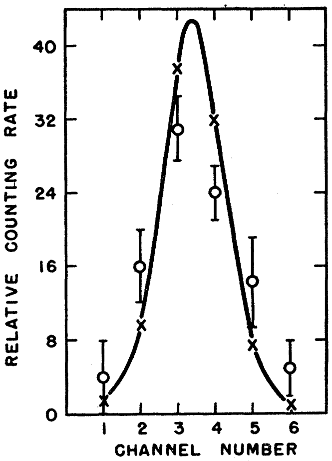

FIG. 1. The circles (o) give the gamma spectrum associated with the decay of Pb^{205} (1.8 counts/minute). The smooth curve drawn through the crosses (×) is the L—x-ray spectrum of lead measured from a mixture of electron-capturing bismuth isotopes.

time interval between the formation of the elements and the deposition of ores, we have continued to search for Pb^{205}. The present note describes experiments in which 1.8 counts/min of 11-kev gamma activity is interpreted as thallium L—x-rays associated with the L-electron capture of Pb^{205}.

Normal lead was bombarded with 1500 μa hr of 21-Mev deuterons in the Argonne cyclotron. The bismuth activities were chemically separated[6] and absorbed on a Dowex anion resin column. Lead was eluted from the column with 0.1N HCl many times during the first three days.[6] After a growth period [Bi^{205} (14-day)→Pb^{205} by electron capture] of two weeks the lead was again eluted, given further chemical purification and mounted for counting. Pb^{203}, decay product of the Bi^{203} on the column, served as a chemical tracer, and was given time to decay before the Pb^{205} counting began. The Pb^{205} radiations were examined with a gamma scintillation spectrometer employing an $\frac{1}{8}$-inch sodium iodide crystal with a beryllium window. The results are shown in Fig. 1.

Assuming the yield ratio of Bi^{205}/Bi^{203} is proportional to the Pb^{206}/Pb^{204} isotopic ratio in normal lead [the $Pb^{204}(d,n)Bi^{205}$ cross section is small compared to the $Pb^{206}(d,3n)Bi^{205}$ cross section and from threshold calculations it seems reasonable to assume that the $Pb^{207}(d,4n)Bi^{205}$ cross section is negligible], we calculate that the L-electron capture half-life of Pb^{205} is approximately 5×10^7 years.

We also examined in the L—x-ray energy region a lead sample[7] enriched in Pb^{204} which had been neutron irradiated in the Materials Testing Reactor and chemically purified by the authors of reference 2. L—x-rays were also observed in this sample. With the aid of the above half-life and the intensity of the L—x-rays in the neutron-irradiated lead sample, the calculated neutron capture cross section of Pb^{204} agrees, within our experimental errors, with the pile oscillator measurement of Pomerance.[8]

We wish to thank D. W. Engelkemeir for the use of his scintillation spectrometer and many helpful suggestions. We also are indebted to W. J. Ramler and J. P. FitzPatrick for the cyclotron bombardments and preparation of the lead targets.

[†] Based on work performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. R. Huizenga and C. M. Stevens, Phys. Rev. **96**, 548 (1954).

[2] Sugihara, Herber, Bennett, and Coryell, Phys. Rev. **95**, 298(A) (1954).

[3] P. F. Shaw and J. R. Prescott, Proc. Phys. Soc. (London) **A67**, 283 (1954).

[4] Herber, Sugihara, Coryell, and Huizenga (to be published).

[5] See, for example, the review by T. P. Kohman, Ann. N. Y. Acad. Sci. (to be published).

[6] Huizenga, Krohn, and Raboy, Bull. Am. Phys. Soc. Ser. II, **1**, 43 (1956); Phys. Rev. (to be published).

[7] Sample was sent to Argonne National Laboratory by T. P. Kohman.

[8] H. Pomerance, Phys. Rev. **88**, 412 (1952).

Mean Lifetime of Negative K-Mesons[*]

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A MEAN lifetime for K^--mesons has been determined by the method previously used[1] for the K^+-meson lifetime. Stacks of stripped 600μ Ilford G.5 nuclear emulsions were exposed to the focused K^--meson beam[2] of the Bevatron so that the particles entered parallel to the emulsion layers. The mesons were produced by 6.2-Bev protons on a copper target and emerged at 90° to the proton beam. A bending magnet was used for momentum selection of the particles. Particles of momenta from 285 Mev/c to 415 Mev/c were obtained in the various exposures used for this experiment. The distance traveled by the particles from the target to the emulsion stack was about 3 meters in all cases.

Plates were scanned independently by the Berkeley, Livermore, and M.I.T.-Harvard groups for K^--inter-

TABLE I. Results of determinations of mean lifetime of K^--mesons.

Group	Total proper time, sec	Number of decays in flight n	Mean lifetime τK^-, sec
Berkeley	3.96×10^{-8}	4	0.99×10^{-8}
Livermore	2.63×10^{-8}	3	0.88×10^{-8}
M.I.T.–Harvard	5.78×10^{-8}	6	0.96×10^{-8}
Total	12.37×10^{-8}		$\tau K^- = (0.95_{-0.25}^{+0.36})\times10^{-8}$

actions in flight and at rest, and for decays in flight. Tracks of grain density appropriate to K-particles of the selected momentum were found near the edge of the plate where they entered and were followed until they decayed in flight, interacted in flight, or came to rest in the emulsion stack. An event was interpreted as a decay in flight if there was only one outgoing prong and if it had a grain density less than that of the incoming K-particle. (No event of this type was found that had a blob associated with it.) An event so interpreted could also possibly be an interaction in flight of a K^--meson and a nucleus with a lightly ionizing π meson emerging. In K^--interactions at rest, less than 3% of the stars were found to be of this nature. Since interactions in flight would be expected to leave the nucleus in a more highly excited state than interactions at rest, the proportion of stars with a single pion and with no other tracks or "blobs" associated would be even smaller. We estimate that certainly less than 15% of the events we have taken to be decays in flight may have been interactions in flight (this corresponds to 3% of all interactions in flight).[3]

The mean lifetime is

$$\tau_{K^-}=\sum_{i=1}^{N} t_i/n=T/n,$$

where N is the number of tracks observed, n is the number of decays in flight observed, $T=\sum_i(t_i)$, and t_i is the proper time during which a particle travels in the emulsion from where it is first observed to the point of interaction or decay in flight, or (if the particle comes to rest) to 2 mm from the end of the track. (The last 2 mm of a stopping track are not included, since a decay in flight would be difficult to identify in this region.) The tables of Barkas and Young[4] were used to calculate T. Table I gives the total proper time of flight T, the number n of decays in flight observed, and the resulting mean lifetime τ_{K^-}, for each of the three groups. The combined result is

$$\tau_{K^-}=(0.95_{-0.25}^{+0.36})\times 10^{-8}\text{ sec.}$$

The error quoted is the statistical standard deviation, other errors being negligible in comparison. If the K^- beam consists of a mixture of particles of different mean lifetimes, the quantity we have measured is an average, of the form

$$\tau_{K^-}=\left(\sum_i \frac{\alpha_i}{\tau_i}\right)^{-1},$$

where α_i is the fraction of the particles entering the stack associated with a mean lifetime of τ_i. Particles of mean lifetime less than 0.3×10^{-8} sec would be highly discriminated against, since less than 1% of those leaving the target would arrive at the emulsion stack. No decay in flight of a τ^- meson was observed.

It is of interest to compare the K^--meson mean lifetime with the various measurements of the K^+-meson mean lifetime. These data, together with results of the work reported herein, are presented in Fig. 1.[5] It is evident that within the experimental error there is no detectable difference between the mean lifetimes of the K^--and K^+-mesons.

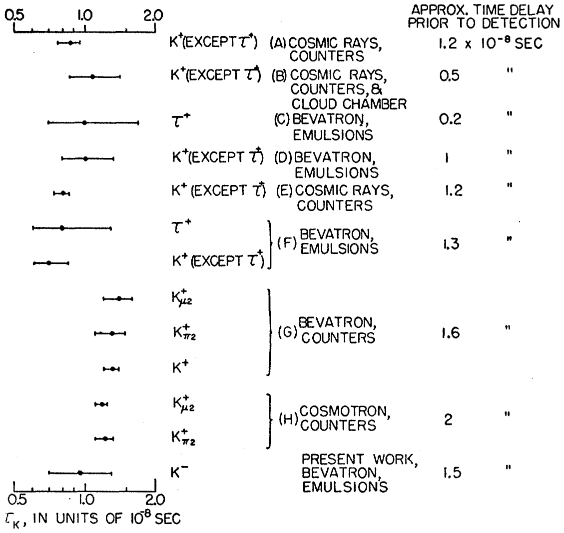

FIG. 1. A comparison of the K^--meson mean lifetime with K^+-meson mean lifetimes reported by various experimenters. (Values are plotted on a logarithmic scale.) (A) L. Mezzetti and J. Keuffel, Phys. Rev. **95**, 859 (1954). (B) Barker, Binnie, Hyams, Rout, and Sheppard, Phil. Mag. **46**, 307 (1955), and Proceedings of the International Conference on Elementary Particles, Pisa, Italy, June, 1955 (to be published). (C) L. Alvarez and S. Goldhaber, Nuovo cimento **2**, 344 (1955). (D) Iloff, Chupp, Goldhaber, Goldhaber, Lannutti, Pevsner, and Ritson, Phys. Rev. **99**, 1617 (1955). (E) K. Robinson, Phys. Rev. **99**, 1606 (1955). (F) Harris, Orear, and Taylor, Phys. Rev. **100**, 932 (1955). (G) Alvarez, Crawford, Good, and Stevenson, Phys. Rev. **101**, 496 (1956). (H) V. Fitch and R. Motley, Phys. Rev. **101**, 496 (1956).

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[1] Iloff, Chupp, Goldhaber, Goldhaber, Lannutti, Pevsner, and Ritson, Phys. Rev. **99**, 1617 (1955).

[2] Kerth, Stork, Haddock, and Whitehead, Phys. Rev. **99**, 641(A) (1955).

[3] No correction for this effect was made in our results.

[4] W. H. Barkas and D. M. Young, University of California Radiation Laboratory Report No. UCRL-2579 (Rev), September, 1954 (unpublished).

[5] It should be noted that some recent cloud-chamber cosmic-ray measurements have yielded a much shorter lifetime for both K^+- and K^--mesons. These results are $\tau_{K^+}=(5.2_{-1.6}^{+3.3})\times 10^{-10}$ sec and $\tau_{K^-}=(4.2_{-1.2}^{+3.8})\times 10^{-10}$ sec. The errors are confidence limits for 50% probability [Arnold, Ballam, and Reynolds, Phys. Rev. **100**, 295 (1955); also Arnold, Ballam, Reynolds, Robinson, and Treiman, Proceedings of the International Conference on Elementary Particles, Pisa, Italy, June, 1955 (to be published)]. Trilling and Leighton have found evidence for short-lived negative V-particles (which may possibly be K-particles), but not for positive V-particles. Their result is $\tau_V=(1.3\pm 0.6)\times 10^{-10}$ sec [G. H. Trilling and R. B. Leighton, Phys. Rev. **100**, 1468 (1955)]. No short-lived component was observed by Fretter, Friesen, and Lagarrique (to be published). They find a mean lifetime for positive K-mesons $\tau_{K^+}=(6.7_{-5.5}^{+\infty})\times 10^{-9}$ sec.