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SEARCH FOR RARE SHAPE TRANSITION AND GQR DECAY IN HOT ROTATING ^{188}Os NUCLEUS*

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In order to search for a rare kind of shape phase transition in hot rotating nuclei, measurements have been performed of high energy gamma rays from the ^{188}Os nucleus at high excitation energy and high spin. In addition, the possibility of observing the Giant Quadrupole Resonance (GQR) built on excited states has been explored. To carry out more detailed measurements, a sum-spin spectrometer was set up in complete 4π configuration. Preliminary results on Giant Dipole Resonance (GDR) decay from hot rotating ^{192}Pt nucleus, obtained with the help of this new device, are presented.

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1. Introduction

The study of high energy gamma rays from the decay of Giant Dipole Resonance (GDR) states built upon highly excited states have established itself as one of the primary tools to understand the dynamics of the hot rotating nuclei. The spectral shape and angular anisotropies of the GDR gamma rays are expected to manifest the variety of shape–phase transitions in the atomic nuclei with increasing temperature and angular momentum.

The selection of the nuclei to be studied and the region of phase space to be probed, are guided by the predictions of theoretical calculations, both microscopic and macroscopic. It is now well established, that all mean field calculations predict a transition temperature T_{c1}, at which the nucleus, irrespective of its ground state deformation, becomes spherical and on rotation becomes oblate, rotating about its symmetry axis [1]. A series of recent

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calculations by Goodman have resulted in the prediction of a second transition temperature T_{c2}, where $T_{c2} > T_{c1}$, in some heavy nuclei [2]. According to these calculations, in a narrow region of the phase space demarcated by the two angular momentum dependent transition temperatures T_{c1} and T_{c2} the nucleus is expected to rotate about the symmetry axis while possessing a prolate shape. Our previous measurements of phase space selected GDR gamma rays from ^{194}Au provided a definite indication of shape transition [3], in particular based on the reversal in the angular anisotropy pattern of the GDR gamma rays for the two different beam energies. The conclusions drawn from the statistical model analysis of the GDR spectra, belonging to narrow domains of angular momentum and temperature, were also found to be in conformity with the angular anisotropy of the high energy gamma rays. This provided further impetus to carry out the investigations in other neighbouring nuclei.

We first report on the measurements of GDR decay in ^{188}Os followed by the results obtained from our search for GQR decay from the same nucleus. Finally we will discuss the performance of the 4π spectrometer and some interesting preliminary result of GDR decay from ^{192}Pt.

2. GDR decay from ^{188}Os

The experimental details and the important parameters of the compound nucleus are given in [4] and will not be presented here. The initial data reduction resulted in gamma-ray spectra gated on the multiplicity folds for the two beam energies and for all the four angles. Two narrow windows, corresponding to 4–6 and 9–12 folds, were chosen to extract the spectra from low and high spin regions of the distribution. The lowest folds of 1–3 were not considered to avoid spurious counts due to possible target contaminants.

The spectra were analyzed by fitting with statistical model calculations using a modified version of the code CASCADE [5]. The theoretical spectra were convoluted with the simulated response matrix for the detector array. The temperature dependence of the level density was calculated using the Ignatyuk/Reisdorf formalism [5]. The fits were carried out in an iterative manner considering spherical, prolate and oblate shapes and the GDR parameters were extracted from the best fits to the spectra. Considering the strong temperature dependence of the GDR width, the GDR widths were reduced in each successive stages of decay in the CASCADE calculations. The robustness of the GDR centroid energy further constrained the calculations. Only those deformations for both prolate and oblate shapes were tried that kept the corresponding centroid of the GDR peak for a spherical shape fixed within 500 keV. The best fit values derived by chi-square minimization and also by visual inspections are given in Table I.

TABLE I

The parameters extracted from the CASCADE fits for 84 and 65 MeV beam energies.

Shape	$E_{\rm beam}$ MeV	E_1 MeV	Γ_1 MeV	E_2 MeV	Γ_2 MeV
Prolate	65	12.0	7.0	15.0	9.0
Oblate	65	13.5	8.0	15.0	9.0
Spherical	65	13.5	9.5	—	—
Prolate	84	13.0	11.5	15.0	12.5
Oblate	84	13.5	10.5	16.0	12.0
Spherical	84	13.5	12.0	—	—

The result of the analysis seems to favour oblate shapes more over spherical or prolate shapes for the 84 MeV data. However, for the 65 MeV spectra, the shape could not be ascertained unambiguously from the statistical model fits. The values of the deformation parameter β obtained from these fits were used in the calculations to fit the angular anisotropy of the high energy gamma rays for the two beam energies. The amplitude of the anisotropy for 84 MeV was found to be marginally less than that of 65 MeV. The anisotropy at 84 MeV could be reproduced assuming a non-collective oblate deformation with the β obtained from the statistical fit (see Fig. 1). This apparent consistency between the statistical model fit and the angular anisotropy is also in conformity with the theoretical prediction of a non-collective oblate shape beyond 1.6 MeV temperature [2]. However, unlike the case of ^{194}Au [3], the angular anisotropy pattern remains same at both energies and does not show any compelling evidence of non-collective prolate shape.

We have also calculated the potential energy surfaces (PES) for ^{188}Os in small steps of temperature and angular momentum to span the relevant phase space. Fig. 2 shows the result of our microscopic–macroscopic calculations for the different equilibrium shapes in the phase space spanning a wide range of temperature and angular momentum. The details of the calculations are to be published elsewhere [6] and will not be discussed here. Our calculations also indicate the most probable shape to be oblate over most of the phase space. At this stage it should be emphasized that the analysis of both line shape and angular anisotropy of the spectra and also the PES calculations should take into consideration the presence of thermal and shape-orientation fluctuations at finite temperature and angular momentum.

The nucleus, being an ensemble of finite number of particles, is expected to experience shape fluctuations. The deformations at minimum energy that we calculate are the so called most probable or mean field deformations and

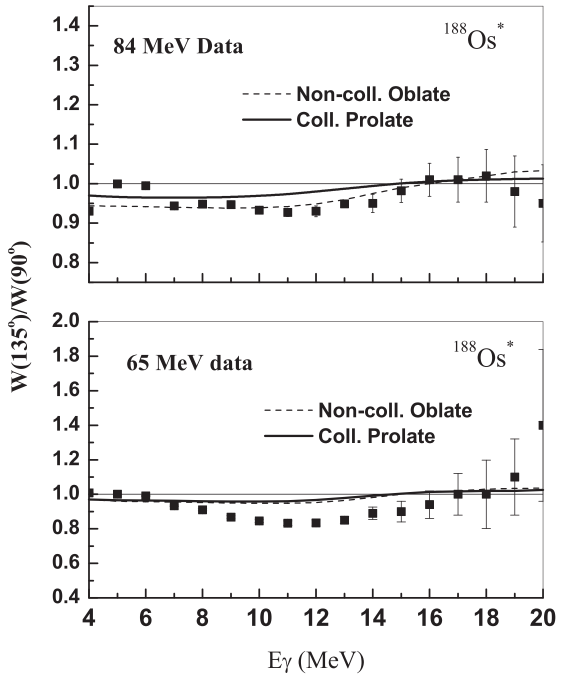

Fig. 1. Angular anisotropy plots for 84 and 65 MeV data for the low spin region corresponding to 4–6 folds. The broken and solid lines are the theoretical calculations assuming non-collective oblate and collective prolate shapes.

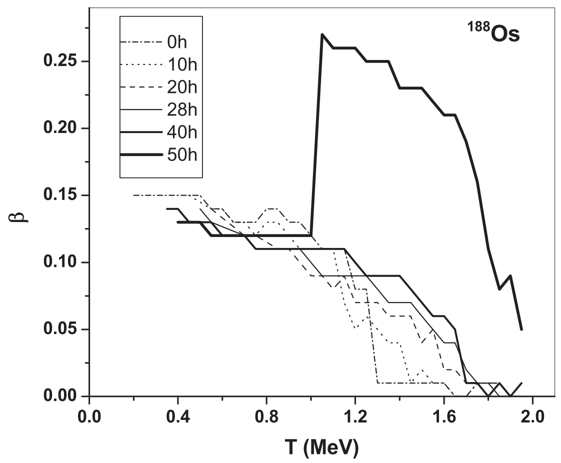

Fig. 2. The deformation parameter β *vs.* temperature for ^{188}Os for different values of angular momentum.

may be different from the average deformation. Similarly, in the experimental analysis the presence of fluctuations leads to the extraction of only the effective shape of the nucleus from the GDR data. However, at low temperatures shape fluctuations are small and average shape is similar to the most probable shape. Fluctuations start smoothing out the sharp transitions at higher temperatures. Moreover, there are still some open problems to be resolved in this field. There have been different metrics suggested by different authors and the calculated fluctuations may vary with these different metrics. Also the exact amount of fluctuation may also vary depending upon the nature of the calculation or its complexity. It has been shown by Hayashi, Hara and Ring [7] and pointed out by Goodman [8] that, compared to calculations that do not include angular momentum projections, the spin projection may lead to well defined minima and can considerably reduce the shape fluctuations. A necessary more complete analysis including fluctuation effects to have better understanding of the data is in progress and is to be reported elsewhere.

3. Search for GQR decay in excited ^{188}Os

In addition to the studies in shape transitions we have also embarked upon a comprehensive programme to search for the hitherto unobserved IVGQR based on excited states. The various non-GQR events that submerge the low yield GQR events are: (a) the high energy tail of the GDR, (b) the Bremsstrahlung gamma rays due to the target/projectile interaction and (c) the cosmic ray background. In addition one also have to ensure that there are not considerable pileup events remaining in the region of interest. All these sources of background are to be peeled off to dig out the IVGQR yield. The estimation of the remnants of all these backgrounds that cannot be fully eliminated by electronics or subtractions is also of paramount importance. The cosmic ray background was measured by switching off the beam and collecting the data for exactly the same duration as that of the beam time. The background data were collected with the same electronics setup and time windows as with the beam.

The left panel of Fig. 3 shows the spectrum taken at 150° with respect to the beam direction after the final data reduction along with the background spectrum collected for the same duration. The right panel of Fig. 3 shows the background subtracted spectrum that shows the definite peak structure centred around 24 MeV. The inset in the right panel of Fig. 3 shows the excess counts in a linearised plot. Fig. 4 presents the final fits to the spectrum including both a GQR component and a parametrised functional form of the Bremsstrahlung spectrum [9]. The final spectrum accounts to some extent for the enhanced counts around the GQR region but not entirely. We have observed the excess yield of high energy gamma rays in the 18–26 MeV region after a meticulous subtraction of the cosmic ray contribution for both beam energies and at all the four angles of measurements. This observation of a definite peak like structure exactly around the GQR region is interesting enough to encourage further measurements and hints towards a possible first observation of the IVGQR on excited state.

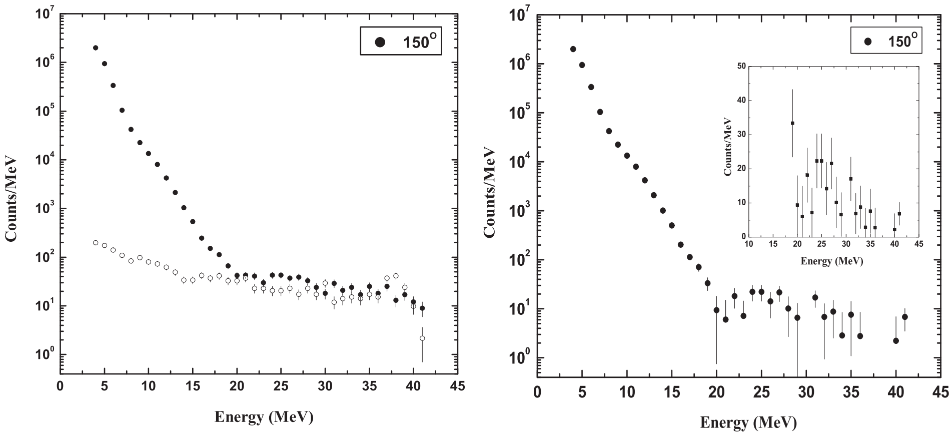

Fig. 3. The left panel shows ^{188}Os spectrum along with the measured background. The right panel shows the background subtracted spectrum and the linearised spectrum in the inset.

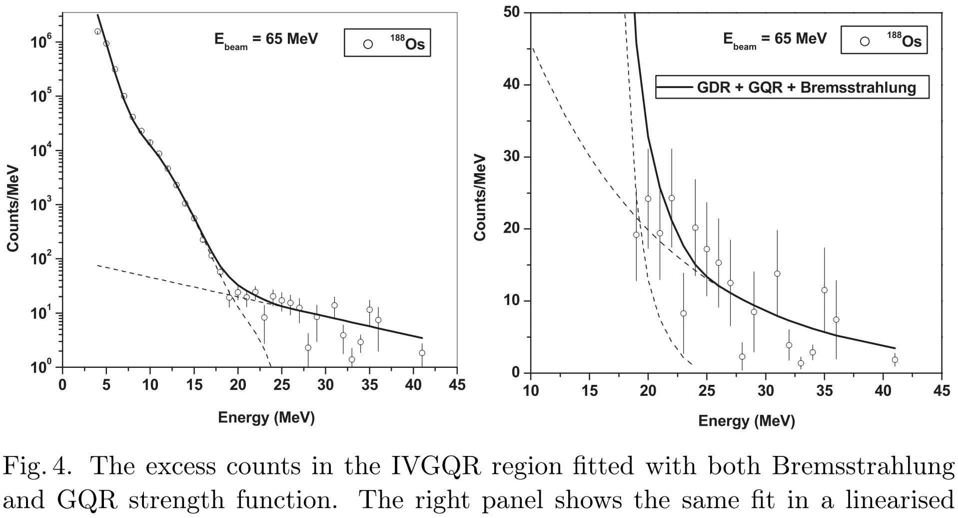

Fig. 4. The excess counts in the IVGQR region fitted with both Bremsstrahlung and GQR strength function. The right panel shows the same fit in a linearised plot.

4. The TIFR 4π spectrometer

A 4π sum-spin spectrometer has been designed, constructed and commissioned at the Tata Institute of Fundamental Research, Mumbai. The spectrometer is a close packed array of 32 conical NaI detectors of pentagonal and hexagonal cross-sections. The 12 pentagonal and 20 hexagonal detectors form a spherical shell of 10 cm inner diameter. The detectors are 7.6 cm long and are viewed by photomultiplier tubes of 2" diameter. An aluminium scattering chamber of 14 cm diameter is placed centrally inside the spherical shell. For in-beam experiments two of the pentagonal detectors placed 180° apart in the array are removed for the beam inlet and outlet. The primary role of the array is to measure the multiplicity and sum-energy of the discrete low energy gamma rays emitted in heavy-ion induced fusion-evaporation reactions. This spectrometer is primarily to be used in conjunction with a high energy gamma ray spectrometer for the detection of phase space selected Giant Dipole Resonance (GDR) gamma rays. In addition, the spin spectrometer can also be used in conjunction with charged particle or/and array of neutron detectors for measuring angular momentum gated charged particle and neutrons. The detailed design and associated electronics are discussed elsewhere [10]. The efficiencies of the detector and the full array was measured using calibrated low energy gamma sources. Extensive simulations were carried out using GEANT4 package to determine the efficiency and the response of the array and are being reported in a separate communication [11].

5. GDR decay from ^{192}Pt

In this section we report about a very recent experiment to search for rare shape-phase transition in excited ^{192}Pt nucleus. The basic motivation continues to be the search for the rare non-collective prolate phase. The compound nucleus was populated by bombarding a self supporting ^{180}Hf target of 2 mg/cm^2 thickness by 65 MeV ^{12}C beam from the TIFR Pelletron accelerator. The experimental arrangement was similar to that of the measurements for ^{188}Os. However, the multiplicity measurements were carried out by the 4π sum-spin spectrometer. The high energy gamma rays were measured at two different angles with respect to the beam direction in order to measure the angular anisotropy of the GDR gamma rays. Extensive numerical simulations were carried out to calculate the response matrix and efficiency of the 4π array for the low energy discrete gamma rays [10, 11]. Numerical calculations were also carried out to extract the multiplicity distribution of the gamma rays from the observed coincidence fold distributions.

The initial analysis of the spectral shape and the angular anisotropy indicate a deformed non-spherical shape for the nucleus at 65 MeV beam energy. The left panel of Fig. 5 shows the high energy gamma rays spectrum taken at 90° with respect to the beam direction after data reduction and gated with 4–6 folds in the spin spectrometer. The full line is statistical model calculation assuming a prolate deformation and convoluted with

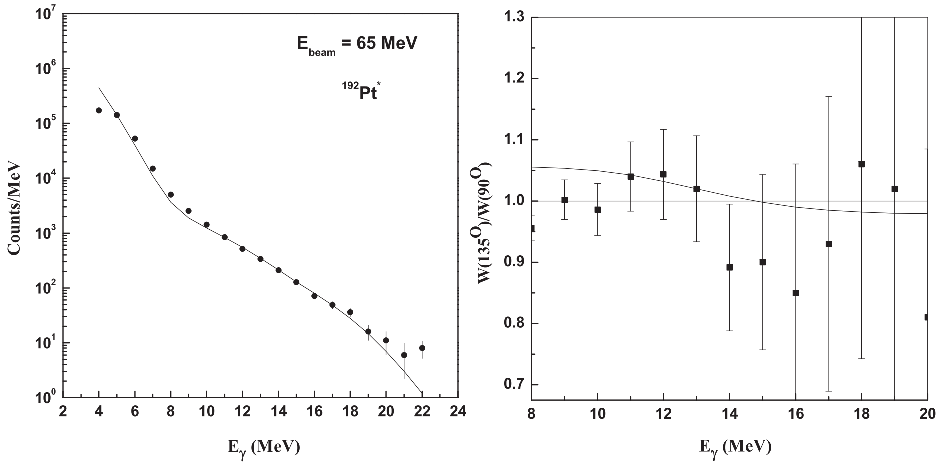

Fig. 5. The left panel shows the GDR spectrum from ^{192}Pt fitted with CASCADE calculations assuming prolate deformation. The right panel shows the angular anisotropy data along with the fit assuming a prolate deformation as extracted from the CASCADE fit.

the detector response matrix. The data for different fold gates for the two different angles have been extracted and fitted with statistical model calculations. The angular anisotropy data have also been fitted with calculations assuming different shapes and deformations. The right panel of Fig. 5 shows the angular anisotropy data with a fit assuming prolate non-collective shape. The pattern is very similar to what was observed earlier in case of ^{194}Au and hints towards a non-collective prolate phase. We have recently completed more measurements at higher beam energies and the analysis to look for a definite shape transition is in progress. We have also carried out detailed potential energy surface calculations for ^{192}Pt. A more complete analysis of the experimental data for both energies, including the fluctuations, are in progress and will be reported elsewhere.

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