Study of the polarization of cumulative protons

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The polarization of cumulative protons escaping from carbon, copper, and lead nuclei at an angle of 162° LS was measured at incident π^- meson momenta of 1.5–5 GeV/c. An appreciable polarization ($\gtrsim 40\%$) of protons with momenta $\geqslant 0.5$ GeV/c was observed.

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In recent years, many experimental and theoretical papers devoted to studying the production of cumulative hadrons in nuclei have been published. The polarization of cumulative nucleons (CN) heretofore has not been studied in depth, although the initial investigation in which large cumulative polarization was observed was carried out at the Institute of Theoretical and Experimental Physics as early as 1966.[1] The polarization of cumulative nucleons produced in the $P(640\ \mathrm{MeV}) + \mathrm{C} \rightarrow p(90\text{–}130^\circ) + X$ reaction was observed in Ref. 2.. The polarization of cumulative Λ^0 hyperons, which turned out to be close to unity, at the escape angle $\theta \sim 90^\circ$, was measured at ITEP.[3] The polarization of cumulative Λ^0 hyperons was also observed in Ref. 4.

This paper is a continuation of a program carried out at ITEP to investigate in detail the nuclear scaling effect. Below we present the results of a measurement of the polarization of protons escaping at an angle of 162° in the $\pi^-, p + A \rightarrow P + X$ reactions in C, Cu, and Pb nuclei in the momentum range 1.5–5 GeV/c of the incident π^- mesons and 6 and 8.5-GeV/c protons. The momentum range of the secondary protons was 0.45–0.75 GeV/c. The measurements were performed in the secondary beam of the ITEP proton synchrotron on the ISTRA-2 apparatus.[5] The polarization was measured from the asymmetry produced as a result of secondary scattering of protons. In calculating the asymmetry we selected the events for which the secondary scattering angle of protons in the analyzer was $\theta > 4^\circ$ and the momentum was $P_p > 0.45$ GeV/c. A positive asymmetry sign corresponds to the proton polarization vector in the direction of the vector $\mathbf{p}_{\mathrm{beam}} \times \mathbf{p}_p$. The preliminary data and a detailed discussion of the method were published earlier.[6]

Table I gives the results of a measurement of the left-right asymmetry of secondary proton scattering for the $\pi^- + A \rightarrow p + X$ reaction. Since the chosen events were insufficient for an analysis of the dependence of the asymmetry on the initial energy, we summed the events over all initial momenta of the primary beam of π^- mesons.

We summed the statistics for the $p + A \rightarrow p + X$ reaction over all A and initial momenta of the primary beam. The asymmetry was $\epsilon = -0.17 \pm 0.09$. The measurements of the scattering asymmetry of the π^+ mesons, which were simultaneously recorded in our experiment, were performed as control measurements. These events

TABLE I. Left-right asymmetry of secondary nucleon scattering for the $\pi \quad + A \rightarrow p + X$ reaction.

P, GeV/c \ A	C	Cu	Pb
0,47	0,08 ± 0,11	0,12 ± 0,11	−0,07 ± 0,08
0,52	0,27 ± 0,17	0,29 ± 0,16	0,08 ± 0,13
0,62	0,66 ± 0.14	0.26 ± 0,22	0,18 ± 0,12

led to a left-right asymmetry of $\epsilon_{\pi^+} = 0.05 \pm 0.11$ within the error limits. The measurements of the asymmetry of secondary proton scattering in the vertical plane are also zero.

Figure 1 shows the data for the $\pi^- + A \rightarrow p + X$ reaction. Figure 1a shows the dependence of the cumulative nucleon polarization on its momentum. In plotting the graph we summed the events measured in all the nuclei. It can be seen that the polarization increases with increasing momentum in the measured range of cumulative nucleon momenta.

Figure 1b shows the dependence of polarization on the atomic mass of the target nucleus. The cumulative nucleon polarization decreases with increasing atomic mass of the target nucleus. The same conclusions can be derived also from Table I.

Since there are no quantitative calculations of the cumulative nucleon polarization which can be directly compared with the results of our experiment, we shall briefly examine the qualitative predictions of the existing theoretical models.

1. The presence of cumulative nucleon polarization casts doubt on the models[7] in which the whole nucleus or its fraction (fireball, cluster, "tube", etc.), becomes highly excited (is heated) as a result of a collision with the incident particle and then is de-excited (cooled) due to emission of a cumulative nucleon.

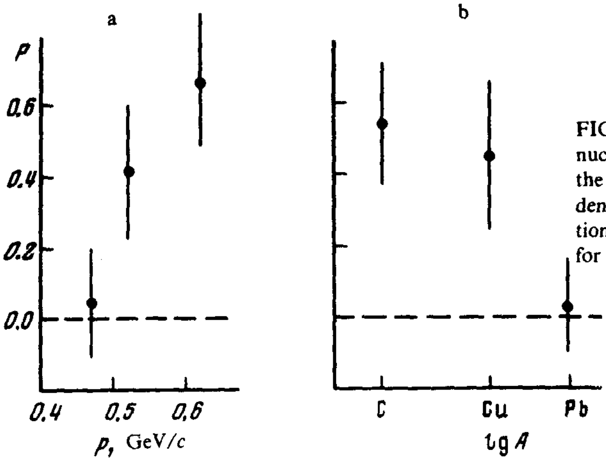

FIG. 1. (a) dependence of the cumulative nucleon polarization on its momentum for the $\pi \quad + A \rightarrow p + X$ reaction; (b) dependence of the cumulative nucleon polarization on the atomic mass of a target nucleus for the $\pi \quad + A \rightarrow p + X$ reaction.

2. Weber and Miller[8] proposed a model for the production of a cumulative nucleon when the incident particle is scattered by the $(A-I)$ nucleons of the nucleus, which balance the momentum of the fast nucleon. The polarization in this model is not understood.

3. The authors[9] attribute the production of cumulative nucleons to the interaction with a pair of correlated nucleons in the nucleus. In this case the main contribution to the cross section comes from the process in which the incident particle interacts with a nucleon whose momentum is in the same direction as that of the incident particle, and the escaping spectator is the cumulative nucleon. The reasons for cumulative nucleon polarization in this model are unclear.

4. Kopeliovich[10] proposed a cumulative nucleon production mechanism in which the incident particle in the primary event produces a proton inside the nucleus, which, as a result of several rescatterings by nucleons of the nucleus, escapes at a large angle. In such a model for the production of cumulative nucleons, their polarization occurs in a natural way, since the scattering in each event is in the same direction under similar kinematic conditions. There should be no A-dependence of the polarization in this model. This conclusion is inconsistent with the data of this paper.

5. A polarization mechanism, which was specially examined within the context of the hard parton collision,[11] predicts a slight dependence of polarization on the incident particle and on the target nucleus and a slight decrease of polarization with increasing cumulative nucleon momentum.

Conversely, the asymmetries in carbon in our experiment are at least 2 times greater than those in lead for all momenta $p > 0.44$ GeV/c, and the polarization increases with increasing momentum.

6. It was suggested[12] that the cumulative nucleons are produced as a result of elastic scattering of the incident particle by a fast nuclear nucleon and that their polarization is the same as that in the elastic scattering with appropriate kinematic variables whose values are calculated within the context of the model. It is known that the polarization in the elastic $\pi^- p$ scattering is $\sim +0.25$ at π^--meson momentum of 2–3 GeV/c and even when $\cos\theta_{\rm cm} \approx 0.990$. The predicted polarization sign agrees with the measured in the case of initial π^- mesons and initial protons. On the other hand, there should be no A-dependence of the polarization within the context of the examined model. We can see, however, that the polarization in carbon is greater than that in lead.

7. The presence of polarization and its A-dependence have been qualitatively predicted.[13] Analyzing the nucleus within the context of the classical shell model, the authors showed that strong absorption in the nucleus leads to an effective selection of certain spin states for the cumulative nucleon recorded in the back hemisphere. However, we have analyzed only the soft, secondary protons for which the polarization does not differ from zero within the error limits.

We can see from the analysis that the polarization is a critical factor in the analysis of the various models and that at present none of the examined models describes the aggregate of the available experimental data.

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