π^-He^4 and π^-O^{16} elastic scattering and excitation of the 3^-(6.13 MeV) level of the O^{16} nucleus by π^- mesons at 1 GeV/c

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We measured the π^-He^4 and π^-O^{16} elastic scattering cross section for π^- mesons with momentum 1.02 GeV/c and the cross section for the excitation of the 3^-(6.13 MeV) level of the O^{16} nucleus in the momentum-transfer interval 0.085–0.145 $(GeV/c)^2$. It was found that the experimental values agree with the results of calculations by the Glauber theory. An indication of a possible difference between the neutron and proton form factors of the transition is obtained.

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Using a setup consisting of two precision magnetic spectrometers with wire spark chambers, a liquid-helium target and water targets, and a system of scintillation counters we measured the differential cross sections for the elastic scattering of π^- mesons with momentum 1.02 GeV/c on the nuclei ^{4}He and ^{16}O, and the cross section for the excitation of the 6.13-MeV (3^-) level of the ^{16}O nucleus in the momentum-transfer interval 0.085—0.145 $(GeV/c)^2$.

The separation of the cases of elastic scattering and of scattering with excitation was carried out by the missing mass method, from the measured momenta of the incident and scattered pions. The rms error in the determination of the missing mass was 5 MeV. The mass spectrum of the helium recoil nuclei revealed a well-separated peak of the ground state of ^{4}He. The mass spectrum of the ^{16}O recoil nuclei revealed a peak of two insufficiently resolved lines corresponding to the ground and excited states of the ^{16}O nucleus with energy 6.13 MeV (3^-). The grounds for excluding an appreciable contribution of the states of the ^{16}O nucleus with energies 6.05 (0^+), 6.92 (2^+), and 7.12 (1^-) MeV in this momentum-transfer interval are the results of experiments on proton scattering and on the measurement of the total excitation cross sections of the ^{16}O level,[1-3] as well as theoretical calculations in the single-inelastic-collision (SIC) approximation, carried out by us.

To obtain the differential cross sections for the elastic scattering and the excitation of the 6.13 MeV (3^-) level, we used the experimental form of the apparatus line, obtained by reducing the missing-mass spectra of the elastic $\pi^- p$ scattering. The sum of the apparatus lines and of the background was fitted to the experimental values. The cross sections were normalized to the elastic $\pi^- p$ events.

Figure 1 shows the obtained values of the differential cross sections of elas-

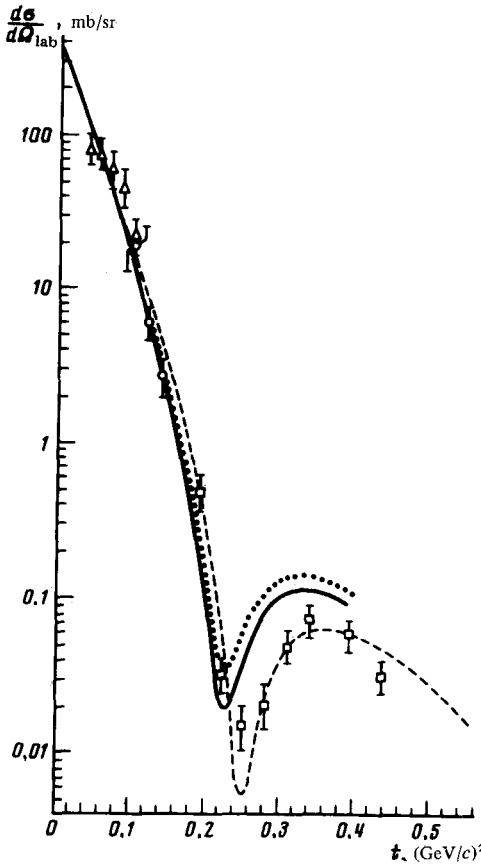

FIG. 1. Differential cross section for elastic π^-He^4 scattering: △—G. Brauti, T_π (kinematic) = 970 MeV[8]; □—M. Querrou, T_π = 1120 MeV[9]; ○—our data, T_π = 890 MeV. Theoretical curves: Solid—890 MeV, dashed—120 MeV, dotted—890 MeV, at equal $\pi^- p$ and $\pi^- n$ amplitudes.

tic π^- He^4 scattering, together with the data of[8,9] and the curves that are the results of our calculation by the Glauber theory.[4] In the calculations we used a separate parametrization of the π^-p and π^-n scattering amplitudes in the form

$$f(q) = \frac{ik\sigma}{4\pi}(1 - i\rho)\exp(-\beta^2 q^2/2).$$

The values of the parameters for the energy 890 MeV, after the reduction of the data of[5], were found to be

$$\sigma_- = 61{,}5 \text{ mb}, \qquad \rho_- = -0.12, \qquad \beta_-^2 = 0.4243 \text{ F}^2$$

$$\sigma_+ = 25.8 \text{ mb}, \qquad \rho_+ = -0.24, \qquad \beta_+^2 = 0.1635 \text{ F}^2$$

for the π^-p and π^-n amplitudes, respectively. For the wave function we assumed the harmonic-oscillator model with parameter $\alpha = 0.535$ F^{-2}. For the energy 1120 MeV we used the set of parameters corresponding to this energy and obtained by reducing the data of the same reference.

Figures 2 and 3 show the results of the measurements of the cross sections

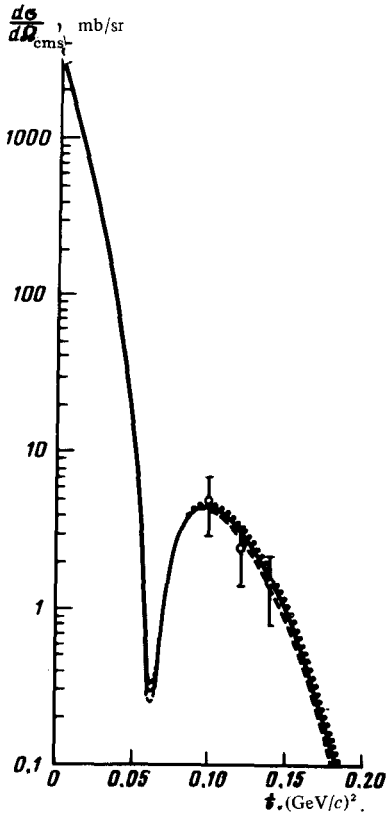

FIG. 2. Differential cross section for the elastic π^-O^{16} scattering: ○—our data, $T_\pi = 890$ MeV. Theoretical curves: limits of variation of the slope parameters of the π^-p and π^-n amplitudes in units of $(GeV/c)^{-2}$: solid—$\beta_-^2 = 10.9$, $\beta_+^2 = 4.2$; dashed—$\beta_-^2 = 12.0$, $\beta_+^2 = 5.0$; dotted—$\beta_-^2 = 10.0$, $\beta_+^2 = 3.5$.

of the elastic π^-O^{16} scattering cross sections and of the excitation cross sections of the $3^-(6.13)$ level of ^{16}O together results of calculations by the Glauber theory. The wave functions of the ground state were chosen to be in oscillator

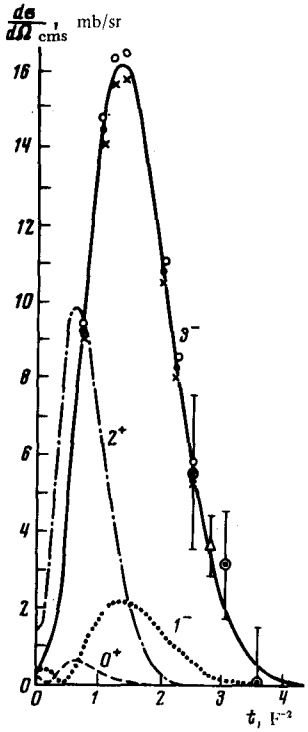

FIG. 3. Differential cross sections of $\pi^- O^{16} \to \pi^- O^{16*}$ scattering with excitation of the level of ^{16}O. Theoretical results: dashed—0^+(6.05 MeV); solid—3^-(6.13 MeV), $o = 3^-$ upper limit, ×—3^- lower limit; dashed dot—2^+(6.92 MeV), dotted—1^0(7.12 MeV). Experimental data: ⊙—$T_\pi = 890$ MeV, △—averaged value over two neighboring angle intervals.

form with parameter $R^2 = 3.22$ F^2. The level excitation cross section was calculated from the formulas of[6] in the SIC approximation with the parametrization indicated above for the πN amplitudes. A correction was introduced for the recoil of the nucleus.

The results of the comparison of the theory with experiment confirm the applicability of the Glauber theory for the description of elastic pion scattering in the angle range up to the second diffraction maximum, and offer evidence that the SIC approximation describes correctly the main features of the excitation of the nuclear levels by high-energy pions. Comparison of the descriptions, by the SIC approximation, of the cross sections for the excitation of the 3^- (6.13 MeV) level of ^{16}O by pions with $T_\pi = 890$ MeV and protons with $T_p = 1$ GeV[7] seems to indicate that the form factors of the transition, obtained from experiments on electron scattering, provide a better description of the differential cross sections for the excitation of the 3^- level by pions than by protons; this may indicate that a difference exists between the neutron and proton form factors.

Attention is called to the fact that pions, unlike nucleons, offer new interesting possibilities of investigating the cross sections for the excitation of nuclear levels, for the purpose of extracting data on the neutron and proton form factors of the transition, on the differences between the proton and neutron distribution densities, owing to the strong energy dependence of the $\pi^- p$ and $\pi^- n$ cross sections in the energy region 0.8—1.5 GeV. In particular, by choosing

the pion energy it is possible to make the $\pi^- n$ cross section much less than the $\pi^- p$ cross section, and if the assumption that the proton and neutron form factors are equal is not accurate, then a manifestation of this inaccuracy will be much weaker in calculations of pion-nuclear cross sections than in the calculations of the nucleon-nuclear cross section. This is precisely the situation at the energy $T_\pi = 890$ MeV. At $T_\pi > 1100$ MeV the $\pi^- n$ and $\pi^- p$ cross sections are approximately equal, and the proton and neutron form factors of the transitions make equal contributions to the cross section. For pp and pn scattering, approximate equality of the cross sections sets in already at $T > 450$ MeV, i.e., practically for almost all energies for which the assumptions of the Glauber theory can be regarded as satisfied.

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