Summary. — The level scheme of $^{65}$Ga has been studied up to an excitation energy of 7035.3 keV and spin-parity values of $(27/2^+)$. Gamma-ray singles, $\gamma\gamma$-coincidences, angular distributions and Doppler shift attenuation have been measured in the reaction $^{63}$Cu($\alpha$, 2$n\gamma$) at 30 MeV. The spin and parity ($J^\pi$) assignments for several states belonging to the previously known bands are confirmed. The mean life and the parity of the 2814.7 keV state, hitherto unknown, are reported. The $J^\pi$ for the 3733.2 keV state is proposed to be $15/2^+$ on the basis of angular distribution data and its decay characteristics to the lower-lying states. Experimental evidence is presented in favour of the 3733.2 keV state of being a band head for a rotation-like $\Delta I = 2$ positive-parity band with the excited members at 4547.5, 5643.5 and 7035.3 keV. The deduced $B(E2)$ results indicate the presence of appreciable collectivity in the other positive-parity band built on the $9/2^+$, 2037.3 keV state. These bands in $^{65}$Ga are discussed and compared with similar bands in the neighbouring odd-$A$ nucleus $^{67}$Ga.

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1. - Introduction

Most of the excited states of the light odd-mass gallium isotopes ($Z = 31$) $^{65-69}$Ga can be grouped into several bands arising from the weak coupling of a quasi-particle occupying the $\pi f_{5/2}$, $\pi p_{3/2}$ and $\pi g_{9/2}$ orbitals to the states of the neighbouring even-even cores. These bands generally exhibit vibrational collectivity due to the vibrational nature of the core states, and is reflected in the observed enhancements of the $B(E2)$ rates over the single-particle estimates by factors of 5–20 for the intra-band transitions. In addition, there is a clear evidence [1] for the existence of a positive-parity quasi-rotational band in the nucleus $^{67}$Ga, built on a $15/2^+$, 3578 keV state, which extends up to $27/2^+$. The energy spacings of this $\Delta I = 2$ band are observed to be in good agreement with the $I(I + 1)$ rotational energy rule. Zhu et al. [2] have recently reported that in $^{65}$Ga also, a similar cascade of several $E2$ transitions terminates on a 3733 keV state. The decay pattern of this state suggests that this is a new bandhead involving a change in structure with respect to the structure of the other bands in this 

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nucleus. However, the spins and parities of the 3733 keV state and the higher-lying states are uncertain. While tentative spin assignments of \( J = (13/2, 15/2) \) and \( (17/2, 19/2) \) have been made for the 3733 and the next higher state at 4547 keV, respectively, negative parity has been tentatively assigned to the other states which decay down to the 3733 keV level \([2, 3]\). Also, there is no lifetime data to supplement the understanding of these levels.

The present work is undertaken to study the characteristics of the 3733 keV state and the higher-energy states which terminate on this level in an attempt to understand whether this sequence of states in \(^{65}\text{Ga}\) constitutes a band similar to the \( 15/2^+ \) band in \(^{67}\text{Ga}\) or not. Information for some lower-lying negative-parity states, relevant to the study of the 3733.2 keV level and some results for the positive-parity band built on the 2037.3 keV level obtained in this work are also presented.

2. – Experimental method

In the present work, the level scheme of \(^{65}\text{Ga}\) has been studied up to an excitation energy of 7035.3 keV using the reaction \(^{63}\text{Cu}(\alpha, 2\gamma)\) at 30 MeV. The \( \alpha \)-beam was provided by the Cyclotron at the Variable Energy Cyclotron Centre, Calcutta. A target of 99% enriched \(^{63}\text{Cu}\) with thickness of 10.3 mg/cm\(^2\) was used for all experiments except for the Doppler shift attenuation (DSA) measurements, for which a 8 mg/cm\(^2\) natural Cu foil was used. This was done to avoid the uncertainties associated with the estimation of the stopping time (required in the analysis of DSA data) of the recoils in the enriched target, which was prepared by deposition. Three large-volume HPGe detectors, one with an anti-Compton shield, with in-beam energy resolutions in the range 2.5–3.0 keV at a \( \gamma \)-ray energy of \( \sim 1 \) MeV, were used. Conventional fast NIM electronics was employed. Measurements of the \( \gamma \)-ray intensities, angular distributions, DSA and \( \gamma\gamma \)-coincidences were made. The angular distributions were measured at five angles between 90° and 145° with respect to the beam direction. In the \( \gamma\gamma \)-coincidence experiments, a total of approximately \( 3.5 \times 10^7 \) events were registered from which the \( \gamma \)-ray coincidence relationships were studied.

Gated spectra were generated by setting appropriate digital gates on the energy and time spectra and subtracting the contributions due to random and the Compton events. The level lifetimes were estimated following the method outlined in ref. [4] and the other references cited therein. The angular distribution coefficients \( (A_0, A_2, A_4) \) were determined from a least-squares fit of the normalised \( \gamma \)-ray yields to \( W(\theta) = A_0 + A_2 P_2(\cos \theta) + A_4 P_4(\cos \theta) \). The spin and parity assignments to the levels were made from the \( \gamma \)-ray angular distribution data on the basis of the \( \chi^2(\sigma, \delta) \) analyses \( (\sigma \text{ is the width of the assumed Gaussian magnetic substate distribution and } \delta \text{ is the } \gamma \text{-ray multipole mixing ratio}) \) performed as described earlier \([4, 5]\) and considerations of the deduced transition rates. The fitted value of \( \sigma \) shows a high degree of alignment. A spin and multipole mixing ratio result is rejected if the corresponding minimum \( \chi^2(\sigma, \delta) \) exceeds the 0.1% confidence limit.

3. – Results and discussion

The singles \( \gamma \)-ray spectrum obtained in the reaction \(^{63}\text{Cu}(\alpha, 2\gamma)\) at 30 MeV is shown in fig. 1. Only the \( \gamma \)-ray lines belonging to \(^{65}\text{Ga}\) are marked in the figure. A partial level scheme of \(^{65}\text{Ga}\) is shown in fig. 2. The energies, intensities and the spin and