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Analyzing Power in Inclusive Proton-Nucleus Cross Sections

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This paper reports measurements of the analyzing power, A_y, in the production of both "backward" protons and forward (quasifree scattering) protons in the reaction $p+A\rightarrow p+X$, using 800-MeV polarized protons. For the backward protons the measurements show large negative A-dependent values of A_y at low momenta, changing to large positive values at high momenta; in the quasielastic region, A_y is large and positive, is smaller than A_y measured in hydrogen, and decreases with increasing A.

The measurement of inclusive cross sections in the reaction $p+A\rightarrow p+X$, in kinematic regions forbidden in p-p reactions on free stationary protons, provides data that are sensitive to the high-momentum components in nuclei. Some of the general aspects of such studies appear in the recent literature[1-7] and several models[1,3,8-10] have been offered that attempt to account for the backward and, in particular, 180° production of high-momentum protons[11] and that differ greatly both in their assumed mechanisms and in their physical models of the nucleus.

Frankel and Woloshyn[12] (FW have recently pointed out how measurements of the analyzing power,[13] A_y, for the reaction $p_{\text{polarized}}+A\rightarrow p+X$ are sensitive to and can distinguish between such models of high-momentum behavior within nuclei. For example, in the single-scattering model[1,2] shown in Fig. 1(a) the incoming proton of momentum $\vec{p}$ lifts a target nucleon of virtual momentum $\vec{k}$ on to the mass shell with observed momentum $\vec{q}$. FW *estimate* the analyzing power from the measured analyzing power[14] for p-p interactions using the values of s and t appropriate to interactions with a bound nucleon of momentum $\vec{k}$. For backwardly detected protons

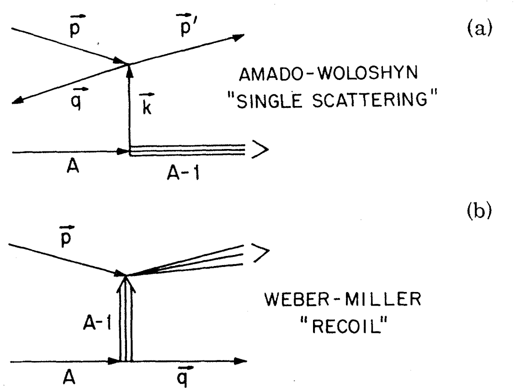

FIG. 1. (a) The single-scattering mechanism without final-state interactions; the struck nucleon is off shell. (b) The recoil mechanism without final-state interactions; the recoiling nucleus is off shell.

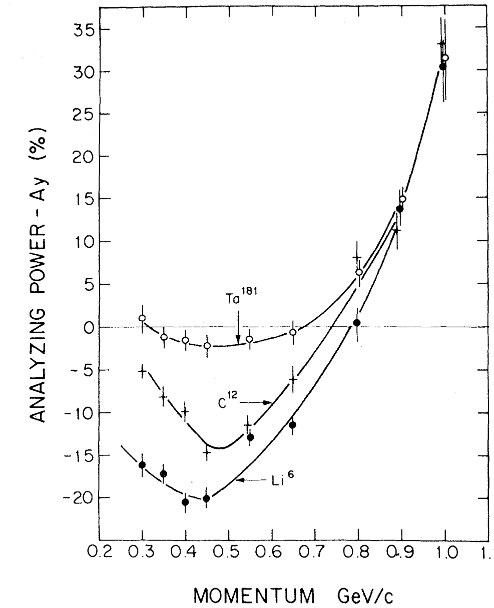

FIG. 2. Analyzing power (%) vs momentum (GeV/c) of detected proton for incident polarized 800-MeV protons; laboratory angle of 75°. Measurements were made at 0.05-GeV/c intervals. Points for different A are occassionally displaced so as not to obscure the statistical error bars in this and Figs. 3, 4, and 5.

these analyzing powers are generally large and negative. In another example FW point out that the model of Weber and Miller[8] shown in Fig. 1(b), in which the incoming proton interacts with arbitrary recoiling off-shell fragments of the nucleus, gives zero analyzing power.

This experiment was undertaken expressly to obtain the first measurement[15] of A_y for backwardly emitted protons of high momenta and in part to test these predictions. It has also obtained data in the quasifree forward region. It utilized the polarized 800-MeV proton beam and the High-Resolution Spectrometer Facility (HRSF) at the Clinton P. Anderson Meson Physics Facility.

Backward data were accumulated at 120°, 101°, 90°, and 75° (lab) where large negative values of A_y were predicted by FW. Since rates fall off rapidly with increasing angle most of the data were taken at the smaller angles. Forward data were taken at 19.3°.

Time-of-flight measurements and dE/dx measurements allowed complete and background-free separation of protons, deuterons, and tritons.[16] The momentum acceptance of the spectrometer[17] was 2.8% (full width at half-maximum). The experiment was monitored on-line by sampling a large fraction of the events recorded on tape, the results at 90° suggesting measurements at 75°. The beam polarization was reversed automatically every two minutes and its polarization was monitored[18] continuously with a hydrogen polarimeter to correct each set of data. Although the polarimeter and the HRS have been well tested[18] we have as a further check remeasured the analyzing power for hydrogen using a (CH 1.1) scintillator target. We find $A_y(\mathrm{H}) = +0.47 \pm 0.02$ in agreement with the free-hydrogen value[14] $A_y = +0.48 \pm 0.02$. At this angle we also measured A_y for quasifree proton scattering over a wide range of momenta.

Figures 2, 3, 4, and 5 show our results for Li^6, C^{12}, and Ta^{181} obtained for both thin and thick targets ranging from 40 mg/cm^2 to 700 mg/cm^2. (A_y was observed to be thickness independent.) A few results are also shown for Be^9. Statistical errors are in all cases larger than the expected systematic errors. Not shown in Fig. 2 are our results for the very highest momenta which are statistically poorer than the plotted results but nevertheless show very large positive values of A_y. They are Li^6 (1.1 GeV/c): $+0.66 \pm 0.24$; Ta^{181} (1.1 GeV/c): $+0.29 \pm 0.06$; C^{12}(1.2 GeV/c): $+0.83 \pm 0.18$; Ta^{181}(1.2 GeV/c): $+0.56 \pm 0.15$.

We have also made the first measurement of A_y for the forward production of protons in nuclei at 19.27° at and near the "quasielastic" peak. Figure 6 shows these results for Li, C, and Ta.

One feature of the forward data is that the analyzing powers are large and positive as observed in the measurement of the forward-going proton in the interaction with free stationary protons

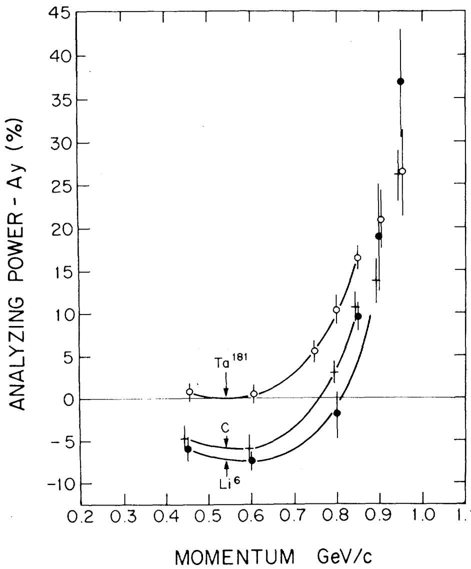

FIG. 3. Analyzing power (%) vs momentum (GeV/c); laboratory angle of 90°.

and, as one might expect, in quasifree scattering. However, it is important to observe that our values of A_y are appreciably smaller than for the free proton and are A dependent. One also sees in Fig. 6 that away from the quasifree peak where the internal momentum of the struck proton is not zero the analyzing powers fall rapidly. If A_y were calculated on the single-scattering hypothesis with the neglect of final-state interactions and at the appropriate s and t corresponding to a moving nucleon, one would not expect such a rapid falloff. Thus we have additional evidence from these analyzing-power measurements that A-dependent final-state interaction effects, known to be important in quasifree scattering, have a sensitive effect on the cross sections for polarized protons.[19]

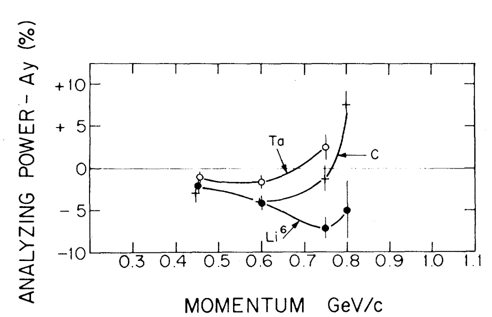

FIG. 4. Analyzing power (%) vs momentum (GeV/c); laboratory angle of 101°.

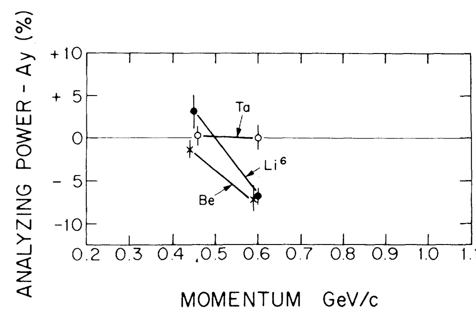

FIG. 5. Analyzing power (%) vs momentum (GeV/c); laboratory angle of 120°.

The backward data show these same features. Although Amado and Woloshyn[3] emphasized the crucial role of final-state interactions on the production of backward protons, the estimates of FW were made for the simple diagram of Fig. 1(a) neglecting final-state interactions. The low-momentum backward protons have an analyzing power of the predicted sign but not as large as predicted by FW. It would be important to extend these measurements to He^3,He^4 to see if in the limit of small final-sate interactions as A is decreased, the full FW predictions are approached. These data also show that as the energy of the backward proton becomes very low (~ 45 MeV), approaching the "evaporation" region, A_y seems to be approaching small values.

At the high momenta the analyzing powers change sign and become positive. Whether the sign reversal is an indication of more complex

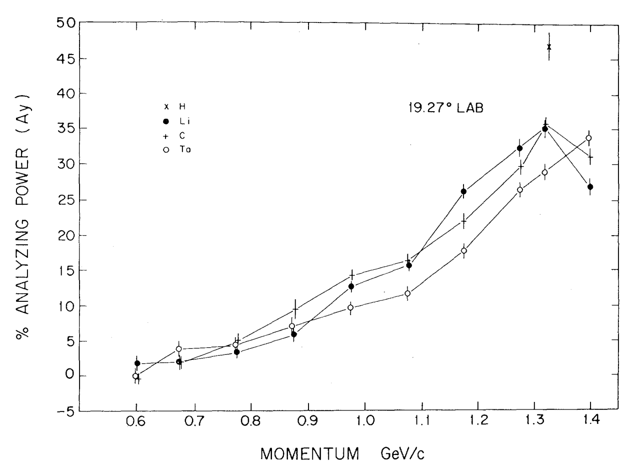

FIG. 6. Analyzing power (%) vs momentum (GeV/c); laboratory angle of 19.3°. The single point at 1.32 GeV/c shown as an X is our measured value for hydrogen which was obtained from the analyzing power we measured for a scintillator target (CH 1.1) and for carbon.

mechanisms than have been proposed or whether the incorporation of final-state interaction effects in the single-scattering model can account for the observed analyzing powers, it will be important to extend such measurements over a wider range of angles, momenta, and A, since the data appear to be rich in new information concerning high-momentum behavior of nuclei.

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