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

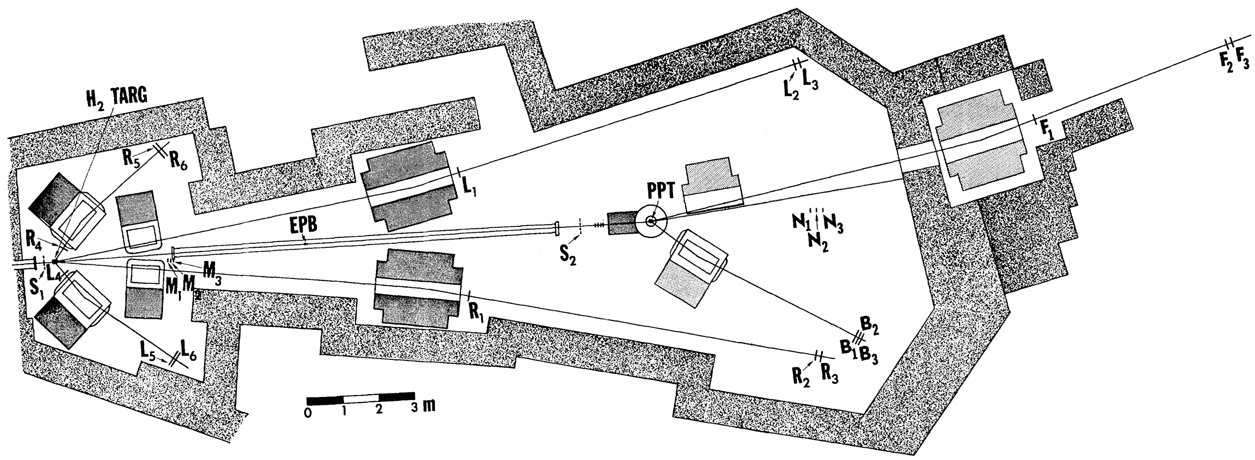

FIG. 1. Layout of the experiment. The polarized beam passes through the H_2 target and its polarization is measured by comparing the number of elastic events seen in the L and R spectrometers of the polarimeter. The beam then scatters in the polarized proton target and the elastic events are counted by the F and B counters. The M and N counters are monitors.

clean elastic signal. Target-empty runs and magnet curves showed that the background was 2% or less. The polarimeter steering magnets let us run at $P_\perp^2 = 0.5$ $(\text{GeV}/c)^2$ where the asymmetry parameter was measured and large. The main systematic asymmetry came from misalignments of the incident beam which was monitored using two segmented wire ion chambers (S_1 and S_2). P_B is given by

$$P_B = A_m / A, \qquad (1)$$

where A is the asymmetry parameter and A_m is the measured asymmetry. For $P_\perp^2 = 0.5$ $(\text{GeV}/c)^2$, A was taken to be 0.10 ± 0.01 by compiling, interpolating, and averaging all available data.[1-6] We determined that P_B varied with ZGS conditions between $54 \pm 6\%$ and $72 \pm 7\%$.

We used the ANL polarized proton target PPT II[7] which contains ethylene glycol doped with $K_2Cr_2O_7$ and is placed in a field of 25 kG and maintained at a temperature of 1°K using a He^4 cryostat. The protons interact with the electrons in the Cr and are pumped into a polarized state by a 70-GHz microwave Carcinotron tube. The proton polarization was measured, with a 107-MHz NMR system using signal averaging, to be $P_T = 36 \pm 3\%$.

The elastic cross section for polarized p-p scattering was measured using the downstream double-arm spectrometer shown in Fig. 1. The solid angle is defined by the F_3 scintillation counter 6×5 in.^{2} at 675 in. from the PPT, giving $\Delta\Omega_{1ab} \approx 6.6 \times 10^{-5}$ sr. The momentum bite defined by F_3 is $\Delta P/P = \pm 8\%$. The overmatched B_3 counter 12×12 in.^{2} detects the recoil proton. Detecting both the scattered and recoil particles isolates a clean signal of elastic p-p events in the chemically complex polarized target. Magnet curves showed that the background from inelastic or nonhydrogen events was less than 5%. The forward and recoil steering magnets let us measure a wide range of $P_\perp^2$ values while only moving the recoil magnet and B counters once. Reversing the magnetic field of the PPT magnet gave some additional steering.

The elastic cross section was obtained in principle from

$$\frac{d\sigma}{d\Omega}(ij) = \frac{\text{events } (ij)}{I_0 N_0 \rho t \, \Delta\Omega}, \qquad (2)$$

where I_0 is the number of incident particles, N_0 is Avogadro's number, and t is the target length of 5 cm. The density ρ of hydrogen protons in the PPT is about 0.07 ± 0.015. It was difficult to measure I_0 since it was typically 5×10^7 protons per pulse, which was too high to be counted and too low for good statistics in radiochemical techniques. Thus, we did not measure absolute cross sections but instead the relative cross sections for the four different initial spin states $\uparrow\uparrow$, $\downarrow\downarrow$, $\uparrow\downarrow$, and $\downarrow\uparrow$. We used the M and N scintillation telescopes to monitor the relative beam intensity through the 2.3-cm-diam PPT. The beam was kept centered to ± 2 mm using the segmented wire ion chambers which also indicated that the beam size was about 1.9 cm full width at halfmaximum. Thus, about 10% of the beam may have missed the PPT and the fraction missing may have varied, causing systematic error of up to 5%. We minimized this error by taking many runs while switching the beam or target polarization every 45 min, assuming that the beam size and position were unrelated to the beam or target spin and did not have a periodicity of 45 min.

Since both the beam and target were only partially polarized (P_B and P_T), the relative cross sections were obtained from the equations

$$\frac{d\sigma}{d\Omega}(\uparrow\uparrow)=\left\langle\frac{d\sigma}{d\Omega}\right\rangle\left[1+\frac{4(N_{\uparrow\uparrow}-N_{\downarrow\downarrow})}{(P_B+P_T)\sum N_{ij}}+C_{nn}\right],$$
$$\frac{d\sigma}{d\Omega}(\downarrow\downarrow)=\left\langle\frac{d\sigma}{d\Omega}\right\rangle\left[1-\frac{4(N_{\uparrow\uparrow}-N_{\downarrow\downarrow})}{(P_B+P_T)\sum N_{ij}}+C_{nn}\right], \quad (3)$$
$$\frac{d\sigma}{d\Omega}(\uparrow\downarrow)=\frac{d\sigma}{d\Omega}(\downarrow\uparrow)=\left\langle\frac{d\sigma}{d\Omega}\right\rangle[1-C_{nn}],$$

where C_{nn} is given by

$$C_{nn}=\frac{N_{\uparrow\uparrow}+N_{\downarrow\downarrow}-N_{\uparrow\downarrow}-N_{\downarrow\uparrow}}{P_BP_T\sum N_{ij}}, \quad (4)$$

and $\langle d\sigma/d\Omega\rangle$ is the spin-average cross section. The N_{ij} are the normalized event rates in each spin state. We obtained the asymmetry parameter A by averaging over either the beam or target polarization. This gave the consistency check

$$A=\frac{N_{\uparrow\uparrow}+N_{\uparrow\downarrow}-N_{\downarrow\uparrow}-N_{\downarrow\downarrow}}{P_B\sum N_{ij}}=\frac{N_{\uparrow\uparrow}+N_{\downarrow\uparrow}-N_{\uparrow\downarrow}-N_{\downarrow\downarrow}}{P_T\sum N_{ij}}$$
$$=\frac{2(N_{\uparrow\uparrow}-N_{\downarrow\downarrow})}{(P_B+P_T)\sum N_{ij}}, \quad (5)$$

which held within statistics.

The data are presented in Fig. 2 where we have plotted the ratios of $d\sigma(\uparrow\uparrow)/d\Omega$, $d\sigma(\downarrow\downarrow)/d\Omega$, and $d\sigma(\uparrow\downarrow)/d\Omega$ to $\langle d\sigma/d\Omega\rangle$ against $P_\perp^2$. Also shown are the values of C_{nn} and A obtained from these cross sections. The positive C_{nn} means that the parallel cross sections (↑↑ and ↓↓) are (10–25)% larger than the antiparallel (↑↓ and ↓↑). Using the optical theorem, this is consistent with our earlier result[4] that $\sigma_{tot}(\uparrow\uparrow)/\sigma_{tot}(\uparrow\downarrow)=1.045\pm0.050$.

The most striking feature of the data is that the three cross sections are unequal by up to a factor of 2 or more. This supports the earlier evidence[1-3] that spin is important in high-energy pp scattering. The ↑↑ and ↓↓ cross sections differ by about 1.5 in the diffraction peak region $P_\perp^2<1$ (GeV/c)^2. The spin dependence is even larger after the first break in the cross section. This supports the suggestion[8] that the three regions seen in elastic pp scattering may be associated with different spin states. We will soon investigate this further.

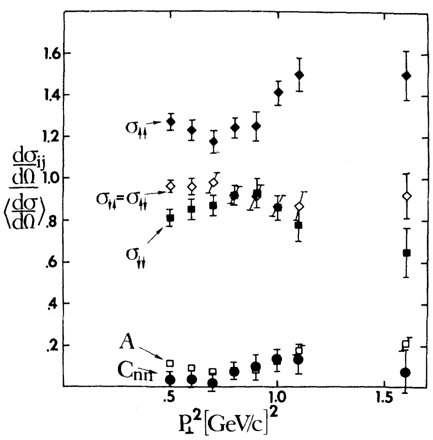

FIG. 2. Differential elastic cross section for pp scattering at 6 GeV/c plotted against $P_\perp^2$. The ratios $d\sigma(ij)/d\Omega$ to $\langle d\sigma/d\Omega\rangle$ are plotted for the different initial spin states. The asymmetry parameter A and C_{nn} are also plotted.

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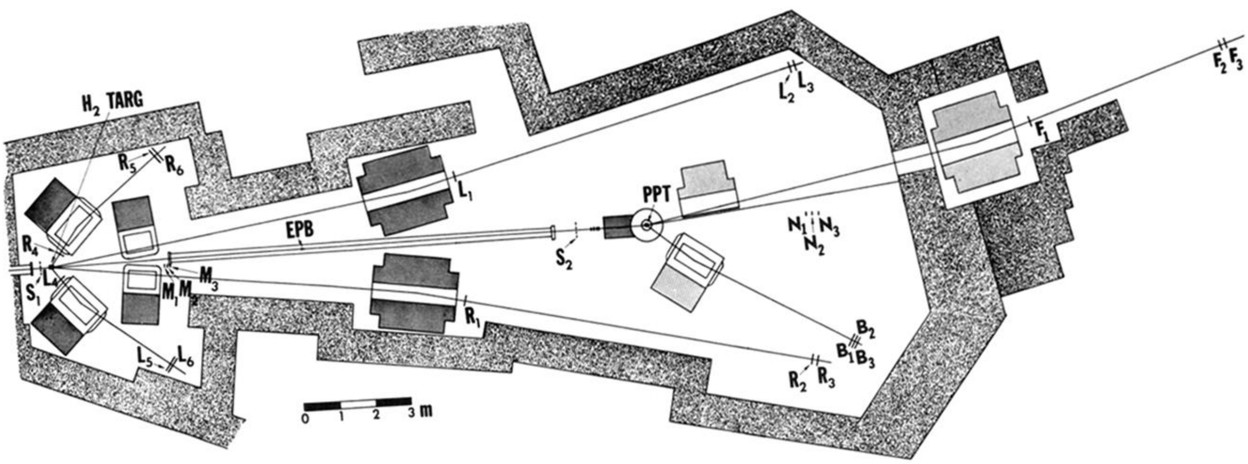

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