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SIGNATURE SPLITTING IN ^{135}Pr

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Abstract

In-beam spectroscopic study of ^{135}Pr was made using 91 MeV ^{120}Sn(^{19}F,4n) reaction. A strong negative parity proton band based on the $h_{11/2}^{-}$ 1/2[550] configuration with α=-1/2 was observed. Possibly α=+1/2 unfavored band is observed. Also two positive parity proton bands are observed most likely based on the $g_{7/2}^{+}$ 5/2[413] configurations with $\alpha=\mp 1/2$. In all cases (except for the $(\pi,\alpha)=(-,+1/2)$ band) the backbending is caused by alignment of two $h_{11/2}^{-}$ 9/2[514] quasi-neutrons. For the strongly decoupled $\pi(-)$ bands the observed signature splitting decreases with increasing rotational frequency. The signature splitting of the positive parity bands increases with rotational frequency and then inverts above the backbending. This is interpreted to be caused by the quasi-neutrons, which drive the γ-deformation to the negative values.

Nuclei in the vicinity of La, Ce, Pr are predicted to be soft in γ-deformation [CHE83]. An investigation was undertaken to study the signature splitting between rotational bands in ^{135}Pr, which is related to γ-deformation. ^{135}Pr was produced by the ^{120}Sn(^{19}F,4n) reaction at 91 MeV using the tandem accelerator at the Brookhaven National Laboratory. Coincidence data were recorded between 4 Compton-suppressed Ge detectors at ~ 40° relative to the beam and 2 unsuppressed Ge detectors at ~ 85°. In addition an array of 11 NaI detectors around the target were used as a multiplicity selector.

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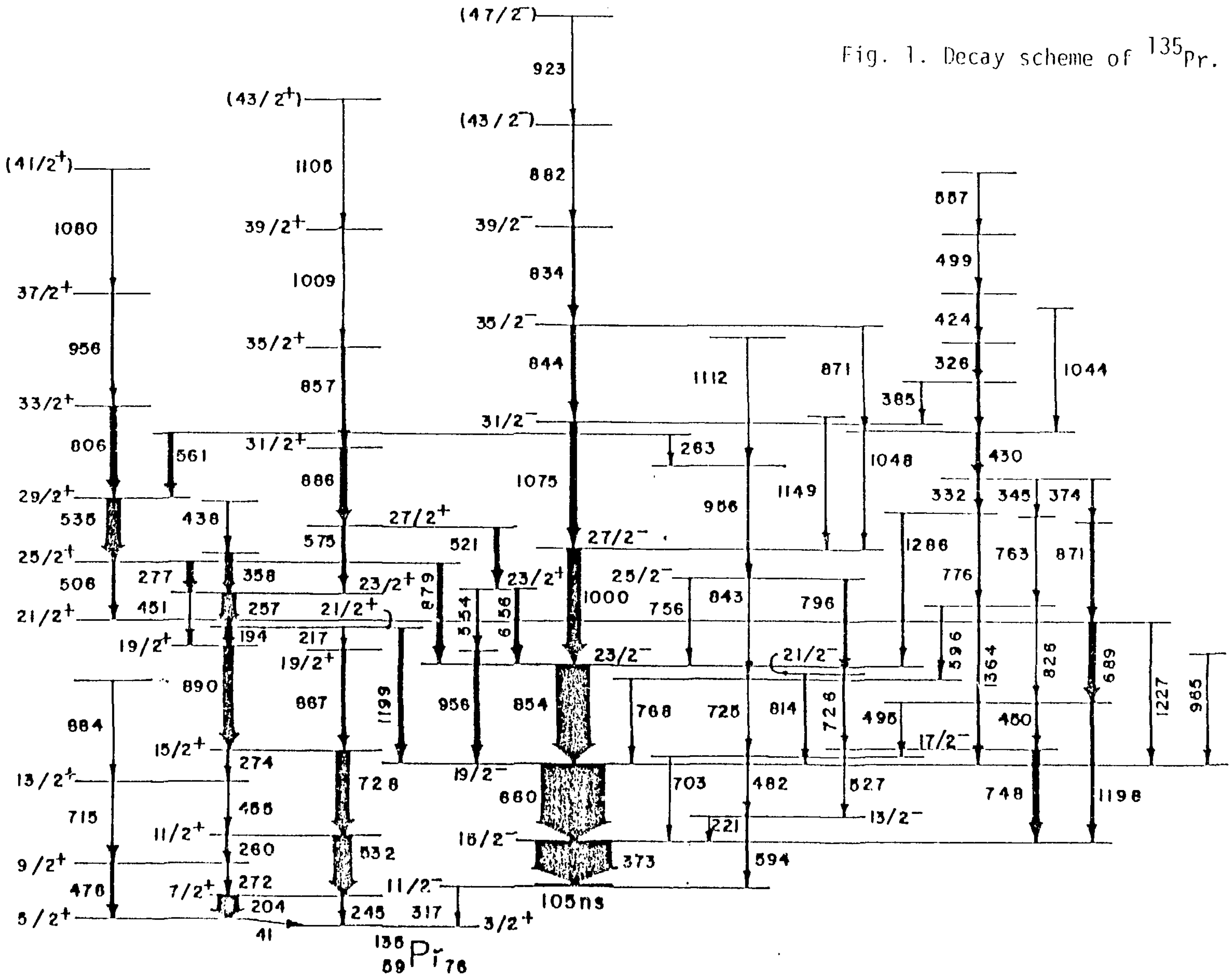

Fig. 1. Decay scheme of ^{135}Pr.

The ^{135}Pr decay scheme is shown in Fig. 1 and it was constructed from $\gamma\gamma$-coincidence, intensity, and angular correlation information. Low-spin studies of ^{135}Pr from in-beam and radioactive decay work [KOR85, WIS75, CON73, EKS72] were valuable in assigning spins and parities of high-spin states. Most of the intensity goes to the proton band which is based on $h_{11/2}^{-}$ 1/2[550] configuration, with signature α=-1/2. There is also some evidence for the α=+1/2 unfavored band. The path through the 843, 725, and 482 keV cascade was chosen because the 482 keV transition was known before [KOR85], over more intense path through 796 and 726 keV cascade. The two bands are strongly decoupled because of the K=1/2 band head. However, by adding 4 neutrons the 13/2⁻ level moves below 15/2⁻ level in ^{139}Pr [PII80] due to the increase of γ from 21° to 34° (slightly oblate, see Fig. 2). The α=±1/2 positive parity bands are most likely based on $\pi g_{7/2}^{+}$ 5/2[413] configuration. There are several M1 connecting transitions observed. The M1 branching fractions from favored band are: 0.05 for the 274 keV, 0.12 for the 260 keV, and 0.91 for 204 keV transitions. On the other hand transitions from the unfavored to favored band are so weak, that they can be seen only from the favored band below. This is in agreement with B(M1)/B(E2) systematics for connected rotational bands [HAG82]. Above the backbending most of the intensity goes to the (π,α)=(-,-1/2) band similarly as it is observed in ^{133}Pr [HIL85].

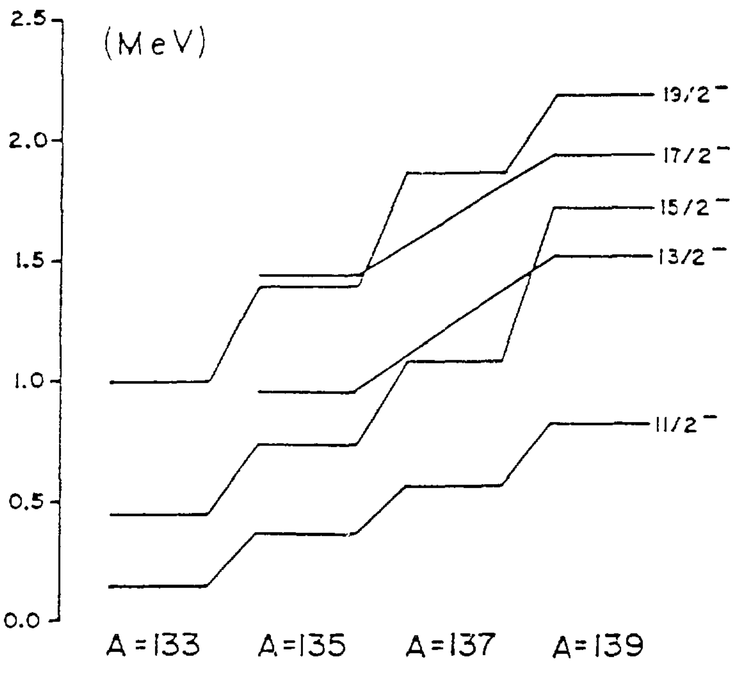

Fig. 2. Systematics of $\pi(-)$ levels in odd-A Pr isotopes. References: A=133 [HIL85], A=135 [KOR85], A=137 [KLE75], A=139 [PII80].

Changes of γ-deformation in rotational nuclei are caused by the balance between the driving forces resulting from the quasi-particle properties before backbending (i.e. its position relative to the Fermi level and trajectory in the e'-γ plane), the behavior of aligning quasi-particles at the backbend, the γ-softness of the core, and the collective rotation [LEA82, FRA83, CHE83, BEN84]. These changes in γ-deformation are thus observed as changes or even inversions [BEN84] of signature splitting. The core is expected to be driven by rotation towards $\gamma \sim -30^0$ (in the Lund convention [AND76, LEA82]). Quasi-particles occupying high-j shell cause the driving force towards $\gamma > 0^0$ when the Fermi level is at the beginning of the shell, toward $\gamma \leq 0^0$ with Fermi level in the middle of the shell, and towards $\gamma < 0^0$ with Fermi level close to the top of the shell [LEA82]. Experiments described in the literature involved ^{159}Tm [LAR84], ^{155,157}Ho [GAR82], ^{81}Kr [FUN83], ^{129}Ce [ARY84]. In those cases the bands were based on mid-shell quasi-particles with aligned quasi-particles at the bottom of another shell. The net driving force was towards $\gamma \geq 0^0$ and decrease of signature splitting was observed.

Fig. 3 shows the aligned angular momentum for three bands in ^{135}Pr. As can be seen the backbending is caused by alignment of two $h_{11/2}^-$ 9/2[514] quasi-neutrons. Experimental energies in the rotating frame, E', are plotted on Fig. 4 and 5. The signature splitting is defined as the difference between E' for opposite signatures. In case of $\pi h_{11/2}^-$ bands the signature splitting decreases with increasing of ω. The theory predicts disappearance of the signature splitting at or after the backbend [CHE83]. This is difficult to test here because the unfavored band is uncertain, and because it was not populated up to the backbend. The $\pi g_{7/2}^+$ bands show increase of the signature splitting up to the backbend with $E'(\alpha=-1/2)-E'(\alpha=+1/2) \cong -100$ keV at the crossing frequency. This is in qualitative agreement with theory, which predicts a value of -280 keV [CHE83]. After the backbending the signature splitting inverts and then appears to approach another inversion. This is illustrated on Fig. 6, in which the energy difference between $\Delta I=1$ levels is plotted vs. middle spin for both signatures [RIE83].

This effect can be explained by alignment of two $h_{11/2}^-$ quasi-neutrons from the top of the shell which is causing a shift towards $\gamma < 0^0$ and a drastic

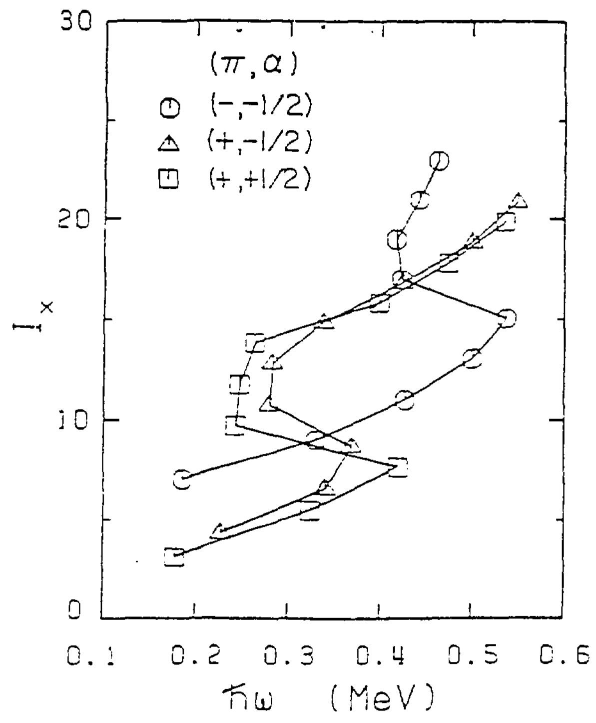

Fig. 3. Aligned angular momentum vs. rotational frequency.

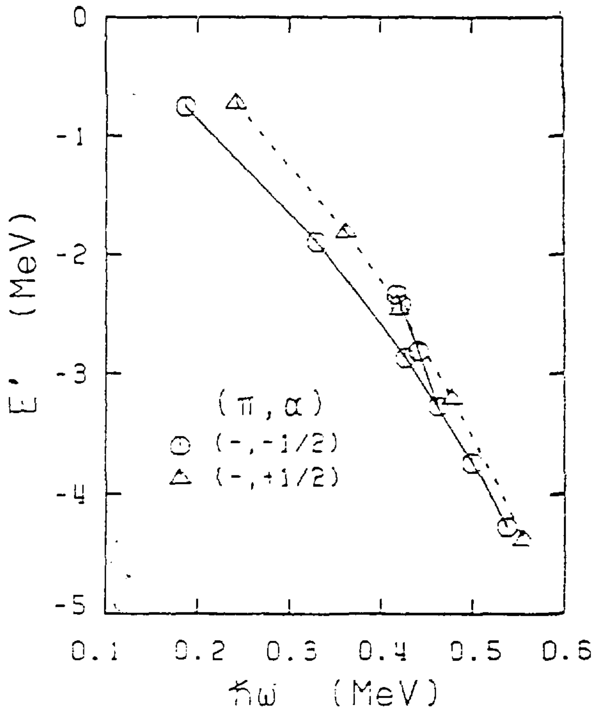

Fig. 4. Energy in the rotation frame vs. rotational frequency.

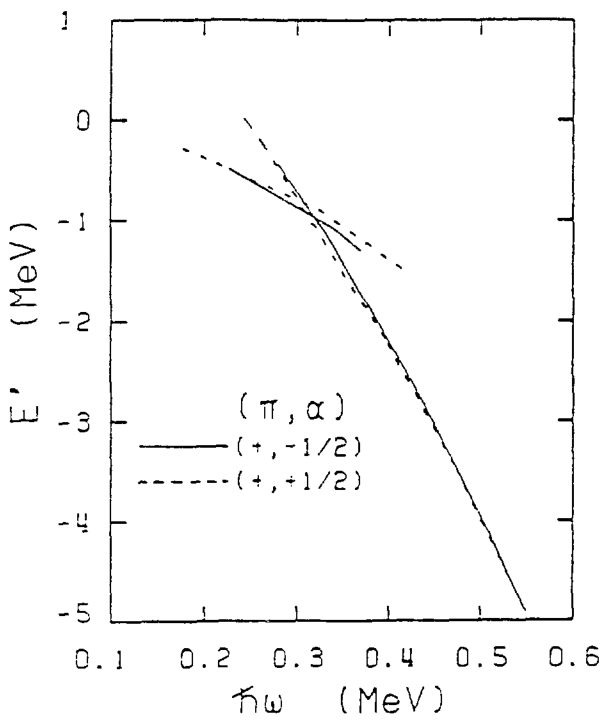

Fig. 5. Energy in the rotation frame vs. rotational frequency.

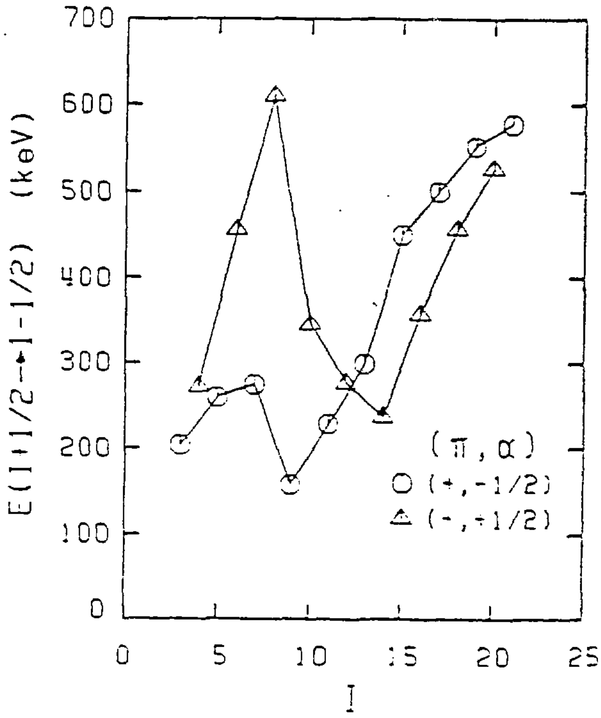

Fig. 6. Energy between levels I+1/2 and I-1/2 vs. middle spin.

change in signature splitting. This negative-γ effect was predicted by Chen and co-workers [CHE83]. One should point out that the inversion of signature splitting agrees with prediction of Bengtsson and co-workers [BEN84] for the case when the Fermi level lies in the upper part of the shell. For higher ω, the system is approaching another inversion again in agreement with the predictions of Ref. [BEN84]. In the positive parity bands of ^{133}Pr [HIL85] signature splitting decreases after backbend, but it does not invert as in ^{135}Pr. The reason is that by removing two neutrons the Fermi level is pushed towards the middle of the $h_{11/2}^{-}$ shell and the negative-γ force decreases.

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