Level structure of odd-odd $^{68}$Ga

A.K. Singh$^1$, G. Gangopadhyay$^1$, D. Banerjee$^1$, R. Bhattacharya$^1$, R.K. Bhownik$^2$, S. Muralithar$^2$, R.P. Singh$^2$, A. Goswami$^3$, S. Bhattacharya$^3,a$, B. Dasmathapatra$^3$, and S. Sen$^3$

$^1$ Department of Physics, University College of Science, University of Calcutta, 92, A.P.C. Road, Calcutta-700 009, India
$^2$ Nuclear Science Centre, New Delhi-110 067, India
$^3$ Saha Institute of Nuclear Physics, Calcutta-700 064, India

Received: 19 June 2000 / Revised version: 5 September 2000
Communicated by D. Schwalm

Abstract. Excited states of $^{68}$Ga have been investigated through the $^{55}$Mn($^{16}$O, 2pn) reaction at projectile energy 55 MeV. The level scheme has been extended up to 7.8 MeV. Altogether six new excited levels could be identified and twelve previously unobserved $\gamma$-transitions have been placed in the modified level scheme.

PACS. 27.50.+e 59 $\leq A < 89$ – 23.20.Lv Gamma transitions and level energies – 23.20.En Angular distribution and correlation measurements

In beam $\gamma$-ray spectroscopic investigation of nuclei in the mass region $A \simeq 60–70$ over the past several years has unveiled many interesting aspects of nuclear structure like transition from oblate to prolate shape, octupole collectivity, gamma instability etc. In addition these experiments have also revealed a variety of excitation modes involving different degrees of freedom which are present in both low and high spin regime. For example, the recent studies of the high spin states of Zn [1] and Ge [2,3] nuclei populated through heavy-ion reaction have revealed a large variety of rotational and vibrational degrees of freedom in these nuclei. All these features cannot be explained within a single theoretical model but, in general, these are understood in terms of the gaps in the Nilsson single particle energy at $Z, N=38$ for prolate and $Z, N=36$ for oblate deformation. In this mass region the $g_{9/2}$ orbital also plays an important role in producing high spin and one can expect a complex interplay between different types of collective modes as well as collective and single particle excitations. For example, the high spin states above $I=8h$ in this region are expected to exhibit this complex interplay originating due to alignment of neutrons in $g_{9/2}$ orbital. In fact, this phenomenon was observed in $^{66,68}$Ge [2,3] and $^{64}$Zn [1]. In the present paper we report the results of our investigation on the high spin states of $^{68}$Ga through heavy ion induced reaction. Like other odd-odd nuclei, $^{68}$Ga also offers an opportunity to study the residual interaction between a single proton and a single neutron.

The level properties of $^{68}$Ga have earlier been studied [5-9] through $(p, \gamma \gamma)$ and $(\alpha, \gamma \gamma)$ reactions. Excited levels up to about 4 MeV in energy and spin-parity up to $11^+$ were already known from these studies. An isomeric level at 1228 keV ($I^*=7^-, T_{1/2}=64$ ns.) was identified through the $(\alpha, \gamma \gamma)$ reaction and has also been studied via the reaction $^{56}$Fe($^{13}$N, n2p) [9]. No other heavy ion fusion-evaporation reaction has been used to study this nucleus. Information on the levels identified and their properties are available in the compilation by Bhat [10].

In the present experiment, the excited states of $^{68}$Ga have been populated through the fusion-evaporation reaction $^{55}$Mn($^{16}$O, 2pn)$^{68}$Ga at a projectile energy 55 MeV using the 15UD Pelletron facility at Nuclear Science Centre (NSC), New Delhi. The target ($\sim 2$ mg/cm$^2$) of Mn was deposited on a 7 mg/cm$^2$ gold foil. The Gamma Detector Array (GDA) at the NSC with seven HPGe detectors (25%) along with Anti Compton Shields were utilised for this purpose. The detectors were placed at 45°, 99° and 153° with respect to the beamline. A charged particle detector array (CPDA) consisting of 14 phoswich detectors was used. Each detector of the CPDA is made up of fast-slow Plastic Scintillators, the front one of which is thin (BC400 – 0.1mm), has a fast rise time and used as a $\Delta E$ detector and the rear one (BC 444 – 5mm) has a slow rise time and is used as an $E$ detector. This combination was used to identify the channels of interest. Each detector was placed at a distance of 6 cm from the target; four in the forward direction, four in the backward direction and the other six around 90° to the beamline giving a solid angle coverage of $\sim 90\%$. More details of the CPDA may be found in [11]. The other nuclei populated in the experiment were $^{68,69}$Ge, $^{65,66}$Ga and $^{65,66}$Zn. Most of the $\gamma$-rays coming from different channels have been found to be non-overlapping. The events were recorded in the list mode with the condition that at least two HPGe detec-
tors recorded a γ-ray. Imposing an additional constraint, through software gating, that the charged particle array records two particle hits helped us in finding out the γ-rays belonging to $^{68}$Ga, as among the residual nuclei produced in the experiment with large cross-section, only $^{68}$Ga were produced via two-proton evaporation.

The pulse height of each detector was gain matched to 0.5 keV/channel. The data were sorted in $4K \otimes 4K$ γ-γ matrices. This γ-γ matrix also contained transitions from $^{65}$Zn because of the incomplete separation between α and p events in the charged particle array, particularly in the backward direction. Figure 1 shows the total projection spectrum (A) of the γ-γ matrix along with the corresponding spectrum (B) with added constraint, mentioned above, on the charged particle. In spectrum A, major transitions coming from $^{68,69}$Ge and $^{65,66}$Ga are indicated. The γ-rays coming from $^{68}$Ga are shown in the spectrum B. It is easily seen that the γ-rays marked in spectrum A are not present in spectrum B and the channel of interest clearly stands out in it. However, the γ-rays belonging to $^{65,66}$Zn are also present in the spectrum, for the reason mentioned above.

It is obvious that due to the presence of an isomeric level of half life 64 ns at 1228 keV ($7^-$), a very narrow gate on the TAC spectrum would yield little fruitful coincidence information between the transitions de-exciting via cascades to this level and those between the low-lying levels. The data were, therefore, analysed using two TAC gates, one of width 50 ns and another of 125 ns by which we could study cascades above the isomeric level at 1228 keV.

The multipolarities of the observed γ-rays are determined through the directional correlation orientation (DCO) ratio measurements. A separate $4K \otimes 4K$ γ-γ matrix has been generated with the events recorded at 99° along one axis and those recorded at 153° along the other axis. The DCO ratio was then determined as

$$R_{\text{DCO}}(\gamma_1) = \frac{I(\gamma_1 \text{ at } 99^\circ \text{ with } \gamma_2 \text{ at } 153^\circ)}{I(\gamma_1 \text{ at } 153^\circ \text{ with } \gamma_2 \text{ at } 99^\circ)}.$$  

Fig. 2. Level scheme of $^{68}$Ga obtained in the present work.

The programme package RADWARE [12] has been used to analyse the data.

The level scheme (fig.2) of $^{68}$Ga has been constructed from γ-γ coincidence data, measured γ-ray intensities and the observed multipolarities deduced from the DCO ratio measurements. Altogether six new excited levels could be identified and twelve previously unobserved γ-transitions were placed in the modified level scheme. In fig.2 the thickness of the lines depicting the transitions indicates the relative intensity.