# High spin gamma ray spectroscopy study of $^{154}$Ho

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## Introduction

The neutron deficient rare-earth isotopes close to the magic nucleus $^{146}$Gd are interesting due to their multitude structural features [1] as a function of neutron number as well as spin. Interplay between single particle excitations and collective ones are observed in most of these nuclei. For nuclei having neutron number less than 88, single particle mode of excitations is seen at low spins. For neutron numbers above N=88, collectivity sets in even at low excitation energies.

We have studied [2] a few Ho isotopes having neutron numbers ranging from 84 to 87. $^{154}$Ho is a good candidate for studying the interplay of both collective and single particle states. We have already established [3] the shape coexistence in $^{153}$Ho even at lower spins. The evolution of structural features in the Ho isotopes with increasing spin and neutron numbers have been studied theoretically with the help of Shell Model (SM) and Total Routhian Surface (TRS) calculations.

In the present work we report on the results of analysis of $^{154}$Ho data beyond that published and presented in [2] based on the experiment at TIFR, Mumbai. High spin states of odd-odd $^{154}$Ho have been populated by $^{141}$Pr ($^{16}$O, 3n) reaction at a projectile energy of 82 MeV from 14-UD Pelletron accelerator. The nineteen Compton suppressed Clover detectors are placed in INGA setup at the following angles: three clovers each at ±40° and ±65°, four Clovers at 90° and three at -23°. The number of two-fold events is $2\times10^9$.

Detailed gamma-ray spectroscopic studies of $^{154}$Ho are very difficult due to its complexity in excitation spectra. We have studied this nucleus before [2] experimentally and theoretically. In the present work we have extensively studied this nucleus and clearly establish the spin-parity of a few energy levels.

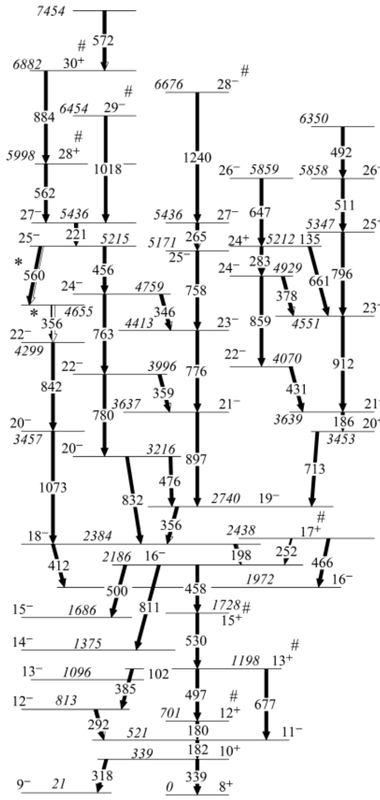

**Fig. 1:** Relevant portion of the level scheme of $^{154}$Ho. The * and # marks are showing the new γ-ray transitions and new assignments of spin and parities for the levels, respectively.

In the present analysis we have confirmed the spin and parity of the high spin levels using angle dependent and IPDCO asymmetric matrices, respectively. A symmetric γ-γ matrix has been used to place different γ transitions in the level scheme. For most of the γ-rays, the DCO and polarization results satisfy earlier assignments. However, for a few, some differences have been noticed. We have also assigned spin-parities of some γ-ray transitions which were not done in the previous works [4, 5]. The DCO measurements in the present work have been certained from a $90^0$ vs $-40^0$ as well as $90^0$ vs $-23^0$ asymmetric matrix. The range of $R_{DCO}$ values are 0.92(2)-0.99(1) for $\Delta J = 1$ and 0.5(1)-0.7(1) or 2.29(7) for $\Delta J = 2$ when gated by an E1 transition. The spin and parity assignments were not mentioned [4, 5] for 180, 497, 677, 530, 458 keV transitions. In the present work, it has been found that 180 and 458 keV are of E1 nature, 497 has M1 nature and 677 has M2 character. 530 keV is E2 transition. The spin-parity for the $16^-$ level at 2186 keV is confirmed.

Previously [4, 5] the spin-parity assignment was tentative for 185, 912, 796, 511, 492, 661, 647, 283, 377, 859, 430 and 713 keV transitions. According to our present data analysis, the 185 keV γ-ray transition is E1in nature, whereas it was previously mentioned as a M1 transition. The parity has been changed for 912, 431, 859, 283 keV transitions at 4551, 4070, 4929, 5212 keV levels, respectively. 796 and 647 keV γ-rays show M2 characters while it was reported as E2 transitions before. In our analysis 661 keV becomes E1 in nature, but it was reported as M1 transitions.

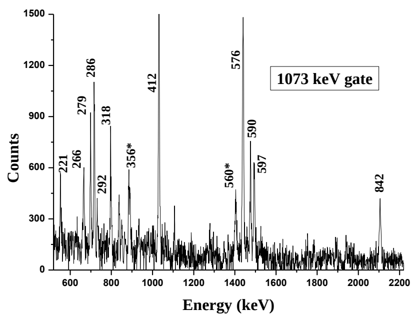


**Fig. 2:** 1073 keV (at 3457 keV) gated spectrum, showing the γ-rays 356 and 560 keV (marked *), those have been placed in the level scheme (Fig. 1) and all other γ-rays in this spectrum belong to partial level scheme of $^{154}$Ho.

In 1073 keV gated spectrum (in Fig. 2), the presence of 356 and 221 keV transitions change –d the earlier reported level scheme [4, 5]. Earlier no connections were made between 1073 keV and 356, 221 keV, though there was another 356 keV transition at 2740 keV level [4, 5]. To resolve the problem, we have placed the two new transitions 356 and 560 keV (Fig. 1) which can be seen in the coincidence spectrum (Fig. 2). We have confirmed parity assignments for the levels at 5998 and 6882 keV. The transitions 562 and 884 keV are E1 and E2 in nature, respectively. For 572 keV γ-ray at 7454 keV level, we can only mention that it is electric transition. The two γ-rays 1018 and 1240 keV at 6454 and 6676 keV levels, respectively are confirmed as E2 and M1 transitions. There is an ambiguity [5] in a placement of 378 and 661 keV transitions at $24^-$ and $24^+$ respectively. According to our data, 378 and 661 keV transitions are in coincidence. It needs further analysis to place them, may be in other position of the level scheme.

In our earlier work [2], substantial signature splitting in the positive parity band in $^{154}$Ho had been reproduced well in the SM calculation with 1 neutron-1 proton multiplet structure. Also, TRS calculation supported a secondary minimum for an oblate structure. There we found the experimental evidences for octupole deformation. More detailed SM calculation and investigation on the signature of octupole deformation are being done.

## Conclusion

In the present work, we have found some new γ-ray transitions and placed them in the level scheme. We not only confirmed the previous assignment of spin-parities but also assigned new spin and parities of some levels. Ambiguity in the placement of 378 and 661 keV needs to resolve.

## References

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