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Quadrupole moment measurements of TSD1 and TSD2 bands in ^{167}Lu

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Abstract
The triaxial strongly deformed (TSD) bands in ^{167}Lu were populated by the ^{123}Sb(^{48}Ca, 4n) reaction with a beam energy of 203 MeV. Gamma rays, requiring five fold or more in prompt coincidence, were detected with the Gammasphere spectrometer. Of particular interests are TSD bands 1 and 2 which have previously been interpreted as zero phonon and one phonon wobbling bands, respectively. Using the Doppler shift attenuation method (DSAM), a preliminary transition quadrupole moment of $6.9^{+0.3}_{-0.3}$ eb was extracted for the TSD1 band. Data analysis continues for TSD2 which is considerably more weakly populated.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Recently, triaxial strongly deformed (TSD) bands in the mass $A \sim 165$ region have received considerable experimental and theoretical attention. Experimentally, over 30 TSD bands are proposed in this mass region in the Lu and Hf isotopes [1]. The wobbling mode, which is uniquely related to the triaxiality of the nuclear system, has been assigned for some of the TSD bands in ^{163,165,167}Lu [2–5]. Triaxial deformed nuclei possess three different moments of inertia and, in principle, can rotate about any of the principal axes, although energetically rotation is favoured about the axis with the largest moment of inertia. The wobbling mode is uniquely related to the rotational motion of a triaxial deformed nucleus and is described [2, 6] as a deviation of the collective rotation away from the principal axis with largest moment of inertia. It is characterized by the wobbling phonon number n_w, where $n_w = 0, 1, 2$, etc. Rotational bands are built on wobbling phonon numbers n_w and have similar intrinsic structures [1].

Since the intrinsic structure of the wobbling bands is expected to be similar, it is crucial to measure the quadrupole moments for the TSD1 and TSD2 bands in ^{167}Lu to provide further evidence for the wobbling interpretation for these bands. For example in ^{163}Lu, the quadrupole moments and inband $B(E2)$ values for the zero and one phonon TSD bands were measured [7] and found to be similar for both bands. The aim of the present work is to measure the quadrupole moments for TSD1 and TSD2 bands in ^{167}Lu using the Doppler shift attenuation method (DSAM).

2. Experimental method

High spin states of ^{167}Lu were populated using the ^{123}Sb (^{48}Ca, $4n$) reaction at a beam energy of 203 MeV. The beam was supplied by the ATLAS accelerator at the Argonne National Laboratory. An $\sim$1 mg cm^{-2} ^{123}Sb target with an $\sim$10 mg cm^{-2} gold backing was used to slow down and stop the recoils. Gamma ray coincidences were measured with the Gammasphere spectrometer which at the time of the experiment consisted of 101 Compton-suppressed Ge detectors. A total of 5×10^9 events requiring five or more suppressed Ge detectors in prompt coincidence, which corresponds to 3.9×10^{11} unfolded triple coincidences, were collected in approximately one week of beam time and used in the off-line analysis.

The DSAM is used to measure nuclear level lifetimes in the few picoseconds range. For DSAM experiments, a thick backing material is added at the back of the target. When the recoiling nuclei traverse the backing material they are slowed down and eventually stopped by atomic and nuclear collisions. The energies of gamma rays emitted while the nuclei are slowing down in the backing material shift due to the Doppler effect. These shifts can be measured at different observation angles and, knowing the electronic and nuclear stopping powers, they can be converted into nuclear lifetimes. The simplest method of extracting lifetime information of nuclear levels using the DSAM is the centroid shift method [8]. The mean energy of a γ ray emitted at an angle θ by a moving nucleus is given by

$$E_\gamma = E_0[1 + F(\tau)\beta_0 \cos\theta] \tag{1}$$

where E_0 is the unshifted γ ray energy, $F(\tau)$ is the fraction of the full Doppler shift and β_0 is the mid-target velocity of the recoiling nucleus. The lifetimes of the excited levels, and thus the quadrupole moments of the bands, can be extracted from the experimental $F(\tau)$ values.

3. Data analysis and results

The data tapes were presorted into compressed disk files by requiring three or more folded clean events with prompt time gates. For DSAM analysis, double-gated spectra for each detector angle were projected from this database. A variety of gating transitions were used to (a) initially identify fully stopped, partially stopped and moving transitions in the TSD bands and (b) produce the final spectra for centroid shift or lineshape analysis.

Two approaches are used for further analysis. In the first, the gates are placed on stopped transitions below those of interest and lifetimes are extracted for higher lying states. This approach has the advantage of higher statistics since the gating transitions are more intense, but the disadvantage of being sensitive to the lifetimes of the sidefeeding transitions. In the

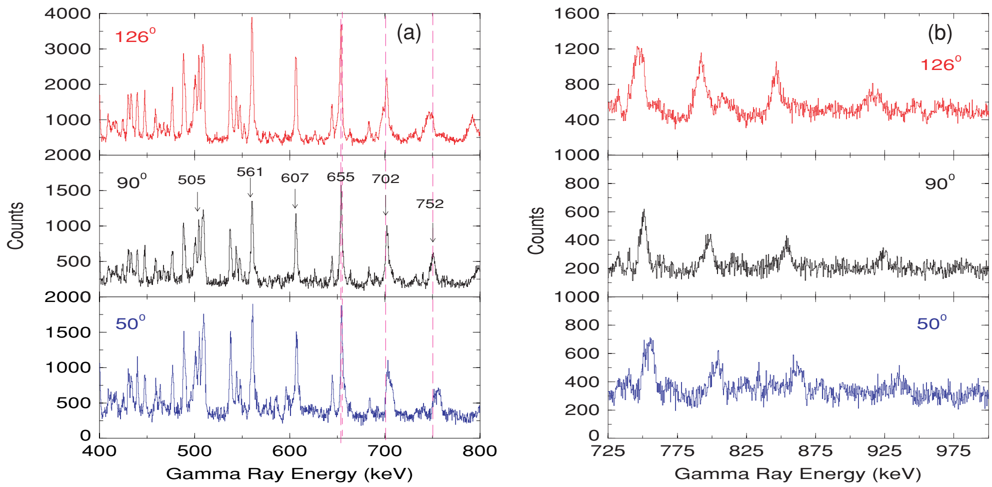

Figure 1. The Doppler shift of transitions in TSD1 observed at 50°, 90° and 126° (122° and 130° combined), respectively. The spectra (a) show the transitions from lower spin states and (b) show the transitions from higher spin states in TSD1.

second approach, gates are placed on the moving component of transitions and the lifetimes are extracted for the states lower down the band. This method is not sensitive to sidefeeding transitions but the statistics are much lower and the position of the gates and the assumed $F(\tau)$ for the gating transitions need to be adjusted angle by angle. The results reported here are primarily from gates set on stopped transitions.

Figure 1 displays that the Doppler shift of the transitions in TSD1 is observed at backward, 90° and forward angles by using the first method. The spectrum for 90° is used to identify the positions of the peaks.

The high energy part of the spectra for the same angles are shown in figure 1(b). The transitions from the higher spin states have only moving components showing that the level lifetimes are getting shorter as we go up the band. As can be seen from figure 1(b), it is difficult to identify peaks from higher spin states in the band. Gates set on the lowest transitions do not reveal the top of the band due to the low statistics. To observe transitions coming from the higher spin levels the second approach, outlined above, gating on moving components, is used. This part of the analysis is still in progress.

The spectra produced by the first method were used to find the centroid shifts. The experimental $F(\tau)$ values were extracted from the least square fits of centroid shifts using the Doppler shift formula (1). The transition quadruple moment Q_t and the side feeding quadrupole moment Q_{sf} were extracted using the program FITFTAU [9] for TSD1. The branching ratios of inband transitions and the side feeding intensities were calculated using data from previous thin target experiment [2] and were used as input parameters for the program, together with experimental $F(\tau)$ values. The stopping powers for the target and the gold backing were calculated using the program SRIM2003[9]. The experimental F(τ) values are fitted by varying Q_t and Q_{sf} until the minimum χ^2 value was reached. For TSD1 $Q_t = 6.9^{+0.3}_{-0.3}$ eb and $Q_{sf} = 4.4^{+0.4}_{-0.2}$ eb were deduced. The fit produced by FITFTAU is shown in figure 2. The ~10–15% systematic error due to the stopping power calculations is not included in the error bars.

[9] Information on the computer code SRIM 2003 can be found in http://www.srim.org/

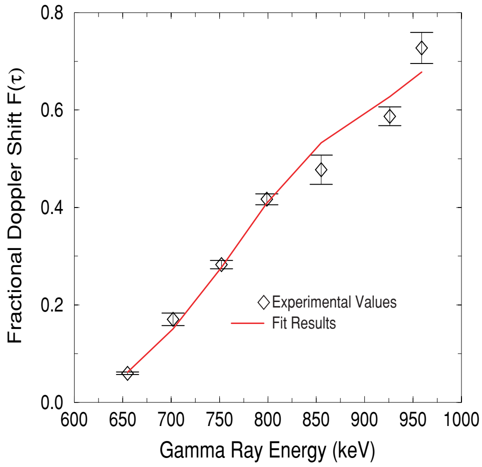

Figure 2. The experimental $F(\tau)$ and the fit produced by the program FITFTAU for the transitions in TSD1.

It is difficult to extract a clean spectrum for TSD2 which is considerably more weakly populated than TSD1. The transition energies of TSD1 and TSD2 are very close for the lower spin states. Therefore, gates set on lower transitions for TSD2 yielded spectra that were dominated by TSD1 transitions. To isolate the TSD2 transitions it is necessary to put the gates on moving transitions in this band, which is in progress.

Our preliminary value of the transition quadrupole moment $Q_t = 6.9^{+0.3}_{-0.3}$ eb for TSD1 is smaller than the neighbouring ^{163,164}Lu [7, 10] which indicates a possible decreasing trend in quadrupole deformation with increasing neutron number. In the future, a lineshape analysis will be performed to extract the transition quadrupole moments for each transitions in the TSD bands to investigate the spin dependence of quadrupole deformation as discussed in [7, 10, 11].

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