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The Formation of Charged П-Mesons by Nucleons

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CHARGED π-mesons may be formed with free nucleons as a result of the following reactions:

$$p + p \to n + p + \pi^+ \text{ or } p + p \to d + \pi^+; \quad (1)$$

$$p + n \to n + n + \pi^+; \quad (2)$$

$$p + n \to p + p + \pi^-; \quad (3)$$

$$n + n \to n + p + \pi^- \text{ or } n + n \to d + \pi^-. \quad (4)$$

At the present time, the most complete experimental data exist from the study of the reaction (1). Some information concerning the interactions $(p - n)$ and $(n - n)$ can be obtained from the experimental study of collisions between nucleons and nuclei. Since even at 500 mev the wavelength of the bombarding particle is small compared with the distance between the nucleons, it can be assumed that at energies large compared with 500 mev, mesons are formed in complex nuclei mostly in individual collisions of nucleons.

On the basis of the hypothesis of charge independence of nuclear forces and symmetry of the properties of positive and negative mesons, it can be assumed that the cross sections of the processes of formation of π^+ and π^- mesons in $(p - n)$ collisions are equal.

If we assume also that charged mesons are formed in $(p - p)$ and $(p - n)$ collisions with equal probabilities, there more positive mesons should be formed than negative when complex nuclei are bombarded with protons, namely: $\sigma(\pi^+)/\sigma(\pi^-) = (A + Z)/A - Z)$. Thus when deuterium, carbon, and in general, nuclei having equal numbers of protons and neutrons are bombarded by protons, we can expect the ratio $\sigma(\pi^+)/\sigma(\pi^-)$ to be equal to 3. The ratio $\sigma(\pi^-)/\sigma(\pi^+)$ should be the same for the bombardment of complex nuclei with neutrons. Results of experimental work[1-3] indicate that when complex nuclei are radiated with protons of 340 to 380 mev, the ratio of the cross sections $\sigma(\pi^+)/\sigma(\pi^-)$ is considerably greater than $A + Z/A - Z$. Measurements of ouptuts of charged mesons at 90° to the beam resulting from bombardment of carbon with neutrons of 270 mev[4] showed that the output of π^- mesons in this case exceeds the output of π^+ mesons by a factor of approximately 15. It should be noted that these experiments were made using bombarding particles of energies close to the threshold of meson formation. If this case, in view of Pauli's principle, the ratio of cross sections $\sigma(\pi^+)/\sigma(\pi^-)$ can increase significantly when nuclei are bombarded with protons, and decrease in the case of bombardment with neutrons as noted by Chew and Steinberger[5].

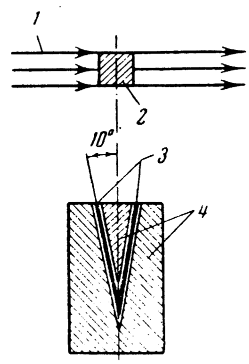

Fig. 1. Experimental arrangement
1. Proton beam. *2.* Target.
3. Photographic plate. *4.* Brass block.

The formation of charged mesons by the action of protons and neutrons on carbon and hydrogen was studied by us in experiments using the synchrocyclotron of the Institute for Nuclear Problems, Academy of Sciences, USSR.

1. *Formation of π^+ and π^- mesons by the action of protons on carbon and hydrogen.* A target of carbonor paraffin was placed in a narrowly collimated beam of protons of 657 ± 8.0 mev[6]. The charged mesons emitted from the target at an angle of 90° were recorded by means of nuclear emulsions. The experimental arrangement is shown in Fig. 1. The photographic plates were placed in the brass block at an angle of 10° to the direction of the incident mesons. The meson stopped within the emulsion was considered positive if it gave rise to a μ-meson trace and negative if it produced a "star".

The differential cross section of formation of mesons was determined according to the following formula:

$$\frac{d^2\sigma}{d\omega dE} = \frac{N}{nN_p t\,[dE/dR]_E}\,\frac{r^2}{S},$$

where N_p is the number of protons that passed through the target; n the number of nuclei on 1 square cm of the target measured in the direction of the incident beam; N the number of mesons found on the emulsion area S; r the distance from the target to the surface of the emulsion; t the thickness of the emulsion; $[dE/dR]_E$ the loss of energy in the emulsion by mesons of energy E.

The number of protons N_p was measured by means of a calibrated ionization chamber. In determining the loss of energy by the mesons, the formula $[dE/dR]_E = 0.067\, R\pi^{0.419}$ derived from the path-energy relation for protons[7] was used.

The number of π^- mesons was taken equal to the number of observed "stars" multiplied by the coefficient 1.37. There was also introduced a correction for the mesons leaving the beam as a result of nuclear interaction. The length of the free path of mesons in brass was thereby taken equal to 104.4 gm/cm^2.

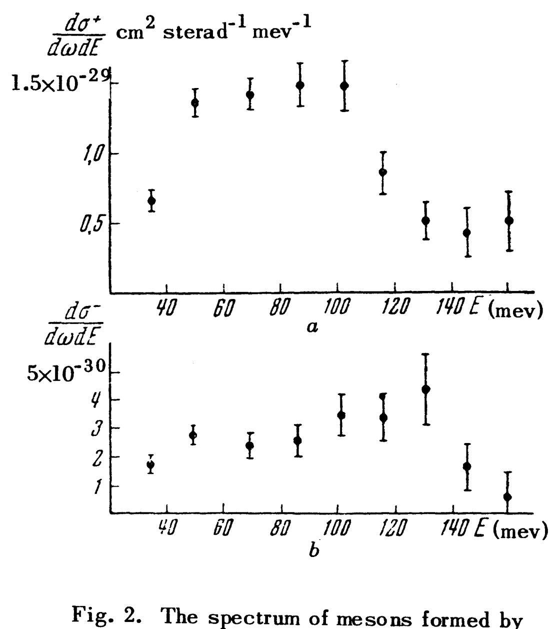

Fig. 2. The spectrum of mesons formed by protons of 657 mev in carbon nuclei and emitted at an angle of 90°. *a.* spectrum of π^+ mesons; *b.* spectrum of π^- mesons.

As a result of examination of the photographic plates irradiated in experiments with a carbon target, there were recorded 629 disintegrations. In the same area of the emulsion, there were found 91 "stars" formed by π^- mesons. The ratio $\sigma(\pi^+)/\sigma(\pi^-)$ was in this case equal to 5.0 ± 0.7. The energy spectra of the π^+ and π^- mesons are shown in Fig. 2. Integration of the spectra gives for the formation cross sections at an angle of 90° $(1.9 \pm 0.4) \times 10^{-27}$ cm^2 sterad^{-1} for positive mesons and $(3.7 \pm 1.3) \times 10^{-28}$ cm^2 sterad^{-1} for negative mesons.

The cross section of formation of π^+ mesons by protons on hydrogen leaving at an angle of 90° was obtained from experiments with paraffin and carbon by subtraction and found to be $d\sigma(\pi^+)/d\omega \approx 0.35 \times 10^{-27}$ cm^2 sterad^{-1} with an accuracy down to a factor of 2.

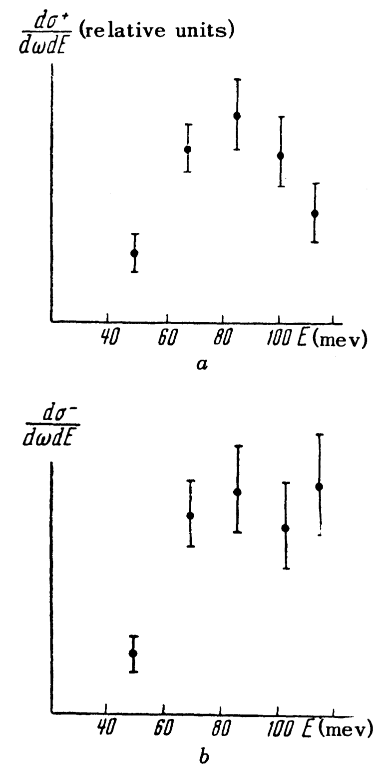

Fig. 3. The spectrum of mesons formed by neutrons in hydrogen and emitted at an angle of 90°. *a.* spectrum of π^+ mesons; *b.* spectrum of π^- mesons.

Comparison of the results of the present experiments with the results of reference 1 shows that the cross section of formation of π^+ mesons in carbon at an angle of 90° increases approximately four times when the energy of the bombarding protons is increased from 381 to 657 mev, while the cross section of formation of π^- mesons increases approximately nine times.

2. *Formation of π^+ and π^- mesons by neutrons on carbon.* Measurements were made of the relative yield of π^+ and π^- mesons at an angle of 90° to the beam for the bombardment of carbon with neutrons. The neutrons were formed as a result of the action of 670 mev protons on the nuclei of beryllium[1]. The method of observing the mesons was similar to that described above. The ratio of the outputs was calculated on the bases of 26 $\pi^+ \to \mu^+$ disintegrations and 102 "stars", formed by the π^- mesons, and found to be equal to $\sigma(\pi^-)/\sigma(\pi^+) = 5.4 \pm 1.1$. This value, within the experimental error, corresponds to the ratio $\sigma(\pi^+)/\sigma(\pi^-)$ determined by bombarding carbon with protons which constitutes a confirmation of the principle of symmetry of charges.

It can be seen, as a result of measurements of the relative outputs of charged mesons formed by protons and neutrons, that in carbon nuclei π^+ and π^- mesons in $(p - n)$ collisions are formed and emitted at an angle of 90° with half the probability of formation of π^+ mesons in $(p - p)$ or π^- mesons in $(n\text{-}n)$ collisions. This indicates that there is a difference in the nature of the process of formation of charged mesons in the $(n - p)$ and $(p - p)$ systems.

3. *Formation of π^+ and π^- mesons in $(n - p)$ collisions.* A vessel containing liquid hydrogen was placed in the path of a neutron beam[8]. Charged mesons formed by the neutrons in hydrogen andleaving the target at an angle of 90° to the direction of the beam were registered by the method described above. As a result of the examination of the emulsion, there were recorded 131 $\pi^+ \to \mu^+$ disintegrations. In the same volume of the emulsion, there were observed 112 "stars" formed by π^- mesons. Thus, the ratio of the number of positive to negative mesons, after applying the correction for stars without rays, was equal to 0.9 ± 0.2. Fig. 3 shows the energy spectra of π^+ and π^- mesons formed by neutrons in hydrogen.

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"Acoustic Excitations" in Superconductors

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1. WE investigated the spectrum of elementary energy excitations in superconductors in the framework of the new phenomenological theory of superconductivity of Ginzburg and Landau. In their work [1,2], they made use of the system of equations for the "effective" wave function and the vector potential A:

$$ih\frac{\partial\Psi}{\partial t} = \frac{1}{2m}\left(-ih\nabla - \frac{e}{c}\,\mathbf{A}\right)^2\Psi + \frac{\partial F_{s0}}{\partial\Psi^*}, \qquad (1)$$

$$\Delta\mathbf{A} = \frac{2\pi ih}{mc^2}(\Psi^*\nabla\Psi - \Psi\nabla\Psi^*) + \frac{4\pi e^2}{mc^2}\mathbf{A}\,|\Psi|^2, \qquad (2)$$

where $F_{s0} = F_{n0} + \alpha|\Psi|^2 + (\beta/2)|\Psi|^4$ is the free energy in the superconducting state, α and β are parameters, $|\Psi|^2$ is the concentration of superconducting electrons. At equilibrium,

$$|\Psi|^2 = n_{s0} = -(\alpha/\beta);\ \alpha = H_{\text{KM}}^2/4\pi n_{s0},$$

where H_{km} is the critical magnetic field for the mass particles. The term $ih(\partial\Psi/\partial t)$ is essential in the investigation of the excitation spectrum, since it is of the same order as the other terms in the equation. The term $1/c^2(\partial^2\mathbf{A}/\partial t^2)$ has been omitted, since $\omega \ll ck$ for the excitations under consideration here.

In the investigation of the excitation spectrum, it is appropriate to employ the equation for the quantum distribution function in addition to the equation for Ψ:

$$f(\mathbf{q},\mathbf{p}) = \frac{1}{(2\pi)^3}\int \Psi^*(\mathbf{q} - {}^1\!/_2 h\vec{\tau})\,\Psi(\mathbf{q} + {}^1\!/_2 h\vec{\tau})\,e^{-i\vec{\tau}\vec{\mathbf{p}}}\,d\vec{\tau},$$

$$\frac{\partial f}{\partial t} = \frac{i}{h}\int\frac{1}{2m}\left(\vec{\eta} - \frac{e}{c}\,\mathbf{A}(\mathbf{r})\right)^2\left[f\left(\mathbf{r} + {}^1\!/_2 h\vec{\tau},\ \vec{\eta} - {}^1\!/_2 h\vec{\theta}\right)\right.$$