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Energy Spectrum of γ-Quanta from the Decay of π^0-Mesons Produced by 660 Mev Protons on Hydrogen Nuclei

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The energy spectrum of γ-quanta from the decay of π^0-mesons produced by 660 Mev protons on hydrogen nuclei has been measured. The angular and energy distribution of π^0-mesons produced in $p-p$ collisions has been obtained by analyzing the γ-quantum spectrum.

1. IN THE AVAILABLE INFORMATION on meson generation, there has been absent up to now information on the energy spectrum of π^0-mesons produced in $p-p$ collisions. This can be explained by the difficulty of investigating the γ-spectrum produced in the decay of π^0-mesons, formed in this reaction with relatively small cross section.

The investigation of this γ-spectrum becomes possible at a proton energy of 660 Mev, because of an increase in the cross section for the formation of π^0-mesons on hydrogen nuclei. In the present work, a differential method was used to measure the gammas from targets of polythene and carbon, continuously bombarded by protons in the integral beam of the synchroton. Relative γ-intensities from the targets were measured by a magnetic pair spectrometer described in Ref. 1.

The basic difficulties in investigating the spectra by the differential method were due to the small cross section for π^0-formation on hydrogen compared to the formation on carbon. The necessary precision of measurement was achieved in the present work by applying the method of cyclic interchange of targets. The change of targets located inside the vacuum chamber of the accelerator was performed automatically every minute. The method of automatically changing targets was developed and applied previously in work described in Ref. 2. Synchronously with the change of targets, the registering system of the spectrometer was also switched, permitting separate counting of γ-quanta formed on separate targets. In this way measurements were made in different parts of the spectra, of the γ-intensity ratios from the polythene and carbon targets. Simultaneously with this, the total γ-intensities from the two targets were measured by means of a telescope containing a scintillation counter and a Cerenkov counter. The telescope registering equipment was also switched in synchronism with the targets.

This method of measuring relative γ-intensities greatly reduced the errors associated with changes in efficiency with time of the registering apparatus, as well as errors due to normalization of the results of separate measurements in different parts of the spectra.

2. The γ-spectrum formed on hydrogen $F_H(\varepsilon_\gamma, \theta)$, is expressed as follows in terms of the γ-spectrum formed on carbon, $F_C(\varepsilon_\gamma, \theta)$, and the ratio of

γ-intensities from the polythene and carbon targets:

$$F_H(\varepsilon_\gamma, \theta) = \frac{1}{2}[F_{CH_2}(\varepsilon_\gamma, \theta) - F_C(\varepsilon_\gamma, \theta)] = = \frac{1}{2} F_C(\varepsilon_\gamma, \theta)\left\{[1 + 2(d\sigma_H^\gamma/d\omega)/(d\sigma_C^\gamma/d\omega)]\ \frac{k(\varepsilon_\gamma)}{k_0} - 1\right\}. \quad (1)$$

Here $(d\sigma_H^\gamma/d\omega)/(d\sigma_C^\gamma/d\omega)$ is the ratio of the differential cross sections for γ-production on hydrogen and carbon as measured at an angle θ; $k(\varepsilon_\gamma)$ is the ratio of the γ-intensities from polythene and carbon at energy ε_γ and angle θ; k_0 is the ratio of the total γ-intensities from these targets at angle θ.

In the present work the measurements of γ-intensities were carried out at an angle of 0° with the direction of the incident protons. The spectrum of gammas formed at 0° by 660 Mev protons on carbon has been measured previously[3]. The magnitude of the relative cross section $(d\sigma_H^\gamma/d\omega)/(d\sigma_C^\gamma/d\omega)$ for the angle 0° was taken from Ref. 4. The magnitudes of the ratios $k(\varepsilon_\gamma)$ and k_0 were measured simultaneously by means of the pair spectrometer and the γ-telescope.

The γ-spectrum of the π^0-decay, due to 660 Mev protons on hydrogen, is shown in Fig. 1. The error bars include the errors in all quantities entering Eq. (1). The gamma energy from the decay of π^0-mesons formed on hydrogen should not exceed the maximum possible energy, which for a bombarding energy of 660 Mev is 470 ± 7 Mev at 0°. The spectrum actually obtained spreads to a somewhat larger energy because of errors in the measurements.

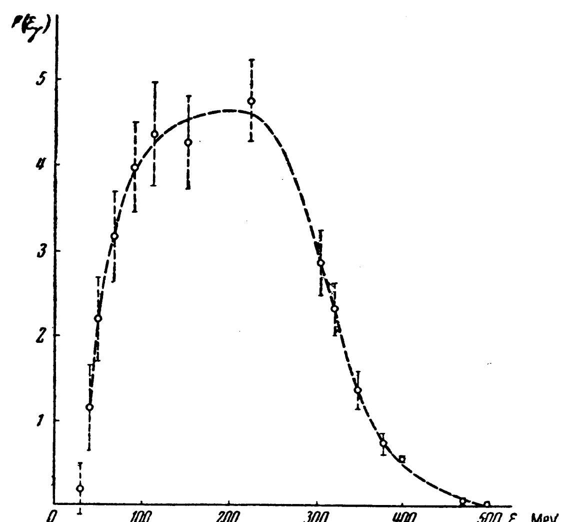

FIG. 1. Energy spectrum of γ-quanta from the decay of π^0-mesons produced in $p - p$ collisions at a proton energy of 660 Mev.

3. The measured spectrum of γ-quanta permits one to determine the energy spectrum and angular distribution of π^0-mesons formed in $p - p$ collisions. The analysis of the γ-spectrum formed on hydrogen is similar to the analysis of the spectrum formed on carbon, and described in Ref. 3. It differs from the latter in that approximations concerning the motion of nucleons in a complex nucleus need not be made.

The gamma spectrum, transformed to the center of mass system of the colliding nucleons, and represented on a semi-logarithmic plot, is almost symmetrical about an energy one half the rest energy of the π^0-mesons. This means that the angular distribution of the π^0-mesons is close to isotropic. In order to determine the energy distribution of π^0-mesons corresponding to the hard gammas ($\varepsilon_\gamma > m_0c^2/2$) represented in Fig. 1 by the smooth curve, the angular π^0-distribution was assumed isotropic. The π^0-energy distribution in the center of mass system found by this means is shown in Fig. 2.

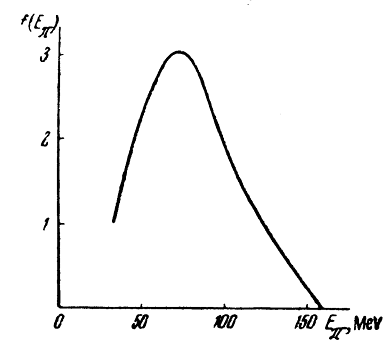

FIG. 2. Energy spectrum of π^0-mesons in the center of mass system of the colliding protons.

The π^0-energy distribution corresponding to the hard γ-spectrum was then further used for a more accurate determination of the π^0-angular distribution corresponding to gammas in the energy region $\varepsilon_\gamma \leqslant m_0c^2/2$. We took a π^0-angular distribution of the form $1 + b\cos^2\theta$, with different values of the constant b, and computed the resulting γ-energy spectrum (Fig. 3). Comparison of the computed with the measured curves shows that the π^0-angular distribution is $1 + (0.3 \pm 0.1)\cos^2\theta$, and consequently only (9 ± 3)% of the total number of π^0-mesons are distributed according to $\cos^2\theta$.

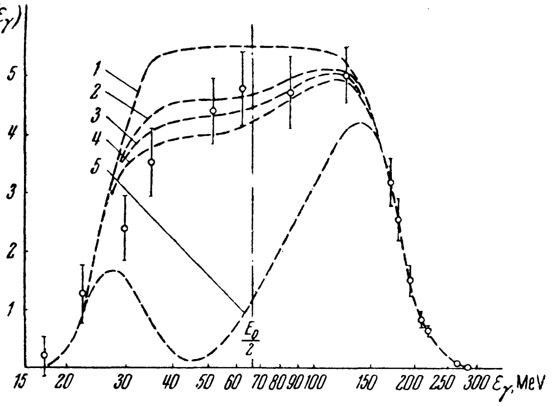

FIG. 3. Energy spectrum of γ-quanta in the center of mass system of the colliding nucleons. o – Experimental points. Dotted curves – spectra computed with different values of the constant b in the meson angular distribution: $1 - b = 0$; $2 - b = 0.2$; $3 - b = 0.3$; $4 - b = 0.4$; $5 - \varphi(\theta) \sim \cos^2\theta$.

This π^0-angular distribution could in turn be used for an improved estimate of the π^0-energy distribution. However, the calculation of the π^0-spectrum with the above determined deviation from isotropicity of the angular distribution leads only to an insignificant change in the energy distribution, substantially smaller than the uncertainties in the spectrum due to measurement errors in the γ-spectrum.

4. It is known that at small collision energies π-mesons are effectively formed in p-states, while the nucleons are emitted in S-states. In the meson angular distribution the term proportional to $\cos^2\theta$ plays the main role, and because of the strong nucleon interaction in the final state, the meson energy is close to the maximum possible. However, for the production of π^0-mesons in $p - p$ collisions, conservation of angular momentum and parity forbids the transition, basic at low energies, wherein the mesons are created in p-states, the nucleons in S-states. The fast increase with energy of the cross section for this reaction means that the transition in which mesons and nucleons are both emitted in s- and S-states cannot be of basic importance. Thus one has to assume that in the reaction $p + p \to \pi^0 + p + p$, the mesons or nucleons are emitted with higher angular momenta. It is clear therefore that the angular and energy distribution of the π^0-mesons may differ from distributions corresponding to emission of π's in p-states and nucleons in S-states. The small transition probabilities for high angular momentum transitions at low collision energies constitute one of the reasons that the π^0-formation cross section in $n - p$ collisions is considerably larger than in $p - p$ collisions.

On the basis of the γ-spectrum analysis in this work, we conclude that the angular distribution of π^0-mesons formed in $p - p$ collisions is nearly isotropic. This result is in agreement with the data of π^0-angular distributions in Ref. 2 and 5, obtained by investigating the angular distribution of gamma quanta.

From the π^0-spectrum formed in $p - p$ collisions, as obtained in the present work, it follows that the π^0-mesons are emitted with energies considerably smaller than the maximum possible: the mean kinetic energy of the mesons is about 45% of the maximum possible. One can try to explain this fact by the absence of strong nucleon interactions in the final state. If all the particles (two nucleons and π^0-meson) would not interact strongly in the final state, then the free energy of the reaction would be distributed among them according to the statistical factor. In this case the π^0-spectrum would be a semicircle on the abscissa with its maximum at an energy equal to one half of $E_{\pi\,\max}$[6]. The angular distribution would be isotropic.

The π^0-spectrum due to 660 Mev protons incident on hydrogen has a maximum at an energy $E_\pi \approx 75$ Mev (Fig. 2), but it looks different from the one described above. The meson angular distribution also deviates somewhat from isotropic. Consequently, at this proton energy, the final state particle interactions should not be neglected. Of special interest in this case would be the analysis of π^0-energy distributions on the basis of a strong bond between the meson and one of the nucleons.

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209