Indian Journal of Pure & Applied Physics
Vol. 57, August 2019, pp. 599-601

Multi-step Coulomb excitation of ^{132}Ba at HIL, Warsaw

Sunil Dutt[a*], M Saxena[b], P J Napiorkowski[b], R Kumar[c], T Abrahahm[b], J M Allmond[d], A Gwalik[e], K Hadynska-Klęk[b], M Hlebowicz[f], J Iwanicki[b], M Kisieliński[b,g], M Komorowska[b,h], M Kowalczyk[b,g], T Marchlewski[b,h], M Matejska-Minda[b,i], F Oleszczuk[f], M Palacz[b], W Piątek[b], L Próchniak[b], I A Rizvi[a], J Samorajczyk[b,e], J Srebrny[b], A Tucholski[b], W Wróblewski[b] & K Wrzosek-Lipska[b]

[a]Department of Physics, Aligarh Muslim University, Aligarh 202 001, India

[b]Heavy Ion Laboratory, University of Warsaw, Warsaw 05077, Poland

[c]Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi 110 067, India

[d]Oak Ridge National Laboratory, Oak Ridge 37830, USA

[e]Faculty of Physics, and Applied Computer Science, University of Łodź, Łodź, Poland

[f]Warsaw University of Technology, Warszawa 00661, Poland

[g]National Centre for Nuclear Research, Świerk 05400, Poland

[h]Faculty of Physics, University of Warsaw, Warsaw 02093, Poland

[i]The H. Niewodniczański Institute of Nuclear Physics PAN Kraków, Kraków 31342, Poland

Received 8 April 2019

To determine the shape of ^{132}Ba Coulomb excitation measurement has been performed at U-200P cyclotron at Heavy Ion Laboratory, University of Warsaw, Poland. A ^{32}S beam of ~90 MeV energy has been bombarded on enriched ^{132}Ba-target to Coulomb excite the latter nuclei. EAGLE gamma-ray spectrometer consisting of 15 single crystal HPGe detectors has been used to detect the deexcited gamma-rays from Coulomb excited Ba nuclei. The data has been collected using Particle-gamma coincidence technique for a period of seven days. The back scattered projectiles have been identified with 48 PiN diodes of 0.5 X 0.5 cm^2 active area mounted in a scattering chamber of ~5 cm radius called as 'Munich chamber'. The energy states up to ~1127 keV energy have been populated in the interested ^{132}Ba isotope. The preliminary results of the data analysis are presented here.

Keywords: Nuclear structure, Coulomb excitation, Transitional nuclei, Barium, p-γ coincidence

1 Introduction

Deformed nuclear shapes play an essential role in a straight forward interpretation of many low lying nuclear-excited states in complex many-body nuclei[1]. Study of the triaxial nuclei is the gateway to understand the interplay of shape transitions between the prolate and oblate deformations. Several experimental and theoretical investigations have been carried out for nuclei of the mass number[2-12] around A ~130 as it covers the transitional region from spherical shapes to strong deformations. In addition to Pt-region, the presence of O (6) like symmetry of the interacting boson model (IBM) along with the interplay of γ-softness and triaxiality was proposed for Xe & Ba isotopes in this mass region[2, 3]. In particular ^{132,134}Ba isotopes were introduced as a good candidate for O (6) like nuclei, although, sufficient experimental data was not available at that time[2]. However later, E (5) symmetry was found in ^{134}Ba[4,5], which shows a transition from O (6) to E (5) structure between these two adjacent isotopes. Recently, several other theoretical studies have been discussed on the transitional Ba-isotopic chain *viz.* microscopic shell model (MCSM) calculations by Teruya *et al.*,[6] IBM-1, interacting vector boson model (IVBM) and semi-empirical formula (SEF) interpretations by Jubbori *et al.*,[7] and pairing plus quadrupole & IBM-1 calculations by Kumar and Gupta[8,9] etc. To complement and validate these studies good experimental data is also required. Low energy levels of Ba-isotopes (A = 124-142), showing a gradual transition of different types of quadrupole collective states, have been shown in Fig. 1. Low lying 2_2^+ state (or $2_2^+/2_1^+$ vs. $4_1^+/2_1^+$ ratio) is an indicator of the nature of γ-deformation and as shown in the figure, varies considerably for Ba-isotopic chain. As most of the stable Ba isotopes are well studied; still experimental data for ^{132}Ba is relatively scarce. The

* Corresponding author (E-mail: sunilduttamu@gmail.com)

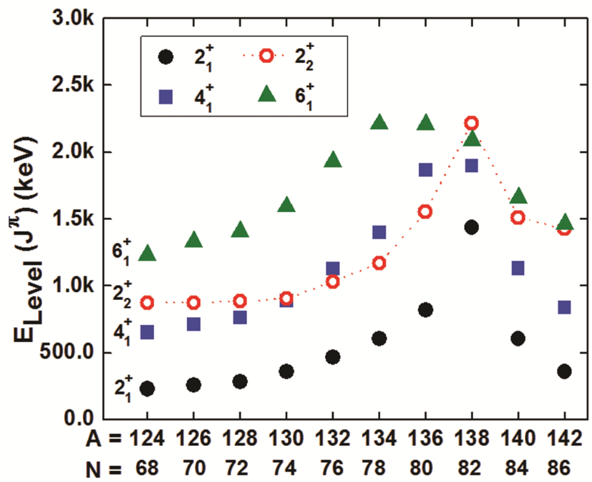

Fig. 1 – Variation of low energy levels in even-A Ba-isotopes.

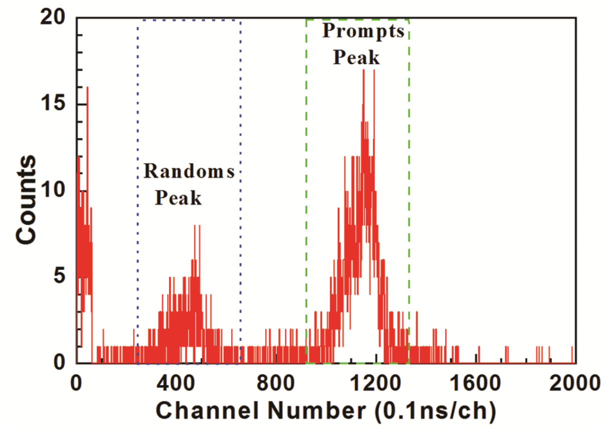

Fig. 2 – Particle gamma coincidence timing spectrum for a specific PiN-diode-HPGe combination. The shaded regions show gates on the random and prompt peaks.

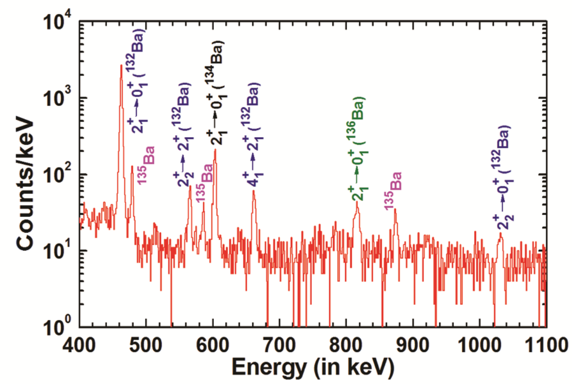

Fig. 3 – Energy calibrated, background subtracted, and Doppler shift corrected gamma-ray spectrum resulted from the present Coulomb excitation experiment of ^{132}Ba with ~ 90MeV ^{32}S projectile for a single HPGe detector.

previous Coulomb excitation measurement for ^{132}Ba was performed in 1985 by Burnett *et al.*[10] via particle spectroscopy with a ^{12}C beam. Therefore, to probe the low-level electromagnetic properties of this isotope of interest, an isobar of the doubly magic ^{132}Sn nucleus, we performed the present experiment at heavy ion laboratory (HIL), University of Warsaw, Poland and the details are presented here.

2 Experimental Details

The present experiment was performed using a 90 MeV ^{32}S beam provided by the U-200P Warsaw cyclotron. Enriched $BaCl_2$ target of ~631 μg/cm^2 thickness (i.e., 410 μg/cm^2 of Ba) on ~ 30 μg/cm^2 carbon foil was used for the measurement. The EAGLE gamma-ray spectrometer consisting of 15 single crystal HPGe detectors was used to detect the de-exciting gamma-rays from the Coulomb excited target nuclei. 48 PiN-diodes of 0.5 X 0.5 cm^2 active area, covering 110°-170° backward angles in the laboratory frame, was used for the detection of backscattered ^{32}S projectile ions. The data was collected with particle-gamma coincidence technique to perform event by event Doppler shift correction. A standard ^{152}Eu source was used for the calibration and efficiency of the HPGe-detectors. A detailed description of the experimental set-up can also be found in reference[11].

3 Data Analysis

The offline data analysis was performed using the ROOT analysis package. A precise Doppler correction was performed to correct for the Doppler broadening effects in the observed de-excited gamma-ray. To remove the background proper timing gates on the random and prompt peaks of the HPGe detector timing (as shown in Fig. 2), and PiN diodes energy were applied. Energy calibrated, background subtracted, and Doppler corrected gamma-ray spectrum for a single HPGe detector has been shown in Fig. 3. In the present multi-step Coulomb excitation measurement of ^{132}Ba states up to the 4_1^+ state in the ground-state band were observed in addition to the second 2^+ state. All observed γ-rays and the relevant transitions from the de-excitation of Coulomb excited nuclei have been tagged in the above figure. The observed level scheme in the present experiment has been shown in Fig. 4. In addition to ^{132}Ba radiation, gamma-ray transitions for other stable Ba-isotopes *viz.* ^{134}Ba, ^{135}Ba, ^{136}Ba & ^{138}Ba have also been observed and are shown in Fig. 3. These isotopes were present as isotopic contamination in the target.

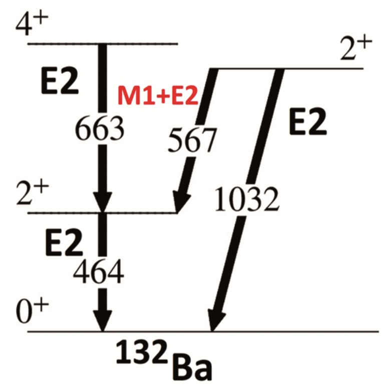

Fig. 4 – Low energy levels of ^{132}Ba nucleus showing γ-ray transitions observed in the present Coulomb excitation experiment. All energies of γ-ray transitions are in keV.

4 Conclusions

The data were analysed with ROOT analysis package and states up to 1.127 MeV energy in ^{132}Ba were observed. This experiment is a complementary measurement to our earlier work[12] which was performed at Inter University Accelerator Center, New Delhi, having the particle detector at forward scattering angles ($15^0 \leq \theta_{Lab} \leq 45^0$). In the present measurement four low-level transitions, namely, $2_1^+ \rightarrow 0_1^+$, $4_1^+ \rightarrow 2_1^+$, $2_2^+ \rightarrow 2_1^+$, and $2_2^+ \rightarrow 0_1^+$ were observed and were presented here. The observed level scheme has been shown in Fig. 4. GOSIA analysis of the data leading to the extraction of matrix elements and BE2s is in progress and will be communicated in further publications.

Acknowledgement

One of the authors (S D) is thankful to Erasmus-Mundus association for the financial support through EMINTE fellowship. Thanks are also due to accelerator staff Heavy Ion Laboratory, University of Warsaw, Poland and Chairman, Department of Physics, A.M.U. Aligarh, India for providing the necessary facilities.

References

1 Bohr A & Mottelson B R, *Nuclear Structure*, Vol II (Benjamin, Reading, MA) (1975).
2 Casten R F & Brentano P V, *Phys Lett*, 152 (1985) 22.
3 Casten R F, Brentano P Von, Heyde K, Isacker P V & Jolie J, *Nucl Phys A*, 439 (1985) 289.
4 Casten R F & Zamfir N V, *Phys Rev Lett*, 85 (2000) 3584.
5 Casten R F, *Nature*, 2 (2006) 811.
6 Teruya E, Yoshinaga N, Higashiyama K & Odahara A, *Phys Rev C*, 92 (2015) 034320.
7 Al-Jubbori M A, Kassim H H & Sharrad F I, *Nucl Phys A*, 955 (2016) 101.
8 Kumar K & Gupta J B, *Nucl Phys A*, 694 (2001) 199.
9 Gupta J B, *Eur Phys J A*, 51 (2015) 47.
10 Burnett S M, Baxter A M, Hinds S, Pribac F, Spear R H & Vermeer W J, *Nucl Phys A*, 432 (1985) 514.
11 Dutt S, Napiorkowski P J, Abraham T, Janiak Ł, Kisieliński M, Komorowska M, Kowalczyk M, Kumar R, Marchlewski T, Matejska-Minda M, Palacz M, Piątek W, Próchniak L, Rizvi I A, Samorajczyk J, Saxena M, Srebrny J, Tucholski A, Wróblewski W, Wrzosek-Lipska K & Zielińska M, *Acta Phys Polonica B*, 47 (2016) 917.
12 Dutt S, Saxena M, Kumar R, Jhingan A, Agarwal A, Banerjee A, Bhowmik R K, Joshi C, Kaur J, Kumar A, Matejska-Minda M, Mishra V, Rizvi I A, Stolarz A, Wollersheim H J & Napiorkowski P J, *Acta Phys Polonica B*, 49 (2018) 535.