Total Cross Sections of Positive π-Mesons on Hydrogen

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Total cross sections of positive π-mesons on hydrogen were determined by the attenuation method, the beam of mesons passing through a scatterer of liquid hydrogen. From the set of measured total cross sections of π^+ mesons on hydrogen and deuterium, carried out by the authors, the contributions to the scattering of the different isotopic spin states at energies between 140 and 400 mev is derived.

EXISTING data on the total cross sections of positive π-mesons on hydrogen obtained by the attenuation method can be divided into two groups. In the first group, precise data with good energy resolution have been obtained recently by Ashkin et al.[1] Their measurements appear continuous with others at higher energy (up to ~200 mev) carried out earlier by Anderson, Fermi et al.[2] The second group of data,[3,4] of a preliminary character, covers the interval of energy from 150 mev to 450 mev. These measurements make it possible to decide whether there exists a maximum of the total cross section $\sigma_t(\pi^+, p)$ in its dependence on the energy, but because of insufficient energy resolution it is not possible to say anything definite about the position of the maximum or the magnitude of the cross section in its neighborhood.

We have made measurements of the total cross sections of π^+ mesons on hydrogen in the energy interval 140 to 230 mev. Positive mesons, produced in a copper target placed inside the vacuum chamber of the synchrocyclotron, passed through a channel made in the vertical mounting of the yoke of the accelerator's electromagnet. Consequently, special shielding against the direct radiation of the synchrocyclotron was not required. The total cross section was determined from the attenuation of the beam of mesons in passing through a hydrogen scatterer. The geometry of the experiment is shown in Figure 1. The target used in the experiment held about 12 liters of liquid hydrogen. The length of the scatterer was 28 cm, which corresponds to 1.97 gm/cm^2 of hydrogen.

As in the experiment on the scattering of negative π-mesons,[5] the beam of π^+ mesons falling on the target was detected by a system of three counters (1,2,3). However, in view of the fact that the beam of positive mesons contains a very great number of protons having the same momentum as the mesons, one of the scintillation counters in the defining telescope (1,2,3) was replaced by a Cerenkov detector. This lowered the effectiveness for registering protons to approximately one hundredth of one per cent, but even this does not exclude the possibility of their being registered completely because the plexiglass used as Cerenkov radiator scintillates slightly. In order to avoid all errors in the measurement of attenuation due to the admixture of protons of low energy, a filter (4.6 gm/cm^2 of polyethylene) capable of stopping protons contained in the meson beam was placed in front of the third scintillator.

Mesons which passed through the last scintillator (4) were registered by a coincidence counting arrangement. In the measurements, to exclude the possibility of error arising from the drift of electronic apparatus, the hydrogen dewar was replaced by a blank at intervals of 5-10 minutes. The identity of the path of the beam through the walls of the dewar and the blank was checked by a special experiment with an intense beam of negative π-mesons. On account of the low current of π+-mesons, the determination of their energy during the measurement runs was extremely difficult. We used another method of measuring the energy, the method of the flexible current bearing conductor immersed in the magnetic field.[6] As a control, the range of the mesons in copper was measured at an energy of 145 mev. This measurement coincided with that obtained by the method of the current bearing filament. The maximum possible inhomo-

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[2] H. L. Anderson, E. Fermi, E. A. Long, and D. E. Nagle, Phys. Rev. 85, 936 (1952).

[3] L. C. L. Yuan and S. J. Lindenbaum, Bull. Amer. Phys. Soc. 28, 13 (1953); Phys. Rev. 92, 1578 (1953).

[4] L. C. Yuan et al, cited in F. de Hoffman et al, Phys. Rev. 95, 1586 (1954).

[5] A. E. Ignatenko, A. E. Mukhin, E. B. Ozerov, and B. M. Pontecorvo, Dokl. Akad. Nauk SSSR 103, 45(1955).

[6] J. J. Thomson, Phil. Mag. 13, 561 (1907); M. C. Kazodaev and A. A. Tyapkin, Report for 1952 of Institute of Nuclear Problems, Academy of Sciences.

geneity in the energy of the beam of mesons which fell on the target was also determined with the help of the current bearing conductor in the magnetic field. This maximum dispersion in energy was determined by the aperture of the collimating system; it was approximately ± 1.5 % of the nominal beam energy. The total uncertainty in the energy (taking into account the slowing down of the mesons in hydrogen, the errors in the measurement, and the initial maximum possible inhomogeneity of the beam in energy) was about ± 6 mev.

It is well known, that in a beam of positive π-mesons of energy from 130 to 200 mev, the admixture of μ^+-mesons remains practically constant.[1] From experiments with beams of negative π-mesons[5] it is seen that in a very wide band of energies above 180 mev, the admixture of μ^--mesons also changes insignificantly. On the basis of the experimental facts presented above, the admixture of μ^+-mesons was measured by absorption only for one energy, 145 mev, and assumed constant for all energies which are of interest for the following. The admixture was (7.0 ±1.5) %.

Under the geometrical conditions of the experiments, (average angle registered by the last detector, θ=8°) the last scintillator was registering an appreciable part of the recoil protons and scattered mesons. The correction taking this effect into account was determined from the known angular distribution at three energies [7-9]. At an energy of 144 mev, where the filter in front of the last scintillator was sufficient to stop all recoil protons, the experimentally measured correction for recoil protons practically coincided with the calculated correction (Table 1).

TABLE I.

	$\sigma_t(\pi^+, p)$ (10^{-27} cm²) measured	Correction: Recoil Protons	Correction: Mesons	$\sigma_t(\pi^+, p)$ (10^{-27} cm²) corrected
Without filter	135,9 ± 4,0	9,7	3,8	149,4 ± 4,7
With filter	147,4 ± 3,8	—	3,8	151,2 ± 3,9

The results of the measurements, with the corresponding corrections inserted, are displayed in Table 2. The errors indicated in the second column are statistical and include uncertainties arising from the insertion of corrections. The first number was obtained with the help of the method of (CH_2-C) differences (with a geometry described earlier in Reference 5); the remaining data were obtained with liquid hydrogen.

TABLE II.

Energy of meson (mev)	Total cross section (10^{-27} cm²)
140 ± 7	133 ± 8
144 ± 6	151 ± 4
164 ± 6	169 ± 5
174 ± 6	193 ± 6
184 ± 6	196 ± 6
194 ± 6	200 ± 6
209 ± 6	179 ± 6
219 ± 6	156 ± 7
229 ± 6	132 ± 7

The numbers indicated in Table 2 for the total cross section in the neighborhood of 195 mev are in good agreement with the data of Ashkin et al.[1] The continuation of the measurements in the direction of higher energy where, up to the present, no direct measurement of the total cross section existed, shows that it reaches its maximum value (200×10^{-27} cm²) at approximately 190 mev. After achieving the maximum, the cross section falls relatively rapidly with further increase in energy. Earlier the position of the maximum of $\sigma_t(\pi^+, p)$ could be judged only from the results of indirect measurements, which were discussed in Reference 10.

[7] W. B. Fowler et al., Phys. Rev. 92, 832 (1953).

[8] M. Glicksman and H. L. Anderson, Bull. Amer. Phys. Soc. 29, 24 (1954).

[9] U. Kruse, H. L. Anderson, W. C. Davidon, and M. Glicksman, Bull. Amer. Phys. Soc. 30, 49 (1955).

[10] A. E. Ignatenko, A. E. Mukhin, E. B. Ozerov, and B. M. Pontecorvo, Dokl. Akad. Nauk SSSR **103**, 209(1955).

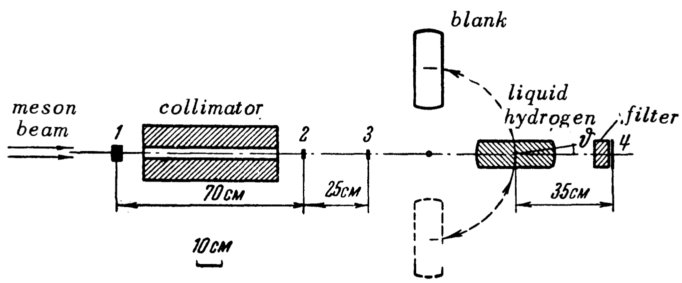

FIG. 1. Scheme of the experiment. *1*--Cerenkov detector; *2,3,4*--scintillation counters.

It is worth noting that the position of the maximum for π^+ mesons coincides with the position of the maximum in $\sigma_t(\pi^-, p)$.

In the neighborhood of the maximum, the magnitude of the total cross section $\sigma_t(\pi^+ p)$ reaches the value $8\pi\lambda^2$ (where λ is the wavelength in the center of mass system) i.e., it reaches the maximum value of the cross section for elastic scattering in P-states with total angular momentum equal to 3/2. As is well known [1,5] for π^--mesons, the magnitude of the cross section in the region of the maximum is also equal to the maximum possible value for the cross section in a $P_{3/2}$ state with isotopic spin T=3/2, i.e., it is $(8/3)\ \lambda^2$.

From the requirement of charge independence, there follows the relation $\sigma_{1/2}=(3\sigma_t(\pi^-, p)-\sigma_{3/2})/2$ which connects the total cross section of the states with isotopic spin T=3/2 ($\sigma_{3/2}$) and T=1/2($\sigma_{1/2}$). It determines the contribution to the scattering of the state with isotopic spin T=1/2. Our measurements of $\sigma_t(\pi^+, p)=\sigma_{3/2}$ up to the energy 230 mev are plotted in Figure 2. At higher energies, the

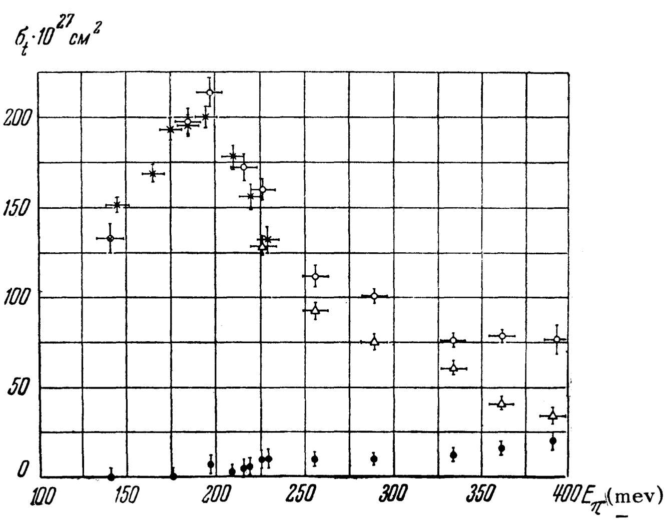

FIG. 2 Total cross sections $\sigma_{1/2}$ and $\sigma_{3/2}$ for π-mesons on nucleons in the states of isotopic spin T=1/2 and T=3/2 $\times$ — $\sigma_t(\pi^+, p) = \sigma_{3/2}$;
Δ — $[\sigma_t(\pi^-, d) - \sigma_t(\pi^-, p)] \approx \sigma_{3/2}$; $\bigcirc$ — $3\sigma_t(\pi^-, p)$;
$\bullet$ — $[3\sigma_t(\pi^-, p) - \sigma_t(\pi^+, p)]/2 = \sigma_{1/2}$

quantity $[\sigma_t(\pi^-, d)-\sigma_t(\pi^-, p)] \approx \sigma_t(\pi^+, p)$ is plotted[10]. For the purpose of comparison, both $\sigma_t(\pi^+, p)$

and $[\sigma_t(\pi^-, d) - \sigma_t(\pi^-, p)]$ are plotted at an energy of 226 mev. As one can see, these quantities agree sufficiently well. In the figure, the energy dependence of $3\sigma_t(\pi^-, p)$ is also shown, as well as the value of $\sigma_{1/2}$ obtained with the help of the relation written down above.

Although the entire set of measurements is consistent with the idea that the interaction of π-mesons with hydrogen in the energy interval 140 to 300 mev takes place principally in a single state with T=3/2, it should be remarked that already at an energy of 250 mev, as one can see from Figure 2, the contribution to the scattering of the state with T=1/2 becomes noticeable.

In Fig. 3, our experimental data are plotted together with the curve of the energy dependence of the total cross section of positive mesons in hydrogen calculated by Bethe et al.[11] This curve corresponds to their "resonance" solution (resonance refers to the phase shift α_{33}, corresponding to the state $P_{3/2}$ with isotopic spin T=3/2). The experimental points are in very good agreement with this solution. It should be noted that the entire set of results of our measurements of the total cross sections of π-mesons in hydrogen and deuterium in the energy interval 140 to 400 mev are well described by the semi-phenomenological "isobar" theory of Tamm et al.[12]

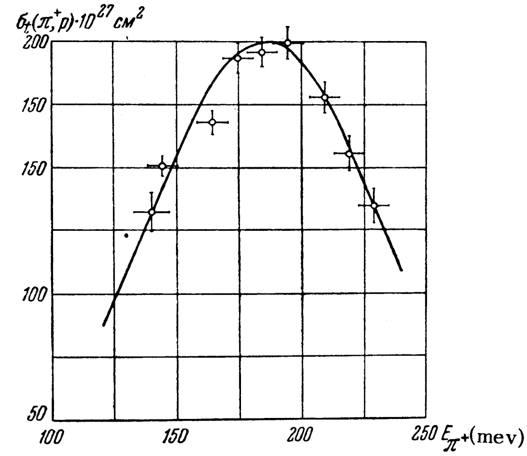

FIG. 3. Total cross section of π^+ mesons on hydrogen $\sigma_t(\pi+, p)$. The solid curve is the "resonance" solution of Bethe et al.[11]

It is of definite interest to compare our measurements of the cross section $\sigma_t(\pi^-, d)$ with the sum of the total cross sections for free particles $\sigma_t(\pi^-, p) + \sigma_t(\pi^+, p)$, which is equal, according to the principle of charge symmetry, to $\sigma_t(\pi^-, p) + \sigma_t(\pi^-, n)$. In Fig. 4 the values of $\sigma_t(\pi^-, d)$[10] are plotted, and also the area of possible values of the sum $\sigma_t(\pi^-, p) + \sigma_t(\pi^+, p)$, indicated by the striped area (values taken from the present work and Ref. 5). It is clear that in the neighborhood of the maximum there is a noticeable decrease of $\sigma_t(\pi^-, d)$ in comparison with the sum $\sigma_t(\pi^-, p) + \sigma_t(\pi^+, p)$.

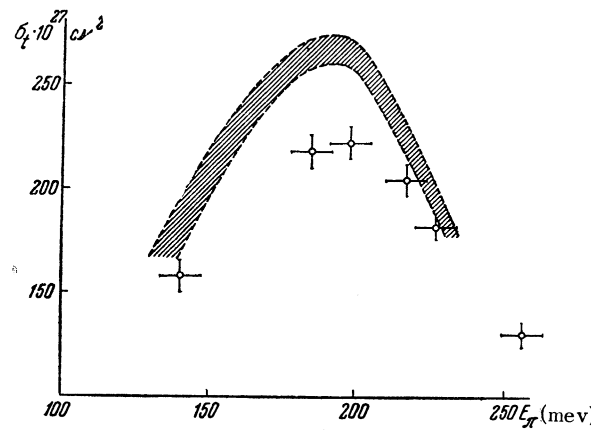

FIG. 4. Comparison of $\sigma_t(\pi^-, d)$ and the sum $\sigma_t(\pi^-, p) + \sigma_t(\pi^+, p)$. O — $\sigma_t(\pi^-, d)$, striped area-- $\sigma_t(\pi^+, p) + \sigma_t(\pi^-, p)$

Such behavior of the cross section of the deuteron is in agreement with theoretical predictions of Tamm[12] and Brueckner.[13] From their calculations in impulse approximation with the inclusion of the effects of multiple scattering one can derive that in the case of interaction in the state of isotopic spin 3/2 there will be observed a noticeable decrease of the total cross section of the deuteron in comparison with the sum of the cross sections of the free nucleons at a phase shift greater than 45°.

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[12] I. E. Tamm, Iu. A. Gol'fand, G. F. Zharkov, L. V. Pariskaia, and V. Ia. Feinberg, Report of the All Union Conference on Quantum Electrodynamics and the Theory of Elementary Particles (31 March-7 April 1955).

Added in proof. After the present paper was written, the use of beams of π^+ mesons, produced by external proton beams, made possible measurements of the total (and differential) cross section of hydrogen at meson energies above 300 mev. The results of that work as well as the recently appeared work of Lindenbaum and Yuan[14] will be discussed in a communication which will appear soon.

[13] K. A. Brueckner, Phys. Rev. 89, 834 (1953).

[14] S. J. Lindenbaum and L. C. L. Yuan, Phys. Rev. 100, 306 (1955).

Translated by A. S. Wightman
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