Observation of negative-parity high spin states of ^{126}Cs

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The nucleus ^{126}Cs was investigated by means of in-beam γ-ray spectroscopy techniques using the Nordball detector system at the Niels Bohr Institute. Excited states of ^{126}Cs were populated via the ^{116}Cd(^{14}N, $4n$)^{126}Cs reaction at a beam energy of 65 MeV. The ^{126}Cs level scheme was considerably extended, especially at negative parity and about 40 new levels and 70 new transitions were added into the level scheme. The previously reported negative-parity rotational bands, built on $\pi g_{7/2} \otimes \nu h_{11/2}$, $\pi d_{5/2} \otimes \nu h_{11/2}$, $\pi h_{11/2} \otimes \nu g_{7/2}$, and $\pi h_{11/2} \otimes \nu d_{5/2}$ configurations, have been extended and evolve into bands involving rotationally aligned $(\pi h_{11/2})^2$ and $(\nu h_{11/2})^2$ quasiparticles. Two new rotational bands have been tentatively assigned the $\pi h_{11/2} \otimes \nu s_{1/2}$ and $\pi g_{9/2} \otimes \nu h_{11/2}$ configurations, respectively.

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The neutron-deficient nuclei in the $A \sim 130$ mass region, lying in a transitional region between the primarily spherical Sn($Z = 50$) nuclei and the well deformed La($Z = 57$) and Ce($Z = 58$) nuclei, are known to be soft with respect to γ deformation. In this mass region, the study of odd-odd nuclei has provided a fruitful ground for the discovery and discussion of a number of interesting nuclear structure phenomena such as signature inversion [1], prolate-oblate shape competition [2], highly deformed bands [3], and most recently the chiral doublet bands [4]. Systematic trends suggest that the doubly-odd $Z = 55$ Cs isotopes will exhibit some of these characteristics. The positive-parity yrast band in ^{126}Cs has been studied for several times [5–8]. Recently, a positive-parity sideband of the yrast band has been identified. This side band and yrast band have been proposed to be candidates for chiral doublet bands in ^{126}Cs [8,9]. However, relatively few studies [10] have focused on the negative-parity level scheme. The aim of the present study was to extend the negative-parity level scheme and search for new rotational bands.

The excited states of ^{126}Cs were populated via the ^{116}Cd(^{14}N,$4n$)^{126}Cs reaction at a bombarding energy of 65 MeV. The ^{14}N beam was provided by the tandem-linac accelerator complex at the Niels Bohr Institute. The Cd target was a foil of thickness of 820 μg/cm^2 with a 1 mg/cm^2 Au backing. The γ-ray spectra were taken with the Nordball detector system consisting of 19 Compton-suppressed HPGe detectors and a LEPS (low-energy photon spectrometer) detector. A total of 8×10^8 γ-γ coincidence events were accumulated in event-by-event mode. In the off-line analysis, the coincidence data were recalibrated to 0.5 keV/channel and sorted into a 4096×4096 channel symmetrized E_γ-E_γ matrix. Multipolarities of the γ-ray were deduced from the analysis of ADO (γ-ray angular distribution from oriented nuclei) ratios [11]. In order to extract ADO ratios, the coincidence data were sorted into two asymmetric matrices whose y-axis was the γ-ray energy deposited in the detectors at any angles and x-axis was the γ-ray energy deposited in the detectors at 37° (148°) and 79° (101°), respectively. Two coincidence spectra observed by the detectors at 37° (148°) and 79° (101°) were obtained from the two matrices by setting a same gate on the y-axis. After correcting for the relative detection efficiencies, the ADO ratio was deduced from the intensity ratio in the two spectra. Typical ADO ratios observed for the known γ-rays were 1.4 for stretched quadrupole or $\Delta I = 0$ dipole radiations and 0.7 for stretched dipole ones. The detailed experimental setup and procedure were described in Ref. [12].

Partial level scheme for ^{126}Cs derived from the present work is shown in Fig. 1 and has been arranged into bands labeled as A, B, C, D, E, F, and G. The low-lying states of ^{126}Cs had been studied through β^+/EC radioactive decay of ^{126}Ba [13], and the ground state has been assigned $I^\pi = 1^+$. High-spin states of ^{126}Cs had been studied by Komatsubara *et al.* [6] and Li *et al.* [10] through in-beam spectroscopy. In addition, Takahashi *et al.* [14] had found an isomer ($T_{1/2} > 1\,\mu s$) at 272 keV excitation energy by means of the lifetime measurements. In Ref. [10], this isomeric state was identified as the band head of the $d_{5/2}[420]1/2^+ \otimes h_{11/2}[523]7/2^- K = (4^-)$ (band B) structure. The present work confirms most of the previously reported levels and transitions in ^{126}Cs [10]. Moreover, all known negative-parity bands are extended to higher spins and two new negative-parity bands have been observed. About 40 new levels and 70 new transitions are added into the level scheme. The placement of the gamma transitions in the level scheme is based upon their relative intensities, energy sums, and coincidence relationships. Spin assignments are adopted from previous work for low spin states and are followed to higher spins with the aid of ADO ratios analysis. Two examples of γ-rays spectra of the newly observed rotational bands are presented in Fig. 2.

In order to discuss the structure of observed bands, experimental aligned angular momenta i_x are extracted and plotted in Fig. 3. The electromagnetic properties of the strongly coupled bands A, B, C, and G are also extracted and compared

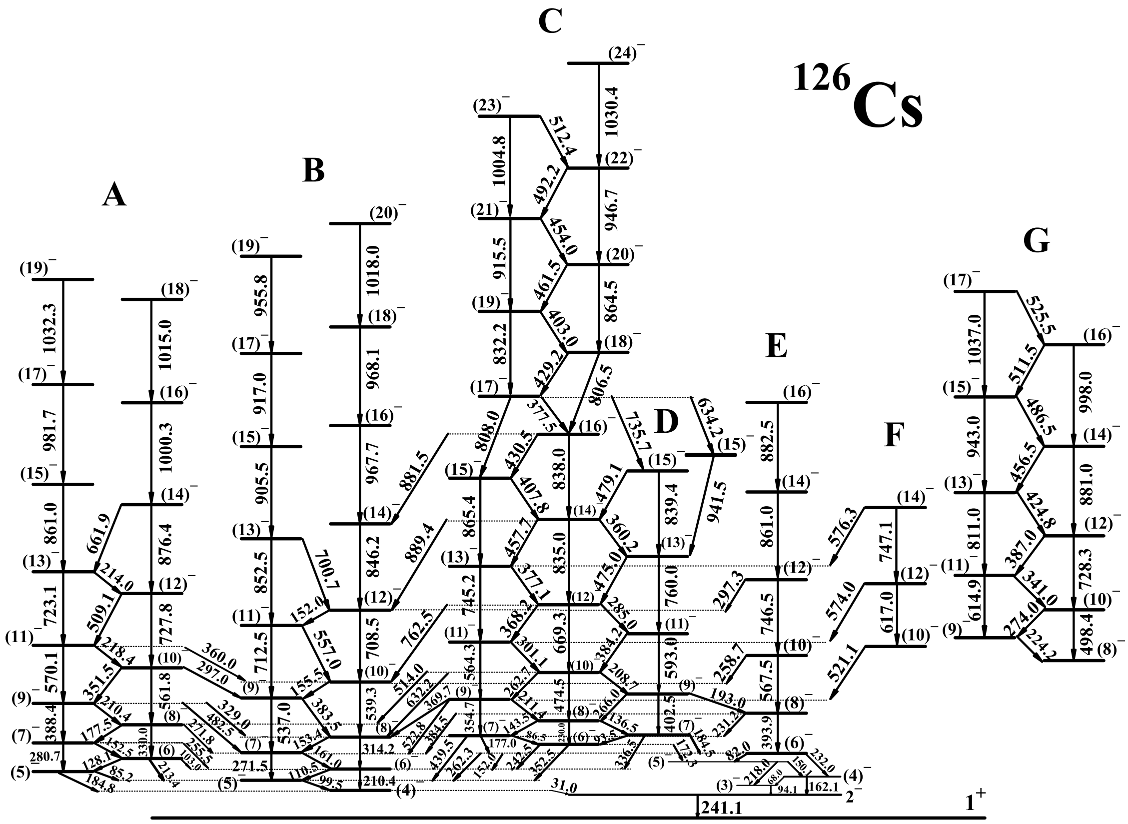

FIG. 1. The level scheme of ^{126}Cs selectively shows only the negative-parity. Energies of γ-rays are given in keV.

with the theoretical estimates of the geometrical model [15], as shown in Fig. 4.

In Ref. [10], bands A and B were observed up to spins $I = (15)^-$ and $(14)^-$, and assigned to be built on the $\pi g_{7/2} \otimes \nu h_{11/2}$ and $\pi d_{5/2} \otimes \nu h_{11/2}$ configurations, respectively. The experimental $B(M1)/B(E2)$ ratios for the coupled bands A and B are shown in Fig. 4(a), along with predictions from the geometrical model for the $\pi g_{7/2} \otimes \nu h_{11/2}$ and $\pi d_{5/2} \otimes \nu h_{11/2}$ configurations for comparison. The agreement between experiment and theory is good both for bands A and B, thereby supporting the configuration assignments previously proposed for the two bands. In the present work, bands A and B have been extended up to spins where the rotational alignment of a pair of quasiparticles occurs. From Fig. 3(a), it is seen that bands A and B show up-bends for frequencies about 0.45 MeV which can be attributed to the rotational alignment of a pair of $h_{11/2}$ protons, as the $(h_{11/2})^2$ neutron alignment is blocked.

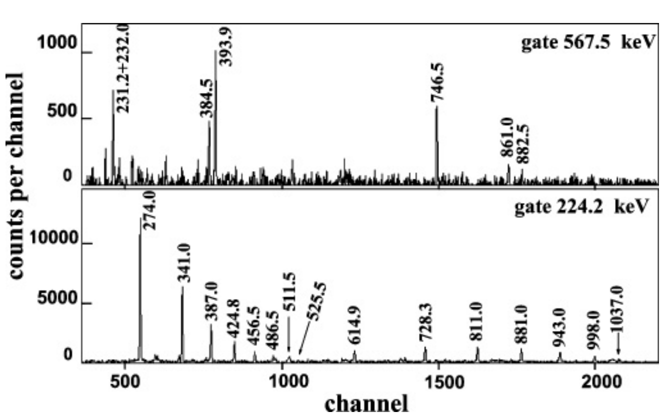

FIG. 2. Sample coincidence spectra.

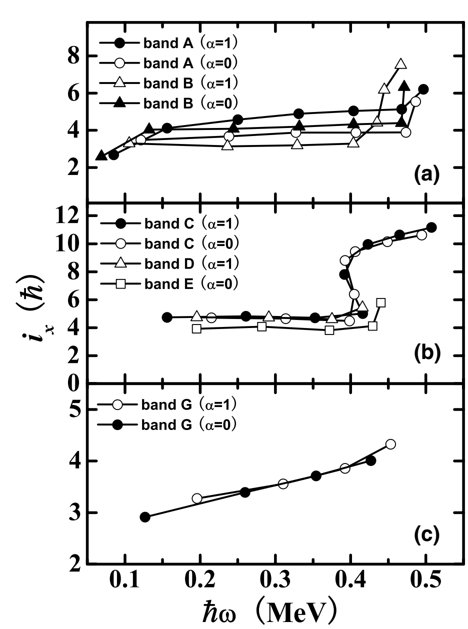

FIG. 3. Experimental alignment plots for the bands in ^{126}Cs. The used Harris parameters are $J_0 = 17.0\hbar^2$ MeV^{-1}, $J_1 = 25.8\hbar^4$ MeV^{-3}.

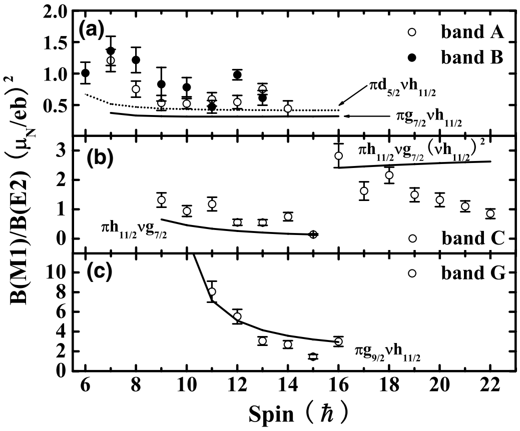

FIG. 4. Comparison of $B(M1)/B(E2)$ values measured (symbols) with those predicted for the configuration (lines) for the bands A, B, C, and G in ^{126}Cs. Parameters used in the calculations of the predicted values: $Q_0 = 3.5\ e$b, $g_R = 0.31$, $g_p(h_{11/2}) = 1.20$, $g_p(g_{9/2}) = 1.26$, $g_p(g_{7/2}) = 0.72$, $g_p(d_{5/2}) = 1.35$, $g_n(h_{11/2}) = -0.21$, $g_n(g_{7/2}) = 0.21$, $i_p(h_{11/2}) = 3.2$, $i_p(g_{9/2}) = 0.5$, $i_p(g_{7/2}) = 1.0$, $i_p(d_{5/2}) = 0.5$, $i_n(h_{11/2}) = 1.9$, $i_n(g_{7/2}) = 0.5$.

The previously known band C based on the $\pi h_{11/2} \otimes \nu g_{7/2}$ configuration [10] has been extended from $(17)^-$ to $(24)^-$ $\hbar$. As shown in Fig. 3(b), band C has a large initial alignment ($\sim 5\hbar$). The large alignment strongly suggests that the $h_{11/2}$ proton is involved in the configuration of band C. Therefore, the first $h_{11/2}$ proton alignment will be blocked. In additional, band C shows an up-bend for frequencies about 0.41 MeV [see Fig. 3(b)]. The alignment may be attributed to the first $h_{11/2}$ neutron alignment. The observed alignment gain is $\sim 6\hbar$, which is consistent with the first neutron alignment. Taking the above information into account, we propose band C to be based on the two-quasiparticle $\pi h_{11/2} \otimes \nu g_{7/2}$ below the band crossing and the four-quasiparticle $\pi h_{11/2} \otimes \nu g_{7/2} \otimes (\nu h_{11/2})^2$ configuration above the band crossing. The extracted $B(M1)/B(E2)$ ratios together with theoretical estimates are shown in Fig. 4(b). At low spins, the theoretical calculations with the $\pi h_{11/2} \otimes \nu g_{7/2}$ configuration reproduce the experimental values. In the band crossing region the experimental $B(M1)/B(E2)$ values show a large increase then decrease. This phenomenon is observed for the first time in the odd-odd Cs isotopes. For the $\pi h_{11/2} \otimes \nu g_{7/2} \otimes (\nu h_{11/2})^2$ configuration with $K = 4$ the theoretical estimate is in quantitative agreement with experimental values of band C above the band crossing. However, the theoretically estimated values are observed to be higher than the experimental $B(M1)/B(E2)$ values in the high-spin region. This discrepancy may imply significant changes in nuclear structure after the alignment of a pair of $h_{11/2}$ neutrons, which are not taken into account in the theoretical estimation. One of the changes may be a decrease of the effective K value of the band. With increasing rotation, the $\pi g_{7/2}(d_{5/2})$ orbitals with lower K are expected to mix into the $\pi h_{11/2} \otimes \nu g_{7/2}$ configuration, resulting in the decrease of the effective K value.

According to the configuration and spin assignments to band C, it is interesting to notice that the signature splitting in the $\pi h_{11/2} \otimes \nu g_{7/2}$ bands of ^{126}Cs is inverted at low spins. This

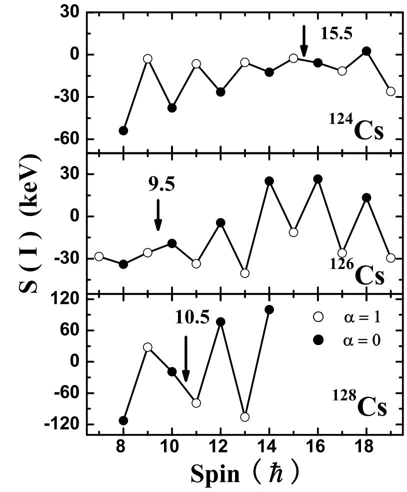

FIG. 5. $S(I)$ versus I for the $\pi h_{11/2} \otimes \nu g_{7/2}$ bands in ^{126}Cs (present work) compared to those in ^{124}Cs [16] and ^{128}Cs [17].

is a new configuration of signature inversion in the $A \sim 130$ mass region. To illustrate further the character of signature inversion in the $\pi h_{11/2} \otimes \nu g_{7/2}$ structure, we compare the typical staggering curves $E(I) - [E(I+1) + E(I-1)]/2$ versus I in Fig. 5 for the $\pi h_{11/2} \otimes \nu g_{7/2}$ bands in ^{124}Cs [16], ^{128}Cs [17], and ^{126}Cs in the present work. It indicates that at the low spins, the $\pi h_{11/2} \otimes \nu g_{7/2}$ bands in ^{124,126,128}Cs indeed show the signature inversion. Two notable features can be seen from Fig. 5. First, the spin value for the inversion point $I_{\rm inv}$ is irregular with increasing neutron number: $15.5\hbar$ for ^{124}Cs, $9.5\hbar$ for ^{126}Cs, and $10.5\hbar$ for ^{128}Cs, respectively. Second, the magnitude of signature splitting in ^{128}Cs is bigger than in ^{124,126}Cs. This phenomenon needs more theoretical work to be explained.

Both bands D and E are observed as single signature sequences. In Ref. [10], band D has been already assigned to the $\pi h_{11/2} \otimes \nu d_{3/2}$ configuration. New observed band E has even spin, signature $\alpha = 0$ and negative parity. Since it is doubly decoupled it should be a combination of quasiparticle orbitals with large signature splitting. The $h_{11/2}[550]1/2^-$ quasiproton orbital is of this type. It must be combined with a quasineutron of signature $\alpha = 1/2$ in order to obtain $\alpha = 0$ for the total signature. Hence, we tentatively adopt the $\pi h_{11/2} \otimes \nu s_{1/2}$ configuration for the band E. Band F were most weakly populated in this experiment. Its configuration could not be proposed because only two transitions were identified.

Another new rotational band, labeled G, has been observed and a spectrum is shown in Fig. 2. Although coincidence relationships between these structure and prominent transitions of the level scheme are not observed, assignment of these structures to ^{126}Cs is most likely due to their population. Thus, this band is tentatively assigned to belong to ^{126}Cs. Band G is observed which has several distinct properties. This band has (1) strong $\Delta I = 1$ transitions relative to the $E2$ crossovers, (2) large ADO ratios for the $\Delta I = 1$ transitions ($R_{\rm ADO} \sim 1.2$), (3) small signature splitting, (4) large the experimental $B(M1)/B(E2)$ ratios at low spin, (5) not connected to the other structures, the band head state is expected to be a relatively long lifetime. These experimental properties are characteristic of the $\pi g_{9/2}$ orbital which originates below the spherical $Z = 50$ gap. Hence, band G in ^{126}Cs is tentatively assigned a similar $\pi g_{9/2} \otimes \nu h_{11/2}$ configuration. It is obvious from the Fig. 4(c) that experimental $B(M1)/B(E2)$ ratios agree well with the expected for the $\pi g_{9/2}[404]9/2^+ \otimes \nu h_{11/2}[523]7/2^-$ configuration. Such a configuration has $K^\pi = 8^-$, leading to the spin assignments of Fig. 1. Bands built on the $\pi g_{9/2} \otimes \nu h_{11/2}$ configuration have systematically been observed in odd-odd Sb and I isotopes [18,19], and also in the odd-odd ^{124}La [20] and ^{128,130}Pr [21,22]. In ^{128,130}Pr, this configuration was associated with the highly deformed rotational band.

In summary, excited states of ^{126}Cs were populated via the ^{116}Cd(^{14}N,4n)^{126}Cs reaction at a beam energy of 65 MeV. The ^{126}Cs level scheme was considerably extended, especially at negative parity and about 40 new levels and 70 new transitions were added into the level scheme. The previously reported negative-parity rotational bands based on $\pi g_{7/2} \otimes \nu h_{11/2}$, $\pi d_{5/2} \otimes \nu h_{11/2}$, $\pi h_{11/2} \otimes \nu g_{7/2}$, and $\pi h_{11/2} \otimes \nu d_{3/2}$ configurations have been extended. Two new rotational bands have been tentatively determined to be based on the $\pi h_{11/2} \otimes \nu s_{1/2}$ and $\pi g_{9/2} \otimes \nu h_{11/2}$ configurations, respectively. Their configurations have been discussed based on alignments, band crossing frequencies, and electromagnetic properties. Signature inversion in the $\pi h_{11/2} \otimes \nu g_{7/2}$ structure is revealed.

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