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ELASTIC SCATTERING OF 300-Mev PIONS BY DEUTERONS

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The interactions of 300 ± 15-Mev π^+ mesons and of 295 ± 10-Mev π^- mesons with deuterium were studied in nuclear emulsions impregnated with lithium acetate whose hydrogen was replaced by deuterium. Cross sections and angular distributions of the π^+ and π^- mesons scattered elastically by deuterium were obtained.

IN the present work the elastic scattering of positive and negative π mesons by deuterium was studied with photographic plates. This process has been little studied experimentally. The literature refers to experiments for only two π-meson energies, 85 and 145 Mev.[1,2] Our measurements were made at 300 Mev.

Type R NIKFI nuclear emulsions were used in the work. Deuterium was introduced into the plates in the form of lithium acetate $CH_3COOLi \cdot 2H_2O$, in which 97% of the hydrogen atoms were replaced by deuterium. The method of processing the plates and the properties of the impregnated emulsion were described earlier.[3] The quantity of salt introduced was determined by spectral analysis of the lithium. The number of deuterium nuclei in the impregnated emulsions was roughly equal to the number of hydrogen ones in ordinary plates, 2.2×10^{22} cm^{-3} on the average.

The plates were irradiated by the synchrocyclotron of the Joint Institute for Nuclear Research. The mean energy of the π^+ mesons in the plates was 300 ± 15 Mev, and that of the π^- mesons was 295 ± 10 Mev. The scanning method and the preliminary results were published earlier.[3]

Cases of elastic scattering by deuterium were selected according to the angle of emission and coplanarity of the tracks of the incident meson, scattered meson, and deuteron. In the small-angle scattering (< 30°) the tracks of the deuterons, as a rule, stopped in the emulsions, and the range-angle relationship served as a supplementary selection criterion.

Since the particles are emitted in scattering of π mesons by protons and deuterons at nearly equal angles, a high accuracy of measurement and a strict accounting for the errors are necessary to separate the scattering by deuterons from the scattering by hydrogen of the gelatin. We have selected the cases in which, within the limits of two standard deviations, the tracks were coplanar. Then, if the measurements agreed within two standard deviations with the relation for scattering by deuterons and did not agree with that for scattering by protons, this case was considered to be elastic scattering by deuterons. When the recoil track ended in the emulsion, the separation of H and D cases presented no difficulties.

Some of the cases could not be identified by the means described above; however, 14 of them were separated by the ionization, determined by grain counting. Measurements of grain density were also carried out for all cases of scattering by the deuteron through angles > 0°.

As a result of the analysis, 286 cases of π^+-p scattering, 104 cases of π^+-d scattering, 203 cases of π^--p scattering and 105 cases of π^--d scattering were found. Nine cases involving π^-

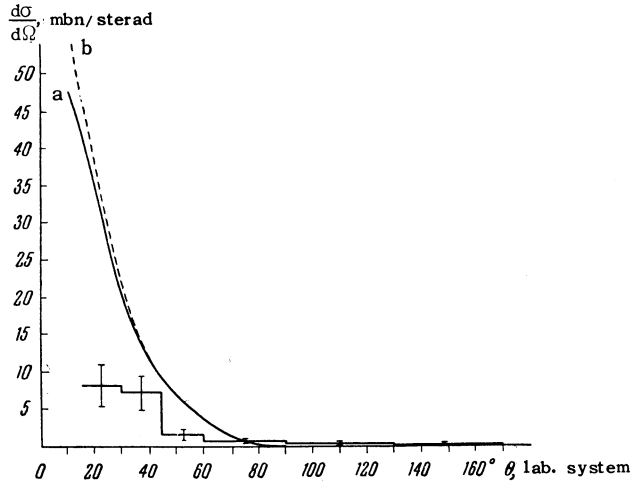

FIG. 1. Angular distribution of π^+ mesons scattered elastically by deuterons: (a) calculated in the impulse approximation neglecting the Coulomb interaction; (b) with account of the Coulomb interaction.

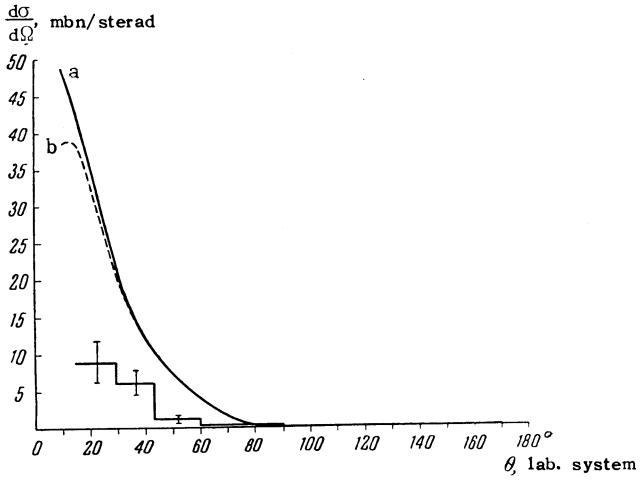

FIG. 2. Angular distribution of π^- mesons scattered elastically by deuterons: (a) calculated in the impulse approximation neglecting the Coulomb interaction; (b) with account of the Coulomb interaction.

mesons, and 26 involving π^+ mesons remained unidentified.

Scanning of control plates which did not contain deuterium showed that the background of two-prong stars, produced in emulsion nuclei and satisfying our criteria for π-d scattering, was small. It was not taken into account in determining the cross section for π-d scattering.

The differential cross sections for scattering of π mesons by hydrogen, and also the results of a phase shift analysis, were published earlier.[4] The increased statistical accuracy here did not change the magnitudes of the cross section and phases, which are in good agreement with the results of other authors.

In the present work we obtained the following integral cross sections for the elastic scattering of π^+ and π^- mesons by deuterium in the angular range $15 - 170°$ in the laboratory system

$$\sigma(\pi^+ + d \to \pi^+ + d) = 21 \pm 6 \text{ mbn},$$
$$\sigma(\pi^- + d \to \pi^- + d) = 14 \pm 4 \text{ mbn}.$$

Corrections were introduced here to take care of cases missed in the scanning, analogously to the way in which this was done for the scattering from hydrogen,[4] and the unidentified cases were taken into account.

The corresponding angular distributions are given in Figs. 1 and 2 in the form of histograms. The solid line was calculated in the impulse approximations,[5] starting from the phases determined by us for π-p scattering.[4] The proportion of elastic scattering was determined here by the factor

$$I(\theta) = \frac{1}{(2\pi)^3}\int \left|\psi_D(r)\right|^2 e^{i\left|(q_0 - q)r\right|^2} dr,$$

which gives the probability that the deuteron is not broken up in the collision. The dashed line gives the angular distributions, calculated with the inclusion of the Coulomb interaction. The theoretical calculations were made by G. M. Vagradov.

Within the limits of experimental error, the angular distributions of π^--d and π^+-d scattering agree, in contradistinction to results on elastic scattering from helium at the same energy,[6] where the cross sections for π^+ and π^- mesons are different at small angles on account of interference of the Coulomb and nuclear scattering. In the case of scattering from deuterium in the region of small angles ($< 30°$), the experimental cross sections are significantly below the calculated ones. This divergence cannot be explained by the influence of the Coulomb force. The cause of the difference is not completely clear. The impulse approximation, while satisfactorily describing the results at 85 Mev,[1,7] does not give agreement with our experimental results at 300 Mev. A rigorous calculation of the multiple scattering in the deuteron in the given case is difficult and, apparently, would not lead to a complete agreement with experiment.

It should be noted that cases of backward elastic scattering ($\sim 7\%$) are observed for a rather high meson energy. According to the impulse approximation, this process should not be present. In addition, 12 cases of absorption of π^+ mesons in deuterium were found. The cross section for this process turned out to be equal to

$$\sigma(\pi^+ + d \to p + p) = 2.4 \pm 0.9 \text{ mbn}$$

In conclusion, the authors wish to thank Prof. I. M. Frank and I. Ia. Barit for help in this work, G. M. Vagradov for useful discussion, and also the group of laboratory workers who took part in the scanning of the plates.

[1] K. C. Rogers and L. M. Ledermann, Phys. Rev. **105**, 247 (1957).

[2] Arase, Goldhaber, and Goldhaber, Phys. **90**, 160 (1952).

[3] Dul'kova, Romanova, Sokolva, Sukhov, Tolstov, and Shafranova, Dokl. Akad. Nauk SSSR **107**, 43 (1956), Soviet Phys. "Doklady" **1**, 154 (1956).

[4] Dul'kova, Sokolova and Shafranov, Dokl. Akad. Nauk SSSR **111**, 992 (1956), Soviet Phys. "Doklady" **1**, 739 (1956).

[5] Fernbach, Green and Watson, Phys. Rev. **84**, 1084 (1951).

[6] Kozodaev, Suliaev, Filippov, and Shcherbakov, J. Exptl. Theoret. Phys. **33**, 1047 (1957), Soviet Phys. JETP **6**, 806 (1958).

[7] R. M. Rockmore, Phys. Rev. **105**, 256 (1957).

[8] K. A. Brueckner, Phys. Rev. **90**, 715 (1953).

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60

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FISSION OF SILVER BY HIGH-ENERGY PROTONS

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Certain parameters for fission of silver induced by protons with energies ranging from 300 to 660 Mev are investigated. An analysis of the experimental data reveals that (1) fission of silver by high-energy protons is characterized by fragments which are predominantly of equal mass; (2) the fission cross section shows no essential change in the region of incident-proton energy which was investigated ($\sigma_f = (3.2 \pm 1) \times 10^{-28}$ cm^2); (3) a large number of charged particles are emitted in fission, indicating a high initial excitation for the fissioning nucleus.

A complete yield curve for the residual nuclei as a function of charge is given along with the differential yield curves for various nuclear interactions: spallation, fission and cascade-evaporation.

EXPERIMENTAL DATA

AT the present time there is available a large body of data concerned with fission in the heavy nuclei (U, Th, Bi) at the end of the periodic table. There is also some information concerning fission of lighter nuclei such as W and Ta. The situation is entirely different with respect to fission of elements at the middle of the periodic table. Aside from the fact that fission does occur in these elements[1] little else is known.

In the present work, using nuclear emulsions, an attempt has been made to obtain certain preliminary information on fission of silver by high-energy protons. A fine-grain nuclear emulsion ("P 9 - sensitive"), sensitive to 45-Mev protons, was irradiated in the intense proton beam from the synchrocyclotron of the Joint Institute for Nuclear Research. The entire area through which the proton beam passed was then scanned with a microscope (all the plates were irradiated with the beam perpendicular to the surface of the emulsion; the same collimator (diameter d = 2 cm) was used in all experiments).

In carrying out the analysis, only those events were selected in which, in addition to the other nuclear disintegration products, (α, p) there were two tracks of highly ionizing fragment-type particles. In order to distinguish the fission events from spallation in heavy elements of the emulsion, we arbitrarily assigned to fission only those events in which the range ratio for the two