THE PRODUCTION OF CHARGED Π MESONS BY 660 MEV PROTONS ON HYDROGEN, DEUTERIUM AND CARBON

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1. *Introduction*

Experiments for investigation of the proton-proton elastic scattering [1] together with measurements of the total cross-section of the p-p interaction [2] permit us to assert that with an energy of the incident proton $E_p =$ 660 Mev, the cross-section of meson production in p-p collisions is only a little less than the elastic scattering. Mesons are produced as a result of the following reactions :

$$p + p \rightarrow d + \pi^+ \qquad (1)$$

$$p + p \rightarrow p + n + \pi^+ \qquad (2)$$

$$p + p \rightarrow p + p + \pi^\circ \qquad (3)$$

Experiments for investigation of reaction (1) lead to the angular dependence of meson distribution of the type $A + B\cos^2\theta^*$ †, which does not undergo any noticeable changes in the energy interval of $E_p = 460 - 660$ Mev [3,4].

Possible transitions to the $^3S_1$ state of the final n-p system are :

$$^1S_0 \rightarrow {}^3S_1\, p_0;\ {}^1D_2 \rightarrow {}^3S_1\, p_2;\ {}^3P_1 \rightarrow {}^3S_1\, s_1.$$

(Here the symbols for the final state are those used in the work of Rosenfeld [5]), and the assumption is that mesons are emitted only in the S and p states.)

The angular distribution together with the energy dependence of the meson production agree with the assumption that the mesons in reaction (1) are produced mainly in the p-state, and that of chief importance is the transition

$$^1D_2 \rightarrow {}^3S_1\, p_2.$$

For reaction (2) with an incident proton energy $E_p =$ 660 Mev, besides the above, transitions in the p-state of the final system of two nucleons are possible. The angular and energy distribution of mesons will be determined to a great extent by the relative contributions of the corresponding transitions.

In the present work the energy spectra and angular distribution of π^+ mesons appearing as a result of reactions (1) and (2), were investigated by the nuclear emulsion method. By the same means, experiments were made for investigating the production of charged π mesons at an angle of 90° on deuterium and carbon nuclei and in n-p collisions.

2. *The method of the experiment*

We investigated the production of mesons by protons on hydrogen in the synchrocyclotron of the Institute of Nuclear Problems of the USSR Academy of Sciences. The high intensity of the proton beam ejected into the atmosphere allowed us to experiment at a significant distance from the synchrocyclotron behind a four-metre concrete shield which assured quite favourable conditions because of the low background. The protons passed through a three-metre steel collimator with the aid of which a beam 20 mm. in diameter was cut out. The proton energy was 657 ± 8 Mev [6]. A flask with liquid hydrogen was set up in the path of the proton beam. The diameter of the volume filled with liquid hydrogen was 12 cm. The π^+ mesons produced in the p-p collisions left the target through the 2 mm. thick glass walls of the flask. With a system of collimators, mesons were sorted out, emitted from a target of a definite volume, at the angles $\theta = 60°$, 75°, 90°, 105° and 120° to the direction of the proton beam and registered by means of nuclear photo-emulsions. The angular resolution of the detector was $\pm$ 1.5°.

The photographic plates were placed in a copper block at an angle of 10° to the direction of the incident mesons. The meson energy was determined by the amount of material they had passed through until they were stopped in the emulsion. The length of the path in the copper block was measured by the coordinates of the meson track end. The developed plates were observed through a microscope with a magnification of 450. The π^+ mesons stopped in the emulsion were identified by the characteristic form of $\pi \rightarrow \mu$ decay.

In the same geometrical conditions, the photo-plates were irradiated in order to determine the background.

† The asterisk (*) denotes quantities which refer to the colliding nucleon in the centre-of-mass system.

About 2000 $\pi \rightarrow \mu$ decays for each angle were used for obtaining the π^+ meson spectra.

3. *The determination of the cross-section*

The differential cross-section of the meson production was determined according to the following formula:

$$\frac{d^2\sigma}{d\Omega d\varepsilon} = \frac{N}{nN_p t\,[d\varepsilon/dR]_\varepsilon} \cdot \frac{r^2}{S} \cdot \frac{\eta_1 \eta_2}{\eta_3}$$

where N_p is the number of protons which passed the target, n is the number of nuclei per 1 cm^2 of the target measured in the direction of the incident beam, N is the number of mesons found in the emulsion area S, r is the distance from the target to the emulsion surface, t is the emulsion thickness, $[d\varepsilon/dR]_\varepsilon$ is the energy loss in emulsion of mesons with an energy ε, η_1 is the coefficient accounting for the mesons leaving the beam as a result of nuclear interaction, η_2 is the coefficient accounting for the portion of mesons suffering the $\pi \rightarrow \mu$ decay before stopping in the emulsion, and η_3 is the efficiency of the $\pi \rightarrow \mu$ decay observation.

The number of protons N_p was determined to an accuracy of 3% with a calibrated ionisation chamber. In determining the meson energy loss, the following formula was used:

$$[d\varepsilon/dR]_\varepsilon = 0.067\, R_\pi^{0.419},$$

resulting from the proton range-energy relation [7]. The emulsion thickness t before the development was measured to an accuracy of 6%. In calculating the coefficient η_1, the length of the meson free path in copper was taken as 104.4 g/cm^2, and its value was kept within the limits from 1.02 for meson energy 30 Mev to 2.35 for meson energy 175 Mev. Corrections considering the decay of π mesons in flight were not large and the values of the coefficient η_2 varied within the limits of 1.04 and 1.10. The observation efficiency was checked by the method of repeated examination, and proved equal to 0.92.

4. *The results of the experiment*

The meson energy distributions at angles of $\theta = 60°$, 75°, 90°, 105° and 120° in the laboratory system (l. s.) of coordinates is shown in fig. 1. For all the angles besides 60° the energy distributions have clearly pronounced maxima in the high-energy parts of the spectrum. The position of these maxima corresponds to the meson energies calculated by the kinematic conditions of the reaction $p + p \rightarrow d + \pi^+$. The broadening of the monoenergetic meson line in this case is due to the following causes: (*a*) the finite value of the angular resolution of the detector, (*b*) the spread in energy of protons in the beam, (*c*) the multiple scattering of mesons, (*d*) the straggling. The calculated values of the energy dispersion agree with the results of the experiment.

The continuous spectrum located in the region of the lower energies corresponds to the mesons produced in the reaction $p + p \rightarrow p + n + \pi^+$. At angles of 75°, 90°, 105° and 120° in the l. s. it proved possible to separate the part of the mesons produced in the reaction $p + p \rightarrow d + \pi^+$ and to obtain the energy distribution of mesons from the reaction $p + p \rightarrow p + n + \pi^+$.

Table I gives cross-sections of the π^+ meson production for the above angles in the l. s. At an angle of 60°, we did not, because of considerable spread in energy of mesons, succeed in isolating the part corresponding to the reaction $p + p \rightarrow d + \pi^+$ and in our experiment only the total cross-section at this angle was measured. Taking into account the cross-section $(d\sigma/d\Omega)_{pp\rightarrow\pi^+ + \{^{d}_{pn}}$ at an angle of 60° and the results of [4] for reaction (1), we may note that the cross-section $(d\sigma/d\Omega)_{pp\rightarrow d\pi^+}$ is about 10% of the cross-section $(d\sigma/d\Omega)_{pp\rightarrow\pi^+ + \{^{d}_{pn}}$. Thus, we may assume that the spectrum measured at the angle of 60° is determined chiefly by the mesons of reaction (2).

TABLE I

θ	60°	75°	90°	105°	120°
$(d\sigma/d\Omega)_{pp\rightarrow\pi^+ + \{^{d}_{pn}} \times 10^{28}$ $cm^2/sterad^{-1}$	14.6 ± 1.6	8.9 ± 0.9	6.4 ± 0.7	3.5 ± 0.5	3.2 ± 0.4
$(d\sigma/d\Omega)_{pp\rightarrow d\pi^+} \times 10^{28}$ $cm^2/sterad^{-1}$	1.4 ± 0.1 †	1.7 ± 0.4	1.8 ± 0.3	1.4 ± 0.3	1.2 ± 0.2
$(d\sigma/d\Omega)_{pp\rightarrow pn\pi^+} \times 10^{28}$ $cm^2/sterad^{-1}$	13.2 ± 1.6	7.2 ± 1.3	4.6 ± 1.0	2.1 ± 0.8	2.0 ± 0.6
$(d\sigma/d\Omega)_{pp\rightarrow pn\pi^+}/(d\sigma/d\Omega)_{pp\rightarrow d\pi^+}$	9.4	4.2	2.6	1.5	1.7

† The value $(d\sigma/d\Omega)^{60°}_{pp\rightarrow d\pi^+} = (1.4 \pm 0.1) \cdot 10^{-28}$ cm^2 sterad is taken from [4].

5. *The transformation of the energy distributions from the laboratory system to the centre-of-mass system*

The meson energy spectra and the cross-sections in the centre-of-mass system (c. m. s.) of the colliding nucleons are of utmost importance for the theoretical interpretation of results.

To transform the cross-section from the l. s. to the c. m. s. we used the following relation:

$$\frac{d^2\sigma^*}{d\Omega^* d\varepsilon^*} = \frac{P^*}{P} \cdot \frac{d^2\sigma}{d\Omega d\varepsilon}$$

$$\text{where } \frac{d^2\sigma^*}{d\Omega^* d\varepsilon^*},\ P^* \text{ and } \frac{d^2\sigma}{d\Omega d\varepsilon},\ P$$

are the differential cross-section and meson momentum in the c. m. s. and in the l. s. respectively. Note that the mesons emitted at a definite angle θ in the l. s. and having different energies, correspond to mesons emitted at different angles θ^* in the c. m. s. Thus, mesons with the kinetic energy ε^* in the interval from 30 to 150 Mev and emitted, for example, at an angle $\theta = 90°$, correspond to mesons emitted in the interval of angles $125° < \theta^* < 153°$ in the c. m. s. Thus, the angular dispersion in the c. m. s. will give a significant distortion of results in such a transformation except in case the mesons are concentrated in a narrow energy interval, or provided the angular dependence $d^2\sigma^*/d\Omega^* d\varepsilon$ differs little from the isotropic one. As a result of the fact that mesons have a wide energy distribution and the angular dependence for mesons of different energy are not known beforehand, the circumstance noted above was accounted for when transforming the meson energy distribution into the c. m. s. For this purpose, the values $d^2\sigma/d\Omega\, d\varepsilon$, multiplied by the corresponding factor P^*/P, were plotted on the diagram at a definite angle. The points corresponding to the meson kinetic energy ε^* of the same value were joined by smooth curves in the entire interval of the angles θ^*. To construct the spectra in the c. m. s., the values $d^2\sigma^*/d\Omega^* d\varepsilon^*$ were taken for the angles $\theta^* = 95°$, $112°$, $125°$, $137°$ and $148°$. These angles in the c. m. s. correspond to the mesons produced in the reaction $p + p \rightarrow d + \pi^+$ with the kinetic energy $\varepsilon^* = 149$ Mev and emitted in the l. s. at the angles $\theta = 60°$, $75°$, $90°$, $105°$ and $120°$.

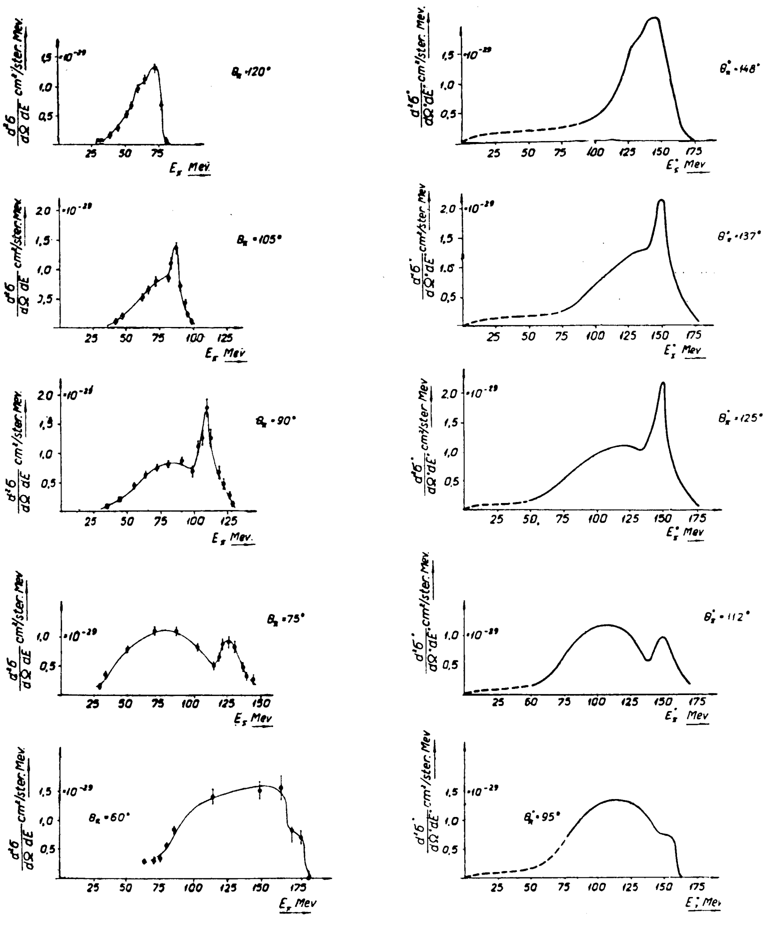

Fig. 1. Energy distributions of π^+ mesons produced by 657 Mev protons in hydrogen at angles $\theta_\pi = 120°$, $105°$, $90°$, $75°$ and $60°$ in the laboratory system and $\theta_\pi^* = 148°$, $137°$, $125°$, $112°$ and $95°$ in the c.m.s.

TABLE II

θ	95°	112°	125°	137°	148°
$\left(\frac{d\sigma^*}{d\Omega^*}\right)_{pp\to\pi^+ + \{^d_{pn}} \times 10^{28}$ cm²/sterad⁻¹	10.5 ± 1.3	9.7 ± 1.1	11.3 ± 1.2	10.7 ± 1.6	11.0 ± 1.3
$\left(\frac{d\sigma^*}{d\Omega^*}\right)_{pp\to d\pi^+} \times 10^{28}$ cm²/sterad⁻¹	1.0 ± 0.07	1.9 ± 0.5	3.0 ± 0.5	3.5 ± 0.7	4.2 ± 0.6
$\left(\frac{d\sigma^*}{d\Omega^*}\right)_{pp\to pn\pi^+} \times 10^{28}$ cm²/sterad⁻¹	9.5 ± 1.3	7.8 ± 1.2	8.3 ± 1.3	7.2 ± 1.7	6.8 ± 1.4
$\frac{(d\sigma/d\Omega)_{pp\to pn\pi^+}}{(d\sigma/d\Omega)_{pp\to d\pi^+}}$	9.5	4.1	2.8	2.1	1.6

$\sigma^*_{pp\to\pi^+ + \{^d_{pn}}$	$(13.4 \pm 2.2) \cdot 10^{-27}$ cm²
$\sigma^*_{pp\to d\pi^+}$	$(3.3 \pm 0.9) \cdot 10^{-27}$ cm²
$\sigma^*_{pp\to pn\pi^+}$	$(10.1 \pm 1.3) \cdot 10^{-27}$ cm²
$\frac{\sigma^*_{pp\to pn\pi^+}}{\sigma^*_{pp\to d\pi^+}}$	3.1

6. *The angular distribution of mesons in the centre-of-mass system*

Figs. 1 and 3 show the energy spectra of mesons produced in reactions (1) and (2) at an incident proton energy $E_p = 657$ Mev at the angles in the c. m. s. mentioned above. Table II gives the cross-sections for π^+ meson production obtained as a result of the integration of spectra, and the ratios of the π^+ meson yield formed as a result of reactions (1) and (2). At the end of the table, total cross-sections are given of π^+ meson production and the ratio of the total cross-section for reactions (1) and (2).

Experimental data of the present work prove that the angular distribution of π^+ mesons formed in p-p collisions at a proton energy $E_p = 657$ Mev is close to the isotropic one in the interval of angles 95° to 148° in the c. m. s. The dependence of $(d\sigma^*/d\Omega^*)_{pp\to\pi^+ + \{^d_{pn}}$ on the $\cos^2\theta^*$ function is presented in fig. 2. If we represent the experimental results in the form of the empirical dependence of the $A(1 + B\cos^2\theta^*)$ type, then by the method of least squares we can find that the angular distribution is expressed by the formula:

$$(d\sigma^*/d\Omega^*)_{pp\to\pi^+ + \{^d_{pn}} = (10.3 \pm 1.8)\ [1 + (0.1 \pm 0.2)\cos^2\theta^*] \cdot 10^{-28}\ \text{cm}^2/\text{sterad}.$$

For mesons formed in the reaction $p + p \to d + \pi^+$ the method of least squares gives, in our case, the following

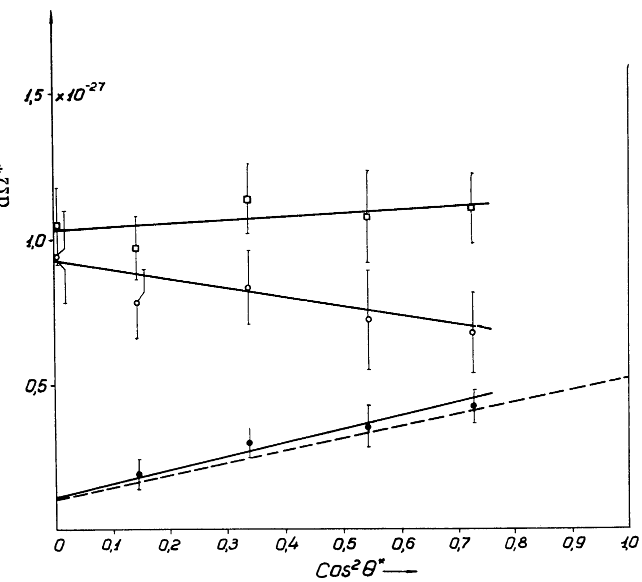

Fig. 2. Angular distribution of π^+ mesons produced in reactions:

$p+p\to\pi^+$+nucleons □
$p+p\to p+n+\pi^+$ ○
$p+p\to d+\pi^+$ ●

angular dependence: $(d\sigma^*/d\Omega^*)_{pp \to d\pi^+} = (4.7 \pm 1.3)$ $[(0.23 \pm 0.13) + \cos^2\theta^*] \cdot 10^{-28}$ cm²/sterad, which agrees with the results of [4] within the limits of experimental errors. (The dotted line in fig. 2 represents the angular distribution of mesons from the $p + p \to d + \pi^+$ reaction, measured in [4]).

Excluding mesons from reaction (1) from the angular dependence $(d\sigma^*/d\Omega^*)_{pp \to \pi^+ + \{^{d}_{pn}}$, we obtain the angular distribution of mesons from reaction (2) in the form: $(d\sigma^*/d\Omega^*)_{pp \to pn\pi^+} = (9.2 \pm 1.8)\,[1 - (0.4 \pm 0.3)\cos^2\theta^*] \cdot 10^{-28}$ cm²/sterad. To interpret these results we shall investigate in more detail the reaction $p + p \to p + n + \pi^+$. We shall further assume that the chief role is played by the s- and p-states of the mesons with respect to the two-nucleon system. We shall assume, moreover, that at our energies, both the S and P states of relative angular momentum of the nucleons at the end of the reaction participate in the meson production.

Possible transitions for the reaction $p + p \to p + n + \pi^+$ under these assumptions are presented in Table III.

TABLE III

Class	Initial state	Final state	Transition	Total ang. momentum projection
Sp	$^1S_0$	$^3S_1p_0$	$^1S_0 \to {}^3P_0$	0
Sp	$^1D_2$	$^3S_1p_2$	$^1D_2 \to {}^3P_2$	0
Ss	$^3P_1$	$^3S_1s_1$	$^3P_1 \to {}^3S_1$	± 1
Ss	$^3P_0$	$^1S_0s_0$	$^3P_0 \to {}^1S_0$	0
Ps	$^1S_0$	$^3P_0s_0$	$^1S_0 \to {}^1S_0$	0
Ps	$^1D_2$	$^3P_2s_2$	$^1D_2 \to {}^5S_2$	0
Pp	$^3P_0$	$^3P_1p_0$	$^3P_0 \to {}^3P_0$	0
Pp	$^3P_1$	$^3P_1p_1$	$^3P_1 \to {}^3P_1$	± 1
Pp	$^3P_1$	$^3P_0p_1$	$^3P_1 \to {}^1P_1$	± 1
Pp	$^3P_1$	$^3P_2p_1$	$^3P_1 \to {}^5P_1$	± 1
Pp	$^3P_2$	$^3P_1p_2$	$^3P_2 \to {}^3P_2$	$\pm 1,0$
Pp	$^3P_2$	$^3P_2p_2$	$^3P_2 \to {}^5P_2$	$\pm 1,0$
Pp	$^3F_2$	$^3P_1p_2$	$^3F_2 \to {}^3P_2$	$\pm 1,0$
Pp	$^3F_2$	$^3P_2p_2$	$^3F_2 \to {}^5P_2$	$\pm 1,0$
Pp	$^3F_3$	$^3P_2p_3$	$^3F_3 \to {}^5P_3$	± 1

The amplitude in the final state takes the form:

$$f = \sum A_{lsjm} Y_{lsjm},$$

where the summation is carried out over all final states. (A_{lsjm} are transition amplitudes, and Y_{lsjm} spherical harmonics.)

The differential cross-section is expressed by the amplitude of the final state in the following way:

$$d\sigma^*/d\Omega^* = f^+ f \qquad (*)$$

Substituting the expression for f in formula (*), we get the meson angular distribution in the form:

$$d\sigma^*/d\Omega^* = a' + b'\cos^2\theta^* + c'\sin^2\theta^*,$$

where a′, b′, and c′ are expressed by A_{lsjm}, or

$$d\sigma^*/d\Omega^* = a + b\cos^2\theta^*,$$

where $a = a' + c'$; $b = b' - c'$.

Note that the term containing $\sin^2\theta^*$ in the angular distribution appears as the result of the participation of the Pp class transitions and on account of the interference of the transitions $^1S_0 \to {}^3S_1\,p_0$ and $^1D_2 \to {}^3S_1\,p_2$. The meson angular distribution of reaction (1) almost coincides with the theoretical distribution determined by the transition $^1D_2 \to {}^3S_1\,p_2$ and shows that the contribution of the term proportional to $\sin^2\theta^*$ due to the interference of the transitions mentioned, is not great. Possibly this is correct for reaction (2) as well, the more so since at the energy $E_p = 440$ Mev [8], no change in the shape of the angular distribution in the direction of an increase of the constant term was noticed for reactions (1) + (2), as compared with reaction (1).

Thus, we see that meson angular distributions for reactions $p + p \to d + \pi^+$ (transitions Sp and Ss) and $p + p \to p + n + \pi^+$ (transitions Sp, Ss, Pp, and Ps) can be written down as $a + b\cos^2\theta^*$; but if the Pp class transitions participate in the meson production process and their contribution compared with other transitions cannot be ignored, then the coefficient $b = b' - c'$ in reaction (2) may decrease, the value of coefficient a increasing in the same reactions; but the reason for this may not only be the contribution of the Pp transitions.

The π^+ meson angular distribution formed in reactions (1) and (2), measured in this experiment, show the approximate equality of the coefficients b′ and c′, and consequently, point to a considerable contribution of the class Pp transitions in reaction (2) at an energy of 657 Mev. This circumstance is reflected in the meson angular distribution in the reaction $p + p \to p + n + \pi^+$, where the coefficient b becomes negative.

7. *An analysis of the spectra of π^+ mesons in the reaction $p + p \to p + n + \pi^+$*

According to the kinematics, mesons formed in the reaction $p + p \to p + n + \pi^+$ have a continuous energy distribution in the interval from 0 to 150 Mev in the c. m. s. Experimental energy spectra (figs. 1 and 3) reach an energy of 175 Mev, which can be explained by the imperfection of the detector. (A certain fraction of the mesons may pass partly through the emulsion or the glass.) Energy distributions measured for angles 95°, 112° and 125° convince us that the spectrum of mesons from reaction (2) has a maximum at around 100 to 125 Mev. A comparison of energy distributions in the measured angular intervals allows us to assume that mesons emitted at angles close to $\theta^* = 180°$ are concentrated in the region of higher energies. As a result of the spectrum deformations mentioned, the angular distribution of mesons for different energy intervals is:

75 - 100 Mev	$1 - \cos^2 \theta^*$
125 - 150 Mev	$0.2 + \cos^2 \theta^*$.

This is in agreement with the conclusions about the importance of the Pp class transitions in producing the π^+ mesons at high energies. Indeed, it has been shown

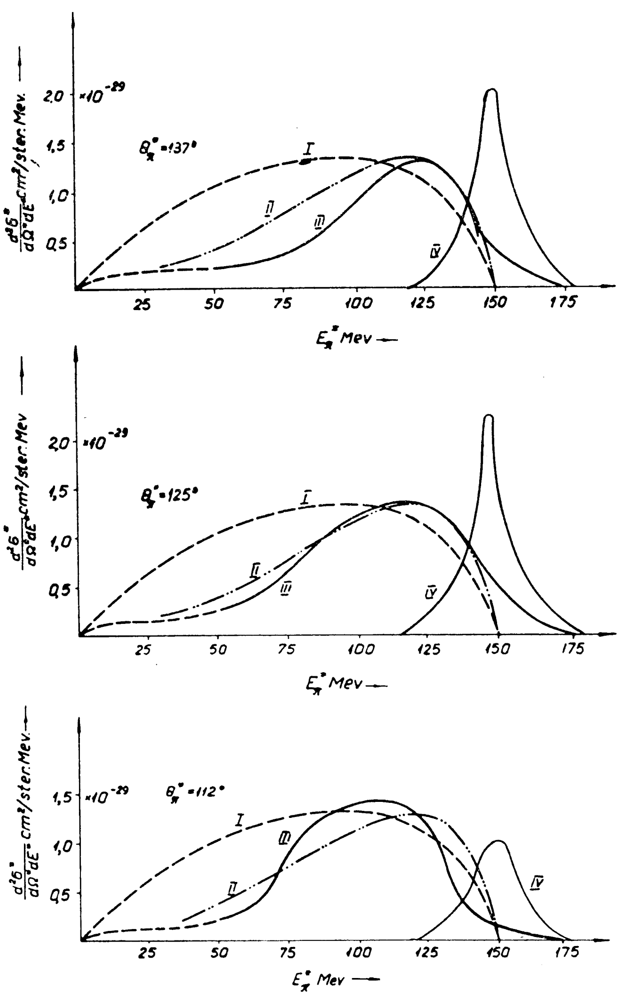

Fig. 3. Energy distribution of π^+ mesons in (pp) collisions at proton energy of Ep = 657 Mev.
Curve I: theoretical, from [9]. Curve II: theoretical from [9]. Curve III: experimental, for π^+ mesons of reaction $p + p \to p + n + \pi^+$. Curve IV: experimental, for π^+ mesons of reaction $p + p \to d + \pi^+$.

above that the Pp class transitions decrease the coefficient b in the expression for the meson angular distribution and increase the constant term. This effect should be more noticeable when the meson is produced at a low energy, leaving a significant amount for a relative movement of the nucleons. In the region of high energies of mesons, the Pp class transitions must be less important and the meson angular distribution will be determined chiefly by Sp class transitions, as a result of which in this energy region meson production is more intense at angles close to 180° than at angles near 90°.

Thus, the form of π^+ meson energy distributions at different angles in the c. m. s. as well as the angular distribution, leads to the conclusion that the Pp class transitions contribute greatly to the cross-section of meson formation at an energy $E_p = 657$ Mev.

For comparison with experimental results, fig. 3 shows theoretical curves describing the meson spectra from reaction (2). We took curves I and II from [9]; they correspond to cases $H \sim$ Const and $H \sim P$, where H is the matrix element of the interaction. The statistical weight was calculated under the assumption, that all the particles in the final state are relativistic. Comparison with experimental data shows that a considerably better approximation is the hypothesis that the matrix element of the interaction depends linearly on the meson momentum (curve II). This dependence of the matrix element may be a consequence of the circumstance that the mesons in the reaction in question are produced with an angular momentum $l = 1$. The best agreement between the theoretical curve II and the experimental data is found at the angle $\theta^* = 125°$. For other angles, a divergence is noticeable, caused by the deformation of the π^+ meson spectra with a change of the angle. The change in the form of the spectrum, as noted above, is due to the circumstance that the final nucleons may have an angular momentum $l = 0$ or $l = 1$, and the relative contribution of the corresponding transitions is different for different angles.

8. *The total cross-section of π^+ meson production in p-p collisions*

The total cross-section of π^+ meson production in p-p collisions at an energy of 657 Mev is $\sigma_{pp \to \pi^+ + \{^{d}_{pn}} = 13.4 \pm 2.2 \cdot 10^{-27}$ cm². From this it is evident that of the inelastic processes in collisions of 660 Mev protons, the greatest part (80%) is the π^+ meson production. Making use of the value $\sigma_{pp\ total} = (41.4 \pm 0.6) \cdot 10^{-27}$ cm² from [2] and $\sigma_{pp\ el} = (24.7 \pm 1.2) \cdot 10^{-27}$ cm² from [10], we get the value of $\sigma_{pp\ inel} = (16.7 \pm 1.3) \cdot 10^{-27}$ cm². Thus, we can conclude that $\sigma_{pp \to \pi^0} = (3.3 \pm 2.5) \cdot 10^{-27}$ cm², which is in agreement with the value of $\sigma_{pp \to pn\pi_0}$ measured in [11].

The value of $(10.1 \pm 2.3) \cdot 10^{-27}$ cm² for $\sigma_{pp \to pn\pi^+}$ is confirmed in [1] and [2].

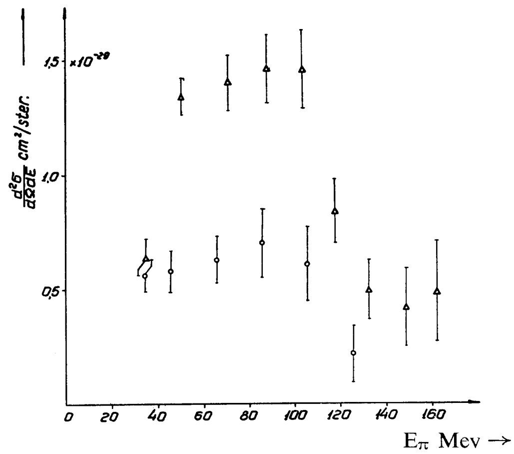

Fig. 4. Energy distribution of π^+ mesons produced by protons in deuterium and carbon at 90°.

9. *The production of charged π mesons on deuterium and carbon nuclei* †

We obtained the energy distributions of π^+ mesons produced by protons with an energy $E_r = 657$ Mev at an angle of 90° on deuterium and carbon nuclei by an analogous method; they are shown in fig. 4, from which it is seen that the spectra have a wide maximum in the energy interval of 50 to 110 Mev.

The cross-sections for π^+ meson production at an angle of 90° on deuterium and carbon nuclei are correspondingly:

$(d\sigma/d\Omega)^{90°}{}_{p+d\rightarrow\pi^+} = (6 \pm 1.5) \cdot 10^{-28}$ cm² per sterad and $(d\sigma/d\Omega)^{90°}{}_{p+C\rightarrow\pi^+} = (1.9 \pm 0.4) \cdot 10^{-27}$ cm² per sterad.

The differential cross-section of π^+ meson production in p-p collisions at an angle of 90° is:

$(d\sigma/d\Omega)^{90}{}_{pp\rightarrow\pi^+ + \{^{d}_{pn}} = (6.4 \pm 0.7) \cdot 10^{-28}$ cm² per sterad.

A comparison of results obtained in proton irradiation of deuterium and carbon with experiments for investigation of the meson production in p-p collisions shows that the ratio of the π^+ meson production cross-sections at an angle of 90° in deuterium and hydrogen is close to unity, while a similar ratio for carbon and hydrogen is 2.5. This effect might be the result of the absorption of mesons in the carbon nuclei.

The ratio of $\sigma(\pi^+)/\sigma(\pi^-)$ at an angle of 90° is ~ 8 for proton collisions with deuterium nuclei, and 5.0 ± 0.7 in collisions with carbon nuclei. A decrease in the ratio $\sigma(\pi^+)/\sigma(\pi^-)$ with an increase in the energy of the bombarding protons indicates a more rapid increase in the cross-section of reaction $p + n \rightarrow \pi^\pm$, as compared with the reactions $p + p \rightarrow \pi^+$ or $n + n \rightarrow \pi^-$.

Relative yields of π^+ and π^- mesons at an angle of 90° to the direction of the beam were measured also in n-p collisions and in carbon bombardments by neutrons. Neutrons were emitted as a result of the charge-exchange of 670 Mev protons in beryllium nuclei. The energy distribution of neutrons in the beam was investigated by V. B. Fliagin, and is given in [12].

The ratio of negative to positive mesons in neutron bombardment of carbon is 5.4 ± 1.1. The ratio of $\sigma(\pi^+)/\sigma(\pi^-)$ at an angle of 90° in neutron bombardment of hydrogen was found to be 0.9 ± 0.2.

I would like to take advantage of this opportunity to express my deep gratitude to M. G. Meshcheriakov, Corresponding Member of the USSR Academy of Sciences, for his guidance. I am grateful also to S. M. Bilenki and Ia. A. Iappa for their help.

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