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ABSORPTION OF SLOWED DOWN π^- MESONS IN PROPANE

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The energy spectra of secondary singly-charged particles produced as a result of absorption of slowed down π^- mesons by carbon also the distributions of angles between the prongs in π-meson stars were obtained with a 4-liter propane bubble chamber. Estimates based on the energy spectra show that the maximum contribution of π-meson absorption by a complex consisting of several nucleons (≥ 4) does not exceed 20%. An analysis of over 200 interactions carried out on an electronic computer by the Monte Carlo method shows that the experimental data are in agreement with the two-nucleon mechanism and, in accordance with preliminary results[7], the probability for π-meson absorption by a pair of different nucleons (np) is two or three times greater than that for absorption by a pair of identical nucleons (pp).

1. In recent years there has been continuous interest in the absorption of pions of both polarities by complicated nuclei. This interest is due both to the fact that the material accumulated in this field is contradictory, and also to the opportunities afforded by pions for the study of nuclear structure[1].

Many investigations with bubble chambers, performed during the last five years[2,6], were devoted to the absorption of pions of both polarities with energies from ~30 to ~300 MeV. On the basis of the obtained data, the authors of [2,3] reached the conclusion that the predominant mechanism for the capture of the pion by the nucleus is the two-nucleon mechanism, and according to the estimates 60—70% of the pions are absorbed in the nucleus by np nucleon pairs. However, the analysis of the experimental data was made in these investigations by direct comparison with the results expected in accordance with the two-nucleon model, and no other possible mechanisms were checked. Yet many facts, for example the observation[4] of a large background (30%) of protons with energies less than 15 MeV, with isotropic distribution in space relative to the direction of motion of the primary meson, indicates the need for such a check, since such a background could result from the absorption of pions by larger nucleon complexes or by the nucleus as a whole.

Wang et al.[4], who investigated the absorption of positive pions by carbon in the energy interval 270 ± 10 MeV, used in the analysis of their experimental data the "explosion" absorption model, according to which the total energy of the absorbed meson is instantaneously distributed over all the nucleons in the nucleus. The authors concluded that the experimental results agreed with the model employed. Finally, in our recent paper[7] we determined the probabilities of the absorption of pions of both signs in carbon by np and pp nucleon pairs at energies from 40 to 70 MeV. The analysis of the results in that paper was also based on the assumption of 100% two-nucleon capture of the pion, and it was concluded that the experimental data agreed with such an assumption within the limits of experimental accuracy.

The conclusions reached in several investigations in which photographic emulsions were used[8-11] turned out to be different. These investigations were devoted to the absorption of stopped negative pions by light nuclei (C, N, O) in the emulsion. On the basis of the investigation of the angular and momentum distributions, principally of the heavy secondary particles (alpha particles and fragments), the authors concluded that at least in 60% of the reactions the absorption can be attributed to a "single-nucleon" mechanism, in which the pion is captured by one nucleon which interacts strongly with the remaining nucleus. However, not all the possible reactions accompanying the absorption of pions were studied in these investigations, owing to the specific nature of the emulsion method. In addition, one of the main facts on which the deductions of these investigations are based, namely the observation of a group of recoil nuclei with momenta equivalent to the momentum of one fast nucleon, admits of an

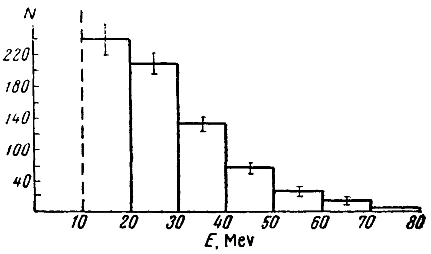

FIG. 1. Energy spectrum of secondary particles in one-prong stars.

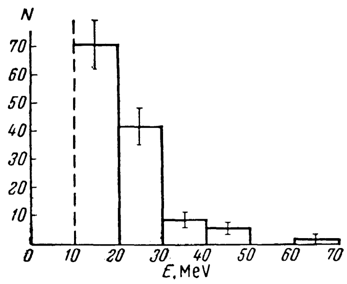

FIG. 3. Energy spectrum of secondary particles in three-prong stars.

ambivalent interpretation.

2. By virtue of the foregoing, certain interest attaches to the investigation of the absorption of stopped negative pions in a propane bubble chamber. Such an experiment has several obvious advantages. First, unlike the emulsion technique, in view of the reliably established fact of "interception" of the negative pions from the mesic-proton orbits by the near-nuclear Bohr orbits in hydrogen-containing substances, the nucleus with which the interaction occurs is established for propane (C_3H_8). Second, the selection of the stopped pions gives with good accuracy the momentum of the interaction, whereas the previously performed experiments with bubble chambers were carried out over wide energy intervals.

We have processed photographs of slowing-down pions obtained with the aid of a 4-liter propane bubble chamber[12] and used previously to investigate the scattering of low-energy pions[13]. In the processing we selected pion tracks with an ionization density that increases towards the end of the range and with an increasing multiple-scattering angle, terminating in a characteristic star with one or more prongs. Previously made estimates[13] show that the admixture of stars produced by the pions "in flight" does not exceed 2%.

Among the secondary particles we observed none that stood out distinctly with respect to ionization density. This gives grounds for assuming that the secondary particles in the stars are exclusively singly-charged particles. Such a deduction is indirectly confirmed also by the results of Ammiraju and Lederman[14], from which it follows that in the reaction where the stopped pion is absorbed by carbon the alpha particles have an average energy of only 7.5 MeV; alpha particles with such energies have too small a range to be registered in a propane bubble chamber.

The selected interactions pertained to the absorption of the stopped pion by the carbon nucleus, and were used to plot the distribution over the angles between the fastest particle and the remaining particles, for stars with ≥ 2 prongs, and also the energy spectra of the secondary particles (Figs. 1—6). The energy of the secondary particles was determined from the total range under the assumption that these particles were exclusively protons. In addition, we plotted the distribution of single-prong stars relative to the projections of the angles between the direction of motion of the primary meson and this single prong (Fig. 7). The latter distribution is symmetrical with respect to 90°, and the ratio of the number of secondary particles emitted in the forward hemisphere (relative to the chosen direction) to the number of particles moving in the backward hemisphere is equal to unity (the "up-down" ratio is also equal to unity). This offers evidence in favor of the assumption that the momentum of the absorbed meson is actually equal to zero.

The distribution of stars with ≥ 2 prongs over the angle between the fastest particle and the remaining particles has a characteristic peak in the

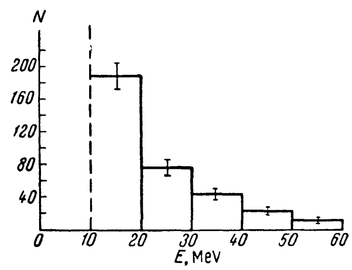

FIG. 2. Energy spectrum of secondary particles in two-prong stars.

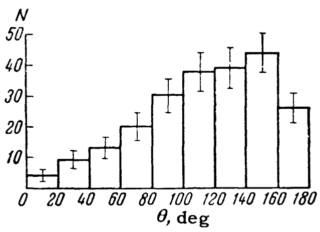

FIG. 4. Distribution with respect to the angle θ between prongs in two-prong stars.

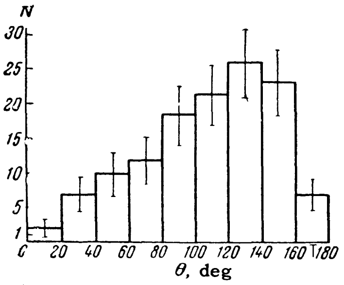

FIG. 5. Distribution with respect to the angle θ between the fastest and remaining particles in three-prong stars.

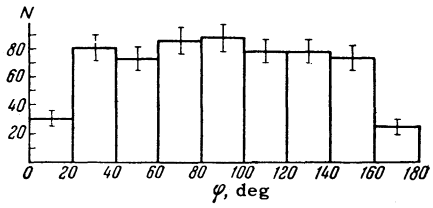

FIG. 7. Distribution with respect to the projection of the angle φ between the prong and the direction of motion of the primary pion for single-prong stars.

region of obtuse angles, with a tendency towards becoming smoother with increasing number of prongs in the star; the anisotropy remains, however. Such a character of the angular distributions makes it possible to state that the secondary particles are not the products of the evaporation of residual nuclei. Simple calculations based on the fact that the greater part of the secondary particles has ranges corresponding to proton energies from 20 to 8 MeV, and carried out under the assumption that these particles can be protons, deuterons, and tritons, show that for two-prong stars, if the evaporation mechanism is suitable, the maximum degree of anisotropy (the ratio of the number of secondary particles moving forward relative to the chosen direction to the number of particles moving backward) cannot exceed 1.5, whereas in experiment the degree of anisotropy reaches 4.7.

Of interest from the point of view of clarification of the pion absorption mechanism are the energy spectra of the secondary particles. For one-, two-, and three-prong stars these distributions (Figs. 1-3) have the following common features: first, the greater part of the secondary particles have short ranges (proton energies smaller than 20 MeV); second, the upper energy boundary of these distributions lies in the proton energy region 60—70 MeV. Qualitatively these facts, and also the already indicated character of the angular distributions, offer evidence in favor of the two-nucleon mechanism for the absorption of a pion by a nucleus, according to which the nucleons from the pair that has absorbed the pion are scattered in opposite directions, each carrying away half the rest energy of the meson (~ 70 MeV).

In the case when the many-nucleon capture mechanism would play an important role, if the meson is absorbed by groups of four and more nucleons, it would be expected that the upper boundary of the energy spectra would lie in the region ~ 110 MeV (this follows from the energy conservation law). Not a single star out of about 1000 was observed with a secondary-proton energy, larger than 75 MeV. This circumstance, however, can also be attributed to the decrease in the chamber registration efficiency for long-range particles, owing to purely geometrical considerations ("transmission power"). On the basis of the experimentally verified distribution of the pions entering the chamber through its cross section area, it becomes possible to calculate the coefficient of correction for the emissions due to the geometry of the chamber. It turned out that the emissions began for ranges corresponding to proton energy 30 MeV, and reached 50% for 60 MeV.

With allowance for the geometrical correction, we have estimated the possible contribution made to the pion absorption by the many-nucleon mechanism. We have used here the following assumptions: The distribution density in the energy spectra is the same for the 60—70 and 70—100 MeV intervals; the fast nucleon from the complex that has absorbed the meson experiences not more than one collision in the nucleus. (The latter assumption is confirmed essentially by our preliminary data[1], and also by subsequent calculations by the Monte Carlo method.) The calculation made under these assumptions shows that the many-nucleon mechanism can cause not more than 20% of all the pion absorptions.

This conclusion is not influenced at all by the fact that among the secondary singly-charged particles there may be deuterons or tritons, since it is made on the basis of the high-energy part of the experimental spectra, where the appearance of such particles is excluded by the conservation laws.

3. We have analyzed with the aid of a computer

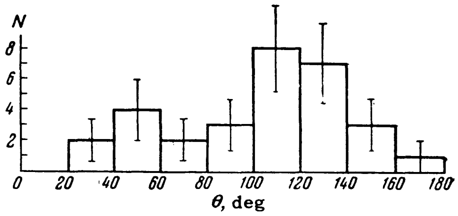

FIG. 6. Distribution with respect to the angle θ between the fastest and remaining particles for four-prong stars.

Table I. Spectrum of secondary particles for single-prong stars. W_{calc}—calculation by the Monte Carlo method.

Energy interval, MeV	W_{exp}	W_{calc}
10—20	0.36	0.43
20—30	0.31	0.18
>30	0.33	0.39

Table II. Spectrum of secondary particles for two-prong stars.

Energy interval, MeV	W_{exp}	W_{calc}
10—20	0.56	0.43
20—30	0.22	0.28
>30	0.22	0.29

2584 cases of pion absorption by the carbon nucleus, using the Monte Carlo method; we have assumed here that the pions are absorbed only by pairs of nuclear nucleons. The nucleus was regarded as a Fermi gas at zero temperature in a rectangular potential well 33 MeV deep. In the calculation of the intra-nuclear cascade, the nucleon collision was regarded as a collision between free particles with the only limitation imposed by the Pauli principle. This assumption is justified by the satisfactory agreement between the calculations and the experiment in the investigation of the interaction between neutrons and complex nuclei[15-17]. The possible reflection and refraction of the nucleon on the nuclear boundary was neglected. The energy distributions were calculated for one- and two-prong stars, and also the angular distribution over the angles between the prongs for the two-prong stars. The results are listed in Tables I—III. It is seen from the tables that the experimental data are in satisfactory agreement with the calculation in which the probability of absorption by an np pair of nucleons was assumed to be 70%. The calculation showed also that owing to the "entangling" of one of the primary nucleons which have captured pions in the nucleus, approximately 10% of the absorption cases can imitate "single-nucleon" capture, in which the meson is absorbed by a single nucleon which interacts strongly with the remaining nucleus.

Thus, from the experimental data obtained in the present work it follows that the absorption of the stopped pions in carbon proceeds predominantly via two-nucleon capture. The possible fraction of the many-nucleon mechanism does not exceed 10—20%.

Calculation by the Monte-Carlo method confirms the previously obtained quantitative result[7].

In conclusion the authors express their gratitude to Professor A. I. Alikhanyan and L. P. Kotenko, whose efforts made possible the performance of this experiment, and also V. P. Protasov, who participated in the initial stages of the work.

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Table III. Distribution with respect to the projection of the angle between the prongs in two-prong stars. W_{calc}—value obtained by the Monte Carlo method.

Angle projection interval, deg	W_{exp}	W_{calc}	Angle projection interval, deg	W_{exp}	W_{calc}
0—20	0.014	0.015	100—120	0.136	0.142
20—40	0.045	0.010	120—140	0.156	0.203
40—60	0.044	0.011	140—160	0.184	0.248
60—80	0.065	0.011	160—180	0.284	0.289
80—100	0.071	0.071			

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175