High spin states in $^{102}$Ag

V. Ravi Kumar$^1$, B.V. Thirumala Rao$^1$, V. Lakshminarayana$^1$, T. Seshi Reddy$^1$, M.L.N. Raju$^1$, K.L. Narasimham$^1$, S. Lakshminarayana$^1$, K. Prema Chand$^1$, B. Mallikarjuna Rao$^1$, K. Parthasaradhi$^1$, R.K. Bhowmik$^2$, S. Muralithar$^2$, R.P. Singh$^2$, G.O. Rodrigues$^2$

$^1$Department of Nuclear Physics, Andhra University, Visakhapatnam-530003, India
$^2$Nuclear Science Centre, New Delhi-110067, India

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Abstract. High spin states are populated in $^{102}$Ag using the reaction $^{16}$O + $^{89}$Y with projectile energies in the energy range 60–80 MeV. Gamma multipolarities are inferred from DCO ratios and coincidence relationships are established among the gamma rays assigned to $^{102}$Ag. A comprehensive level scheme is constructed with four band systems, two of positive parity and the other two of negative parity. The present study extended spins up to 19$^-$ in the main negative parity band. A new band is populated in the present work and is similar to the one observed in $^{105}$Ag.

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I. Introduction

Studies on odd-odd nuclei are being extensively carried out in recent years to obtain information on coupling schemes of the two unpaired particles, nuclear structure and Coriolis effects. Considering an odd-odd nucleus as being made up of an even-even core and two valence nucleons (a proton and a neutron) one could couple their angular momenta in different ways, depending upon their alignment behaviour. It is well known [1] that in a nucleus with prolate deformation a nucleon occupying a low $\Omega$ orbital of a high $j$ state, tends to decouple from the core due to Coriolis effect and aligns its angular momentum at right angles to the symmetry axis. On the other hand a nucleon occupying a high $\Omega$ orbital is strongly coupled to the core and aligns its spin along the symmetry axis. The above two are the limiting alignments and actual alignment between the limiting cases depends on the neutron and proton Fermi surfaces. There are thus four limiting combinations of alignment of spin of the two odd particles and they were classified [2] into "peaceful" and "conflicting" types of coupling. Low energy states in even-even nuclei in transitional regions show characteristics of quasirotation and the energies are usually fitted into rotational sequences employing a variable moment of inertia approach. Low energy levels of odd-odd nuclei can therefore be described in terms of valence nucleon coupling to the quasirotational excitation of the core. Such quasiparticle-axially symmetric rotor coupling calculations were made extensively and employed to fit experimental energy levels in even-even [3], odd [4] and odd-odd [5] nuclei. It is of interest to carry out such comparisons over a wide range of nuclei.

In recent studies a number of odd-odd nuclei in different mass regions were produced [6–10] in high spin states using fusion-evaporation reactions with heavy ion projectiles and in some cases the resultant bands were compared with two-quasiparticle-rotor coupling models. Pople et al. [5] produced $^{106}$Ag with 49 MeV $^{14}$N projectiles on $^{96}$Zr and populated four quasi-rotational bands, two of which were of positive parity and the other two of negative parity. Three of these bands could be fitted with their two-quasiparticle rotor model calculations. The fourth band based on 10$^-$ state at 2442 keV could not be fitted into their scheme and was considered to be a band built on a four-quasiparticle state. Subsequently Treherne et al. [2] produced $^{102}$, $^{104}$Ag and compared the high spin level structures with their two-quasiparticle rotor model calculations. In each of these nuclei, they observed two positive parity bands based on two quasi-particle configurations $[\pi g_{9/2} \otimes vd_{5/2}]$ and $[\pi g_{9/2} \otimes v g_{7/2}]$.

They also observed one negative parity band based on an 8$^-$ state in each of these nuclei. This band was considered to be built on a state of configuration $[\pi g_{9/2} \otimes vh_{11/2}]$, on the basis of similarity in the band head energy systematics with $vh_{11/2}$ energy behaviour in the neighbouring odd mass Pd nuclei. This assignment was in agreement with that of the earlier study [5] in $^{106}$Ag. The gamma flow pattern and band population systematics in the three Ag odd-odd nuclei indicated a need for further investigation of $^{102}$Ag and $^{104}$Ag nuclei. The present study is specifically undertaken to search for the four quasi-particle negative parity band in $^{102}$Ag similar to the one observed in $^{106}$Ag and possibly extend known bands to higher angular momenta by producing the nucleus in the reaction of $^{16}$O projectiles on $^{89}$Y. The
results indicated population of the expected band. The principal negative parity band is extended to higher spins in the present study.

II. Experimental details

High spin states in $^{102}$Ag were populated using the reaction $^{99}$Y($^{16}$O,3n)$^{102}$Ag at different projectile energies in the range 60–80 MeV. The experiment was carried out at the Nuclear Science Centre, New Delhi with the 15UD Pelletron [11], using the Gamma Detector Array (GDA) system [12] consisting of five Compton Suppressed HPGE detectors and a 14 BGO detector multiplicity filter. A 5 mg/cm$^2$ ($\gamma_2$O$_3$) target on Au backing (5 mg/cm$^2$) was employed in the experiment. The multiparameter data were recorded in event mode using the online data acquisition system, CAMAC interfaced to the Microvax computer. Details on the mode of data processing were furnished in an earlier article [13].

Excitation functions for the reaction were initially studied by recording the singles spectra at projectile energies 63, 67, 72, 76 and 80 MeV. The yields of different evaporation channels were estimated from the corresponding principal gamma intensities. The yields were theoretically estimated using the statistical model codes CASCADE and PACE and found to be in agreement with the trends observed in the experiment. In addition to $^{102}$Ag (produced in 3n channel) of interest in the present study about an equal amount of $^{102}$Pd was found to be produced through p2n channel. The product nuclei $^{101}$Pd, $^{101}$Ag and $^{99}$Rh were also observed through p3n, 4n and z2n channels in considerable amounts. Coincidence data were acquired at 72 and 80 MeV in the present study and about $30 \times 10^6$ events were collected at each energy.

A total $E_\gamma - E_\gamma$ 4K x 4K matrix was generated from the data of all the detectors at each projectile energy with multiplicity condition $M > 1$ and $M > 2$ to reduce the low multiplicity events such as those arising from Coulomb excitation of Au (backing) and radioactivity. Coincidence spectra for the different gamma gating energies could be obtained from these matrices. A separate $E_\gamma - E_\gamma$ 4K x 4K matrix was also generated summing the data from detectors at angles 99° and 153° separately for DCO ratio analysis to infer the multipolarities of the transitions.

III. Results

The singles spectrum recorded with the detectors at 99° was analysed to determine the energies and relative intensities of the gamma ray transitions. In the present study several gamma rays associated with the channel of interest ($^{102}$Ag) were found to be complex containing contributions from the product nuclei of other channels. Several gamma rays specifically belonging to other product channels were also observed. Assignment of gamma transitions of specific interest to the present experiment as well as the determination of the relative intensities was therefore carried out from coincidence spectra, whenever interferences could not be resolved from singles spectra. In the case of the 555 keV transition it was not possible to resolve the problem even with coincidence studies. Hence the total intensity is reported. The energies and relative intensities of gamma rays thus assigned to the product nucleus $^{102}$Ag are furnished in Table 1. The table also contains the placement information, the values of DCO ratios and spin assignments for the different transitions. It may be observed that $R_{DCOM}$ and $R_{DCOQ}$ are separately furnished and they correspond to the ratios derived for gating on known dipole and quadrupole transitions respectively. In the table, possible contamination sources in the case of complex gamma rays are also indicated.

The placement information of the different transitions furnished in Table 1 is obtained from coincidence studies with different gates. A comprehensive level scheme derived from the present coincidence studies is shown in Fig. 1. It may be seen from Fig. 1 that the present data indicates the population of four different band systems, two of positive parity and the other two of negative parity.

Salient features of comparison of the present study with the earlier study [2] are outlined below.

**Band based on the 382 keV state**

All the transitions and coincidence relationships in this band are in conformity with those of previous study.

**Band based on the 181 keV state**

In this case also the principal transitions and their coincidence relationships proposed in the previous study are confirmed.

The coincidence spectrum recorded with gate on 141 keV is shown in Fig. 2. The weak transitions of energies 196 keV and 1147 keV tentatively placed in the scheme in the previous work are confirmed (they are marked with an asterisk, *) and the level at 3043 keV indicated in the previous work is established. From the present data a new transition of energy 1248 keV is introduced in this band and placed above the 2847 keV state. The coincidence spectrum recorded with gate on 1248 keV is shown in Fig. 3. An additional line at 651 keV is also indicated in Fig. 3. This transition is also observed in gates of all transitions in this band. The established coincidence relationships, non-observation of coincidence with the 1147 keV transition and the relative intensities are the basis for the suggested placement of the 651 keV transition. In view of its low intensity this assignment may be treated as tentative. Thus the highest energy level in this band is now of energy 4746 keV. Interband transition of energy 464 keV connecting the two bands between 846 keV and 382 keV states is also confirmed. The two transitions of energies 415 keV and 1183 keV proposed in the previous work are not observed in the present study.

**Band based on the 1549 keV state**

This band is extended to higher energies and ordering of some of the transitions is revised based on the present coincidence data.

(i) The decay pattern between the states of energies 1549 keV and 2921 keV confirm the earlier results.