Investigation of the cross section of the (π^-, p) process as a function of the atomic number of the nucleus at an energy ~1 GeV

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We measured the dependence of the cross sections for the interaction of 1.43-GeV/c negative pions with atomic numbers, in the reaction $\pi^- + A \rightarrow p +$all on the atomic number A of the nucleus at the maximum momentum transfer to the proton. We observed that when the experimental cross sections are described a relation of the type $\propto A^n$ the exponent n for light nuclei (from Li to Cu) is approximately double the value of n for heavy nuclei (from Cu to Bi).

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The spectra of the protons from the reactions

$$\pi^- + A \rightarrow p + \text{all} \quad , \qquad (1)$$

were measured with the three-meter magnetic spectrometer of the Institute of Theoretical and Experimental Physics[1,2] and optical spark chambers, in the l. s. momentum and proton-emission angle ranges determined by the geometrical efficiency $\epsilon(p, \cos\theta)$ of the apparatus (Fig. 1). We present here the data on the cross sections σ of the process (1), averaged over the region of effective registration of the protons:

$$\sigma = \int \frac{d^2\sigma(1)}{dp\,d\Omega}\,\epsilon(p, \cos\theta)\, dp\, d\Omega \, . \qquad (2)$$

The measurements were performed with a beam of 1.43-GeV/c negative pions on the following nuclear targets: ^{6}Li, ^{7}Li, ^{9}Be, ^{12}C, ^{27}Al, ^{32}S, Cu, ^{115}In, ^{181}Ta, ^{209}Bi. We chose mainly monoisotopes of sufficient purity (with the exception of the ^{7}Li and Cu targets with natural isotope mixture, and the ^{6}Li target, which contained ~10% of ^{7}Li). For background measurements and for calibration purposes, we used also an "empty" target and polyethylene (CH_2) target. The nuclear lengths of all the targets were approximately equal (~0.1 L_{nuc}).

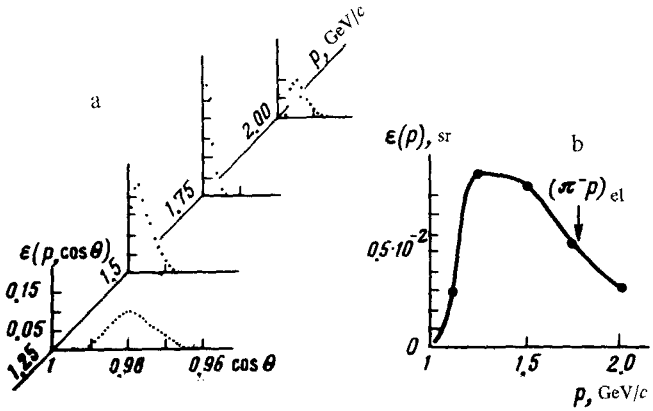

FIG. 1. Geometrical efficiency of the installation for the registration of the protons from the reaction $\pi^- + A \to p +$ all at 1.43 GeV/c: a) vs. the proton emission angle θ for different proton momenta, b) vs. the proton momentum and integrated over the subtended solid angle.

Special measures were taken to ensure practically identical geometrical experimental conditions for the different nuclei. In the calculation of the cross sections we used the ratios of the numbers of the registered fast protons (operations of master) to the numbers of π^--meson fluxes passing through the targets. The results of scanning of a fraction of the film data (~ 5000 photographs) were used to establish more precisely the experimental background conditions and to introduce the corresponding corrections. The reduction of the photographs (more than 100 000) yielded detailed spectra of the process (1).

The final cross section values contained, besides corrections for the absorption of π^- and p in the target material (~ 8.0%)[3] also for the change in the geometrical efficiency of the registration of the protons as a result of ionization energy losses (~ 2.5%).

Figure 2 shows in a log-log scale and in relative units the obtained cross sections and the corresponding statistical errors as functions of ln$A$ (A is the atomic number of the nucleus).

Analysis has shown that the entire aggregate of the investigated nuclei cannot be described by a single power-law function of the type $\sigma \propto A^n$ ($\chi^2 = 66$, $P(\chi^2) \leq 10^{-4}$). The best approximation of the experimental data was obtained with the exponent n ranging from $n = 0.49 \pm 0.02$ in the nuclear region ^{7}Li—S to $n = 0.20 \pm 0.04$ in the range of nuclei Cu—^{209}Bi. Another interesting result is the presence of considerable irregularities in the function $\sigma(A)$ for the lattice of the investigated nuclei (^{6}Li—^{9}Be). Particular interest attaches to the difference between the cross sections of the process (1) on the ^{6}Li and ^{7}Li, which goes considerably beyond the experimental error, even though the two nuclei differ only by a single neutron in the $1p_{3/2}$ shell.

To describe the results we used as the initial approximation the eikonal model of the multiple rescattering, which is analogous to the Glauber approximation

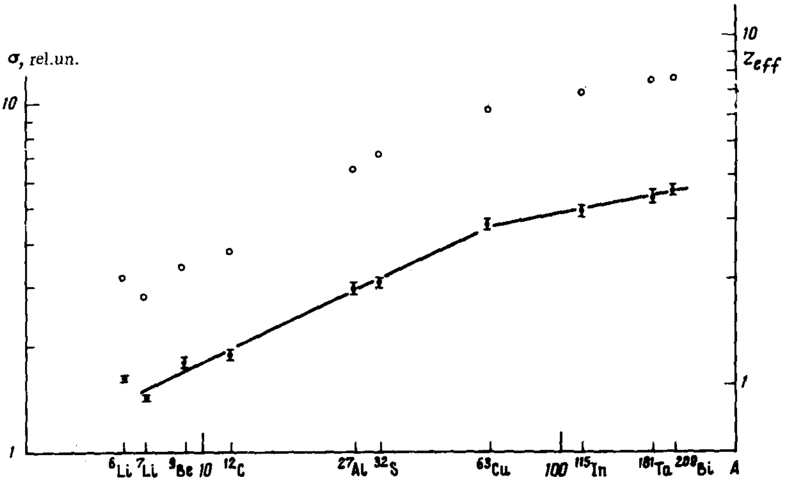

FIG. 2. Dark circles—the cross section of the reaction $\pi^- + A \to p +$ all vs. the atomic number A of the nucleus for high-energy protons emitted forward at a small angle. Open circles—dependence of the effective number of protons Z_{eff} on the atomic number of the nucleus (theoretical calculations). Lines—piecewise approximation of the cross section by the relation $\sigma \propto A^n$.

for incoherent reactions. In this model, as small emission angles of the high-energy protons in the reaction (1), the following expression is obtained for the cross sections:

$$\frac{d\sigma_A(1)}{d\Omega dp} = Z_{eff}\left[\frac{d\sigma_p}{d\Omega\, dp} + \frac{N}{Z}\frac{d\sigma_n}{d\Omega\, dp}\right], \tag{3}$$

where p and Ω are the momentum and solid angle, respectively, of the proton emission; σ_p and σ_n are the cross sections of the reaction (1) on elementary particles—free protons and neutrons,

$$Z_{eff} = Z\int d^2\mathbf{b}\, dz\, \rho(\mathbf{b}, z)\exp[-\sigma_0^{inel}\int_{-\infty}^{z}(A-1)\rho(\mathbf{b}, z')dz'] \times \exp[-\sigma_1^{inel}\int_{z}^{\infty}(A-1)\rho(\mathbf{b}, z')dz'], \tag{4}$$

$\rho(\mathbf{b}, z)$ is the single-particle density of the nucleus, which corresponds in the case of the nuclei Li, Be, and C to the harmonic oscillator potential with parameters taken from[4], and in the case of the remaining nuclei it corresponds to a Woods-Saxon density with the parameters from[5]; N is the number of neutrons in the nucleus, Z is the charge of the nucleus;

$$\sigma_1^{inel} = \frac{1}{A-1}[(Z-1)\sigma_{\pi^- p}^{inel} + N\sigma_{\pi^- n}^{inel}], \tag{5}$$

$$\sigma_1^{inel} = \frac{1}{A-1}[(Z-1)\sigma_{pp}^{inel} + N\sigma_{pn}^{inel}] \qquad (6)$$

are the inelastic cross sections for the interaction of the incoming negative pion and the outgoing proton with the nucleons of the nucleus.

The results of the calculation of Z_{eff} are also shown in Fig. 2. When the experimental cross sections are compared with the calculation data one must bear in mind the following: a) the quasielastic backsacttering contributes only to σ_p; b) the inclusive cross section of the elementary reaction (1) in the beam fragmentation region is larger for protons than for neutrons.[6] For these reasons, we can assume in first-order approximation that $\sigma_n \ll \sigma_p$ and $\sigma_A \sim Z_{eff}$. It is seen that the $Z_{eff}(A)$ dependence duplicates in the main the variation of the measured cross section. This circumstance can be quantitatively due to the fact that the transparency of the nuclei decreases with increasing A and in contrast with the case of light nuclei, where the knocked-out protons could be emitted from all impact distances, these protons can be emitted here in practice only from an external "ring" (periphery) of the nucleus, of thickness $x \sim l_{fr}^2/R$, where l_{fr} is the free-path length in the nucleus of the produced proton. The area of this ring remains $\sim 2\pi Rx \sim$ const as $A \to \infty$, and this can slow down appreciably the growth of the cross section with increasing A. The fact that $Z_{eff}(A)$ agrees well with the relation $\sigma(A)$ in the interval $^{12}C - ^{209}Bi$, within the limits of the experimental accuracy, indicates that the data obtained at the primary momentum 1.43 GeV/c can be interpreted without resorting to the hypothesis of "bare" particles.[7,8]

The good agreement of the function $Z_{eff}(A)$ with the experimental data for light nuclei, particularly Li isotopes, favors the assumption that $\sigma_n \ll \sigma_p$. Attention is called to the fact that in the theoretical calculations for $Z_{eff}(A)$, where account is taken of the effects of screening and distribution of the proton and neutron densities in the nucleus, irregularities analogous to those observed in the function $\sigma(A)$ appear in the region of the lightest nuclei.

[1]Yu. A. Borodin *et al.*, Preprint ITEF No. 53, 1973.
[2]Yu. A. Borodin *et al.*, Prib. Tekh. Eksp. No. 3, 235 (1974).
[3]V. S. Barashenkov and V. D. Toneev, Atomizdat, 1972 [sic!].
[4]R. J. Glauber and G. Matthiae, Nucl. Phys. **B21**, 135 (1970).
[5]P. V. R. Murthy, Preprint UMHE 75-2, Univ. of Michigan, 1975.
[6]B. M. Abramov, I. A. Dukhovskoĭ, V. V. Kishkurno, L. A. Kondratyuk, A. P. Krutenkova, V. V. Kulikov, I. A. Radkevich, Yu. F. Tomashuk, and V. S. Fedorets, Pis'ma Zh. Eksp. Teor. Fiz. **23**, 176 (1976) [JETP Lett. **23**, 156 (1976)].
[7]E. L. Faĭnberg, Problemy sovremennoĭ fiziki (Problems of Modern Physics), Nauka, 1972, p. 248.
[8]N. N. Nikolaev, Preprint ITF-18, Moscow, 1975.