SOVIET PHYSICS JETP VOLUME 37 (10), NUMBER 3 MARCH, 1960

SCATTERING OF 5–10 Mev PROTONS ON He^3

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Submitted to JETP editor April 17, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 663-666 (September, 1959)

The angular distribution of protons, elastically scattered on He^3, has been measured for five values of the incident energy. The protons were recorded by their tracks in photographic plates. The differential cross sections so obtained are compared with theoretical values calculated under two different assumptions regarding the character of the exchange force. The nucleon-nucleon interaction with Serber exchange forces is in better agreement with experiment. The energy dependence of the cross section does not reveal the discreet levels in the Li^4 nucleus.

THE elastic scattering of protons, at different energies, by He^3 is of interest for determining the states of Li^4 and similarly the excited states of the α particle.

The well-known 22-Mev excited state of He^4 is ascribed isotopic spin $T = 0$;[1] consequently, the ground state of Li^4 cannot be similar to this state of He^4. On the basis of the experimental data mentioned in reference 1, it is necessary to assume that the excited state in He^4 with isotopic spin $T = 1$ is at an excitation energy of 24 or 25 Mev. The similar ground state of Li^4 must be unstable with respect to the decay to $He^3 + p$. The existence of this state would be revealed in resonance effects in p-He^3 scattering (or n-T scattering), although the width of the level is large. In this connection, it is desirable to have systematic data on p-He^3 scattering over a wide energy interval.

On the other hand, from a comparison of the experimental data on the scattering of nucleons on light nuclei (in particular, of protons on He^3) with the corresponding theoretical calculations it is possible to try to extract information concerning the forces acting between two nucleons in a many nucleon system.

Experiments on the scattering of protons on He^3 described in the literature are at $E_p^{Lab} = 1.01$, 1.60, 2.25, and 3.52;[2] 4.97,[3] 8.6,[4] and 9.75[5] Mev. In the present work we obtain curves for the angular distribution of protons scattered on He^3 nuclei at $E_p^{Lab} = 9.6$; 8.6; 7.9; 6.8 and 5.5 Mev.

9.6-Mev protons were obtained from the cyclotron directly, while lower-energy protons were obtained by slowing them down ahead of the collimator of the scattering chamber. The gas-filled target had windows closed with iron foil of thickness 6 mg/cm^2 and filled with He^3 to a pressure of about 800 mm mercury. Another target, but empty, was exposed to measure the background, which turned out to be very small for all scattering angles, with the exception of the smallest angle (20°). At 20°, the background increased with decreasing proton energy from 20% at 9.6 Mev to 70% at 5.5 Mev. The proton current in the target was measured using a Faraday cylinder, placed after the target and joined to the integrator.[6] The scattered protons were recorded on photographic plates, situated 125 mm from the center of the gas-filled target at angles from 20 up to 155° at 15° intervals. Each plate was placed at an angle of 4° to the scattered protons. All the plates were exposed together, but the magnitude of the exposure at different angles was regulated by a remotely controlled shutter, placed between the target and each of the plates. In counting the number of proton tracks in the plates, those tracks were chosen which had a given direction and originated in the surface of the emulsion.

The measured results for the differential cross sections for the scattering of protons on He^3 are presented in Figs. 1 to 5 (the energy of the proton is given in the laboratory system). The data of Sweetman (black points) are also included in Fig. 2 and taken from reference 4.

Theoretical calculations of the p-He^3 scattering cross section have been carried out recently by Bransden and Robertson[7] and also by Innas et al.[4] The calculations in reference 7 were carried out using Wheeler's[8] resonating-group structure method. The spatial dependence of the interaction potential between each pair of nucleons was chosen to be a Gaussian:

$$V(r) = V_0 e^{-\mu r^2}$$

with $V_0 = -45$ Mev and $\mu = 0.2669 \times 10^{26}$ cm^{-2}, while two forms were taken for the exchange op-

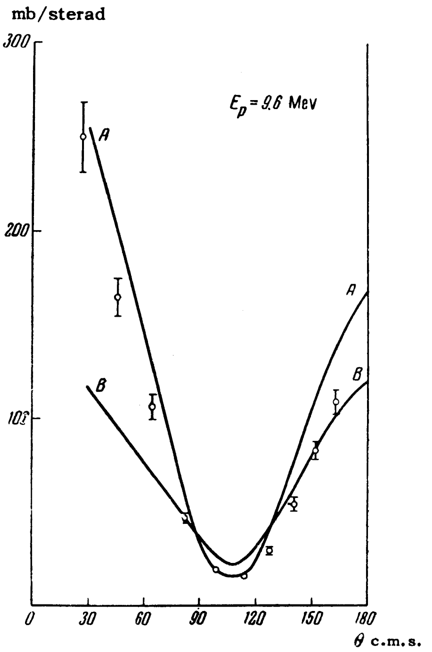

FIG. 1

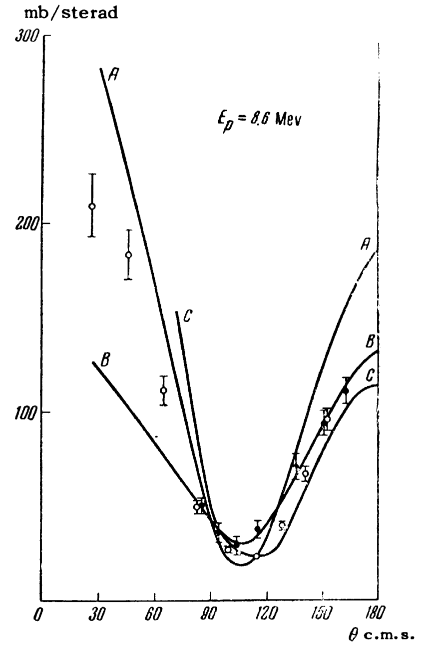

FIG. 2

erator, Serber's and symmetric. The theoretical curves for both variants are drawn in the figures: (A) $\sigma(\theta)$ for Serber exchange forces[7] and (B) for symmetric exchange force.[7] The curves were obtained by interpolation of the angular distributions p-He^3 scattering given in reference 7. It is seen that the symmetric variant consistently disagrees with the experimental data. The Serber variant overestimates the absolute magnitude of the cross section at all angles of the interval, but reproduces the angular distribution better. With increasing energy the agreement of the Serber variant with the experimental data improves. It is possible, that with a slight change in the parameters of the potential (for example the spatial dependence) the Serber variant might be in better agreement with the experimental data over the entire energy interval.

In reference 4, the scattering of protons on He^3 is calculated using the optical model and taking into account spin-orbit coupling. The calculations were carried out with the p-He^3 interaction potential in the form of a square well of depth V_0 and for a "shaped" well:

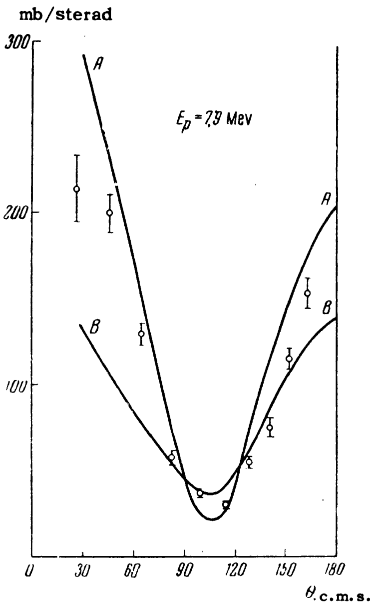

FIG. 3

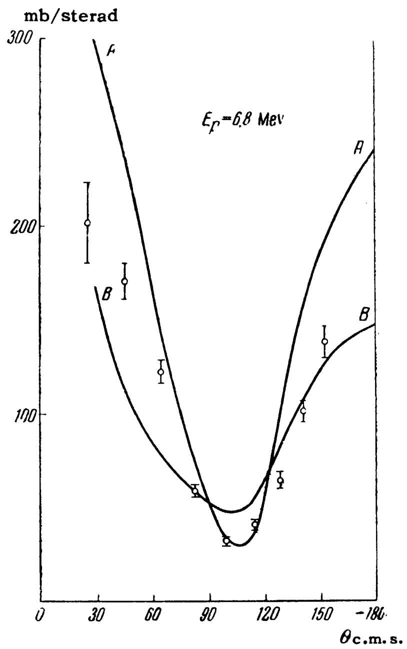

FIG. 4

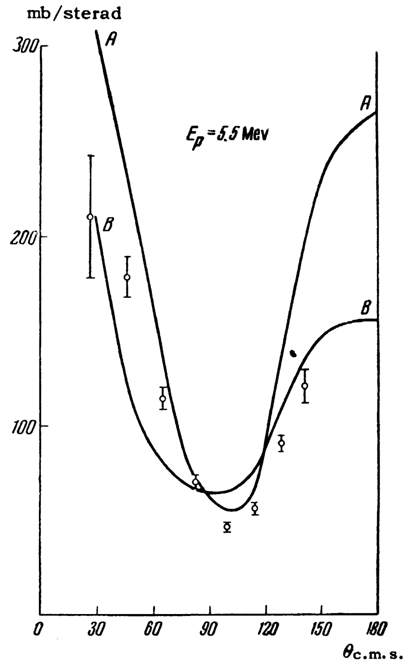

FIG. 5

$$V = -V_0/[1 - \exp\{(r - R)/d\}]$$

with $V_0 = 30$, 36, and 42 Mev, $d = 0.5 \pm 0.1 \times 10^{-13}$ cm, and $R = (1.26\, A^{1/3} + 0.7) \times 10^{-13}$ cm. The energy of the spin-orbit coupling was taken as a rectangular well in the form: $1.2\,(\beta V_0/R^2)\,\boldsymbol{\sigma}\cdot\mathbf{L}$, while for a "shaped" well:

$$\beta\left(\frac{1}{r}\frac{\partial V}{\partial r}\right)(\sigma\mathbf{L}), \qquad \beta = \hbar^2/\mu M c^2,$$

where μ is the meson mass and M is the nucleon mass.

In Fig. 2 is drawn the differential cross section $\sigma(\theta)$, calculated in reference 4 using the optical model and taking into account spin-orbit coupling with $V_0 = 36$ Mev (curve C). It is seen that it is in qualitative agreement with the experimental results. Theoretical curves for $\sigma(\theta)$ at 9.6, 7.9, 6.8, and 5.5 Mev are not given and therefore comparison with experimental data cannot be made. However, curves for $E_p^{Lab} = 4.97$ and 9.75 Mev with V_0 equal to 30 and 36 Mev are presented in reference 4 and they are in qualitative agreement with the experimental data of Sweetman[3] and Lovberg,[5] respectively.

The satisfactory agreement between theory and experiment in p-He^3 scattering in the non-resonance domain, up to proton energies of ~ 10 Mev, apparently indicates the absence of resonance effects in the scattering in this energy domain. This indicates that the Li^4 nucleus does not have a well defined state with a life-time noticeably greater than the time of the nuclear collision. Therefore the assumption made in reference 1 on the ground state of Li^4 and similarly on the second excited state of He^4 with an energy of 24 or 25 Mev and isotopic spin $T = 1$ is not confirmed by p-He^3 scattering experiments.

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Translated by K. Smith
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