Lifetimes of τ, $K_{\mu 3}$, and K_e Decay Modes*

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The proportions of the various decay modes of K^+ mesons produced by the 2.9-Bev proton beam of the Brookhaven Cosmotron have been investigated in two emulsion stacks separately exposed at different distances from the target. An analysis of the observed ratios of different decay modes has been made in order to determine the various partial lifetimes, the $K_{\mu 2}$ and $K_{\pi 2}$ lifetimes being used as a secondary standard. The results indicate that within experimental error all the partial lifetimes are consistent with a unique value.

I. INTRODUCTION

OUR present knowledge about the lifetime of heavy mesons has been considerably advanced since the advent of artificially produced K^+-meson beams at Berkeley and Brookhaven.[1] The most important results on the lifetimes of K^+ mesons have been obtained by counter experiments.[2,3] It is now established that the lifetimes of $K_{\mu 2}$ and $K_{\pi 2}$ are identical. In addition, the lifetime of τ^+ determined by photoemulsion techniques is found to be, within experimental error, the same as that of $K_{\mu 2}$ and $K_{\pi 2}$.[4,5] For the remaining two types of K^+ mesons, $K_{\mu 3}$ and K_e, direct experimental data on their lifetimes are still wanting. One can only obtain a qualitative estimate of the order of magnitude of the $K_{\mu 3}$ and K_e lifetimes from the fact that the observed ratios of the five different types of K^+ mesons remain almost the same under various experimental conditions of production and observation. This gives a strong indication that the lifetimes of K^+ mesons must be, if not all identical, at least very close to each other.

The lack of direct experimental data on the lifetimes of the $K_{\mu 3}$ and K_e arises principally from the fact that they constitute a quite small percentage of the K^+-meson beam and their identification is not as straightforward as that of the $K_{\mu 2}$, $K_{\pi 2}$, and τ. However, an approach to the problem of the $K_{\mu 3}$ and K_e lifetimes can be made, if we restrict ourselves to a relative measurement using the well-established lifetimes of the $K_{\mu 2}$ and $K_{\pi 2}$ as a secondary standard. In this respect, the photoemulsion lends itself quite conveniently to this purpose, for it has the advantage of recording all K^+ mesons constituting the beam and enabling an analysis to be made of their respective proportions.

The object of this paper is to describe the method by which we have attempted to estimate the lifetimes of K^+ mesons and also to discuss the methods used to discriminate different types of K^+ mesons.

II. EXPERIMENTAL

We have used two stacks of Ilford G-5 stripped emulsions, each composed of 48 pellicles, 3 in.×3 in. ×400 μ. The emulsions were punched with two small holes serving as a reference for their alignment. They were packed between two Bakelite plates and aligned by means of two Lucite pins passing through the holes of each pellicle.

The two stacks, with surfaces horizontal, were exposed separately to the K^+-meson beam of the Brookhaven Cosmotron.[6] The K^+ beam was produced by the 2.9-Bev internal proton beam incident on a Cu target $\frac{1}{8}$ in.×$\frac{1}{8}$ in.×$\frac{1}{2}$ in. The K^+ mesons emitted at 60° with respect to the circulating proton beam passed through a pair of strong-focusing magnets and were momentum-analyzed by a bending magnet. The currents in the three magnets were previously calibrated by wire measurements to obtain the focus condition for the required momentum at the exposure position.

The first stack, designated as "Stack *a*," was exposed at an over-all distance of 3.52 m from the target, with a circulating proton flux of 8.02×10^{12}. The second stack, designated as "Stack *b*," was exposed afterwards at a distance 75 cm further than "Stack *a*," the circulating proton flux in this exposure being 1.60×10^{13}.

After the K^+-meson exposure, both stacks were irradiated to the 1.5-Bev π^- channel beam. These π's, crossing the plates at 90° with respect to the direction of the K^+ beam, serve afterwards to calibrate ionization measurements in each emulsion.

After the exposure was completed, the emulsions were unpacked and printed with a grid on the sticking side of each pellicle,[7] in order to facilitate the tracing

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[1] A general survey on the lifetimes of K mesons has been presented at the 1956 Rochester High-Energy Conference by L. Leprince-Ringuet and S. Goldhaber. See *Proceedings of the Sixth Annual Rochester Conference on High-Energy Physics* (Interscience Publishers, Inc., New York, 1956), Chap. 5, pp. 1, 24.

[2] V. Fitch and R. Motley, Phys. Rev. **101**, 498 (1956).

[3] Alvarez, Crawford, Good, and Stevenson, Phys. Rev. **101**, 503 (1956).

[4] L. Alvarez and S. Goldhaber, Nuovo cimento **2**, 344 (1955).

[5] Harris, Orear, and Taylor, Phys. Rev. **100**, 932 (1955).

[6] For the characteristics of the K^+ beam setup we refer to: R. M. Sternheimer, Brookhaven Internal Report, August, 1955 (unpublished).

[7] Technique due to Goldhaber, Goldsack, and Lannutti, University of California, Radiation Laboratory, Report UCRL-2928 (unpublished).

of tracks through successive plates. The emulsions were then mounted on glass and processed together by the usual temperature method.

III. SCANNING PROCEDURE

The average momentum of K^+ mesons in the two stacks was determined by the range of stopped protons near the entrance of the beam. They were $P_a=270$ Mev/c in stack a and $P_b=275$ Mev/c in stack b; the gradient along the beam entrance edge was, respectively, 6.8 Mev/c per cm and 3.9 Mev/c per cm. This leads to an expected range for K mesons in both stacks of about 2.9 cm.

To select K^+ mesons in our two stacks, we have used the systematic "on track" scan. All tracks at 1 cm from the entrance edge were selected, provided they had satisfied the following criteria: (1) a projected length greater than 3 mm, (2) a projected angle less than 5° with the mean direction of the beam, and (3) an ionization in an appropriate range. Each track was followed until it came to rest or had exceeded the expected range by 1.5 cm; each ending was then inspected under high magnification to search for a decay secondary.

TABLE I. Groups of K^+ mesons observed in stacks a and b. Ionizations are referred to 1.5-Bev cross π^- beam.

	K_L Secondary ionization $I\leq 1.3$	K_G Secondary ionization $I>1.3$	τ	Total
Stack a	205	12	15	232
Stack b	180	5	16	201

In this way, six middle plates of each stack were completely scanned. 232 K^+-mesons were found in stack a and 201 in stack b. For the sake of convenience we divided the K^+ mesons with a single charged secondary into two groups, K_L and K_G, according to their ionization (with respect to the 1.5-Bev cross π beam) $I\leqslant 1.3$ or $I>1.3$, respectively. The results are tabulated in Table I.

We next consider the scanning efficiency for each group of K^+ mesons. There is no question for the τ; its detection is without bias. To test the efficiency for detecting the gray secondaries of K_G, we note that this group contains τ' and $K_{\mu 3}$. The ratio τ'/τ found in these two stacks can indicate our scanning efficiency for this class. (The discussion on the identification of τ' will be presented in the following section.) For the moment, we content ourselves with the result we have found: the ratio τ'/τ found in the two stacks combined is 9.5/31. This implies that no appreciable correction is needed for the group K_G.

The efficiency for detecting a near-minimum secondary depends strongly on its geometry. To estimate the percentage of missed cases, we first consider the histogram of Fig. 1, showing the distribution in depth of

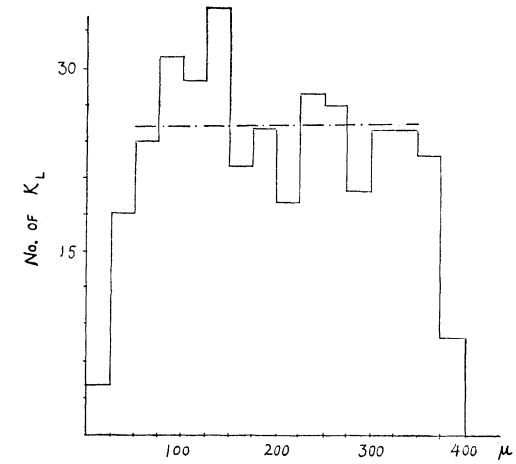

FIG. 1. Depth distribution of endings of stopped K_L.

endings of the K_L group found in both stacks. We note that there are less K_L's found in the layers of 50 μ depth near the upper surface and at the bottom of each emulsion. Otherwise the distribution seems uniform as indicated by the straight line. From this distribution we estimate about 13.5% of K_L's are missed in the scan owing to their ending too near the extreme surfaces.

Next, we consider the angular distribution of the secondaries of K_L ending in the middle of emulsion; this is given in Fig. 2. The distribution is essentially isotropic, except for those emitted at an angle steeper than 60° with the plane of the emulsion; the fraction thus escaping observation is estimated to be about 5.5%. From the angular distribution shown in Fig. 2, we are led to the conclusion that there is no significant anisotropy in the emission of secondaries of near-minimum ionization.

IV. ANALYSIS OF GROUP K_G

Of the 17 secondaries classified in the group K_G, 14 have been followed to an ending inside the stack and

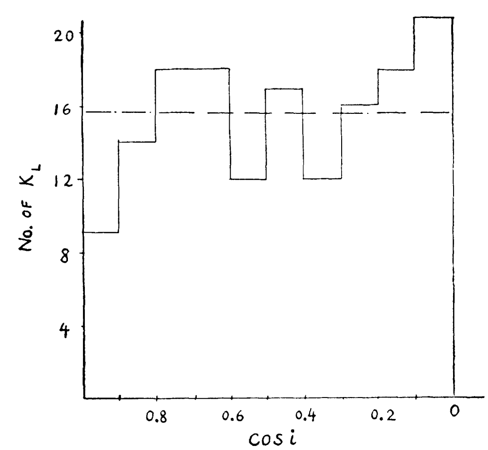

FIG. 2. Angular distribution of near-minimum secondaries emitted in the middle layer of the emulsion.

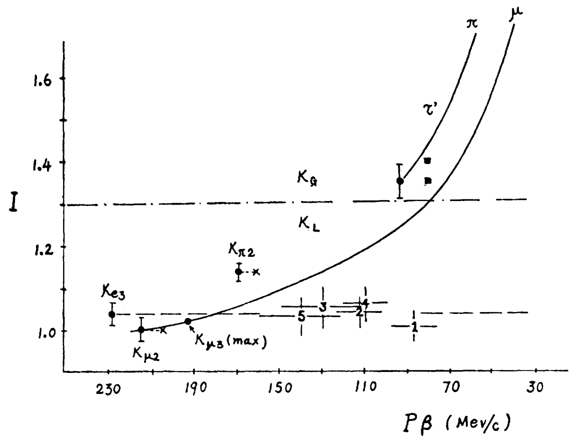

FIG. 3. Calibration curve of ionization (with respect to the 1.5-Bev π^- cross beam) *vs* $P\beta$ for the emulsions of this experiment. The measured ionization values for secondaries of $K_{\mu 2}$ and $K_{\pi 2}$ are indicated in the figure at the *a priori* value of $P\beta$. The crosses represent the weighted mean of measured $P\beta$. Five cases of secondaries of K_e are marked on the figure.

allow a definite identification of their primary K^+ mesons. We find six $K_{\mu 3}$ and eight τ'.

The remaining three secondaries go out of the stack; of these only two allow ionization and scattering measurements. The results are as follows:

Case 1: $I=1.34\pm0.07$, $P\beta=80\pm16$ Mev/c;

Case 2: $I=1.40\pm0.05$, $P\beta=81\pm12$ Mev/c.

If we refer these measurements to our $I-P\beta$ calibration curve obtained for these stacks (Fig. 3),[8] we see two points (squares) lying between the μ and π curves. In default of sufficient length for further measurement, it was not possible to decide their nature without ambiguity. If we assume an equal probability for these unidentified secondaries to be either a μ or a π, we find the total number of τ' to be 9.5.

V. IDENTIFICATION OF SECONDARIES OF GROUP K_L

The method used in the present work to identify the near minimum K^+ secondaries is based on ionization and scattering measurements, which, in conjunction with the well-established properties of different decay modes, can lead to definite results.[9]

Among the secondaries of 385 K mesons of group K_L in our two stacks, 45 have a dip angle (i) less than 7°. For each of these secondaries, extensive measurements of ionization and scattering were carried out on successive portions. All ionization measurements were made with blob counts and were referred to 1.5-Bev π mesons chosen in the near vicinity of the secondary; the statistical error on each measurement is less than 4%. The average blob density of the 1.5-Bev cross π beam is around 20/100 μ, about 3% below the plateau determined by blob count on tracks of electron pairs. The results of the ionization measurements of this class of K_L are presented in Fig. 4. The histogram shows two clear-cut peaks: one around $I=1.00$ and another at $I=1.14$.

Scattering measurements were made with the Molière-d'Espagnat method. Sufficient length of the secondary is used to reduce as much as possible the statistical error. The results of these measurements are presented in Fig. 5. In an attempt to facilitate the discussion, we have tentatively separated the distribution into three histograms. A specific number is labeled in each square, serving to relate it to the corresponding square in the histogram representing the ionization distribution (Fig. 4).

If we consider the ten cases with ionization grouped around the peak at higher I in the histogram of Fig. 4, we see that their $P\beta$ values, represented in the histogram of Fig. 5 are all compatible with the expected $P\beta$ value of the secondary from $K_{\pi 2}$. If we take the weighted mean value of ionization and $P\beta$, we find: $\bar{I}=1.14\pm0.02$ and $\langle P\beta\rangle_{\text{Av}}=162\pm14$ Mev/c; the quoted errors are standard derivations from the mean.[10]

This identification is further supported by the following results we have obtained among other K's of our two stacks. We have observed one K_L having a secondary ($i=13°$) at $I=1.14\pm0.04$ and associated

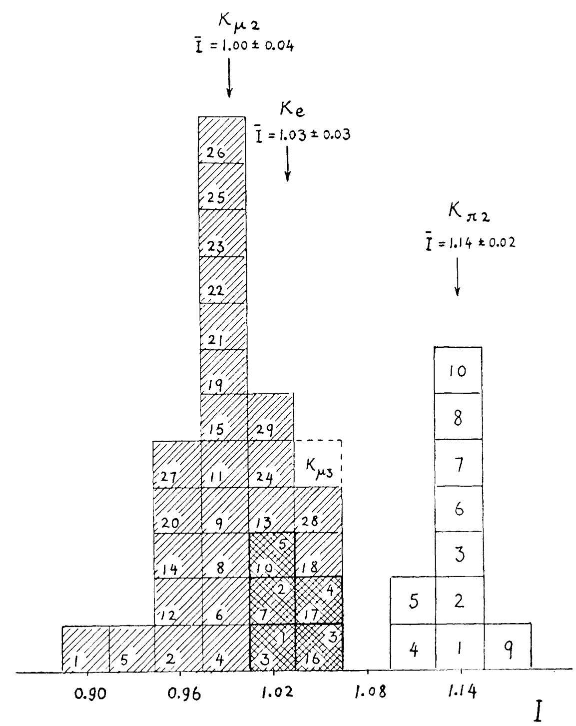

FIG. 4. Histogram showing the distribution of ionization (with respect to 1.5-Bev π^- cross beam) of 45 near minimum secondaries (K_L group) having dip angle less than 7°.

[8] Hoang, Kaplon, and Yekutieli, Phys. Rev. **102**, 1185 (1956).

[9] A similar method has been used by Smith, Heckman, and Barkas, Nuove cimento (to be published).

[10] Mean values quoted in this section are weighted averages; the errors are root-mean-square deviations.

with an electron pair; a complete analysis of this case shows that it is definitely a $K_{\pi 2}$.[11] In another case of K_L, the secondary ($i=12°$) with an ionization $I=1.13 \pm 0.05$, initiates a star 2.5 mm from its point of emission. The secondary is thus a π meson and can only belong to the $K_{\pi 2}$ class.

The case labeled with $K_{\mu 3}$ is also definite. The charged secondary has an ionization $I=1.06\pm 0.02$ and $P\beta=153\pm 10$ Mev/c; it is associated with an electron pair; the possibility of a $K_{\pi 2}$ is completely ruled out in this case.[12]

There are five cases in histogram b of Fig. 5 which have the characteristics of an electron. They all have a low value of $P\beta$, $P\beta \leq 150$ Mev/c measured by scattering, while their ionization is on the plateau, their mean being $\bar{I}=1.03\pm 0.03$; these cases can be attributed to K_e. However, we have to bear in mind that, from the point of view of scattering measurements, three of these five cases have $P\beta > 120$ Mev/c and can still belong to the tail of the $K_{\mu 2}$ distribution. On the other hand, if we refer to the $I-P\beta$ calibration curve of our present plates (Fig. 3), we note that the two cases marked as 3 and 5 in histogram b of Fig. 5 need only have their measured $P\beta$ increased each by one standard derivation to bring them on the μ curve; with this condition, the possibility that these two cases belong to the high-energy part of $K_{\mu 3}$ secondaries cannot be completely ruled out. This, however, does not seem too likely in view of the small percentage of $K_{\mu 3}$ among K^+ mesons.

Finally, we consider the remaining 29 cases. Referring to the histogram of their ionization, Fig. 4, we see that they are well grouped around a peak at lower I. Their $P\beta$, as shown in histogram c of Fig. 5, ranges from 147 to 266 Mev/c, with a peak around $P\beta=200$ Mev/c. Actually, this group can contain secondaries of $K_{\mu 2}$, the high-energy tail of $K_{\mu 3}$, and also K_e. In view of experimental errors, a separation of the different components forming this group is not possible. However, we can estimate what will eventually be the proportions of $K_{\mu 3}$ and K_e on the basis of phase space considerations starting from the positively identified cases of $K_{\mu 3}$ and K_e at lower energy. As we have indicated in the previous section, in the K_G class we have found 6 definitely identified $K_{\mu 3}$ and two probable ones with secondary energy lower than 63 Mev (corresponding to $I=1.3$, limit of separation for K_L). Thus we should expect at most some 9 cases of $K_{\mu 3}$ in the K_L group of which only one is expected to have a dip angle less than 7°. Actually, we have already found a well-identified case of $K_{\mu 3}$ (marked as such in the histograms) among the 45 K_L's we are considering here. Thus it seems that the number of additional cases of $K_{\mu 3}$ which may be present among these 29 must be rather small. The same considerations applied to K_e, assuming the decay mode $K_e \rightarrow e+\pi^0+\nu$, lead to the conclusion that its contribution is at most two cases with dip angle $\leq 7°$.

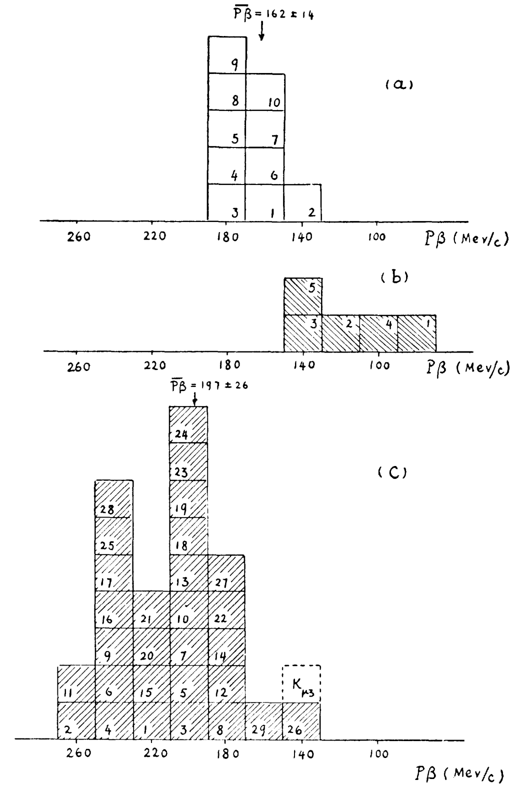

FIG. 5. Histograms showing the distribution of $P\beta$ values of 45 secondaries of K_L with dip angle less than 7°. The corresponding onization measurements are represented in Fig. 4.

Therefore, it seems reasonable to conclude that the great majority, 27 out of the 29 cases, are actually $K_{\mu 2}$. If we select the 27 cases having both ionization and $P\beta$ as a best fit for $K_{\mu 2}$, we find: $\bar{I}=1.00\pm 0.04$ and $\langle P\beta\rangle_{\text{Av}}=197\pm 26$ Mev/c. This value of $P\beta$ is completely consistent with that expected for secondaries of $K_{\mu 2}$.

In order to improve our statistics on the different types of K^+ mesons found in each of two stacks, ionization measurements have also been carried out with 74 other secondaries of the K_L group having a dip angle between 7° and 15°. These measurements were carried out with slightly less accuracy than in the previous measurements, the error on each measurement being of the order of 5%. The results are presented in the two histograms of Fig. 6.

A comparison of these histograms with the previous one (Fig. 4) shows a similar separation in ionization as obtained for the class with dip angle i less than 7°, and no appreciable difference in the mean ionization values is observed for the two classes of dip angles. Consequently, it seems that as far as the identification of secondaries from $K_{\pi 2}$ is concerned, we can rely solely

[11] For detailed discussion, we refer to a previous publication: Cester, Hoang, Kaplon, and Yekutieli, Nuovo cimento 3, 1471 (1956).

[12] A complete description and analysis of this case has been published: Hoang, Kaplon, and Yekutieli, Phys. Rev. 101, 1834 (1956).

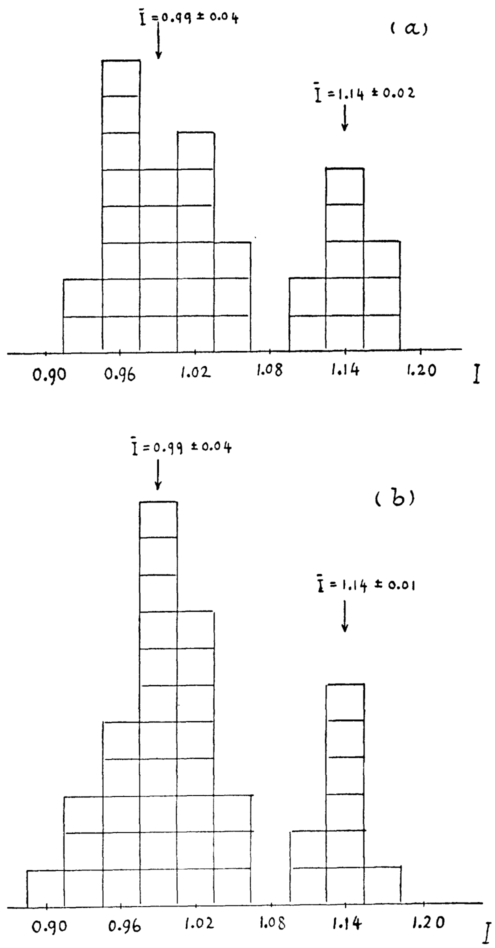

FIG. 6. Histograms of distribution of ionization (with respect to the 1.5-Bev π^- cross beam) of near-minimum secondaries having a dip angle $7°<i\leq 15°$ (a) 34 cases of stack a; (b) 40 cases of stack b.

on ionization. With this criterion, the contamination of $K_{\mu 3}$ will be negligible since it has already been shown that the possible percentage of $K_{\mu 3}$ in this ionization region is extremely small.

VI. RATIO OF VARIOUS DECAY MODES OF K^+ MESONS

In Table II we have summarized the results of the analysis of secondaries of K^+ mesons observed in "stack a" and "stack b." We shall now attempt to estimate the percentage of different decay modes in each stack. The procedure used here has described in a previous work.[8]

We shall make no distinction between τ and τ'; their combined percentage is obtained from the statistics of their cases observed in each stack and no specific correction is necessary.

For $K_{\pi 2}$, the percentage is deduced from the number of cases with dip angle $i\leq 15°$, identified as such by ionization, and making the appropriate geometrical correction.

For $K_{\mu 3}$, K_e, and $K_{\mu 2}$, we first set lower and upper limits for their percentages. The lower limit is determined by accepting only the well identified cases divided by the corrected total number of K^+ mesons in the stack. For the upper limits, we proceed as follows. For the $K_{\mu 3}$ and K_e we include all possible cases, and in addition the extra cases indicated by phase space considerations; for the $K_{\mu 2}$, we take as an upper limit all K_L which are not $K_{\pi 2}$. The most probable percentage is then calculated by taking the geometric mean of the lower and upper limits thus determined.[13] The results are presented in Table III.

The percentages in the two stacks are nearly the same and are comparable to results found by Smith *et al.*,[9] Ritson *et al.*,[14] Whitehead *et al.*,[15] and Crussard *et al.*[16] under different conditions of production and observation.

VII. LIFETIME ESTIMATE

For this purpose, we choose as a secondary standard the lifetime of $K_{\mu 2}$ and $K_{\pi 2}$ which has been accurately determined by counter techniques.[2,3] The proper lifetime, T, of a certain type of K^+ meson can then be deduced from its proportions p_a and p_b observed in stacks a and b with respect to this standard type (of lifetime T_0) in the same stack.

If $x_a=352$ cm and $x_b=427$ cm are the distances of the two stacks from the target and P/mc the reduced momentum of the K^+ beam, it is easily seen that

$$\frac{p_a}{p_b}=\exp\left[(x_b-x_a)\frac{mc}{P}\left(\frac{1}{Tc}-\frac{1}{T_0c}\right)\right].$$

Setting $\Delta x=x_b-x_a$ and $\Delta T=T_0-T$, we have

$$\frac{\Delta T}{T}=\left(\frac{cT_0}{\Delta x}\right)\left(\frac{P}{mc}\right)\ln\left(\frac{p_a}{p_b}\right),\quad T=\frac{T_0}{1+(\Delta T/T)}.$$

Actually the momentum P_b in stack b has been found slightly higher than that of stack a. Nevertheless, we can make a compromise by modifying this momentum along with the distance of the stack, if we write

$$\left(\frac{x_b}{cT}\right)\left(\frac{mc}{P_b}\right)=\left(\frac{x_b'}{cT}\right)\left(\frac{mc}{P_a}\right),$$

[13] Our reason for using the geometric rather than the arithmetic mean of the lower and upper limits arises from the fact that for two values, a and b, with arithmetic and geometric means m and n, respectively, $a\leq n\leq m\leq b$. Since in our situation the lower limit (a) is deduced from positively identified cases while the upper limit (b) is essentially an estimate, we prefer a mean which gives more weight to the lower limit.

[14] Ritson, Pevsner, Fung, Widgoff, Zorn, Goldhaber, and Goldhaber, Phys. Rev. **101**, 1085 (1956).

[15] Whitehead, Stork, Peterson, Perkins, and Birge, University of California Radiation Laboratory Report UCRL-3295 (unpublished).

[16] Crussard, Fouche, Hennessy, Kayas, Leprince-Ringuet, Morellet, and Renard, Nuovo cimento **3**, 730 (1956).

TABLE II. Classification of K^+ mesons observed in stack a and b.[a]

		Stack a	Stack b
τ		15	16
K_G	τ'	6 identified (s.s.) $\frac{1}{2}\times 1$ probable $(I-P\beta)$	2 identified (s.s.) $\frac{1}{2}\times 2$ probable
	$K_{\mu 3}$	5 identified (s.s.) $\frac{1}{2}\times 1$ probable $(I-P\beta)$	1 identified (s.s.) $\frac{1}{2}\times 2$ probable
K_μ $i\leq 7°$	$K_{\pi 2}$	6 sure $(I-P\beta)$	4 sure $(I-P\beta)$
	K_e	1 sure $(P\beta=85)$ $\frac{1}{2}\times 1$ probable $(P\beta=120)$ (p.s.c.$\simeq$1)	1 sure $(P\beta=110)$ $\frac{1}{2}\times 2$ probable $(P\beta=130, 144)$ (p.s.c.$\simeq$1)
	$K_{\mu 3}$	1 definitely identified (p.s.c.$\simeq$1)	(p.s.c.$\simeq$1)
	$K_{\mu 2}$	19 most probable $(I-P\beta)$	10 most probable $(I-P\beta)$
K_μ $7°<i\leq 15°$	$K_{\pi 2}$	10 sure (I)	9 sure (I)
	K_e, $K_{\mu 3}$, $K_{\mu 2}$	24	31
$K_L i>15°$ nonmeasurable		143	123

[a] Legend: (s.s) stopped secondary; $(I-P\beta)$ identification by ionization and scattering; (I) identified by ionization; (p.s.c) phase space consideration.

with

$$x_b'=x_b\left(\frac{P_a}{P_b}\right)=\frac{270}{275}x_b.$$

Following this modification, we substitute $\Delta x=x_b'-x_a=68$ cm, and set $P=P_a=270$ Mev/c.

If we choose for the secondary standard the lifetime of $K_{\mu 2}$ which constitutes the majority of the K^+ beam, we find for T_0 the following value according to Fitch *et al.*[2] and Alvarez *et al.*[3]:

$$T_0=(1.20\pm 0.19)\times 10^{-8}\text{ sec.}$$

The results of our estimation are tabulated in Table IV(a). The errors quoted in the last column are computed from the statistical errors of the proportions of K^+ mesons as listed in Table III. We have also included for comparison the lifetime of the group $(K_{\mu 2}+K_{\pi 2})$ which serves as a test of the method.

Since the lifetime of $K_{\pi 2}$ has been found to be identical to that of $K_{\mu 2}$, we can, alternatively, take the group $(K_{\mu 2}+K_{\pi 2})$ together as a standard for comparison.[17] This proceedure has the advantage of reducing the statistical error. The results are presented in Table IV(b). It is to be noted that the results we have obtained by referring either to $K_{\mu 2}$ alone or to the group $(K_{\mu 2}+K_{\pi 2})$ are completely consistent.

VIII. DISCUSSION AND CONCLUSION

The results obtained for the lifetimes of $K_{\pi 2}$, $K_{\mu 2}$, and $(K_{\mu 2}+K_{\pi 2})$ listed in Table IV(a) and IV(b) can be used to test the consistency of our method. Comparing these results with the expected value $T_0=1.20$, we conclude that there is possibly a systematic error of 25% inherent in the method; this error is taken into account in the total error.

The lifetime of $(\tau+\tau')$ that we have found is in good agreement with the data obtained by Alvarez *et al.*[4] and by Harris *et al.*[5] In this connection, we note that if we apply the present method to the data given by Harris *et al.*, we obtain a lifetime 1.65×10^{-8} sec, slightly different from the value given by the authors.

For the lifetimes of $K_{\mu 3}$ and K_e, there is no evidence of any appreciable difference from that of $K_{\mu 2}$ and $K_{\pi 2}$. This conclusion is further substantiated by the value obtained for their composite lifetime which is subject to less error than their individual values and can be evaluated in the following way. The identification of $(\tau+\tau')$ on the one hand and $K_{\pi 2}$ together with $K_{\mu 2}$ on the other is the most reliable; consequently the remaining percentage, deduced from these three types of K^+ mesons, will give a reliable indication of the proportion of $(K_{\mu 3}+K_e)$ contained in the beam. Their composite lifetime thus computed is 1.84×10^{-8} sec if we refer to $K_{\mu 2}$ alone and is 0.82×10^{-8} sec if we refer to the group $(K_{\mu 2}+K_{\pi 2})$ as a standard. Since these values do not show any significant deviation from the individual lifetimes of $K_{\mu 3}$ and K_e we have found separately, and

TABLE III. Percentage of various decay modes in two stacks.

	Stack a	Stack b
$(\tau+\tau')$	7.9 ± 1.7	8.1 ± 1.8
$K_{\pi 2}$	23.5 ± 5.8	20.6 ± 5.5
$K_{\mu 2}$	60.1 ± 12.0	61.5 ± 14.8
$K_{\mu 3}$	4.2 ± 1.3	4.0 ± 1.8
K_e	4.7 ± 3.5	5.5 ± 3.2

[17] Measurement of the total lifetimes of K^+ mesons excluding τ has been made by Iloff, Chupp, Goldhaber, Goldhaber, and Lannuetti, Phys. Rev. 99, 1617 (1955).

TABLE IV. Lifetime estimation.

(a) Secondary standard $K_{\mu2}$, $T_0=1.20\pm0.19$

	Proportion with respect to $K_{\mu2}$ in stack a p_a	in stack b p_b	$\Delta T/T$	T in 10^{-8} sec	Errors (statistical) in 10^{-8} sec
$K_{\pi2}$	0.391	0.335	0.456	0.83	0.08
$(K_{\mu2}+K_{\pi2})$	1.391	1.335	0.120	1.00	0.01
$(\tau+\tau')$	0.132	0.132	0.	1.20	0.17
$K_{\mu3}$	0.070	0.065	0.214	0.99	0.13
K_e	0.078	0.089	−0.386	1.95	0.56

(b) Secondary standard $(K_{\mu2}+K_{\pi2})$, $T_0=1.21\pm0.12$

	Proportion with respect to $(K_{\mu2}+K_{\pi2})$ in stack a p_a	in stack b p_b	$\Delta T/T$	T in 10^{-8} sec	Error (statistical) in 10^{-8} sec
$K_{\pi2}$	0.281	0.251	0.331	0.91	0.06
$K_{\mu2}$	0.719	0.749	−0.118	1.37	0.12
$(\tau+\tau')$	0.094	0.098	−0.126	1.39	0.06
$K_{\mu3}$	0.056	0.049	0.418	0.86	0.02
K_e	0.074	0.067	0.297	0.93	0.03

since their percentages are estimated to be comparable, we are led to the conclusion that their individual lifetimes must not be significantly different.

In conclusion, if we take the average values of lifetimes listed in Table IV(a) and IV(b), and include, in the total error, an error of 25% due to the uncertainty of the method, we have for final results:

$$(\tau+\tau') \quad T=(1.30\pm0.33)\times10^{-8}\text{ sec},$$
$$K_{\mu3} \quad T=(0.88\pm0.23)\times10^{-8}\text{ sec},$$
$$K_e \quad T=(1.44\pm0.46)\times10^{-8}\text{ sec}.$$

Within experimental error they are all very close to the lifetime of $K_{\pi2}$ and $K_{\mu2}$. We can conclude by noting that, to date, there exists no experimental evidence indicating any significant differences in the relative production rates or decay lifetimes of the various modes of K^+-meson decay.

In addition, we note from our observation of isotropy of the decay secondaries of the K_L class (mainly $K_{\mu2}+K_{\pi2}$) that no preferred direction with respect to the plane of production for decay exists. This is an additional indication of the spinless nature of these particles (though of course it is not sufficient).

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