# Coulomb excitation of $^{90}$Zr

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## Introduction

The nucleus $^{90}$Zr has a closed $N = 50$ neutron shell and therefore it has often been the subject of extensive experimental and theoretical investigations. This is reflected in the large number of studies investigating the low-lying excited states of $^{90}$Zr, by means of Coulomb excitation [1], inelastic scattering of electron [2], proton [3], neutron [4], $\alpha$-particle [5] and heavy ions [6], as well as fusion-evaporation [7] and transfer reactions [8]. However, for $^{90}$Zr, many of these investigations were confined to the first excited $0^+$, $2^+$, $4^+$, $5^-$, $6^+$, $8^+$ states that are thought to have a simple nuclear structure arising from the distribution of the last two protons over the $2p_{1/2}$ and $1g_{9/2}$ orbitals. Studies on the first excited octupole state, $3^-_1$ are a rarity.

Unlike the $3^-_1$ state in neighbouring stable Zr isotopes, the $3^-_1$ state in $^{90}$Zr ($E_x = 2.748$ MeV) has not been probed by the model independent Coulomb excitation technique either, owing to its higher excitation energy. The existing experimental estimates of the $B(E3)$ values for the $^{90}$Zr have a wide range and there are inconsistencies in the existing data leading to different conclusions on the collectivity of the octupole excitation mode. Even among the limited number of such studies, the reported $B(E3)$ values are widely discrepant, ranging from 0.027 $e^2b^3$ from $^{17}$O inelastic scattering ($^{17}$O, $^{17}$O$'$) , 0.046 $e^2b^3$ from $(\alpha, \alpha')$, 0.056 $e^2b^3$ from $(n, n')$, 0.079 $e^2b^3$ from $(p, p')$ to 0.086 $e^2b^3$ from inelastic scattering of electrons and $^6$Li ions.

In the light of such discrepancies, unambiguous quantitative assessments of collective properties for the $3^-$ state in $^{90}$Zr is crucial.

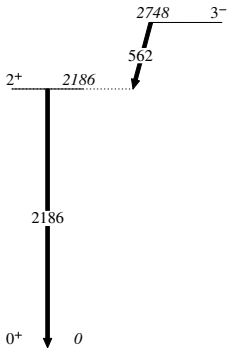


FIG. 1: Partial level of $^{90}$Zr showing the first $2^+$ and $3^-$ states.

The main motivation of the present work is to obtain an estimate of the octupole transition probability, $B(E3)$, for the excitation of the $3^-$ state in the $^{90}$Zr nucleus using the Coulomb excitation technique, and compare the result with existing estimates to understand the underlying collectivity in this transition.

## Experimental details and Data analysis

In this experiment, the Coulomb excitation of $^{90}$Zr has been performed using 85 MeV $^{32}$S beam provided by TIFR-BARC Pelletron Linac Facility at TIFR, Mumbai. The beam energy was so chosen that the excited states could be populated by purely electromagnetic interaction between projectile and target with negligible contribution from nuclear interaction. The target used was 12.5 mg/cm$^2$ thick nat-Zr where $^{90}$Zr is the most abundant isotope (51.4%). The decay transitions were detected by the INGA consisting of 17 clover HPGe detectors arranged

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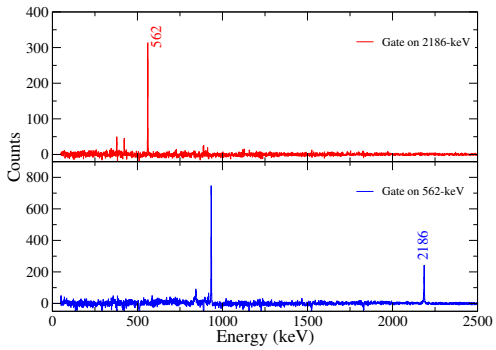


FIG. 2: Excitations of $2_1^+$ and $3_1^-$ in $^{90}$Zr nucleus.

in different angles w.r.t to the beam direction. Time-stamped data were acquired using digital data acquisition system. The data were sorted using MARCOS and RADWARE packages by constructing $E_\gamma - E_\gamma$ matrices to unambiguously identify the population of different excited states.

### Results and Discussions

Since nat-Zr target contains different isotopes, the characteristic $\gamma$-lines of each isotope have been used as a signature of excitations of corresponding energy levels. First observation of the population of $3^-$ state in $^{90}$Zr via Coulomb excitation could be confirmed by the presence of the 562-keV, $E1; 3_1^- \rightarrow 2_1^+$ transition in coincidence with the 2186-keV, $E2; 2_1^+ \rightarrow 0^+_{\text{g.s.}}$ transition (as seen in fig-2). Previous attempts of Coulomb excitation on $^{90}$Zr were limited to the $2^+$ level only. Additionally, the population of second excited states (*i.e.* $4_1^+$) in $^{92,94}$Zr could be achieved by means of multi-step Coulomb excitation. These transitions could be identified by coincidence measurements with the $2_1^+ \rightarrow 0^+_{\text{g.s.}}$ transitions in respective isotopes. The inclusive $\gamma$-ray spectrum, however, makes it difficult to extract the $E3$ transition probability as the information on the direction of emission of $^{90}$Zr is lost. As a remedy, particle-gamma coincidence technique is desirable and a measurement has been planned in this regard. Comparison with contemporary theoretical calculations will help us to understand the underlying octupole collectivity. Some preliminary results will be presented.

### Acknowledgments

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