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BRIEF REPORTS

Brief Reports are short papers which report on completed research or are addenda to papers previously published in the **Physical Review.** *A Brief Report may be no longer than four printed pages and must be accompanied by an abstract.*

High-spin results for ^{155}Tb

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High-spin states in ^{155}Tb have been identified via the weak $p4n$ exit channel of the ^{36}S + ^{124}Sn reaction using the Gammasphere array. The $\pi h_{11/2}$ yrast band has been established up to $I^{\pi} = 67/2^-$ filling an important gap in the $N = 90$ high-spin systematics. The variation of the first $i_{13/2}$ neutron backbend as a function of proton number for $N = 90$ isotones and trends regarding the phenomenon of signature splitting and signature inversion in the odd-Z nuclei are discussed.

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A near panoply of high-spin phenomena has been observed in the $N = 90$ nuclei, including, for example, rotational alignment of pairs of high-j neutrons and protons, rich multiple-quasiparticle band structures, drastic rotation induced shape changes leading to band termination, and, at the very highest spins observed in normally deformed nuclei, evidence for the diminishing of pairing correlations; see Ref. [1] and references therein.

Figure 1 shows a plot of proton number versus observed maximum spin for the $61 \leqslant Z \leqslant 72$, $N = 90$ isotones prior to this work. The sudden drop below $Z = 66$(Dy) reflects the fact that only light ion ($A \leqslant 11$) induced compound nuclear reactions can be used to produce high spins in the $Z \leqslant 65$ nuclei via the dominant neutron evaporation channels. In contrast, the $Z \geqslant 66$ nuclei may be created via [heavy ion (HI),xn] reactions using heavier beams ($A \sim 30$–50), thus allowing the population of much higher spin states. In the case of ^{155}Tb ($Z = 65$), the extremely low maximum spin value $I = 31/2$ [2] is also due to the fact that this nucleus had not been studied using a modern escape suppressed Ge detector array. The present work uses the multiple-detector array Gammasphere [3] to pick out the weak $p4n$ reaction channel and establishes the $\pi h_{11/2}$ yrast band in ^{155}Tb to spin values above $30\hbar$.

High-spin states in $^{155}_{65}$Tb$_{90}$ were populated using the ^{124}Sn(^{36}S,$p4n$) reaction at a beam energy of 160 MeV. The beam was provided by the 88″ Cyclotron at Lawrence Berkeley National Laboratory and γ-ray coincidences were detected using the early implementation of the Gammasphere array consisting of 34 escape suppressed Ge detectors. The target consisted of two stacked foils of ^{124}Sn, each of thickness 500 μg cm^{-2}. Approximately 1.5×10^9 threefold or higher suppressed coincidence events were collected. Analysis has been performed utilizing the cube inspection program LEVIT8R [4]. Preliminary results on this work have been reported in Ref. [5].

Although the neutron evaporation channels leading to Dy isotopes accounted for about 95% of the observed reaction cross section, the wonderful ability of the new generation of Ge detector arrays to resolve weak channels, combined with sophisticated analysis software, has enabled a great deal of

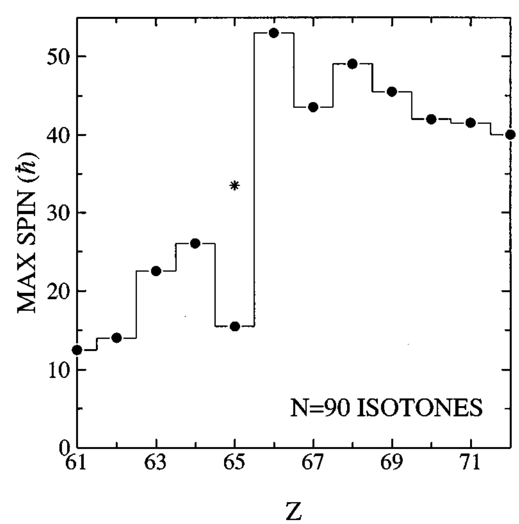

FIG. 1. Observed maximum spin versus Z for the $N = 90$ isotones. The asterisk indicates the new value for ^{155}Tb ($Z = 65$) obtained in the present work.

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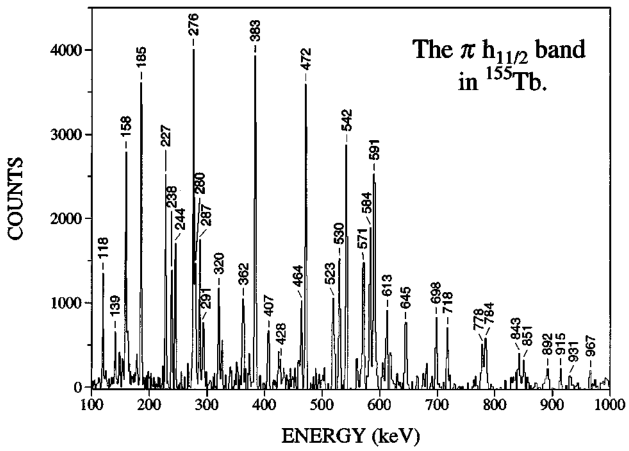

FIG. 2. Summed γ-ray coincidence spectrum for the $h_{11/2}$ band in ^{155}Tb.

new high-spin information to be extracted for the weak ($\approx 1\%$) $p4n$ (^{155}Tb) and αxn (^{152,153}Gd [6]) channels. In ^{155}Tb we have populated the $\pi h_{11/2}$ yrast structure and a coincidence spectrum of this band is shown in Fig. 2. The deduced level scheme is presented in Fig. 3 and is built upon previous work which had established this sequence up to the $31/2^-$ level [2]. Due to the weakness of the ^{155}Tb channel and the complexity of the spectra, it has not been possible to extract accurate transition strength $[B(M1)/B(E2)]$ ratios.

In Fig. 4 an aligned angular momentum plot [7] is displayed for the $\pi h_{11/2}$ ^{155}Tb band with the first (AB) $i_{13/2}$ neutron backbend occurring in both signatures[1] near $\hbar\omega\sim 0.27$ MeV. The upbend for the $(\pi,\ \alpha)=(-,-1/2)$ sequence at high rotational frequency signifies the gradual alignment of the second (B_pC_p) $h_{11/2}$ proton pair [8]. These new results on ^{155}Tb are valuable since they allow key systematic trends to be mapped out for a full set of $N=90$ nuclei. For example, Fig. 5 shows the $N=90$ systematics for the first $i_{13/2}$ band crossing frequency. In the odd-Z cases the different crossing frequencies for the $(-,+1/2)$ and $(-,-1/2)$ bands are due to the large initial signature splitting in energy of the $h_{11/2}$ sequences. The divergence of the even-Z and odd-Z crossing frequencies at low Z values ($Z<67$) is interesting, especially since the quadrupole deformations for Eu, Gd, Tb, and Dy are expected to be very similar [9]. It seems possible that in the even-even Gd and Dy cases, the complicated nature of the band crossing region, where not only the ground state band $\rightarrow AB$ crossing takes place, but also the beta vibrational band $\rightarrow AB$ crossing, as well as the ground state $\rightarrow BCAD$ crossings that occur with strong interaction strengths [10,11], results in the crossing frequency for the former $(g\rightarrow AB)$ being perturbed slightly.

The phenomenon of signature inversion in rotating nuclei was first observed in $N\approx 90$ odd-Z nuclei (see Ref. [12] and references therein), and a great deal of work has taken place on this subject utilizing a wide variety of models. The $h_{11/2}$ bands in even-N Ho, Tm, and Lu isotopes have received most attention (see, for example, Refs. [13–23]), but now our data on ^{155}Tb, combined with the recent results on ^{153}Eu [24] and ^{151}Pm [25], allows the full systematic study of signature splitting from $Z=61$ to 71 to be investigated.

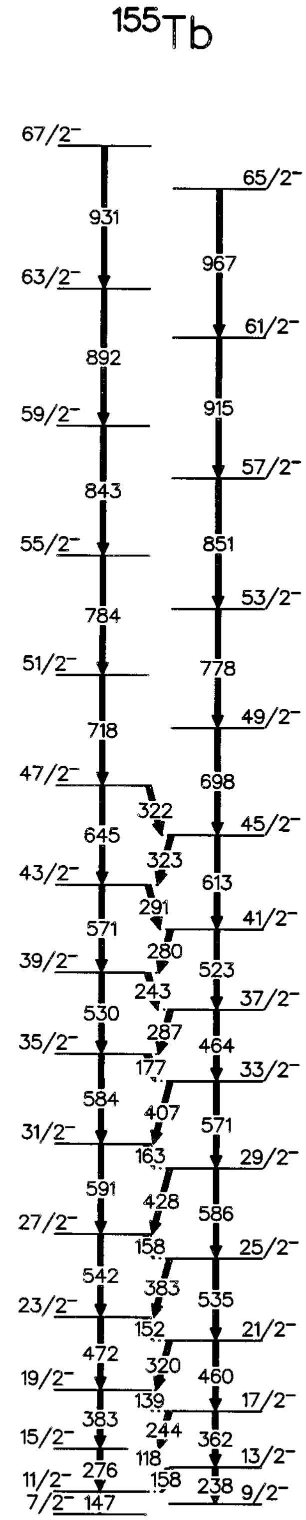

FIG. 3. Level scheme for the $h_{11/2}$ band in ^{155}Tb. The $\frac{7}{2}^-$ level is at an excitation energy of 250 keV [2].

[1]Signature is the quantum number associated with the rotation of a deformed nucleus around a principal axis by 180° and is defined, for an odd-A nucleus, as $\alpha=\frac{1}{2}(-1)^{I-1/2}$.

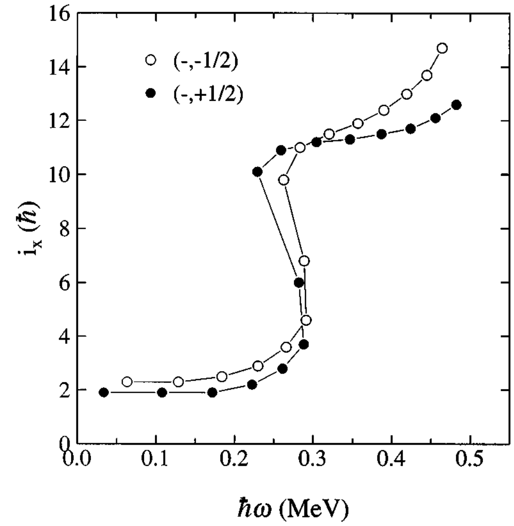

FIG. 4. Alignment plot for the $h_{11/2}$ band in ^{155}Tb. The Harris reference parameters used were $\mathscr{J}_0 = 32\ \hbar^2$/MeV and $\mathscr{J}_1 = 34\ \hbar^4$/MeV^3.

The energy splitting (divided by $2I$) between adjacent levels in the two signatures of the $h_{11/2}$ sequences as a function of spin is shown in Fig. 6. The signature inversion effect occurs when the initially energetically unfavored $\alpha = +1/2$ (solid circles) drops below the favored $\alpha = -1/2$ (open circles).

Four systematic trends can be seen in Fig. 6. First, there is a larger signature splitting at low spin observed for the Tm and Lu isotopes as compared to the lower Z isotones. This may be understood in terms of the lower quadrupole deformation of Tm and Lu compared with those of Ho, Tb, Eu, and Pm nuclei which are predicted to be rather similar [9]. A reduction in the triaxial γ deformation with decreasing Z [15] would also be consistent with this signature splitting trend. Second, a sudden quenching of the signature splitting occurs at $I = 33/2$. This is associated with polarization effects due to the rotational alignment of a pair of $i_{13/2}$ neutrons. Third, in the Ho, Tm, and Lu isotopes this leads to signature inversion above $I = 33/2$. This latter effect has been discussed, using a triaxial particle-rotor model [15,22], in terms of a shape change from negative to positive values of the triaxial shape parameter γ, induced by the rotational alignment of $i_{13/2}$ neutrons. Other interpretations based on, for example, γ vibrations built on a symmetric shape [19] and also the interacting boson-fermion model [23] have been suggested. For Z values less than 67, however, signature inversion above the backbending point does not occur and, in fact, seems to appear increasingly less likely for lower Z values. Finally, there is a trend at the highest spins, for a reversal back to the low-spin signature ordering. This reversal occurs at a higher spin for increasing Z, for example, near spin $I \approx 25$ in Ho, $I \approx 30$ in Tm. Understanding this rich interplay of signature effects in this long chain of $N = 90$ odd-Z nuclei is a theoretical challenge. It is possible that signature-dependent shapes for the $\pi h_{11/2}$ bands, as suggested in Ref. [27], may play an important role, as could octupole correlations, which become especially strong in ^{151}Pm and ^{153}Eu [24,25,29].

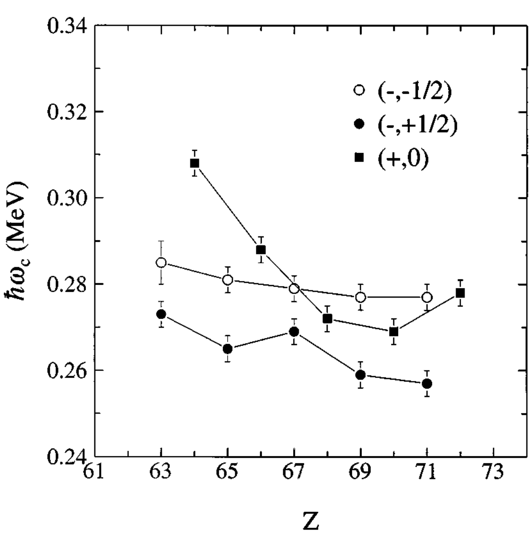

FIG. 5. The systematics of the first $i_{13/2}$ (AB) neutron crossing frequency for $N = 90$ nuclei.

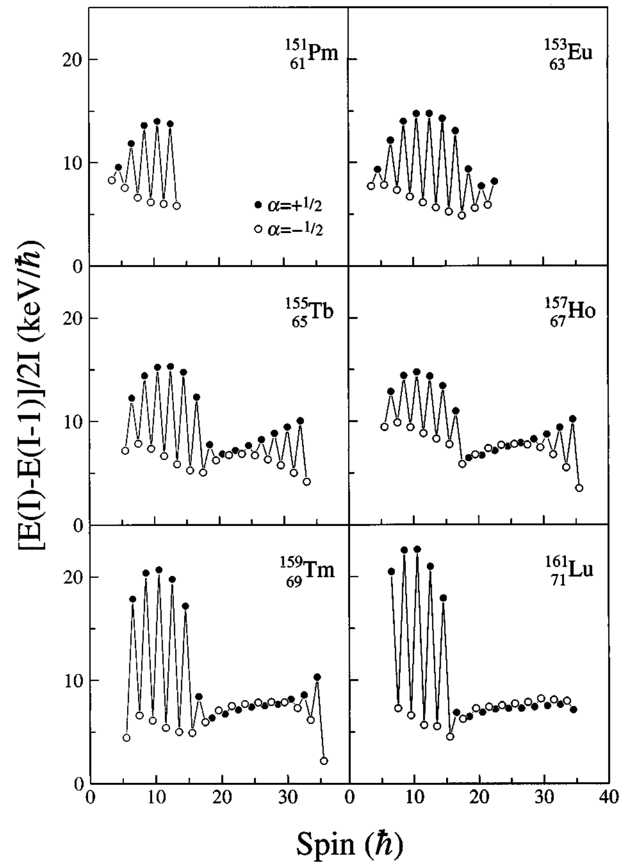

FIG. 6. Signature splitting in the odd-Z $h_{11/2}$ bands of $N = 90$ nuclei. The data sources are as follows: ^{151}Pm [25], ^{153}Eu [24], ^{157}Ho [27], ^{159}Tm [28], and ^{161}Lu [26].

In summary, high-spin states in ^{155}Tb have been observed for the first time. The $\pi h_{11/2}$ band has been established to a spin of $I = 67/2^-$. These results help complete the $N = 90$ high-spin yrast systematics from $Z = 61$ to 72. The trends in signature splitting and inversion and the backbending behavior as a function of proton number were discussed.

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