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Scaling of differential cross section ratios in inelastic (p, p') reaction with nuclei at 1 GeV

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This work is a part of the experimental program in the framework of which the effects from scattering off nucleon associations (nucleon correlations or NCs) in nuclei [1] are studied with a 1 GeV proton beam at the synchrocyclotron of the Petersburg Nuclear Physics Institute (PNPI, Gatchina) [2, 3]. We study the polarization P and differential cross section $\sigma^{\text{incl}} = \frac{d^2\sigma}{d\Omega dK}$ of the (p, p') inclusive reaction with nuclei as a function of the scattered proton momentum K. The scattered protons are detected by means of the magnetic spectrometer equipped with a polarimeter based on multiwire proportional chambers [3]. The measurements are performed in a wide range of the scattered proton momentum K covering the pN quasielastic peak and a high momentum region ($K > 1530\,\text{MeV}/c$ for the scattering angle of 21°) up to the momentum corresponding to excited levels of the nucleus under investigation. In the high momentum region, a structure in the polarization and cross section data has been observed earlier in the scattering of the ^{12}C and ^{40}Ca nuclei. It was suggested that the K momentum intervals II, III, and IV of the structure [3] are related to proton quasielastic scattering off two-, three-, and four-nucleon correlations in the nuclei being studied.

In this article we present differential cross section ratios η(Fe/C), η(Fe/Si), and η(Fe/Ca) for the scattering off the ^{12}C, ^{28}Si, ^{40}Ca, and ^{56}Fe nuclei. The cross sections of the (p, p') reaction with the nuclei were measured at a scattering angle of $\Theta = 21°$ as a function of the scattered proton momentum K. The data was obtained in the aforementioned kinematical region of the scattered proton momenta. In the momentum range of $K = 1535{-}1635\,\text{MeV}/c$, quasielastic $(p, p'\text{NC})$ reactions are kinematically preferable since NCs are more massive than nucleons. The value of the transferred four-momentum Q to a nucleus stays almost constant and is equal to $\approx$600 MeV/c. So the Bjorken kinematical-structure variable $x_{\text{B}} = \frac{Q^2}{2m\nu}$ (where m is the nucleon mass) is only determined by energy transfer ν, i.e., by the scattered proton momentum K. The K range mentioned above covers an interval of the $x_{\text{B}} = 1.4{-}4$ [3]. Minimum momentum ($K_{\text{N}}^{\text{min}}$), which a nuclear nucleon must have in order to scatter a beam proton with the final momentum K, is a monotonically increasing function of the K. As an example, in the scattering on the ^{12}C nucleus having only two energy-shells, at $K >\sim 1575\,\text{MeV}/c$ the averaged $K_{\text{N}}^{\text{min}}$ value is bigger than that of the Fermi momentum k_{F} for carbon nucleus ($\sim 220\,\text{MeV}/c$) and as a consequence, the contribution from quasielastic scattering off the uncorrelated nuclear nucleons is essentially suppressed [2].

The cross section ratios found in this work $\eta(\text{Fe}/B) = \sigma^{\text{incl}}(^{56}\text{Fe})/\sigma^{\text{incl}}(B)$ (circles), where B corresponds to the ^{12}C, ^{28}S, or ^{40}Ca nucleus, are presented in figure as a function of the scattered proton momentum K. The dashed vertical line indicates the momentum range of $K > 1575\,\text{MeV}/c$, where the momentum $K_{\text{N}}^{\text{min}}$ mentioned above is over the Fermi momentum k_{F} for the ^{12}C nucleus. Momentum K ($\sim 1480\,\text{MeV}/c$) corresponding to a maximum of the pN quasielastic peak is marked by an arrow. The dash-dotted horizontal lines correspond to the ratios of appropriate atomic numbers of the nuclei under investigation.

As can be seen in Fig. 1, within the momentum intervals III and IV, indicated by dotted-line segments, the cross section ratio η(Fe/C) does not depend substantially on the scattered proton momentum K (i.e., scaling). The value of the η(Fe/C) in the interval IV is slightly higher than that in the interval III. According to [4], observation of such steps in the ratio is a crucial test of the dominance of inclusive scattering off the NCs. Note that the momentum intervals III and IV, determined from the ratio η(Fe/C), coincide with the interval III and IV, observed from the polarization

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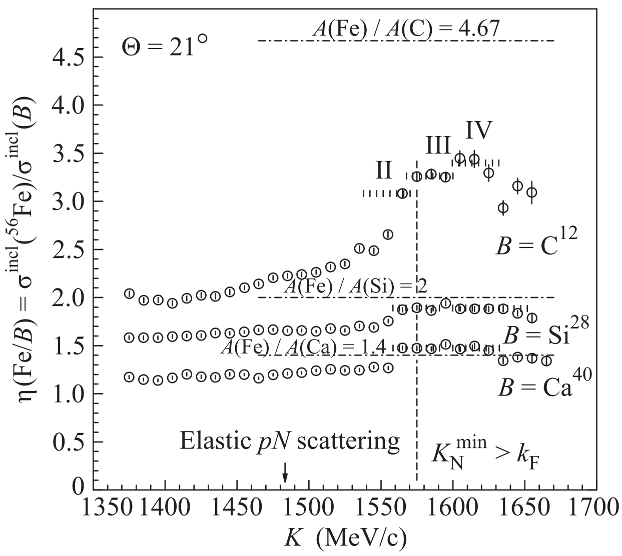

Fig. 1. Scattering cross section ratios $\eta(\mathrm{Fe}/B) = \sigma^{\mathrm{incl}}(^{56}\mathrm{Fe})/\sigma^{\mathrm{incl}}(B)$ (circles), where B corresponds to the ^{12}C, ^{28}Si, or ^{40}Ca nucleus, versus the scattered proton momentum K. The dashed vertical line indicates the momentum range of $K > 1575$ MeV/c, where the momentum $K_{\mathrm{N}}^{\mathrm{min}}$ mentioned above is over the Fermi momentum k_{F} for the ^{12}C nucleus. Momentum K (~ 1480 MeV/c) corresponding to a maximum of the pN quasielastic peak is marked by an arrow. The dash-dotted horizontal lines correspond to the ratios of appropriate atomic numbers of the nuclei under investigation. The dotted-line segments cover the K intervals II, III, IV, and 1560–1635 MeV/c. These intervals were defined in the text

and cross section measurements in the (p,p') reaction with the ^{12}C nucleus [3], which presumably correspond to scattering of three- and four-nucleon correlations. A possible cause for step-function behavior of the cross section ratio η(Fe/C) can be related to that the averaged nucleon density $\langle\rho_{\mathrm{Fe}}(r)\rangle$ of the ^{56}Fe nucleus is slightly bigger than that $\langle\rho_{\mathrm{C}}(r)\rangle$ of the ^{12}C nucleus [4, 5]. We do not see in figure the step-function behavior of the cross section ratios η(Fe/Si) and η(Fe/Ca) in the range of $K = 1560-1635$ MeV/c covering the momentum intervals III and IV observed in the ratio η(Fe/C). Throughout this K region we observe a scaling of the cross section ratios (a value of the ratio is independent of K). It is possible that the averaged nucleon density already in the ^{28}Si nucleus is equal to that corresponding to the saturation of nuclear forces. So that the averaged nucleon density in the nuclei ^{28}Si, ^{40}Ca, and ^{56}Fe is practically identical. In this case the step transition of the cross section ratio between the intervals III and IV may be absent. It is interesting that values of the ratios η(Fe/Si) and η(Fe/Ca) in the momentum range of $K = 1560-1635$ MeV/c are close (within the systematic errors of the cross section measurements [3]) to those of the atomic number ratios $A(\mathrm{Fe})/A(\mathrm{Si}) = 2$ and $A(\mathrm{Fe})/A(\mathrm{Ca}) = 1.4$, respectively (dash-dotted lines in figure). Note, according to the model of short-range nucleon correlations (SRC) [4, 5], a limiting value of the scattering cross section ratio $\eta(A/A')$ in the region of dominant scattering off the NCs is equal to the atomic number ratio A/A'. As for the cross section ratio η(Fe/C), it is noticeably smaller (by about 25 %) than the atomic number ratio $A(\mathrm{Fe})/A(\mathrm{C}) \approx 4.67$ (dash-dotted line in Fig. 1). In the SRC model [4, 5], a value of the cross section ratio $\eta(A/A')$ is proportional to that of the ratio $\sigma'(A)/\sigma'(A')$, where $\sigma'(A)$ is the scattering cross section on a nucleon correlation considering the distortion of the initial and scattered proton waves in a A nucleus. A magnitude of the distortion is the bigger the larger the nucleus atomic number. Due to this and substantial difference of the atomic numbers of the ^{56}Fe and ^{12}C nuclei, a value of the ratio $\sigma'(\mathrm{Fe})/\sigma'(\mathrm{C})$ can be much smaller than 1. And as a consequence, a value of the cross section ratio η(Fe/C) can be noticeably smaller than its limiting value.

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