leads to the determination of the energy of the incoming photon, as long as one can establish the nature of the three particles involved and measure at least 6 of their 9 kinematical parameters (θ, φ, and momentum for each particle). In all of our cases, the primary energy could be determined. For 53 events the experimental information was redundant, which allowed us to estimate that our accuracy in the photon energy determination is about ± 50 Mev.

The energy distribution of the meson pairs observed is given by the histogram in Fig. 1(a).

In order to obtain the cross section, one has to know the spectrum of the photons entering the chamber. This has been determined (a) by measuring the total energy of the electron pairs produced both in the field of the proton (true pairs) and in the field of the electron (triplets) by the same beam that created the meson pairs,[1] (b) by assuming that the pair production cross section is given by the Bethe-Heitler formula and that the triplet cross section is equal to the pair cross section in the energy range from 400 to 1000 Mev.[2] The γ-ray spectrum thus deduced is given by the solid curve in Fig. 1(a), based on a sample of about 1000 pairs and triplets.

Correcting the histogram of Fig. 1(a) with this spectrum, one obtains the energy dependence of the cross section [Fig. 1(b)]. Though the statistics are poor, one can state that the cross section increases steeply from 450 to 550 Mev (threshold is at 322 Mev), then seems to fall to about $\frac{1}{2}$ of its maximum value, at around 1 Bev.

The scale of the cross-section histogram has been gauged by determining the ratio (No. meson pairs/No. electron pairs and triplets) for a sample of 16 000 pictures, which contained 54 of the 90 meson pairs. The absolute values of the cross section thus have a statistical uncertainty of 14%, besides any systematic error due to the use of the Bethe-Heitler equation.

For the cases of triple meson production, where one neutral particle is involved, the energy of the primary photon could be determined in only one case, and was found to be ~ 890 Mev. Assuming that the photons that produce reactions (2) and (3) are essentially those above 700 Mev (threshold is at ~ 520 Mev), the cross section for these processes seems to be of the order of 10 μb, in the energy range from 700 to 1000 Mev.[3]

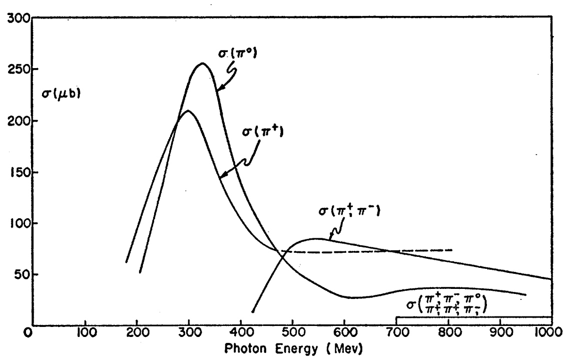

FIG. 2. Summary of the available information on cross section for single and multiple meson photoproduction in hydrogen. The multiple meson data are those obtained from the cloud chamber work. The results for single meson production derive from counter experiments (see quotation 4); the dotted line for $\sigma(\pi^+)$ above 450 Mev is tentatively deduced by multiplying by 4π the data for the differential cross section at 90°.

In Fig. 2 we have plotted our results together with the available data for single meson photoproduction in H_2.[4] It is interesting to note that $\sigma(\pi^+,\pi^-)$, at its maximum, is about $\frac{1}{3}$ of the resonance value for $\sigma(\pi^+)$, and that this is only a portion of the over-all cross section for double meson production, which includes also $\sigma(\pi^+,\pi^0)$ and $\sigma(\pi^0,\pi^0)$. The magnitude and shape of the cross section suggest that, as in single meson production, the process may be dominated by an excited state. Momentum and angular distribution of the emitted particles are not inconsistent with such a picture, though they do not provide compelling evidence in favor of it.

We want to acknowledge gratefully Dr. K. C. Rogers' collaboration in the early part of this work and to thank the laboratory staff and the accelerator crew for the operation of the synchrotron.

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[1] A report on the analysis of these electromagnetic interactions will be published later.

[2] This is supported by our experimental work quoted in reference 1, and is in approximate agreement with the theories; for these see the discussion by F. Rohrlich, Revs. Modern Phys. (to be published).

[3] One must keep in mind that some of the 90 events assigned to reaction (1) might actually be cases of triple meson production where the π^0 is emitted with high energy in the forward direction. This, however, should be rare enough not to affect our analysis substantially.

[4] For $\sigma(\pi^+)$: Up to 450 Mev, see H. Bethe and F. de Hoffmann, *Mesons and Fields* (Row, Peterson and Company, Evanston, 1955), Vol. 2, p. 150. At higher energies, for data on differential cross sections, see Woodward, Heinberg, Wilson, and Zipoy, Bull. Am. Phys. Soc. Ser. II, 3, 32 (1958). For $\sigma(\pi^0)$: J. I. Vette, Ph.D. thesis, California Institute of Technology, 1958 (unpublished), and results for differential cross section by P. C. Stein and K. C. Rogers and by DeWire, Jackson, and Littauer, Bull. Am. Phys. Soc. Ser. II, 3, 33 (1958).

Lifetime and Decay of the $K_2{}^0$ Meson*

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THE lifetime of the $K_2{}^0$ meson has been determined by comparing the yield of $K_2{}^0$ decays in two exposures which differ by a factor of four in mean flight time from production target to detector.

An earlier short-distance exposure[1,2] established the existence of long-lived neutral particles in the secondary radiation from a target in the 3-Bev proton beam of the Brookhaven Cosmotron. The observations established limits on the mean life: 4×10^{-9} sec$<\tau<10^{-6}$. Subsequently, the observed lack of anomalous K^0 decays in bubble chamber studies of V-particle production in π-p collisions set a limit $\tau>3\times10^{-8}$ second.[3] Analysis

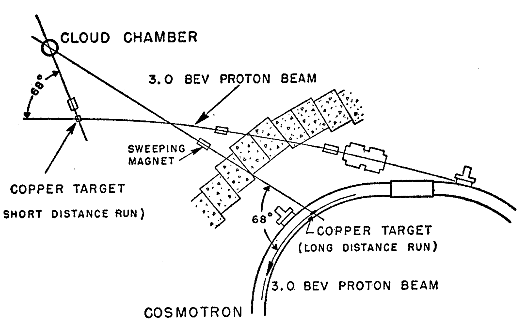

FIG. 1. Experimental arrangements for lifetime study.

of anomalous K^0 decays in cosmic rays have yielded lifetime estimates: $\tau>0.6\times10^{-8}$ sec,[4] and $\tau<10^{-7}$ sec.[5]

The short-distance exposure had been carried out by using the Columbia 36-in. magnet cloud chamber with its entrance window at a distance of 16 feet from a copper target in the external proton beam of the Cosmotron. The experiment has now been repeated with a distance of 70 feet from target to entrance of chamber. The increased distance arrangement was subject to the important constraints that the angle made by the K_2^0 line of flight with the proton beam direction be held fixed to $68°\pm1°$ and that neither the cloud chamber nor the Cosmotron could be conveniently moved. This was achieved by placing the target in the nearest curved section of the Cosmotron. The arrangements are shown in Fig. 1.

Some checks were made to verify that the angle had been maintained at 68°. These consisted of studying (a) the distribution in the number of prongs of neutron-induced stars (Fig. 2), and (b) the spectrum of fast protons ejected from the entrance window of the chamber by neutrons in the beam (Fig. 3). These data indicate that the neutron spectra were identical in both runs, in support of the angle measurement of $68°\pm1°$. The small discrepancy in the percentage of two-prong stars (Fig. 2) is precisely accounted for by the slightly higher fraction (20% in the second run as compared with 17% in the first) of argon in the helium-argon cloud-chamber gas mixture.

Normalization of the two exposures was made to the number of neutron-induced stars in the gas. In the short-distance exposure we obtained 139 K_2^0 decays for 9369 neutron stars, while in the long-distance exposure we had 34 K_2^0 decays and 4887 neutron stars. A small correction is made for the slightly higher proportion of argon in the second run, which leads to a higher cross section for star production. Finally a correction is made for the relative scanning efficiency

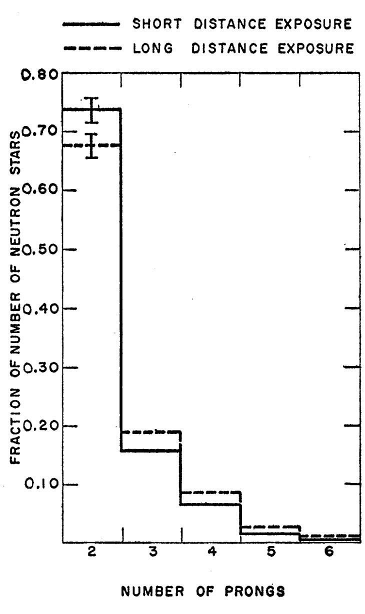

FIG. 2. Prong distributions of neutron-induced stars in the cloud-chamber gas.

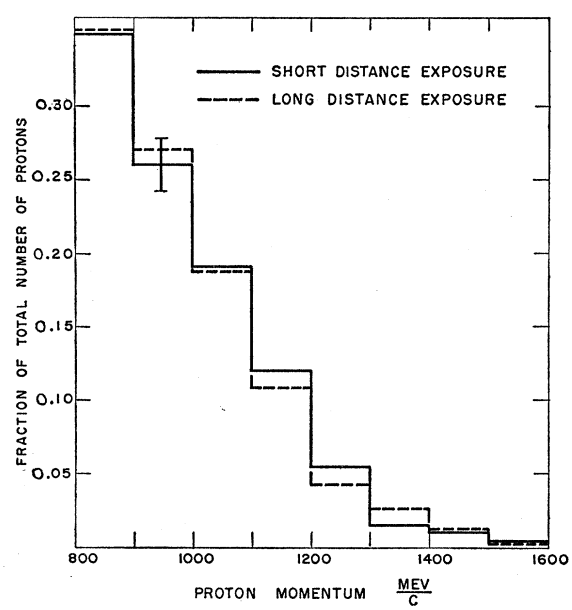

FIG. 3. Momentum distributions of protons ejected from the $\frac{1}{16}$-inch Lucite wall by neutrons in the K_2^0 beam.

in the two runs. Second and third scannings lead to an estimate that the scanning efficiency in the first run was (85 ± 15)% of the second run. Including these corrections, the ratio of the yield of the second exposure to that of the first is

$$R=0.43\pm0.11. \quad (1)$$

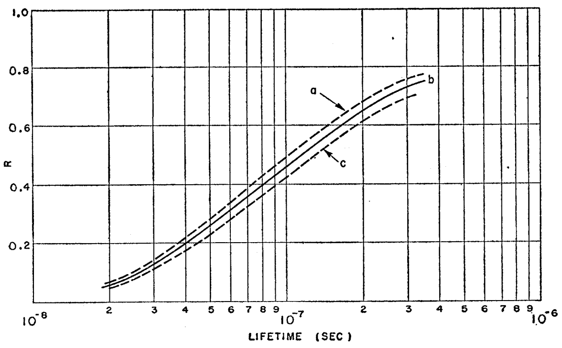

FIG. 4. Dependence of the lifetime on the ratio, R, of yields in the two exposures. Curve a is computed with the use of a spectrum of K^0's derived from an energy-dependent matrix element of the form γ^2-1, Gaussian momentum distribution in the target nucleus, and isotropic angular distribution in the center-of-mass system. Curve b has isotropic and energy-independent matrix element, and Fermi momentum distribution. Curve c has energy-independent matrix element, Gaussian distribution, and $\cos^2\theta$ angular dependence in the center-of-mass system.

This ratio is given as a function of τ, the mean life of the K_2^0, by

$$R=\frac{\int P(\beta\gamma)\exp[-t_L(\beta\gamma)/\tau]\{1-\exp[\Delta t(\beta\gamma)/\tau]\}d(\beta\gamma)}{\int P(\beta\gamma)\exp[-t_S(\beta\gamma)/\tau]\{1-\exp[\Delta t(\beta\gamma)/\tau]\}d(\beta\gamma)}, \tag{2}$$

where $t_L(\beta\gamma)$, $t_S(\beta\gamma)$ are the flight times for the long- and the short-distance runs respectively for K_2^0 mesons of momentum $m\beta\gamma c$ which have a spectral distribution $P(\beta\gamma)$ at 68°; $\Delta t(\beta\gamma)$ is the time of traversal of the chamber. In Fig. 4, we have plotted the relation between R and τ as given by Eq. (2), using an intermediate and two extreme shapes for $P(\beta\gamma)$ as computed by Sternheimer[6] for associated production of $Y-K$ pairs in a complex nucleus by incident 3-Bev protons. Applying Eq. (1) to Fig. 4, using curve b, we obtain:

$$\tau=(9.0_{-2.5}^{+3.5})\times10^{-8}\text{ second.}$$

An estimate of the K_2^0 lifetime can be obtained from the known K^+ branching ratios[7,8] and lifetime[9] by application of charge independence and the $\Delta T=\frac{1}{2}$ selection rule[10] ($T=$total isotopic spin). The K_2^0 lifetime is the reciprocal of the sum of the partial rates for the decay modes $(\pi^\pm\mu^\mp\nu)$, $(\pi^\pm e^\mp\nu)$, $(\pi^+\pi^-\pi^0)$, and $(\pi^0\pi^0\pi^0)$. The partial rates for the decays involving three π mesons are evaluated as in reference 10. For the decay modes involving leptons, we have assumed that the partial rates in the K_2^0 decay are equal to those in K^+ decay, and that there is no asymmetry in charge, as is to be expected[11] with the large K_2^0/K_1^0 lifetime ratio measured. This leads to an estimated K_2^0 lifetime of $\tau\sim5\times10^{-8}$ second. A similar result has been obtained by Okun[12] using a specific model for the K-meson decay interaction.

No decays have been found which do not fit one of the modes $(\pi^\pm\mu^\mp\nu)$, $(\pi^\pm e^\mp\nu)$, $(\pi^+\pi^-\pi^0)$. Limits of the order $<1\%$ may be placed on the existence of the two-body modes $(\pi^+\pi^-)$, $(\mu^+\mu^-)$, (e^+e^-), $(\mu^\pm e^\mp)$ for K_2^0 decay. The absence of the lepton modes is in agreement with current ideas on the universality of the weak interactions. The absence of 2-pion decay is to be expected on the basis of CP invariance.[11,13,14] A discussion of the reverse argument—what do we learn about time reversal from the data contained herein—is given in the accompanying Letter by Weinberg.[15] He concludes that the existence of the reaction[16] $\theta^0\rightarrow2\pi^0$ implies a close identity of the $\pi^+-\pi^-$ and $2\pi^0$ phases, a result which is difficult to understand on any other grounds than CP invariance or accident.

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Time-Reversal Invariance and θ_2^0 Decay*

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RECENT experiments[1] show that the θ_2^0 decays much more slowly than the θ_1^0 $(\tau_2/\tau_1\sim900)$[2] and that the mode $\theta_2^0\rightarrow\pi^++\pi^-$ occurs infrequently ($\lesssim0.6\%$) if at all. This is just what one would expect if CP (or C) were conserved in K^0 decay[3]; conversely, we may ask how much support is given to CP invariance by these experiments,[4] and what additional support may be gained by similar experiments in the near future.

Since we do not assume CP invariance, we must define θ_1^0 and θ_2^0 as linear combinations of θ^0 and $\bar{\theta}^0$