Odd-even staggering in the $\pi g_{9/2}\nu g_{9/2}$ band in ^{72}Br

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High-spin positive-parity states in ^{72}Br have been studied using the ^{16}O+^{58}Ni reaction. The $\pi g_{9/2}\nu g_{9/2}$ decoupled band in ^{72}Br has been observed up to $\sim$10 MeV excitation energy and the expected odd-even staggering has been delineated. A larger signature splitting is observed for this band in ^{72}Br than in the same collective structures in the heavier ^{74,76,78}Br. No signature inversion at low spin is observed for this band in ^{72}Br, in contrast to the heavier isotopes, ^{74,76,78}Br, in which signature inversion is observed below $\sim 10\hbar$. The observations are in general agreement with theoretical models in this mass region which predict no signature inversion for nuclei with less than 39 protons and neutrons. [S0556-2813(99)02811-3]

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The mass region around $A\sim 70$ is well known for its complicated interplay between single-particle and collective degrees of freedom. Spherical structures coexist with more deformed shapes associated with the proton intruder $g_{9/2}$ orbital. Indeed, prolate decoupled $\Delta I=2$ bands built on the $g_{9/2}$ orbital have been observed in the odd-A Br isotopes [1]. The odd-odd Br nuclei are of special interest since they are amongst the heaviest nuclei where proton and neutron excitations in the same orbital ($g_{9/2}$) are possible. In odd-odd ^{74}Br [2], ^{76}Br [3,4], and ^{78}Br [5] decoupled bands built on the $\pi g_{9/2}\otimes\nu g_{9/2}$ configuration have been previously established. However, in ^{72}Br only indirect evidence of the presence of a decoupled band built on this configuration was reported [6,7], based on similarities of the lower level scheme to the corresponding ones in ^{74,76,78}Br. Thus, an extension of the level scheme of ^{72}Br to higher excitations is important in order to search for evidence of this configuration in this isotope. Moreover, a study of ^{72}Br is of interest in understanding the behavior of $N=Z+2$ nuclei.

A signature inversion occurs within the $\pi g_{9/2}\otimes\nu g_{9/2}$ band in ^{74,76,78}Br below spin $I\sim 10\hbar$. The same phenomenon has been observed in other odd-odd isotopes in this mass region, specifically ^{80}Rb [8], ^{82}Y [9], and ^{84}Nb [10]. Cranked mean-field and particle-rotor models have been used to interpret the occurrence of signature inversion (see Ref. [11], and references therein). However, a comprehensive interpretation of the phenomenon is still lacking. Of special interest in the study of ^{72}Br is a model introduced by Bengtsson *et al.* [12], which predicts that signature inversion can occur in the $A\sim 80$ mass region in nuclei with proton or neutron numbers between 39 and 47. According to this model, ^{72}Br is not eligible for signature inversion, while in the heavier odd-odd Br isotopes such an inversion has been established [2–5,11]. Hence, an extension of the level scheme of ^{72}Br to higher excitations provides an opportunity to verify this prediction.

Excited states in ^{72}Br have been investigated using the ^{16}O+^{58}Ni reaction at 59.5 MeV at ATLAS with the Gammasphere array at the target position coupled to the fragment mass analyzer. Experimental details have been summarized in an earlier publication [13]. Preliminary results of the ^{72}Br study have been previously reported [14]. γ-γ coincidences, as well as γ-recoil mass coincidences, have been recorded. Although measurements of the directional correlations (DCOs) of the transitions allow definitive multipolarity assignments, only tentative spin and parity assignments have been made because of uncertainties in the determinations of the spins of the lower levels.

The level scheme of ^{72}Br deduced in the present work is shown in Fig. 1. The low-spin members of the positive-parity yrast band in ^{72}Br have been previously established [6,7]. The ground-state $(3)^+$ assignment was based on the coupling of both the proton and neutron in the low-Ω $g_{9/2}$ orbitals, 3/2$^+$[431]. The $\alpha=0$ partner of the positive-parity band was previously known up to (10^+) and the $\alpha=+1$ partner up to spin (15^+) [7]. Hence, no staggering could be deduced from the known levels. In the present work the rotational cascades have been extended up to (18^+) and (21^+), respectively, and up to a maximum excitation energy of 9.8 MeV. All of the transitions of the band above the (8^+) level are shown in the mass-72 gated spectrum of Fig. 2. The placements of all of the transitions labeled in Fig. 2 were confirmed by γ-γ coincidences, without requiring a $A=72$ mass gate. The DCO ratios of the transitions of both signature partners up to spin (17^+) are consistent with stretched quadrupole character. Although the uncertainties in the spin assignments for the lower levels render the higher spin assignments tentative, the similarities in the ^{72}Br cascades at higher excitation with those in the heavier ^{74,76,78}Br isotopes support the present assignments.

The energy staggering between the levels in the odd- and even-spin branches of the decoupled band in ^{72}Br is displayed in Fig. 3. Staggering was also observed in the experimentally deduced $B(M1)/B(E2)$ ratios for those levels for which the cascade $M1$ transitions were observed. Indeed, while the $B(M1)/B(E2)$ values for the (11^+) and (13^+) levels are $\sim 10\mu_N^2/(e\,\mathrm{b})^2$, the value for the (10^+) state is

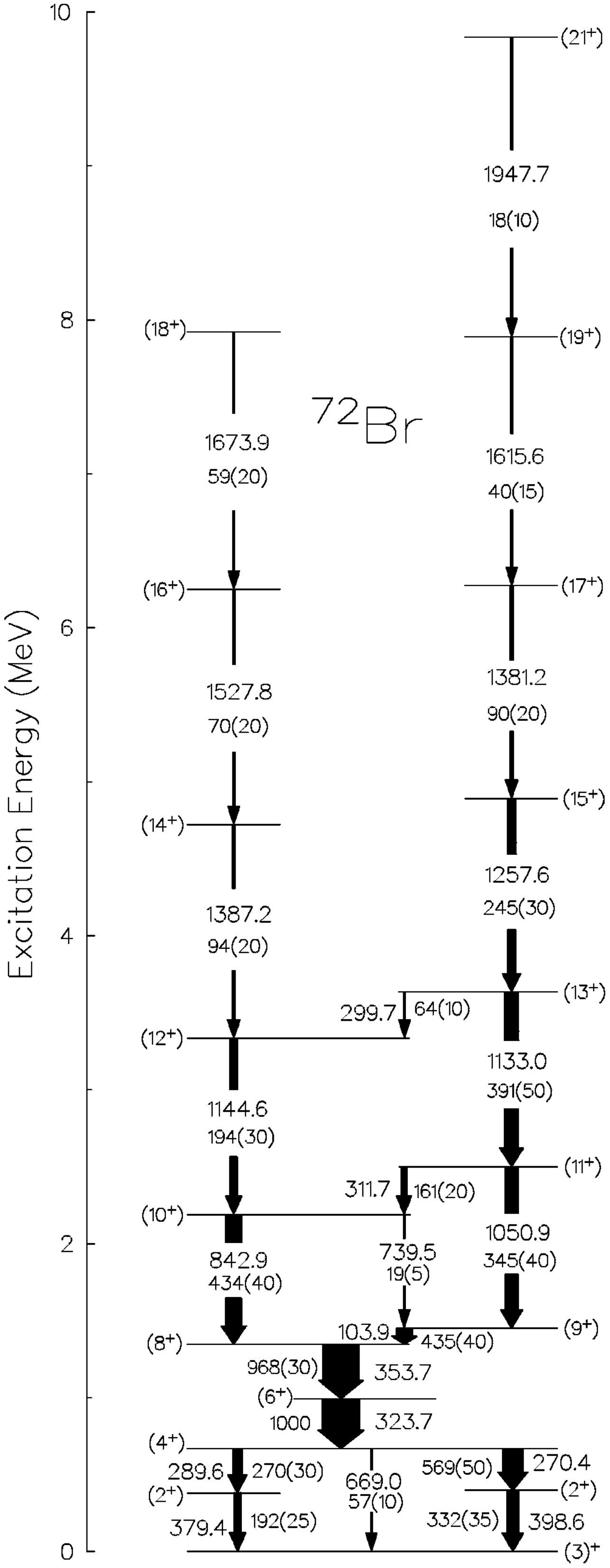

FIG. 1. Partial level scheme of ^{72}Br obtained in the present work. The transitions are given in keV units, with intensities relative to the 323.7-keV transition (with uncertainties in parentheses). The ground-state spin-parity is taken from Ref. [15]; other spin and parity assignments are discussed in the text.

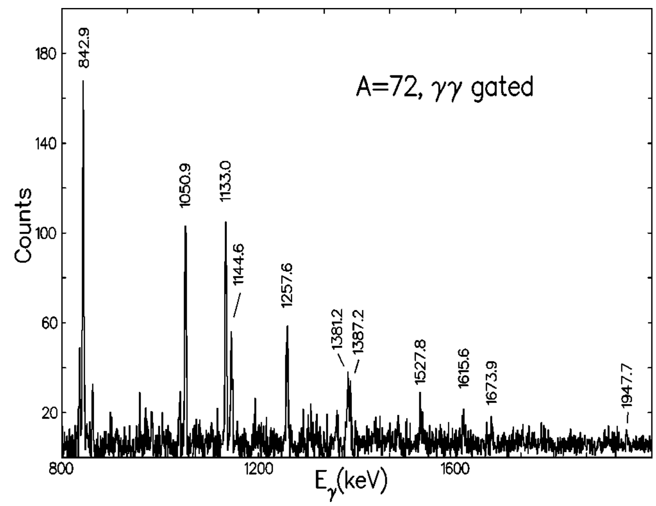

FIG. 2. Spectrum obtained from the sum of gates on the 103.9-, 270.4-, 289.6-, 323.7-, 353.7-, 379.4-, and 398.6-keV transitions in an $A=72$-gated matrix.

only $0.03(1)\mu_N^2/(e\,\mathrm{b})^2$ and for the (12^+) level an upper limit of $\sim 0.12\mu_N^2/(e\,\mathrm{b})^2$ was estimated. The staggering in the $B(M1)/B(E2)$ ratios originates most likely from the corresponding staggering in the $B(M1)$ values established from lifetime measurements in ^{74}Br [11].

Similar bands in ^{74,76,78}Br [2–5] have been interpreted as based on the $\pi g_{9/2}\otimes\nu g_{9/2}$ configuration. The staggering established in ^{74,76}Br has been included in Fig. 3 for comparison, while the staggering in ^{78}Br has been omitted for reasons of clarity. Based on the similarities, the same interpretation is suggested for ^{72}Br and, hence, the band is proposed to be of positive parity. However, in ^{74,76,78}Br a

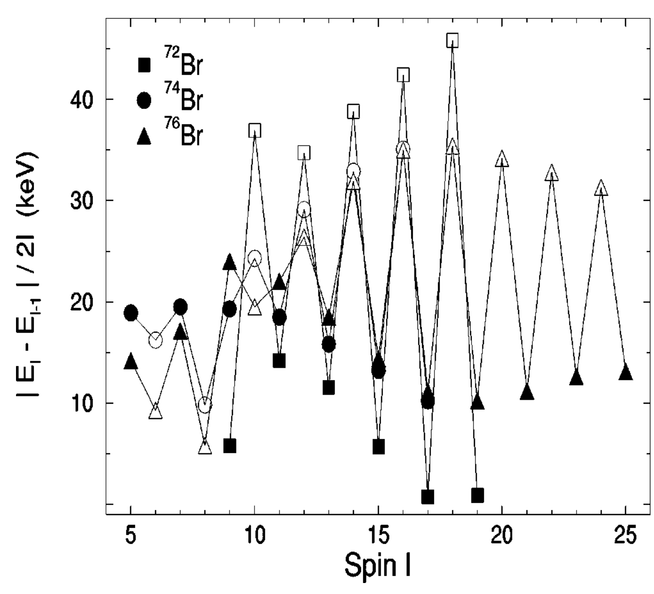

FIG. 3. Energy differences between the states with I and $I-1$ divided by twice the spin between signature partners of the positive-parity bands in ^{74}Br [2], ^{76}Br [3,4], and ^{72}Br (present work). Open symbols correspond to the $\alpha=0$ partner; closed symbols to the $\alpha=+1$ one.

decrease in the signature splitting and subsequent signature inversion takes place between the signature partners of the band below spin $I \sim 10\hbar$. In contrast, in ^{72}Br the signature splitting remains large, and no signature inversion is seen, down to the lowest spins observed. The lower $\Omega = 3/2$ values of the $g_{9/2}$ orbitals for the valence protons and neutrons in ^{72}Br can account for the larger signature splitting observed in this isotope, since the coupling is stronger for lower-Ω orbitals. The fact that no signature inversion is observed in ^{72}Br is in accordance with the theoretical expectations of Ref. [12], which predicted no signature inversion for nuclei with less than 39 protons and neutrons in this mass region.

In summary, the $\pi g_{9/2} \otimes \nu g_{9/2}$ decoupled band in ^{72}Br has been observed up to ~ 10 MeV excitation energy. The expected staggering between the signature partners of the band is also present. The energy staggering is larger in ^{72}Br than in ^{74,76,78}Br, due to the lower-$\Omega = 3/2$, $g_{9/2}$ orbitals involved in ^{72}Br. In contrast to the corresponding bands in ^{74,76,78}Br, no signature inversion is observed in ^{72}Br at low frequency, in accordance with theoretical predictions.

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