TABLE I. Two-neutron spectroscopic amplitudes (Ref. 2).

$^{18}O \rightarrow ^{16}O$		$^{62}Ni \rightarrow ^{64}Ni$	
$2s_{1/2}{}^2$	0.450	$2p_{3/2}{}^2$	0.677
$1d_{5/2}{}^2$	0.893	$1f_{5/2}{}^2$	1.039
		$2p_{1/2}{}^2$	0.504

TABLE II. Peak ($\theta \sim 40°$) cross sections (μb/sr) for transitions from $1d^2$ states in ^{18}O to $2p^2$ and $1f^2$ states in ^{64}Ni.

	$2p_{3/2}{}^2$	$2p_{1/2}{}^2$	$1f_{7/2}{}^2$	$1f_{5/2}{}^2$
$1d_{5/2}{}^2$	1.8	3.7	0.6	4.0
$1d_{3/2}{}^2$	3.8	0.08	3.9	0.09

Part of this factor probably comes from our underestimate of the amount of configuration mixing in both the oxygen and nickel nuclei. The two-neutron transfer in a grazing collision requires more neutron correlation than is achieved with the few configurations listed in Table I. Of course, it is also possible that indirect processes contribute to the reaction. But a study[8] of the effect of indirect processes on the ($^{18}O, ^{16}O$) reaction on the Sn isotopes showed that the 0^+-to-0^+ ground-state transition was dominated by direct transfer, when the direct transfer is not Q forbidden.

Table II shows the strong dependence of the transfer cross section on whether $j_A = l_A \pm \frac{1}{2}$ and $j_B = l_B \pm \frac{1}{2}$. This is a consequence of the coherent contribution of $S=0$ and $S=1$ transfers. The (t,p) reaction, which is dominated by $S=0$ transfer, shows a much weaker j_B dependence,

$$\sigma_{tp}(j_B = l_B + \tfrac{1}{2})/\sigma_{tp}(j_B = l_B - \tfrac{1}{2}) \approx (l_B + 1)/l_B .$$

This suggests that comparison of the ($^{18}O, ^{16}O$) and (t,p) reactions between the same initial and final nuclear states may be a fruitful way to unravel the j structure of zero-coupled pairs in the ground states of medium-weight nuclei.

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Backbending in Odd-A Ho Isotopes*

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We have shown that backbending can occur in rotational bands of odd-A nuclei. The $\mathcal{J}$ versus ω^2 plots for the lowest $h_{11/2}$ band in $^{157, 159, 161}$Ho are rather similar to the ones for the adjacent even-even nuclei. This is interpreted to mean that the $h_{11/2}$ proton is not strongly involved in the mechanism producing the backbending in this region.

Since the discovery[1] of "backbending" in the ground-state rotational bands of ^{160}Dy and ^{162}Er, this effect has been extensively studied in many even-even nuclei.[2] The sudden decrease of the rotational frequency (transition energy) with increasing spin and moment of inertia has been found to occur in many deformed nuclei of the rare-earth region at spins of about (12 or 14)$\hbar$. It has also been observed in other regions of the nuclide chart, though one cannot always be sure that the same process is involved. On the other hand, it does not seem to occur in some other strongly deformed rare-earth nuclei, especially in neutron-richer isotopes. In this Letter we present data which show for the first time that backbending can also occur in rotational bands of odd-A nuclei. We will also try to show that the occurrence of backbending in certain bands of odd-A nuclei gives rather detailed information about the causes of backbending in the neighboring even-even nuclei.

We used the $(^{11}B, 4n)$ reaction on ^{150}Sm, ^{152}Sm, and ^{154}Sm to study the γ decay of high-angular-momentum states in ^{157}Ho, ^{159}Ho, and ^{161}Ho. The beam was delivered by the Lawrence Berkeley Laboratory 88-in. cyclotron, and the energy used was 51 MeV for the ^{154}Sm target and 58 MeV for the other two. The reaction $^{159}Tb(\alpha, xn)$ was also used to make ^{157}Ho ($x = 6$) and ^{159}Ho ($x = 4$), but the γ spectra from the boron bombardments showed less background. The heavy ions also had the advantage of being below the Coulomb barrier for lead, so that they could be stopped directly behind the targets (rolled metallic foils about 10 mg/cm^2 thick). In this way the use of a detector at 0° with respect to the beam was made possible. This detector and another one at 90° were 3.2-cm-diam, 1-cm-thick planar Ge detectors. Coincidences were taken between these two counters and a coaxial Ge(Li) diode at 120°.

A typical spectrum is shown in Fig. 1. The strongest lines observed are transitions in the ground-state rotational band of ^{157}Ho, which is

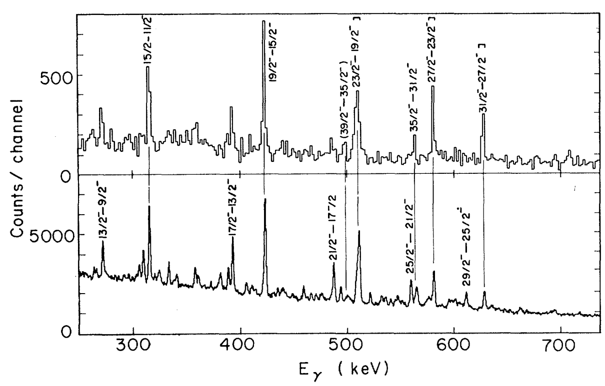

FIG. 1. Partial γ-ray spectra following the reaction $^{150}Sm(^{11}B, 4n)^{157}Ho$. The lower spectrum is the sum of all coincidences recorded by one detector in a multidimensional coincidence measurement. The upper spectrum comes from the same data with gates set in the other detector on the three transitions with brackets above them.

based on the $\frac{7}{2}$ [523] member of the $h_{11/2}$ orbit. The Coriolis interaction mixes this band with the other $h_{11/2}$ bands, compressing the band and lowering the energy of the $j + R'$ (where R' is even) levels relative to the others. This causes an oscillation in the level energies, so that in order to see the relative moment-of-inertia changes only every other level should be considered. Thus, the band divides into two groups of levels, the favored ones ($I = j + R'$) and the unfavored ones ($I = j + R' - 1$). It has been shown previously that in the limit of large Coriolis interaction (e.g., at high angular momentum) the favored levels form a band which has the particle decoupled from the symmetry axis of the core and aligned along the rotation axis.[3] Although we believe the unfavored levels behave similarly, this Letter is focused on the behavior of the favored levels because they could be traced to higher angular momentum and because, as members of the developing decoupled band, they are somewhat simpler to understand.

Data on the favored levels in the three nuclei are compiled in Table I. The lower part of the decay scheme obtained from these data agrees with that reported previously,[4] and a more complete report on the upper parts will be published elsewhere.[5] The assignments up to spin $\frac{35}{2}^-$ can be considered certain since all the transitions could be shown to be in coincidence with the next lower transition. All the crossover γ rays have the angular anisotropy expected for stretched quadrupole transitions ($I \rightarrow I - 2$) and the population in the band decreases with increasing spin as is typical for a (HI, xn) reaction. The $\frac{39}{2}^-$ state in each of the three nuclei can only be assigned tentatively; the respective transitions appear in the summed coincidence spectra [cf. Fig. 1(b)], but our counting statistics do not allow us to decide unambiguously if they feed the cascades from the top. A rather striking feature of the spectra is the fact that they show a high density of lines up to a certain energy and then few, if any, lines above that point. This suggests that both parts of the ground band (favored and unfavored) backbend at about the same transition energy.

The backbending of the favored levels in the three nuclei can be seen in Fig. 2 which shows the dependence of the moment of inertia on the rotational frequency. The moments of inertia were calculated from the formula

$$2\mathscr{J}(I, \omega)/\hbar^2 = (4R' + 6)/\Delta E, \quad (1)$$

TABLE I. Energies, intensities, and A_2 coefficients for the favored levels of the ground-state band in ^{157}Ho, ^{159}Ho, and ^{161}Ho. The energies and the A_2 coefficients are given for the crossover transitions, whereas the intensities are the sum of crossover and cascade transitions depopulating the level.

	^{157}Ho			^{159}Ho			^{161}Ho		
I	$E_I - E_{I-2}$ (keV)	Int.	A_2 [a]	$E_I - E_{I-2}$ (keV)	Int.	A_2	$E_I - E_{I-2}$ (keV)	Int.	A_2
$15/2^-$	315.9 ± 0.3	(100 ± 16)	0.25 ± 0.09	317.8 ± 0.3	(100 ± 15)	0.20 ± 0.09	312.2 ± 0.3	(100 ± 15)	0.21 ± 0.08
$19/2^-$	424.3 ± 0.3	70 ± 4	0.24 ± 0.07	408.4 ± 0.3	69 ± 4	0.20 ± 0.07	397.0 ± 0.3	85 ± 5	0.26 ± 0.06
$23/2^-$	513.0 ± 0.3	49 ± 7	0.19 ± 0.09	486.4 ± 0.3	47 ± 3	0.20 ± 0.08	472.4 ± 0.3	69 ± 4	0.25 ± 0.06
$27/2^-$	583.2 ± 0.3	21 ± 2	0.23 ± 0.08	550.7 ± 0.3	31 ± 3	0.24 ± 0.08	534.5 ± 0.3	48 ± 3	0.24 ± 0.06
$31/2^-$	630.9 ± 0.5	13 ± 2	0.24 ± 0.08	592.5 ± 0.4	17 ± 2	0.18 ± 0.09	573.3 ± 0.6	24 ± 2	0.26 ± 0.07
$35/2^-$	565.9 ± 0.9	8 ± 2	0.15 ± 0.10	587.1 ± 0.6	11 ± 2	0.15 ± 0.09	568.9 ± 0.8	11 ± 2	0.21 ± 0.13
$(39/2^-)$	(500.1 ± 0.9)	2 ± 1	0.23 ± 0.18	(547.3 ± 1.0)	5 ± 2	0.30 ± 0.20	(544.8 ± 1.0)	6 ± 3	0.20 ± 0.20

[a] The A_2 coefficients were determined from the angular anisotropies (0° and 90°) using the approximation that $A_4 = 0$. For comparison, the five stretched $E2$ transitions in the energy range $300 < E_\gamma < 600$ keV from the similar reaction ^{159}Tb(^{11}B, $4n$)^{166}Yb have (Ref. 8) an average $A_2 = 0.23$ (and $A_4 = -0.06$), though a slightly larger value would probably be more typical for the (HI, $xn\gamma$) reactions.

where $R' = I - j$, $\Delta E = E_{I+2} - E_I$, and $\hbar\omega = \Delta E/2$. Equation (1) is valid only when the extra particle is completely decoupled.[3] Since this is not the case here, these $\mathcal{J}(I, \omega)$ values for the odd nuclei do not represent moments of inertia of the core, but only lower limits, and they should be raised by increasing amounts as one goes to lower I values. However, it can be seen that this cannot change the conclusion that the band backbends. That property is determined only by the $\hbar\omega$ values and follows immediately from the lower transition energies at higher spin values. The neighboring even-even nuclei[2,6] are also shown in Fig. 2, and lie above the odd-A nuclei for the reasons just discussed; nevertheless, the similarity in the backbending of the odd-A and even-even nuclei is apparent.

A detailed examination of Fig. 2 shows that (1) the odd-A Ho nuclei backbend at about the same rotational frequency (transition energy) as the even-even nuclei; (2) the odd-A nuclei backbend at slightly lower R' values ($I - j$), but higher actual spin values I; (3) the energy of the backbending state is about the same in the odd-A and even-even nuclei, since the former have fewer transitions, but higher-energy ones (not fully decoupled); and (4) the character of the backbend in the Ho nuclei is similar to that in the Er nuclei, and probably more marked than the average of those in Er and Dy. More data on these Ho levels and on those of other nuclei are needed to confirm and extend these conclusions and to provide similar information on the unfavored levels. But at present it seems safe to conclude from the above comparison that backbending in the odd-A Ho isotopes is generally rather similar to that in the adjacent even-even nuclei.

This conclusion is in contrast to the situation recently found in the odd Er isotopes,[7] where no backbending was observed, even though the data extended well beyond the region (of spin or $\hbar\omega$) where the even-even nuclei backbend. It seems likely that this difference in behavior can be related to the underlying cause of backbending. Since the occupation of the $h_{11/2}$ orbital by the odd particle does not significantly change the backbending properties, it seems that this orbital cannot be closely involved in the mechanism (or cause) of the backbending behavior. On the other hand, the fact that occupation of the $i_{13/2}$ orbital in the odd Er nuclei does affect the backbending properties specifies this orbital as (the) one that is closely involved. The direction in which back-

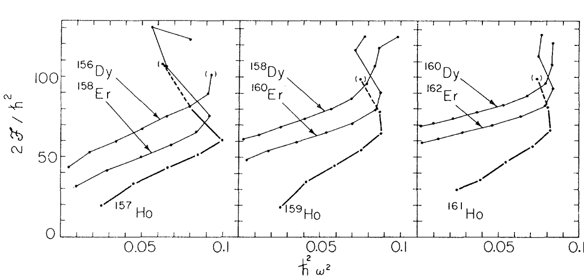

FIG. 2. A comparison of backbending in ^{157,159,161}Ho with their even-even neighbors. The even-even curves are the usual ones of this type, and the odd-A bands are treated as described in the text.

bending is affected (enhanced or diminished, hastened or delayed) in the Er nuclei has given information for comparison with specific models.[7] The point we want to emphasize here, however, is that the odd particle can, in general, serve as a probe to tell if a particular orbital is or is not closely related to the cause of the backbending.

To summarize, we have shown that rotational bands in odd-A nuclei can backbend, and in particular that those in the light Ho isotopes do so. These data indicate that the $h_{11/2}$ protons are not, or nearly not, involved in the mechanism of backbending. A similar experiment would be especially useful in the Os region where it is not clear whether $i_{13/2}$ (or even $j_{15/2}$) neutrons or $h_{9/2}$ protons are mainly responsible for the backbending. It could also be that the backbend in the Os region is due to a different effect, and this might show up in the behavior of the odd-A nuclei in that region.

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Measurement of Elastic Proton-Proton Scattering in Pure Initial-Spin States*†

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An experiment was done using an accelerated polarized proton beam and a polarized proton target. The elastic cross section for proton-proton scattering at 6.0 GeV/c and $P_\perp^2=0.5-1.6$ (GeV/c)^2 was measured in the spin states ↑↑, ↓↓, and ↑↓ perpendicular to the scattering plane. The cross sections were found to be unequal by up to a factor of 2.

During recent years there has been an increasing interest in the importance of spin in high-energy strong interactions. This has come from the very successful experiments using polarized proton targets at Berkeley,[1] CERN,[2] and Argonne National Laboratory (ANL).[3] The ANL zero-gradient synchrotron (ZGS) has now accelerated a beam of 5×10^8 protons to 6 GeV/c with a polarization of $72\pm7\%$. The acceleration of a polarized beam is discussed in our earlier paper[4] and a detailed accelerator paper to be published.[5]

Our experiment used both a polarized target and a polarized beam. A high-energy polarimeter shown in Fig. 1 measured the beam polarization P_B. It consists of two identical double-arm spectrometers, each containing magnets and scintillation counters, which each measure proton-proton elastic scattering from a liquid-hydrogen target—one the scattering of the forward particle to the left and the other to the right. The lab solid angle defined by the counters L_3 and R_3 is $\approx4\times10^{-5}$ sr and the momentum bite is $\Delta P/P\approx\pm6\%$. The overmatched counters L_6 and R_6 detected the recoil protons which gave a very