ON THE ABSORPTION OF π^+ MESONS WITH ENERGIES OF ABOUT 50 Mev BY CARBON NUCLEI

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Stars arising from the absorption of π^+ mesons with an energy of 50 ± 20 Mev in carbon nuclei were investigated with the aid of a propane bubble chamber. The formation cross section of such stars was equal to 145 ± 36 mb. The distribution of stars according to the number of prongs was obtained, the average number of prongs being 2.6 ± 0.3. A significant anisotropy in the angular distribution of prongs relative to the direction of motion of the π^+ meson was observed. The basic source of this anisotropy was evidently a pre-absorption scattering of π^+ mesons from the individual nucleons inside the nucleus. The distribution of two-pronged stars by angles between the prongs is given.

A significant number of stars from the interaction of low-energy π^+ mesons with carbon nuclei were found while looking through photographs obtained earlier[1] in a study of π^+-μ^+-e^+ decay using a propane bubble chamber[2] of diameter 9 cm and depth 7 cm.

The inelastic interactions of π^+ mesons with complex nuclei has been studied with scintillation counters, photoemulsions, and Wilson cloud chambers. The investigations carried out with scintillation counters[3-5] consisted of measuring the attenuation of the π^+ beam intensity and did not allow separation of the absorption of π^+ mesons from other inelastic processes. In the work with photographic plates,[6-8] it was impossible to identify the nuclei involved in the interaction. Finally, the work with cloud chambers[9-10] was restricted to an investigation of only the energetic prongs of the stars (for example, Byfield et al.[10] considered prongs belonging to protons with energies ≥ 40 Mev), since the carbon target, unavoidably relatively thick, absorbed the low-energy charged particles. Under these conditions the photograph of the event was far from complete.

In spite of this large amount of work, it is interesting to investigate the inelastic interactions of π^+ mesons with complex nuclei using a bubble chamber, since this enables us to get additional information on the subject through some peculiarities of the method. For example, using the bubble chamber for the solution of similar problems, it is possible simultaneously to identify the nucleus involved in the interaction, to separate the absorption of π^+ mesons from other inelastic processes, and to get a fuller photograph of the event than in cloud chambers, since protons with energies ≥ 3 Mev, corresponding to prong lengths ≥ 0.5 mm, can be observed.

In connection with the above it seemed interesting to us to investigate with the propane bubble chamber the character of the stars coming from the absorption of low energy π^+ mesons by carbon nuclei. This question was investigated with a propane bubble chamber earlier,[11] but only for 250 — 270 Mev pions. Since in our case the pion energies were quite a bit lower than 250 Mev, it is interesting to compare the results we obtained with the results of reference 11.

The conditions of the experiment, a diagram of which is given in reference 1, were the following. The formation of π^+ mesons took place in a polyethylene target placed in the 670-Mev proton beam from the synchrotron chamber. The mesons coming from the target were deflected by an electromagnet to pass through a collimator in a four-meter concrete shield into the measurement area, where the bubble chamber was located. A filter to slow down the pions was placed immediately in front of the chamber. All the photographs were taken for two values of the energy of the pions as they came out of the collimator. In this work only those photographs were examined which were taken for an incident pion-beam energy of 273 Mev, that is, when the mesons incident on the collimator came from a target 30 cm thick at an angle 0° to the direction of the incident proton beam, and when a 15.5 cm thick copper filter was placed in front of the chamber. The average pion energy in the middle of the chamber was 50 ± 20 Mev for this filter. The estimate of the error in the value of the energy of the pions was made by an analysis of their absorption curve in copper, obtained with scintillation counters. The pion energy losses in going through the propane chamber were also taken into consideration.

The scanning and analysis of the photographs taken was done on a reprojector;[12] the scanning, as already described, was done while the work was being carried out.[1] To eliminate distortions dependent on the regions of the chamber a region with a diameter of 6 cm was separated and only those stopping and interaction events which occurred in this region were noted. The pion interaction events with both hydrogen and carbon were determined.

To separate out the elastic scattering of pions from hydrogen, measurements were made of the angles between the pion track and each of the secondary tracks in all cases where the given interaction could have taken place. It was reckoned that elastic pion scattering on hydrogen took place wherever the measured angles satisfied the kinematic relations.

Among the stars showing up in the scanning were stars occurring both with and without the absorption of a pion. Those stars were counted as occurring without pion absorption one of whose prongs had the form characteristic of π^+-μ^+-e^+ decay. To decide which of the remaining stars occurred with pion absorption, the length of each prong was determined; and the longest prong, according to probability, was ascribed to a π^+ meson and the others to protons. If the bubble density of the track assigned to the pion did not markedly increase towards the end, then 1 — 1.5 cm was added to its length, corresponding to the known path of a pion to its full stop. Then the energy of all the particles in a star was found under the assumption that each of them stopped inside the chamber. It was taken that the star formation occurred with pion absorption if the energy of all the particles added to the binding energy of the original carbon nucleus was greater than the binding energy of the residual nucleus plus 70 Mev. From all the possible residual nuclei, that one was chosen whose binding energy was the closest to the binding energy of the original carbon nucleus. Whenever this condition was not fulfilled, but either all the particles of the star stopped in the chamber or all the particles which did not terminate inside had strong blackening for a sufficiently great length, so that none of them could be a π^+-meson track, we considered that we had here too a π^+ absorption process, although some of these might have been actually charge exchanges of a π^+-meson with a carbon nucleus. This method of choice was justified by the fact that, for pion energies of the order of 50 Mev, the upper limit of the charge exchange cross section is only a few percent of the absorption cross section,[13] so that this process could not essentially influence the character of the results. All the rest of the stars, satisfying none of the conditions enumerated above, were placed by us in the "doubtful" group. Typical photographs of stars occurring with π^+-meson absorption, are given in Figs. 1 and 2.

In all, 2360 stereo photographs were scanned, and 180 stars satisfying the conditions for π^+-meson absorption were discovered. Eight of these 180 stars had an indeterminate number of prongs. In addition, 65 stars were found which by our conditions of selection were accounted "doubtful." Considering that half of the "doubtful" stars occurred with π^+ absorption by carbon nuclei, and taking into account an admixture of μ^+ mesons in the pion beam, determined from the absorption curve of pions in copper, the absorption cross section for π's with energies 50 ± 20 Mev by carbon atoms was found to be 145 ± 36 mb.

The distribution of stars formed by π^+ mesons in their absorption by carbon nuclei is given by the solid line in Fig. 3 in terms of the number of prongs. In constructing this distribution, only those prongs were considered whose length was not less than 0.5 mm, and it was supposed that half the "doubtful"

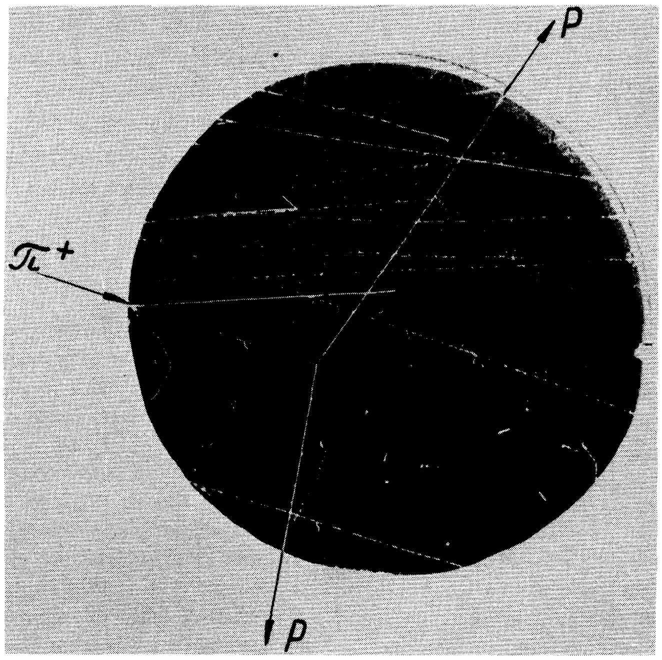


FIG. 1. Two-pronged star resulting from the absorption of a π^+ meson by a carbon nucleus.

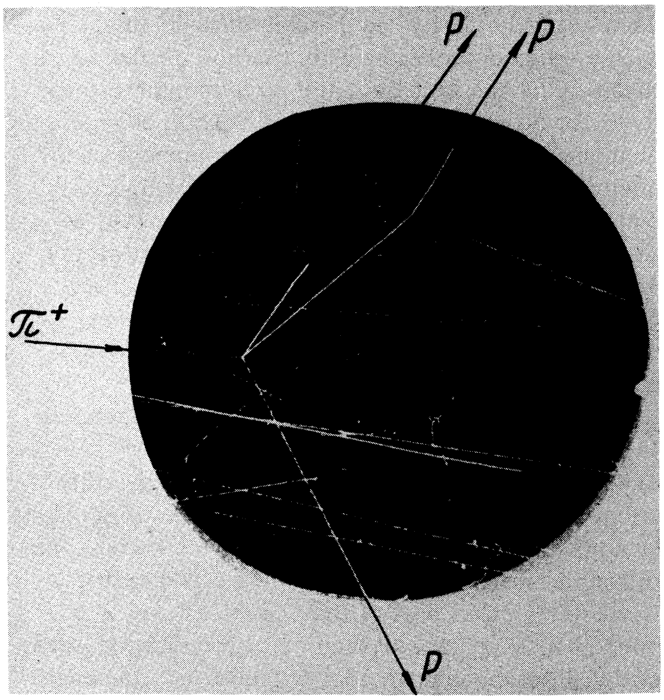


FIG. 2. Three-pronged star resulting from the absorption of a π^+ meson by a carbon nucleus.

stars occurred with π^+-meson absorption by carbon nuclei. The experimental points in Fig. 3 are shown together with their errors, calculated using statistical considerations and the fact of the presence of "doubtful" stars, which were the basic source of errors for one- and two-pronged stars. In the same figure, the dotted line shows an analogous distribution obtained in reference 11 for 115 stars formed by π^+ mesons of energy 250 — 270 Mev upon being absorbed by carbon nuclei. It is evident from Fig. 3 that the distributions shown of stars according to number of prongs agree well with each other, within the limits of experimental error. This obviously indicates the absence of a

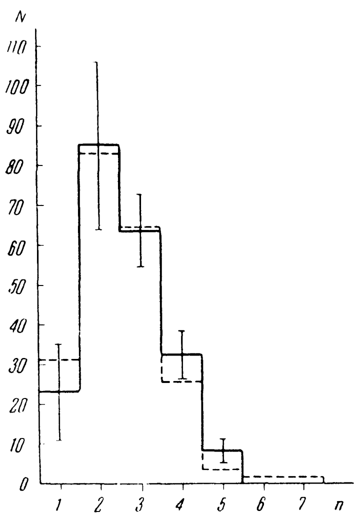


FIG. 3. Distribution of stars by number of prongs. N — number of stars, n — number of prongs in the stars. The solid line is the results of the present work, the dotted line is the data obtained in reference 11 for 115 stars produced in the absorption of 250-270 Mev energy π^+ mesons by carbon nuclei.

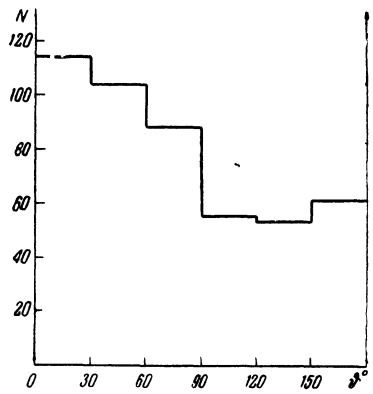
strong dependence in these similar distributions on the energy of the incident π^+ mesons. We further note that the star distributions obtained are characterized in their dependence on the number of prongs by an average of 2.6 ± 0.3 prongs. To calculate the error in the average number, statistics and the presence of "doubtful" stars were taken into account.

For 172 stars formed by π^+ mesons during their absorption by carbon nuclei, a distribution of prongs was constructed as a function of the magnitude of the angle ϑ, the projection of the angle between the direction of motion of the π^+ meson and the prong onto the plane perpendicular to the optical axes of the stereo camera. It is evident from this distribution, shown in Fig. 4, that there was observed a strong anisotropy of prongs relative to the direction of motion of the π^+ meson. In fact, the number of prongs N_f in the forward hemisphere relative to the π^+ meson direction of motion was 1.81 times greater than the number of prongs N_b in the back hemisphere. If the degree of observed anisotropy is characterized by the ratio $(N_f - N_b)/(N_f + N_b)$, this quantity is equal to 0.29 ± 0.05. Again, the error calculation for the magnitude of the anisotropy took into account statistics and the presence of "doubtful" stars. To trace the variation of the anisotropy as a function of the number of prongs in the stars, the ratio $(N_f - N_b)/(N_f + N_b)$ was calculated for stars with various numbers of prongs. The following data were obtained:

Number of prongs in star:	1	2	3	4	5
$\frac{N_f - N_b}{N_f + N_b}$:	$1.00^{+0.29}_{-0.56}$	$0.36^{+0.09}_{-0.1}$	0.36±0.08	0.18±0.09	0.20±0.16

It is evident from these data that some tendency is observed for the anisotropy to increase as the number of prongs in a star decreases. The observed anisotropy cannot be connected with the

FIG. 4. Angular distribution of prongs relative to the direction of motion of the π^+. θ is the projection of the angle between the π^+ meson direction of motion and the prong on the plane perpendicular to the optical axes of the stereo camera. N is the number of prongs in each 30° interval of the angle θ.



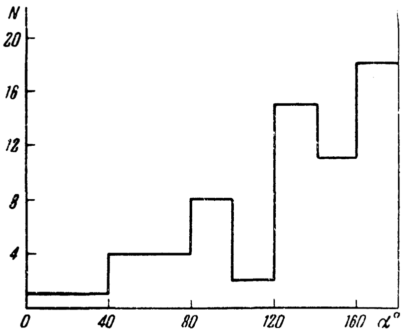


FIG. 5. Distribution of two-pronged stars as a function of the angle between the two prongs. α is the angle between the two prongs, N is the number of two-pronged stars, and the interval of the angle α is 20°.

process of absorption of a π^+ meson by a nucleon pair. This result is not hard to understand if one considers the kinematical relations or makes use of the experimental data on the distribution of two-pronged stars in terms of the angle α between the two prongs. One can see from this distribution, shown in Fig. 5, that there exists a significant group of stars in the α interval 120° to 180° which evidently correspond to the known process of π^+-meson absorption by a nucleon pair. The proton distribution in this group as a function of the magnitude of the angle ϑ is isotropic, as should be expected from the kinematic relations. This fact strengthens the result obtained before about the impossibility of explaining the observed anisotropy by absorption of the π^+ meson by a nucleon pair.

It is reasonable to suppose that the chief sources of anisotropy are quasi-elastic scattering of π^+ mesons by protons and their exchange scattering by neutrons inside the nucleus, since in these processes the protons can only be ejected in the forward hemisphere relative to the π^+-meson direction of motion. Under this supposition, there ought to exist (as an analysis of the data shows), besides the stars resulting from π^+-meson absorption without previous scattering by inside nucleons, a significant group of stars in which the π^+ meson experiences a quasi-elastic or exchange scattering from individual nucleons inside the nucleus and is then absorbed. Of course, the picture of star formation proceeding with π^+-meson absorption in two states is highly schematic, since the time separation of these two processes inside the nucleus is rather arbitrary.

If the values of the cross sections of the processes $\pi^+ + p \rightarrow \pi^+ + p$, $\pi^+ + n \rightarrow \pi^0 + p$, $\pi^+ + n \rightarrow \pi^+ + n$ and the processes $\pi^- + n \rightarrow \pi^- + n$, $\pi^- + p \rightarrow \pi^0 + n$, $\pi^- + p \rightarrow \pi^- + p$ are taken into account, one can conclude, on the basis of the hypotheses given above, that the degree of anisotropy $(N_f - N_b)/(N_f + N_b)$ for the stars occurring with π^--meson absorption must be significantly less than that observed in the present work.

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