Photoproduction of K^0 Mesons from Aluminum Nuclei

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Results are presented of an investigation of K_2^0-meson production from aluminum nuclei at 10° to γ beams with maximum energies of 4 and 4.7 GeV. The cross sections for K_2^0-meson production in the momentum range 0.95 GeV/c $\le p_K \le p_K^{max}$ are 11.0 ± 1.54 and 21.1 ± 1.96 b/sr eq·γ respectively. An estimate of the upper limit of the cross section for the reaction $\gamma + p \to K^0 + \Sigma^+$ yields for the same energies 1.86 ± 1.07 and 1.51 ± 1.06 b/sr.

THE investigation of K^0-meson photoproduction is of interest both from the point of view of studying the K^0-meson production mechanism itself, and for the purpose of determining the intensities of K^0-meson beams with electron accelerators.

According to Drell's model[1], the dominant process in the photoproduction of K^0 mesons by high-energy photons in the reaction

$$\gamma + p \to K^0 + \Sigma^+ \tag{I}$$

should be one-particle exchange via the vector meson K^* (982 MeV/c^2). The differential cross section for such a process is maximal at an angle $\theta = m^*/k$ (where m^* is the K^*-meson mass and k is the γ-quantum energy), and should increase with increasing energy of the incoming γ quantum.

This problem is also of interest because there are only very scanty data on K^0-meson photoproduction at high energies, and have been obtained furthermore at small photoproduction angles[2-4].

We describe in our paper a method used for the registration of K^0 mesons and for the determination of their momentum spectrum, and present experimental results for the two maximal energies E^{max} of the γ-quantum bremsstrahlung beam, namely 4 and 4.7 GeV. The photoproduction angle was 10° for an aluminum foil 1 radiation unit thick. The experiments were performed with the extracted bremsstrahlung beam of the Erevan electron accelerator. The experimental setup is shown in Fig. 1.

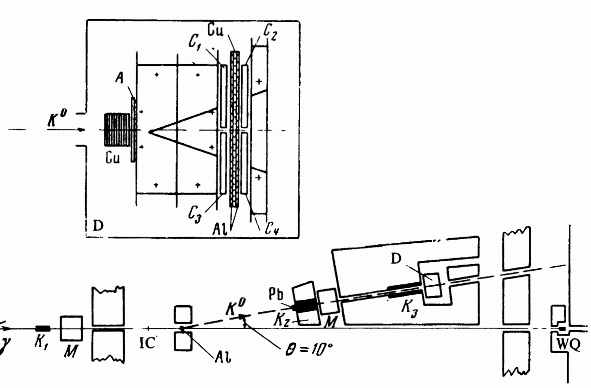

FIG. 1. Experimental setup: W–tungsten target (0.14 rad. un. of length), K_1–K_3–collimators, M–clearing magnet, IC–ionization chamber, Al–target (1 rad un. of length), Pb–lead absorber (20 cm) D–detector, C_1–C_4–scintillation counters, A–anticoincidence counter, WQ–Wilson quantameter.

Neutral particles produced in the aluminum target passed through a lead absorber Pb 20 cm thick, which served to absorb the electron-photon component of the beam, a clearing magnet M, and a system of collimators (K_2, K_3) shaping the K_2^0-meson beam. The recording apparatus was located 15.5 m away from the target and consisted of a copper regenerator Cu, 15 cm thick, two wide-gap spark chambers, and a scintillation telescope $C_1 - C_4$ separating the pair of particles produced upon decay of the neutral particle in the gas chamber (V^0 event). The flight direction of the neutral K_2^0 mesons was determined by the dimensions and the relative placement of the collimators K_2 and K_3, the target, and the detector, and was known accurate to 2×10^{-3} rad. The beam was monitored simultaneously and independently by a Wilson quantameter WQ and a thin-wall ionization chamber IC.

In coherent regeneration, the K_1^0 meson conserves the flight direction and the momentum of the K_2^0 meson[2]. By measuring the space angles θ_1 and θ_2 between the flight direction of K_2^0 and the decay $\pi^\pm$ mesons registered in the spark chambers as a result of the reaction

$$K_2^0 \to K_1^0 \to \pi^+ + \pi^-, \tag{II}$$

we can obtain the K_2^0-meson momentum spectrum. Altogether, 800 V^0 events were observed and processed. For each of them we determined the following quantities: a) the angle θ_c between the K_2^0-meson flight direction and the plane of the V^0 event (Fig. 2a); b) the coordinates x, y, z of the vertex of the "fork"; c) the dimension of the vertex of the "fork" or the shortest distance between the crossing lines, $d = (\Delta x^2 + \Delta y^2 + \Delta z^2)^{1/2}$ (Fig. 2b); d) the angles θ_1 and θ_2 between the K_2^0-meson flight direction and the branches of the "fork." A V^0 event was regarded as coherently regenerated if $d < 5$ mm and $\theta_c \le 0.01$ rad, corresponding to the first two intervals of the distribution in Fig. 2a. We determined the momentum of the K_1^0 meson for such cases from the measured angles θ_1 and θ_2 under the assumption that the selected events are K_1^0 decays into two $\pi^\pm$ mesons. The rms error in the determination of the K_1^0-meson momentum by this method was 1–1.5% in the interval from 1 to 3.5 GeV/c. As a check, the distribution of the lifetime in the K_1^0-meson rest system was constructed for all the pairs selected in accordance with this criterion (Fig. 2c). The obtained lifetime was $(0.9 \pm 0.065) \times 10^{-10}$ sec, in good agreement with the known K_1^0-meson lifetime $\tau(K_1^0) = (0.862 \pm 0.006) \times 10^{-10}$ sec[5].

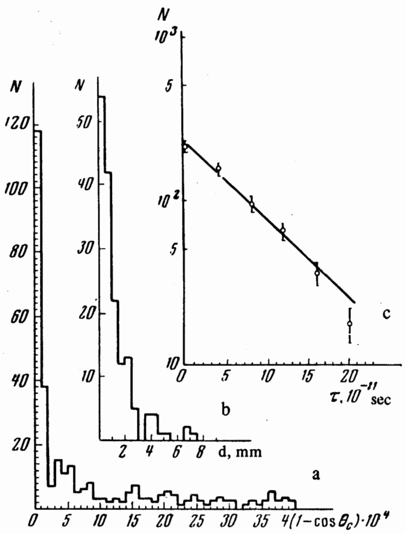

FIG. 2. Distributions of the noncomplanarity angle θ_c in units of $4(1-\cos\alpha_c)\times 10^4$ (a), of the vertex dimension d (b), and of the K_1^0-meson lifetime in the K_1^0 rest system (c).

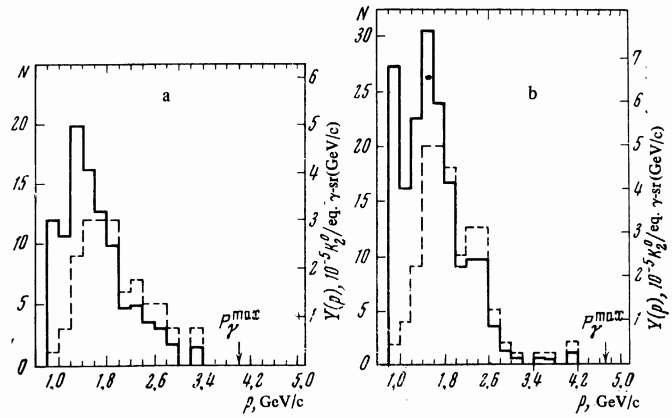

FIG. 3. Momentum spectrum and yield of K_2^0 mesons: a) E^{max} = 4.0 GeV, b) 4.7 GeV. Dashed histogram—spectrum registered by the apparatus, solid—true K_2^0-meson yield.

It should be noted that the momentum spectrum registered by the apparatus differs significantly from the true spectrum of the produced K_2^0 mesons. This disparity is connected with a number of factors that influence the K_2^0-meson registration efficiency and depend on the K_2^0-meson momenta. There exist also a number of correction factors that do not depend on the momentum, but nonetheless distort the momentum spectrum of the K_2^0 mesons. Among the momentum-dependent factors are: 1) the probability of K_2^0-meson decay in flight ahead of the regenerator, 2) the probability of K_2^0-meson absorption in the lead absorber, 3) the probability of coherent regeneration, 4) the probability of K_1^0-meson registration, or the geometrical efficiency of the apparatus, 5) the probability that the $K_1^0 \to \pi^+\pi^-$ decay products pass through the counters and the absorber between the counters (the absorber was placed between the counters to decrease the background events produced by low-energy photons and electrons). All these factors were accounted for by the Monte Carlo method, using a special program and the Razdan-3 computer. For momenta $p_K \leq 0.95$ GeV/c, as shown by the calculation, the registration efficiency was so low that it was impossible to obtain exact data concerning the yield of the K_2^0 mesons. All the results that follow pertain therefore to $p_K > 0.95$ GeV/c.

Among the factors that do not depend on the momentum are: 1) the probability of K_1^0-meson decay into charged particles, $K_1^0 \to \pi^+\pi^-$ (69%), 2) the scanning efficiency, 3) the efficiency of the scintillation counters and of the spark chambers, 4) correction for the dead time of the electronic logic circuitry after each operation.

The obtained true K_2^0-meson spectra are shown in Figs. 3a and 3b in the form of solid histograms. The same figures show, in the form of dashed histograms, the momentum spectra of the particles registered by the setup, without allowance for the correction coefficients. The K_2^0-meson yield at the employed γ-beam energies, summed over all the momenta from 0.95 GeV/c to the maximum ones, in units of K_2^0/eq. γ-sr, turned out to be

$$(4.42 \pm 0.62)\cdot 10^{-5}, \quad E_\gamma^{max} = 4.0 \text{ GeV},$$

$$(8.48 \pm 0.79)\cdot 10^{-5}, \quad E_\gamma^{max} = 4.7 \text{ GeV}.$$

In the calculation of the K_0^2 photoproduction cross section it was necessary to introduce, in addition to the corrections listed above, also a correction for the absorption of the γ quanta in the target (w_γ), and to take additional account of the K_2^0 mesons in the nucleus (a_K), where they are produced, and the absorption in the remainder of the target (w_K)[6]. A calculation based on a simplified optical model of the nucleus yields the following cross sections for the production of K_2^0 mesons on aluminum:

$$d\sigma/d\Omega = 11.0 \pm 1{,}54 \ \mu\text{b/eq.}\gamma\text{-sr} \qquad E_\gamma^{max} = 4.0 \text{ GeV},$$
$$d\sigma/d\Omega = 21.1 \pm 1{,}96 \ \mu\text{b/eq.}\gamma\text{-sr} \qquad E_\gamma^{max} = 4.7 \text{ GeV}.$$

Subtraction of the data at A^{max} = 4.0 GeV from the data at E_γ^{max} = 4.7 GeV yields the total cross section for K_2^0 meson production, for photons with average energy $\overline{E}_\gamma$ = 4.35 ± 0.035 GeV at an angle 10° in the momentum interval 0.95 GeV/c $\leq p_K \leq p_K^{max}$.

To obtain the total K_2^0-meson production cross section we used the following procedure. For each of the employed γ-beam energies we determined the K_2^0-meson yield from the formula

$$Y_{E_\gamma}(p_{K_i}) = \frac{n(p_{K_i})}{\eta(p_{K_i})\,\eta\Delta\Omega N_\gamma \Delta p}, \tag{1}$$

where $Y_{E_\gamma}(p_{K_i})$ is the yield of K_2^0 mesons with momentum p_{K_i} at a maximum γ-beam energy E_γ; $n(p_{K_i})$ is the number of registered K_1^0 mesons in the momentum interval Δp with momentum p_{K_i}; $\eta(p_{K_i})$ is the product of the efficiencies that depend on the momenta of the K_2^0 mesons; η is the product of the efficiencies that are independent of the momenta; $\Delta\Omega$ is the solid angle determined by the target dimensions and the last collimator K_3, and N_γ is the number of equivalent γ quanta. For each momentum interval we then determined the yield difference from the formula

$$\Delta Y(p_{K_i}) = [Y_{4.7}(p_{K_i}) - Y_{4.0}(p_{K_i})]. \tag{2}$$

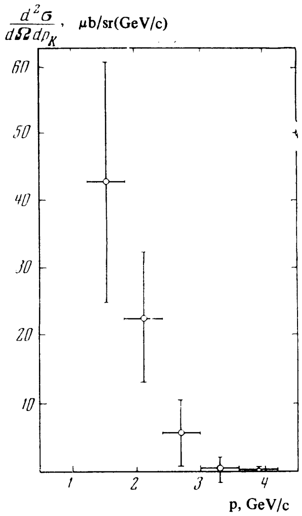

FIG. 4. Differential cross section for the production of K_2^0 mesons by a photon at a photon energy 4.35 ± 0.35 GeV.

i	p_{K_i}, GeV/c	$E_\gamma^{max} = 4.0$ GeV		$E_\gamma^{max} = 4.7$ GeV		$\Delta Y(p_{K_i})$
		$n(p_{K_i})$	$Y_{4.0}(p_{K_i})$	$n(p_{K_i})$	$Y_{4.7}(p_{K_i})$	
1	1.5	33	3.68±0.64	49	6.25±0.89	2.57±1.09
2	2.1	25	1.64±0.33	40	2.99±0.47	1.35±0.57
3	2.7	13	0.656±0.18	19	1.09±0.25	0.334±0.3
4	3.3	3	0.125±0.071	3	0.14±0.099	0.015±0.11
5	3.9			2	0.088±0.062	0.088±0.062

The statistical error for each momentum interval was determined from the expression

$$\sigma(\Delta Y(p_{K_i})) = \left[\frac{[Y_{4.7}(p_{K_i})]^2}{n_{4.7}(p_{K_i})} + \frac{[Y_{4.0}(p_{K_i})]^2}{n_{4.0}(p_{K_i})}\right]^{1/2}. \quad (3)$$

The differential K_2^0-photoproduction cross section, shown in Fig. 4, was determined from the formula

$$\frac{d^2\sigma}{d\Omega\, dp_K} = \frac{\Delta Y(p_{K_i})}{N_A t (w_{K_i} a_{K_i})\, \omega_\gamma} \frac{\bar{E}_\gamma}{\varphi \Delta E_\gamma}, \quad (4)$$

where $\Delta Y(p_{K_i})$ is given by (2), N_A is Avogadro's number, t is the target thickness, $(w_{K_i} a_{K_i})$ is the correction for K_2^0-meson absorption in the target, w_γ is the correction for γ-quantum absorption in the target, $\bar{E}_\gamma$ is the average γ-quantum energy, ΔE_γ is the difference between the two accelerating energies corresponding to the subtracted data, and φ is the deviation of the bremsstrahlung spectrum from the $1/E_\gamma$ spectral dependence (the calculated number of photons in the interval ΔE_γ, divided by the number of photons in the same interval, assuming that the spectral dependence is $1/E_\gamma$).

The table lists the measured K_2^0-meson yields $Y(p_{K_i})$ at E_γ^{max} equal to 4.0 and 4.7 GeV, and the differences between the former and the latter. The total K_2^0-meson production cross section can be obtained from these data by integrating (4) over the momentum interval from p_K^{min} to p_K^{max}. We assume

$$\frac{d\sigma}{d\Omega} = \frac{\bar{E}_\gamma}{N_A t w_\gamma \Delta E_\gamma \varphi} \sum_{i=1}^{i=5} \frac{\Delta Y(p_{K_i})}{w_{K_i} a_{K_i}} \Delta p. \quad (5)$$

The calculation yields for the total K_2^0 meson photoproduction cross section a value 42.66 ± 21.0 μb/sr.

The foregoing data for the cross section, yield, and momentum spectrum of the K_2^0 mesons pertains to reactions of the type

$$\gamma + N \to K_2^0 + \ldots, \quad (III)$$

where one actually measures the cross section of the production of K_2^0 mesons in conjunction with other possible strange particles. In addition, the presence in the bremsstrahlung spectrum of the γ quanta of different energies, and the use of an aluminum target, leads to considerable difficulties in the analysis of individual reaction channels. However, comparison of our data with the data obtained with the aid of bubble chambers[7,8] on K_2^0-meson production, and also with earlier results[2,4], leads to the conclusion that, owing to the rapid growth of the total cross section with increasing energy E_γ, most K^0 mesons are more readily produced in inelastic interactions with multiple pion production.

An investigation of the high-energy part of the momentum spectrum permits a rough estimate of the upper limit of the cross section of reaction (I). The K^0-meson momentum at a given photoproduction angle and a given γ-quantum energy is maximal for the reaction (I). The next process in which the K^0-meson momentum is sufficiently high is the reaction

$$\gamma + p \to K^0 + Y^*(1385). \quad (IV)$$

The momentum of the K_2^0 meson produced in reaction (I) or (IV) can be described with sufficient accuracy by the relations $p_K = p_\gamma - 0.6$ (in GeV/c units) for reaction (I) and $p_K = p_\gamma - 0.86$ for the reaction (IV). Therefore all the K_2^0 mesons whose momenta lie in the interval $(p_\gamma - 0.86) < p_K \leq (p_\gamma - 0.6)$ are due to the reaction (I); the photon energy should be in this case in the range from E_γ^{max} to $E_\gamma^{max} - 0.26$ GeV. An estimate of the upper limit of the cross section for reaction (I), made under these assumptions, yields 1.86 ± 1.07 μb/sr for $E_\gamma^{max} = 4$ GeV and 1.51 ± 1.06 μb/sr for $E_\gamma^{max} = 4.7$ GeV.

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