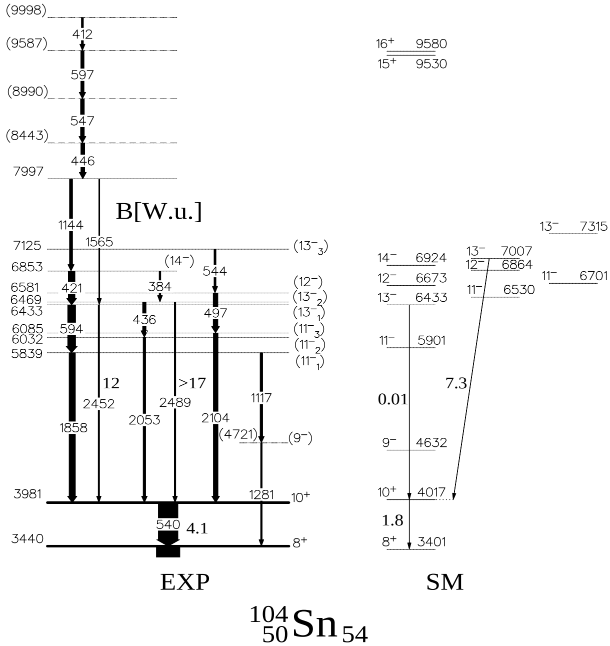

Fig. 1. Partial level scheme of excited states in ^{104}Sn. Next to the γ–ray transitions the $E2$ resp. $E3$ transition strenghts are given in W.u.

For the state at 7997 keV excitation energy and higher lying states the spin assignment was not possible because of lack of experimental information for the connecting transitions. The cascade on top of this state has dipole character. Due to statistical uncertainties the order of these γ-rays remains undetermined. From the dipole character of these transitions, and the fact that no further shell model states of pure neutron configurations are expected at this energy, it can be concluded, that these states represent proton particle-hole excitations. In the neighbouring nucleus ^{105}Sn a similar band structure has been identified as a magnetic rotation shears band [7].

3. Discussion

The interpretation of the level scheme shown in Fig. 1 is based on the coupling of four valence neutron particles in ^{104}Sn, that occupy in the ground state the $(d_{5/2},g_{7/2})^4$ configuration outside the closed ^{100}Sn core. The excited states with angular momentum larger than $10\hbar$ are created by raising a neutron to the intruder $1h_{11/2}$ orbital.

We have performed calculations using the shell model code OXBASH [10] in the $\nu 2d_{5/2}, 1g_{7/2}, 3s_{1/2}, 2d_{3/2}$ and $1h_{11/2}$ model space. The results of the calculations are shown in Fig. 1 for the interaction set given in ref. [11]. All the experimental levels in the range of excitation energy 5.8 – 7.2 MeV could be accounted for in the calculations as seen in Fig. 1. While the excitation energies could be reproduced for most of the levels in the calculations the energy spacing between the 13^-_2 and 13^-_1 states is not satisfactory, while the agreement is good for the 13^-_3 and 13^-_1 splitting energy.

The comparison of the reduced transition probabilities determined from the experiment and those deduced from the calculations is shown in Fig. 1 for selected transitions. The $E2$ transition strength from the two-quasiparticle 6^+ state, known from a previous measurement [4], is not reproduced by any calculation when the neutron effective charge of 1.44 is used ($B(E2)_{EXP} =$ 4.1(6) vs. $B(E2)_{SM} = 0.76$). The main component of the $6^+ \to 4^+$ transition in the calculation is the spin flip transition $1g_{7/2}2d^3_{5/2} \to 1g^2_{7/2}1d^2_{5/2}$, which has a small reduced matrix element, and thus produces a small B(E2) value. A significant improvement is achieved when the single particle binding energy of the $3s_{1/2}$ orbital is increased. The wave function of the 4^+ state contains then more of the $1g_{7/2}3s_{1/2}$ configuration, which is not possible for the 6^+ state, and hence the total reduced matrix element is increased by a strong stretched component $1g_{7/2}2d_{5/2} \to 1g_{7/2}3s_{1/2}$. Similar behavior is observed for the $10^+ \to 8^+$ reduced transition probability. Recently the $6^+ \to 4^+$ transition in ^{102}Sn was studied yielding an effective charge $e_\nu \geq 1.6e$ [12]. The large effective charge is pointing to a low-lying $I^\pi = 2^+$ state in ^{100}Sn as also deduced from the systematics of $I^\pi = 2^+$ energies in ^{56}Ni and ^{100}Sn isotopes and isotones [6]. This is at variance with the small polarization charge found for protons in ^{98}Cd [1].

In general also the $13^- \to 10^+$ $E3$ transition strengths, the first observed close to ^{100}Sn, are not reproduced by the calculations when an effective $E3$ neutron charge of 1.0 is used. Especially the $E3$ decay of the 13^-_2 state is enhanced and can not be interpreted as a single particle transition. The $B(E3) = 27(10)$ W.u. indicates an admixture of the collective phonon vibration of the ^{100}Sn core to the stretched single particle $1h_{11/2} \to 2d_{5/2}$ transition as known in the ^{208}Pb [13, 14] and ^{132}Sn [15] double magic regions for appropriate single particle orbitals. In this cases the strong $E3$ transition is measured in the core nuclei, whereas the present result is the first indication of an $E3$ core excitation in the ^{100}Sn region. The coherent interaction of protons and neutrons in identical orbitals in ^{100}Sn may cause an effective decrease of the phonon energy and its stronger coupling with the shell model states. To confirm this phenomenon in the ^{100}Sn region the knowledge of the high spin states in the closer neighbours of the core nucleus is indispensable.

4. Conclusion

The present experiment is the first step for a systematic investigation of core excitations in ^{100}Sn, which opens the field for high precision studies with the new γ arrays EUROBALL and Gammasphere. For the first time in the ^{100}Sn region enhanced $E3$ transitions are identified, which imply a low lying (~ 3 MeV) $I^{\pi} = 3^{-}$ state in ^{100}Sn. For $E2$ transitions a large effective charge is found, which along with the systematics of 2^{+} states in ^{56}Ni and ^{100}Sn isotones and isotopes points to a low lying (≤ 3 MeV) $I^{\pi} = 2^{+}$ state in ^{100}Sn.

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