A Measurement of the K_1^0 Lifetime*

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On the basis of about 5000 K^0 decays into two charged pions in a hydrogen bubble chamber, we have measured the K_1^0 lifetime to be $\tau_1 = (0.843 \pm 0.013) \times 10^{-10}$ sec.

I. INTRODUCTION

WE present here a measurement of the mean lifetime for the decay $K^0 \to \pi^+\pi^-$, based upon the analysis of approximately 5000 events.[1] This represents a tenfold increase in the size of the sample used in any previously published experiment.

II. EVENTS

A. Production of Events

The source of K^0 mesons was the annihilation at rest of antiprotons. A total of 650 000 pictures, exhibiting 735 000 antiprotons, was taken with the 30-in. Columbia-Brookhaven hydrogen bubble chamber placed in the low-momentum separated beam at the Brookhaven AGS.

B. Scanning

The three stereoscopic views were scanned twice. It was required that the "V" be visible in all three views. Scanners were instructed to accept all V's within a radius of 15 cm in any view, of a $\bar{p}$ annihilation vertex, whether or not the V points toward the vertex.

We estimate a scanning efficiency of 0.95 ± 0.05. We shall indicate the extent to which a length-dependent bias in scanning may affect our result.

C. Measurement and Data Analysis

For each of the 10 411 V's the neutral track and the two charged prongs were measured in three views. The geometrical reconstruction program NP54 was used to obtain the direction in space of all tracks, and the momenta of the charged tracks. Of the original sample, 8685 survived this program, and the remainder were not remeasured.

The GRIND kinematics program was used to fit the events to the decay hypothesis $K_1^0 \to \pi^+\pi^-$. The fitting was done in two ways; first, using all the measured quantities (three constraints or 3C), and second, ignoring the direction of the K^0 (1C). In the latter procedure the χ^2 for the fit is independent of the length of the K^0 track.

III. SELECTION OF EVENTS

The events are now required to satisfy the following conditions:

(a) The χ^2 for the 1C fit must be less than 3.84. Statistically, 95% of the events should meet this criterion; in fact, only 90% do. The rejected V's consist not only of true $K^0 \to \pi^+\pi^-$ events, but also of three-body K^0 decays and non-K^0 events. After this cutoff the sample contains 7778 events free of any length-dependent bias. Such a bias may, however, be introduced when the K^0 decay is associated with a specific $\bar{p}$ annihilation vertex, as is done in the 3C fit.

If the origin of a K^0 has been correctly identified and measured, the χ^2 for the 3C fit should have approximately the same probability level as that for the 1C fit. The 3C χ^2 was, therefore, required to be less than 10. There is a class of events which does not meet this criterion; this is due to one of three causes: the V has been associated with the wrong annihilation vertex, the K^0 has undergone elastic scattering prior to decay, or the topology of the event may make it difficult to locate the vertex of the V or the annihilation. After remeasurement to all possible vertices, there are still 97 such events. These will be eliminated from our sample.

The elastic scattering cross section at 330 MeV/c, the mean K^0 momentum, is about 16 mb, and thus we expect that 50 events would scatter before decaying. The remaining 47 events could be expected to change the lifetime by at most 0.5% which is considerably less than the statistical error.

(b) The dip angle of the V, as determined from the 1C fit, must be less than 60°.

(c) The distance of the V from the annihilation vertex must be between 0.4 and 12.0 cm.

(d) In order to minimize the scanning bias, we have selected as a fiducial volume a cylinder of radius 23.2 cm and height 24 cm. This choice is based upon our requirement that the charged prongs of a K^0 have at least 5 cm of visible track length. No significant change in our results occurs when a longer visible length is demanded. It is required that *both* the annihilation vertex and the vertex of the V lie within this volume. There are 5279 events which have met all the fiducial criteria.

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[1] This determination of the K_1^0 lifetime and that of P. Franzini, L. Kirsch, R. J. Plano, P. Schmidt, and J. Steinberger [Phys. Rev. **140**, B127 (1965)] are based on the same data. However, the latter was only intended to be a check of experimental procedure, and had not been examined for systematic errors.

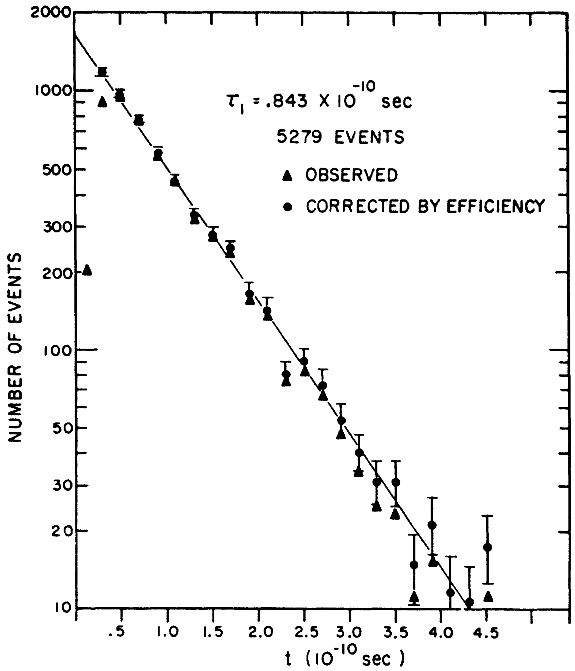

FIG. 1. Number of decays $K_1^0 \to \pi^+\pi^-$ as a function of time.

IV. LIFETIME

The mean lifetime for this sample of events was determined using the maximum likelihood method. The likelihood function is given by

$$\mathcal{L}=\prod_{i=1}^{N}\left\{\frac{\lambda e^{-\lambda t_i}}{e^{-\lambda(t_{\min})_i}-e^{-\lambda(t_{\max})_i}}\right\},$$

where t_i is the proper time of the ith event, $(t_{\min})_i$ is the time in which the ith event travels the minimum accepted length of 0.4 cm, and $(t_{\max})_i$ is the time for the ith event to travel the maximum accepted length of 12 cm, or to the edge of the fiducial volume, whichever is closer.

In writing the likelihood function in this form, we assume no error in the measurement of t_i. This is, of course, not correct since there is an error in this number due to the error in the measurement in the momentum and track length of each K^0. In the present experiment this effect changes the value of the likelihood function by about 0.1%, and thus has been ignored.

The parameter λ measures the loss of K^0's from the beam. The maximum value of the likelihood function yields

$$\lambda=(1.186\pm0.019)\times10^{10}\ \mathrm{sec}^{-1}.$$

Let λ_1 be the K_1^0 decay rate and let λ_s parametrize the loss of K^0's due to the K^0p elastic scattering:

$$\lambda_s \propto \sigma(p)p,$$

where σ is the elastic-scattering cross section at momentum p. Using the mean momentum for this sample gives

$$\lambda_s=0.0012\times10^{10}\ \mathrm{sec}^{-1}.$$

Thus,

$$\lambda_1=\lambda-\lambda_s=(1.185\pm0.019)\times10^{10}\ \mathrm{sec}^{-1}.$$

V. CHECKS

A. Momentum Bias

In order to check that the lifetime is independent of K^0 momentum, the data are divided in eight parts corresponding to intervals of 100 MeV/c in K^0 momentum. The lifetime obtained from all the data was compared to the eight values obtained above, using a χ^2 test. The probability of this χ^2 is 18%.

B. Length Bias

The lifetime was calculated using different values for the short- and long-length cutoffs. No significant change in the lifetime was observed.

The events are plotted in the histogram of Fig. 1. The triangular points are the observed number of events, and the solid dots are the same events divided by the geometric detection efficiency for the corresponding bin. This efficiency is given by

$$\epsilon(t)=\sum_{i=1}^{N}\delta_i(t)\times f_i\Big/\sum_{i=1}^{N}f_i,$$

where

$$f_i=[e^{-\lambda_1(t_{\min})_i}-e^{-\lambda_1(t_{\max})_i}]^{-1},$$

and

$$\delta_i(t)=1,\qquad (t_{\min})_i<t<(t_{\max})_i;$$
$$=0,\qquad \text{otherwise.}$$

The straight line has the value of λ_1 given by the maximum-likelihood method. The χ^2 probability for this line as compared to the corrected points is 45%. These points show no significant tendency to fall below the line at either very short or very long times.

C. Systematic Errors

The lifetime would be systematically altered if the K^0 momentum were in error. This momentum was calibrated in another experiment.[2] The error in mo-

TABLE I. Recent values of the K_1^0 lifetime.

Authors	K_1^0 lifetime in units of 10^{-10} sec
Chretien *et al.*[a]	0.87 ±0.05
Kreisler *et al.*[b]	0.86 ±0.04
Golden *et al.*[c]	0.885±0.025
This experiment	0.843±0.013

[a] Chretien *et al.*, Phys. Rev. **131**, 2208 (1963).
[b] M. Kreisler, O. Overseth, and J. Cronin, Phys. Rev. **136**, B1974 (1964).
[c] R. L. Golden *et al.*, *Proceedings of the 1962 International Conference on High Energy Physics at CERN*, edited by J. Prentki (CERN, Geneva, 1962), p. 839.

[2] J. Kim, L. Kirsch, and D. Miller, Phys. Rev. **140**, B1334 (1965).

mentum, based upon this procedure, will affect the lifetime by less than 0.2%.

VI. CONCLUSION

We obtain a value for the mean life for $K^0 \rightarrow \pi^+\pi^-$ of

$$\tau_1 = (0.843 \pm 0.013) \times 10^{-10} \text{ sec.}$$

This result is in agreement with the recently published values of the K_1^0 lifetime given in Table I.

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$2\pi^0$ Mass Spectrum and Determination of the Spin of the f^0 Using $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$ at 10 BeV/c*

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The properties of the π^0-π^0 system have been studied using the interaction $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$ at 10 BeV/c, by observing only the four gammas produced. The $\pi^0\pi^0$ mass spectrum shows a strong f^0 peak centered at 1275 ± 25 MeV. A broad second enhancement, extending from threshold to $\sim$800 MeV, cannot be interpreted definitively because of a large background (only in this mass region) of gammas from $3\pi^0$ events. The f^0 differential production cross section falls off initially as e^{At}, where $A \approx 10$. For small four-momentum transfer events ($t \lesssim 5m_\pi^2$), the $\pi\pi$ scattering distribution in the f^0 rest frame agrees well with $[P_2(\cos\theta_{\pi\pi})]^2$, where P_2 is the second Legendre polynomial. This indicates that the simplest one-pion-exchange model is applicable under these conditions, and allows us to conclude that the f^0 spin is 2, not 0 or 4. The f^0 production cross section times its branching ratio for $2\pi^0$ decay is 20 ± 5 μb. The g^0 meson (2π resonance at 1670 MeV) is not observed and an upper limit of 5 μb is set for its production cross section times its branching ratio into $2\pi^0$'s.

THE properties of the π^0-π^0 system have been studied using the interaction $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$ at 10 BeV/c.

Two enhancements are observed in the $\pi^0\pi^0$ mass spectrum. The first stretches across the low end of the spectrum, from threshold to $\simeq$800 MeV. The second is identified as the f^0 meson.[1] The spin of the f^0 is determined, using a one-pion-exchange model, to be $J = 2$, in agreement with earlier indications.[2]

The experimental apparatus has been described previously,[1,3] and consists essentially of a liquid-hydrogen target followed by a brass-plate spark chamber which detects those γ rays produced within $\pm 14°$ of the beam direction.

Since we measure only γ-ray angles, we must have a method of pairing the γ's properly into π^0's, as well as a method for determining the π^0 momentum.

In any system the angle ϕ between the π^0-decay γ rays must be between some minimum value, $\phi_{\min}$, and 180°. For high-momentum π^0's, this γ-γ opening-angle spectrum peaks sharply at $\phi_{\min}$, which is given by $\phi_{\min}/2 \approx \tan(\phi_{\min}/2) = m/p$, where m and p are the π^0 mass and momentum. To determine the most likely of the three possible pairings of the four γ's into two π^0's, it is assumed that both π^0's decay, in the lab system,

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