Relevance of Single-Particle and Collective Excitations in Zirconium Isotopes Populated by Neutron Transfer Reactions in the $^{90}$Zr+$^{208}$Pb System


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INTRODUCTION

A significant amount of experimental data on heavy ion transfer reactions collected in the last decade has been shown to be quantitatively described in a reaction model which includes elementary degrees of freedom, surface vibrations and single particles [1]. The focus in this work is put on the selective properties of the reaction mechanism by studying the population strength and the structure of the states excited by neutron transfer channels in $^{90}$Zr+$^{208}$Pb. New γ ray transitions have been also consistently incorporated into known level schemes.

The $^{90}$Zr+$^{208}$Pb multinucleon transfer reactions have been studied in the PRISMA + CLARA set-up [2, 3, 4], where projectile-like products have been detected in the PRISMA magnetic spectrometer, while the coincident γ rays have been detected in the CLARA γ-array. Trajectory reconstruction in the spectrometer provides the identification of the light fragments in their charge, mass and velocity. These allow to attribute electromagnetic transitions to each of the transfer channels.

RESULTS AND DISCUSSION

Based on the γ rays observed in our measurement (see Figs. 1 and 2), and the adopted energy, spin and parity of levels (see Ref. [5] and references therein), level schemes of the states of $^{89-94}$Zr isotopes excited in this measurement have been constructed and updated.

New γ transitions have been observed. For the assignment of the new γ transitions, we took advantage of the total kinetic energy loss (TKEL) distribution for each of the discussed transfer channels. A selection of the populated states can be achieved by setting different gates on the TKEL distribution, as illustrated in Ref. [4].

To have a better insight into these new γ transitions, where applicable, we compared the γ spectra with those obtained in the $^{40}$Ca+$^{90}$Zr reaction [4], which showed that in the case of the presently studied $^{90}$Zr+$^{208}$Pb, the transitions from higher spin states are more pronounced.

In general, in the even-even Zr isotopes, the strongest observed transitions are those from the decay of yrast states. In particular, in $^{90}$Zr (the $+2n$ channel), states up to spin $16\hbar$ and excitation energy of about 7.5 MeV were clearly identified. In the negative parity band, a strong excitation of 3-, 5- and 7- states has been observed. Besides the yrast states, only higher order 2+ and 4+ states have been identified, although with lower intensities. As for even-odd isotopes, the transfer mechanism populates strongly the high spin states in both, positive and negative parity bands. It is interesting to notice that in the $^{90}$Zr and $^{91}$Zr above the excitation energy of ~2.5 MeV, only the highest known spin states have been populated. The observed population of states with high excitation energy and spin is closely connected with the character of the transfer mechanism, which, at this low bombarding energy
tends to maximize the transferred angular momentum. A similar situation has also been observed for lighter systems (see for example [6] and reference therein).

The same argument holds for $^{90}$Zr, where coupling of its $9/2^+$ ground state to $2^+$ and $3^-$ would result in $13/2^+$ and $15/2^-$ stretched configurations, respectively. The properties of these particle-phonon states should be to a large extent determined by the properties of the corresponding phonon states. In $^{90,92,94,96}$Zr, all the $2^+$ states decay predominantly to the ground state, with the $B(E2)$ ranging from 0.055 $b^2e^2$ in $^{96}$Zr to 0.008 $b^2e^2$ in $^{92}$Zr. On the other side, the decay pattern of the $3^-$ states changes considerably when going from $^{90}$Zr to $^{96}$Zr. Among possible qualitative explanations, the $3^-$ collective states may correspond to a complex superposition of cross shell excitations, which produce a strong mixing of different configurations. One can hardly make conclusion about the nature of these states from the energy information only, especially for such complex wave functions, and additional measurements of other relevant properties, such as the strength of electromagnetic transitions, are required.

CONCLUSION

Multinucleon transfer reactions have been studied in the $^{90}$Zr+$^{208}$Pb system. A thorough examination of the γ spectra revealed γ transitions not previously reported, which, whenever possible, have been incorporated into known level schemes. Presented results generally support multinucleon transfer as a mechanism able to populate states of specific structure. Most of the excited states have been identified with yrast states. The possibility of the coupling of the ground state of the odd Zr nuclei to the $2^+$ or $3^-$ vibration quanta in the stretched configuration has been investigated, which showed that in most of the studied isotopes, the decay modes and the energies of the $2^+$ states in even isotopes are similar to the corresponding ones in odd isotopes, expected from a particle-vibrational picture.

REFERENCES