BACKBENDING IN THE 1/2^-[541] BAND IN $^{181}$Ir


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A backbending has been observed in the 1/2^-[541] band in the odd-proton nucleus $^{181}$Ir at $\hbar \omega \sim 0.3$ MeV, with $\Delta i_x \sim 6.5 \hbar$, in contrast with only an upbend observed near this frequency in the "core" nucleus $^{180}$Os. The nature of this backbend is explored in the framework of the cranked Hartree–Fock–Bogoliubov approximation.

The highly neutron-deficient iridium nuclei have been something of an enigma as far as the understanding of their structure and the nature of their collectivity is concerned. The neighboring even—even core nuclei (Os) have been studied in detail in recent years [1,2] and, to a considerable extent, explained in terms of the cranked shell model (CSM) [3]. The CSM accounts reasonably well for the lowest crossing frequencies in the Os isotopes [3], although detailed attempts to differentiate between upbends and backbends have not been so successful, even in self-consistent cranking calculations [4]. A detailed understanding of the backbending phenomenon in the Ir nuclei is, however, still elusive. For example, while the first backbend has been observed in $^{184}$Os and $^{182}$Os at frequencies of $\hbar \omega \sim 0.30$ MeV and 0.26 MeV, respectively, only an "upbend" is observed in $^{180}$Os ($\hbar \omega \sim 0.26$ MeV). On the other hand, no backbending had been observed in the odd mass Ir isotopes with $A \geq 185$; however, an upbend was reported in the ground state band in $^{185}$Ir at $\hbar \omega \sim 0.27$ MeV [5]. This upbend, in fact, contradicted earlier suggestions [6] that the $h_{9/2}$ proton alignment was responsible for the backbending in this region. The first backbend in this region is now understood as arising from the alignment of a pair of $i_{13/2}$ neutrons [1–3]. To extend the systematics of the Ir isotopes, the nucleus $^{181}$Ir was studied at Notre Dame some time ago [7] and, although no definite conclusions could be drawn because of poor statistics obtained for the states spanning the backbending region, the possibility of a backbending was strongly indicated. This was indeed intriguing since it is in contrast with the behavior of the core nucleus $^{180}$Os and, in principle, a neutron backbend should not be different for different isotones. It has been argued that the difference in the backbending behavior in Os and Ir isotopes could, perhaps, arise from the larger deformations of the 1/2^-[541] proton orbital and calculations of equilibrium deformations seemed to support this hypothesis [8]. It is, however, not supported by our $B(E2)$ measurements on $^{181}$Ir and $^{180}$Os, which show similar ground state deformations for these two nuclei [9].

In an attempt to clarify this Ir–Os puzzle, we have performed high spin measurements on $^{181}$Ir specifically to explore the backbending phenomenon. In this letter, we report evidence for a backbend in the ground state band of $^{181}$Ir which occurs at $\hbar \omega \sim 0.3$ MeV.
and corresponds to an alignment gain $\Delta i_x \approx 6.5 \hbar$. We also present results of theoretical calculations performed to investigate the raison d'être of this backbend.

The high spin measurements were performed at the tandem-superconducting linac facility at the Argonne National Laboratory. A beam of 160 MeV $^{35}$Cl ions incident on a thick ($\sim 5$ mg cm$^{-2}$) target of enriched $^{150}$Nd produced the $^{150}$Nd($^{35}$Cl, 4$n$)$^{181}$Ir reaction. $\gamma$–$\gamma$ coincidence measurements were made with 4 Ge detectors placed at forward and backward angles in the reaction plane to maximize the yield for E2 transitions. An 8-element, large NaI(Tl) sumspectrometer (SS) was employed to ensure selection of high-spin states by requiring that at least 3 of the 8 elements of the SS fire for an event to be acceptable. The summed gated spectrum, after appropriate Compton and randoms subtraction, is shown in fig. 1; the $\gamma$-rays belonging to the yrast band in $^{181}$Ir are connected by dashed lines. The other $\gamma$-rays in the spectrum belong to the "side-bands" [7].

Up to spin $33/2^-$, these measurements confirm the earlier Notre Dame results [7]. In addition, two more strong $\gamma$-rays of $E_\gamma = 570$ and 600 keV, respectively, are observed in the coincidence spectra which are placed above the previously known level scheme to form the $(37/2^-)$ and $(41/2^-)$ levels. The ordering of these additional $\gamma$-rays is ascertained from their relative intensities and their E2 character is assumed on the basis of the geometry of our detector set-up which was designed to maximize yields for E2 transitions. These two extra transitions are enough to confirm the existence of a backbending in the yrast band.

The backbending is clearly evident in the customary plot of the aligned angular momentum ($i_x$) versus the rotational frequency ($\hbar\omega$), which is shown in fig. 2b. The parameters employed for the Harris expansion used in this plot are the same as that for the core nucleus $^{180}$Os, viz. $\theta_0 = 21.7 \hbar^2$/MeV and $\theta_1 = 171.4 \hbar^4$/MeV$^3$ [1]. The alignment gain deduced from this plot is $\sim 6.5 \hbar$ and occurs at $\hbar\omega \sim 0.3$ MeV; this is consistent with the alignment gain ($\sim 8 \hbar$) expected from breaking of an $i_{13/2}$ neutron pair as indicated by our calculations described below.

We have performed preliminary calculations within the framework of the cranked Hartree–Fock–Bogoliubov (CHFB) approximation [10]. Our cranked hamiltonian ("routhian") operator has exactly the same form as in the CSM of ref. [11]. As in the CSM, the deformation parameters of our axially symmetric
oscillator shells $N = 4, 5$ for protons and $N = 5, 6$ for neutrons, with a phenomenological core moment of inertia parameter $\varpi_c$ approximately substituting for the remaining shells. The value $\hbar^2/\varpi_c = 0.4$ MeV, fitted to the low-lying yrast levels of $^{180}$Os was also used for $^{181}$Ir.

For each value of $\omega$, the total energy and total angular momentum $\langle J_x \rangle = \langle J_0 \rangle + \varpi_c \omega$, the sum of the microscopic and core contributions, were calculated. The results of the calculations for the favored members of the $1/2[541]$ band of $^{181}$Ir are summarized in fig. 2a and 2c. It is seen, first of all, that the theory fails to reproduce the backbend established by experiment, yielding instead a gentle upbend coinciding with the attenuation of the neutron pairing, which vanishes at the critical frequency $\hbar \omega = 0.293$ MeV.

Closer examination of our wave functions reveals that the upbending actually involves a combination of the rotation-alignment (RAL) of two $i_{13/2}$ neutrons and the Coriolis antipairing (CAP) effect [15]. The latter cannot be seen in the CSM, which artificially freezes the pairing gaps. In contrast, the proton gap diminishes very slowly. The protons show no significant RAL or backbending effects until much higher frequencies. Thus the neutron upbend is the only anomaly predicted by our calculations for the favored $1/2[541]$ band up to $\hbar \omega = 0.5$ MeV. The calculated alignment gain from neutron pair breaking is $\sim 8\hbar$.

Because of the inherent limitations of the cranking method [16], it is often necessary to settle for qualitative agreement. It is interesting that such qualitative agreement can be obtained in the case of the neighboring even nucleus $^{180}$Os, for which our calculations yield first an upbending, homologous to the one in $^{181}$Ir and involving the same mechanism, followed by a backbending at a higher frequency of $\hbar \omega = 0.40$ MeV. This backbending is of a novel kind, involving the RAL of two protons, one being in an almost pure $h_{11/2}$ and the other in an $h_{9/2}$ orbital. This result is at variance with the interpretation of ref. [17], in which both protons are suggested to be of the $h_{9/2}$ type. The implication for $^{181}$Ir is that the corresponding backbend cannot occur for either the favored $1/2[541]$ ($h_{9/2}$) or the unfavored $1/2[541]$ ($h_{11/2}$) band because of the blocking effect [15]. Verifica-

\[ N = 6 \text{ proton shell also plays a role but only for } \hbar \omega > 0.4 \text{ MeV.} \]

\[ \text{Details to be published elsewhere.} \]
tion of this prediction would require going to higher spins.

The kind of qualitative agreement obtained for \(^{180}\text{Os}\) is clearly lacking in the case of \(^{181}\text{Ir}\), since, first of all, the theory predicts an upbend, while experiment reveals a backbend, and, second, the theoretical crossing frequency of \(\hbar \omega \approx 0.23 \text{ MeV}\) is much lower than the experimental value of \(\hbar \omega \approx 0.3 \text{ MeV}\). However, it is quite commonplace for self-consistent cranking calculations to predict an upbend in situations in which experiment gives a backbend [4], and to underestimate crossing frequencies. This is largely due to a combination of the pairing collapse and the inherent defects in the cranking method. The CSM, which artificially keeps the pairing gaps fixed, does a little better on the crossing frequency, yielding a value of \(\hbar \omega \approx 0.28 \text{ MeV}\), but the interaction strength of \(V \sim 135 \text{ keV}\), in conjunction with an aligned angular momentum of \(\sim 7.4 \hbar\), is too strong to give backbending. Taking all these factors into account, and the approximate agreement for the aligned angular momentum, it would not be unreasonable to conclude from these calculations that \(i_{13/2}\) neutron alignment is the main mechanism responsible for the backbending in \(^{181}\text{Ir}\). On the other hand, the reality of the accompanying pairing collapse is still a moot issue [18], since it depends on the nature of the trial variational wave function.

There still remains the disappointing fact that our model cannot explain how the upbend in \(^{180}\text{Os}\) mutates into a backbend in \(^{181}\text{Ir}\) nor the increase in the crossing frequency. It is unlikely that manipulation of the input parameters within reasonable bounds would change the qualitative picture very much, although increasing \(e_2\) and \(\Delta_n\) would tend to sharpen the upbend. Beyond that, there may be some essential physical features missing from our model that are required for an explanation. The possibilities include quadrupole pairing and \(\gamma\)-deformation [17], the latter being often alluded to in connection with this region. The possibility of \(\gamma\)-deformation, however, may necessitate some significant revisions of the usual cranking codes, as emphasized recently by Mottelson and Hamamoto [19].

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References

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