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# Measurement of the Lifetimes of the $\Lambda^0$ Hyperon and $K_1^0$ Meson*

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The lifetimes of the $\Lambda^0$ hyperon and the $K_1^0$ meson were measured in a spark-chamber experiment. With 2260 events the $\Lambda^0$ lifetime was found to be $(2.31\pm0.10)\times10^{-10}$ sec. The $K_1^0$ lifetime was measured to be $(0.86\pm0.04)\times10^{-10}$ sec with 545 events.

## INTRODUCTION

In an experiment to measure the decay parameters of the $\Lambda^0$ hyperon,[1] a sample of $\Lambda^0$ hyperons and $K_1^0$ mesons was obtained in associated production from $\pi^-$ mesons on protons. We have used a portion of these to determine the lifetimes of the $\Lambda^0$ hyperon and the $K_1^0$ meson. There are considerable discrepancies in the reported values[2] of the $\Lambda^0$ and $K_1^0$ lifetimes, all of which have been measured in bubble or cloud chambers. We feel that it may be of value to report measurements of these lifetimes made with spark chambers since the possible systematic errors and biases with the method of measurement described below are quite different from those of the bubble-chamber methods.

The experimental arrangement is shown schematically in Fig. 1 and is described in detail in Ref. 1. Briefly, the $\Lambda^0$ hyperons and $K_1^0$ mesons were produced by interactions of an incident $\pi^-$ beam with the polyethylene plates of the first spark chamber. Counters C3 and C4 selected the decay of the $\Lambda^0$ or $K_1^0$ in a 12-gap thin-foil spark chamber, 11.5 cm in length. The decay particles then passed into a carbon-plate chamber which contained 11 plates of 2.27 g/cm² each. The decay region for the particles was on the order of three mean decay lengths. The geometry was simple, and accurate measurements of the potential path for each event could be made. The decay region was defined by two parallel planes; the transverse extent of the chamber was sufficient to eliminate the need for any side correction. The lifetime measurements for the two particles are discussed separately.

## $\Lambda^0$ LIFETIME DETERMINATION

A $\Lambda^0$ event was selected for measurement when one of the decay prongs made an angle of less than 20° with the $\Lambda^0$ line of flight. It was also required that this prong, assumed to be the proton, had to stop in the carbon-plate chamber, penetrating at least two carbon plates but not more than nine. The line of flight was determined by the decay vertex and the production point in the first spark chamber. The decay vertices were located by extrapolation of the prongs to their intersection. The location of an individual vertex had an rms error of 0.14 cm. Two vertical fiducial lines (see Fig. 1), $11.43\pm0.01$ cm apart, marked the decay region.

To avoid edge effects, only those events were accepted for analysis that decayed 0.3 cm or further downstream from the first fiducial line. The actual flight path was found by measuring the distance along the line of flight to the decay vertex from a plane parallel to the spark-chamber plates, 0.3 cm downstream from the first fiducial mark. The potential path was determined as the distance from this 0.3-cm plane to a cutoff plane downstream which was also parallel to the spark-chamber plates. This cutoff was varied in the analysis in order to search for and eliminate possible scanning biases against events which decayed very near the downstream end of the foil chamber.

The $\Lambda^0$ momentum was determined from the range of the decay proton and the opening angle between the two decay products. The reproducibility of this method was better than 1%, and the uncertainty in the determination of the $\Lambda^0$ momentum because of the finite plate thickness in the range chamber varied from $\pm5\%$ to $\pm1.7\%$ for decay protons stopping after two and nine plates, respectively.

Errors in the determination of the proton momentum by range could have occurred because some stop by interaction. In order to evaluate the effect of these

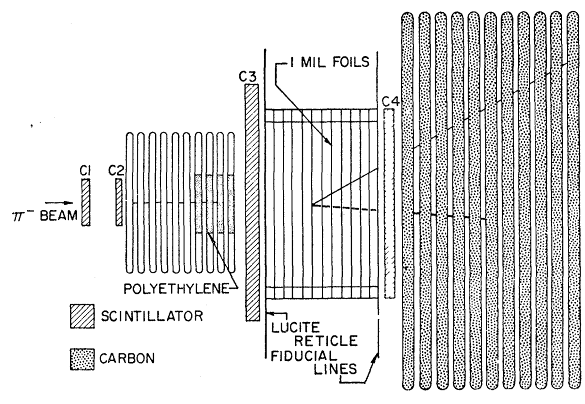


FIG. 1. Schematic diagram showing experimental apparatus. An example of an event has been sketched in.

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[1] J. W. Cronin and O. E. Overseth, Phys. Rev. **129**, 1795 (1963).
[2] See Tables III and IV for recently published values, and *Proceedings of the 1962 International Conference on High Energy Physics at CERN*, edited by J. Prentki (CERN Scientific Information Service, Geneva, 1962), p. 839, for a complete compilation of values reported.

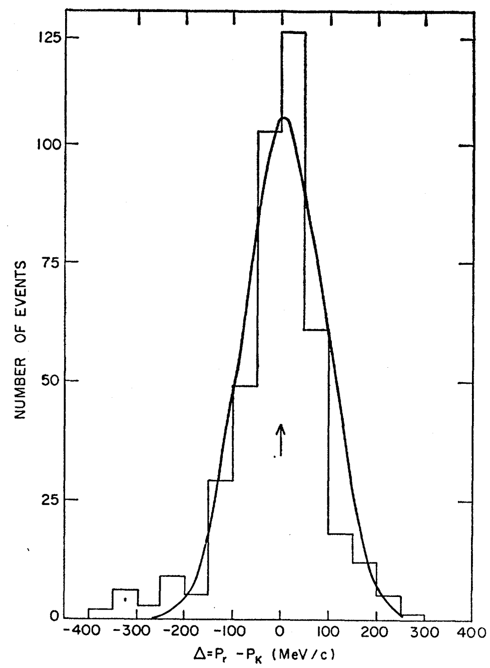


FIG. 2. Comparison of $\Lambda^0$ momentum calculated from decay angles $P_k$ with that computed from proton range and decay opening angle $P_r$. The abscissa is $\Delta = P_r - P_k$, and the ordinate is the number of events in a given interval of $\Delta$.

events on the lifetime, we compared the $\Lambda^0$ momentum determined by range $P_r$ with the $\Lambda^0$ momentum $P_k$ determined by the angles the decay prongs made with the line of flight for a sample of events. The latter method, though not as accurate, does not depend on the proton range. Figure 2 shows the distribution of $\Delta = P_r - P_k$. The distribution is Gaussian and has a peak at $+4$ MeV/$c$, which demonstrates that the two methods of momentum determination agree. There is a small tail of events for which the range momentum determination is much less than the kinematic determination, corresponding to events in which the decay proton stops by interaction before the end of its range. The momentum distribution of the $\Lambda^0$-decay protons extended up to 750 MeV/$c$; protons with 600 MeV/$c$ or less would stop by range in the range chamber. Knowing the momentum distribution of protons and assuming a uniform stopping rate by interaction, we have computed the expected distribution of momentum errors. We find that the number of events with less than 200 MeV/$c$ should be twice the number with errors greater than 200 MeV/$c$. The latter events appear clearly as the tail of the Gaussian. Since the average $\Lambda^0$ momentum for our sample was 580 MeV/$c$, we have estimated the corrections to the $\Lambda^0$ lifetime due to these momentum errors to be $-2\pm1\%$.

The method of event selection eliminated almost all of the $K_1^0$ contamination. The number of $K_1^0$ decays that have one pion making an angle of 20° or less with respect to the line of flight is 15% of the $\Lambda^0$ hyperons. In addition, only those $K_1^0$ decays for which the smaller angle pion stops by interaction would be included in our $\Lambda^0$ sample. This fraction was estimated to be 5% of the pions, so that the total $K_1^0$ background in our sample was about 1%. Since the mean decay lengths for the $K_1^0$ and $\Lambda^0$ were not significantly different, the correction for the $K_1^0$ background was neglected.

TABLE I. Results of the determinations of the $\Lambda^0$ lifetime for various downstream cutoffs of the fiducial volume of the decay chamber.

| Cutoff (cm) | $\tau_\Lambda$ ($10^{-10}$ sec) |
|---|---|
| 0.0 | $2.22\pm0.06$ |
| 2.0 | $2.33\pm0.08$ |
| 3.0 | $2.36\pm0.09$ |
| 4.0 | $2.38\pm0.10$ |

The lifetime was computed by the Bartlett $S$-function method.[3] Table I shows the results obtained as a function of the cutoff distance from the downstream limit of the chamber. The results for cutoffs of 2.0, 3.0, and 4.0 cm agree within statistical errors, indicating the scanning efficiency was uniform to within 2 cm of the downstream end of the chamber. The stability of this result constituted the main check for uniform scanning efficiency. Accepting the result for the 3.0-cm cutoff, we determine the lifetime to be $(2.36\pm0.09)\times10^{-10}$ sec from 2260 events. Correcting for the protons that stopped by interaction, we obtain $\tau_{\Lambda^0} = (2.31\pm0.10)\times10^{-10}$ sec. Figure 3 shows a plot of the time distribution of decays. The drop from exponential behavior occurs because the longest decay times for a fixed spatial cutoff are available only to the low-momentum events in the sample.

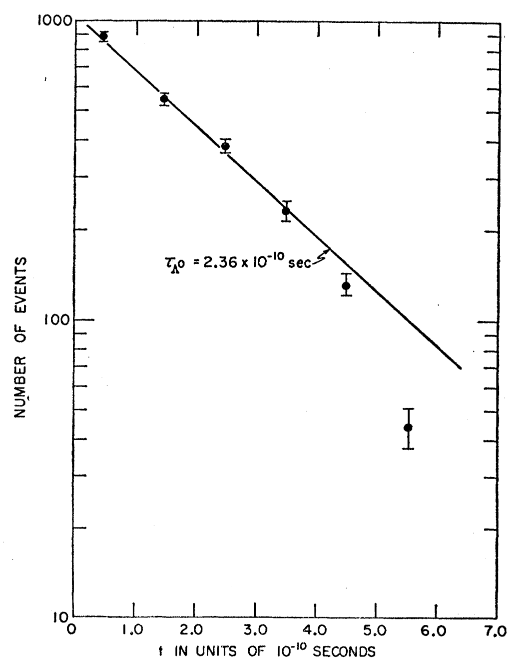


FIG. 3. Distribution of decays for $\Lambda^0$ hyperon sample.

[3] M. S. Bartlett, Phil. Mag. 44, 249 (1953).

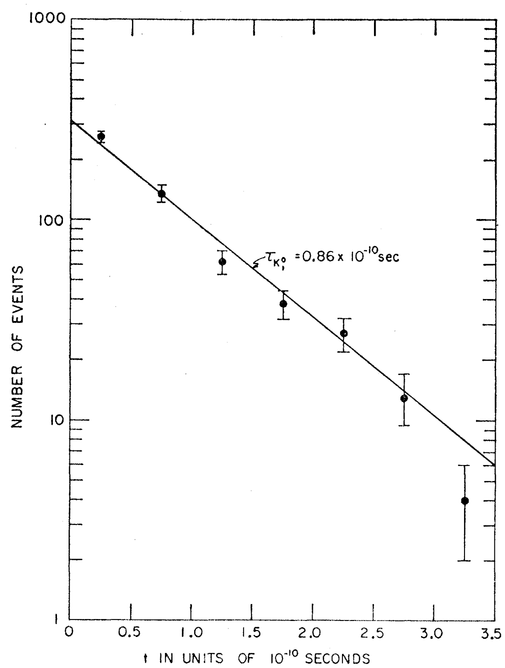


FIG. 4. Distribution of decays for $K_1^0$ meson sample.

### $K_1^0$ LIFETIME DETERMINATION

The $K_1^0$ decays were selected such that each decay prong made an angle of at least 30° with the $K_1^0$ line of flight, in order to eliminate contamination from $\Lambda^0$ hyperons in the sample. Only $K_1^0$ events were accepted in which a $\Lambda^0$ decay was not seen, since the greater ionization of the proton from $\Lambda^0$ decay occasionally caused spark robbing from the faster pion tracks. This effect could introduce a bias against the detection of longer lived $K_1^0$ mesons. The measurements made on the acceptable $K_1^0$ events were the same as on the $\Lambda^0$ decays except that no decay prong range information was used.

The momentum of the $K_1^0$ was determined from the angles of the decay pions with respect to the $K_1^0$ line of flight. This method was reproducible to about $1\frac{1}{2}\%$. For long-lived events, the reproducibility was better because of the smaller uncertainties in the direction of the line of flight. The average momentum of the sample was 475 MeV/$c$.

In order to test against possible scanning biases, the cutoff at the downstream end was varied as in the $\Lambda^0$ measurement. Also, as in the $\Lambda^0$ measurement, only those events were accepted for analysis that decayed 0.3 cm or further downstream from the first fiducial line. Lifetimes were computed for various downstream cutoffs by the Bartlett $S$ function and are summarized in Table II. Since the lifetime determination does not show a statistically significant variation with downstream cutoff, we chose the value obtained for the 0-cm cutoff. Since, for the $K_1^0$ decays, many occurred near the front of the decay chamber, we also varied the upstream cutoff plane, and no significant difference in lifetime resulted when values other than 0.3 cm were used in the analysis. Thus, accepting the value for the entire effective volume of the decay chamber except for a small cutoff at the upstream end, we find the lifetime of the $K_1^0$ meson to be $(0.86\pm0.04)\times10^{-10}$ sec as determined from 545 events. Figure 4 shows the time distribution of these decays.

TABLE II. Results of the determinations of the $K_1^0$ lifetime for various downstream cutoffs of the fiducial volume of the decay chamber.

| Cutoff (cm) | $\tau_{K_1^0}$ ($10^{-10}$ sec) |
|---|---|
| 0.0 | 0.86±0.04 |
| 2.0 | 0.89±0.05 |
| 4.0 | 0.83±0.05 |

TABLE III. Recently published values of the $\Lambda^0$ lifetime.

| Author | $\Lambda^0$ lifetime in $10^{-10}$ sec |
|---|---|
| Humphrey and Ross[a] | 2.69±0.11 |
| Fung[b] | 2.52±0.08 |
| Garfinkel[c] | 2.44±0.11 |
| Block *et al.*[d] | 2.36±0.06 |
| This experiment | 2.31±0.10 |

[a] W. E. Humphrey and R. R. Ross, Phys. Rev. **127**, 1305 (1962).
[b] S. Y. Fung, Bull. Am. Phys. Soc. **7**, 619 (1962).
[c] A. F. Garfinkel, Nevis Report 104, 1962 (unpublished).
[d] M. M. Block, R. Gessaroli, S. Ratti, L. Grimellini *et al.*, Phys. Rev. **130**, 766 (1963).

### CONCLUSION

The lifetimes of the $\Lambda^0$ hyperon and the $K_1^0$ meson have been determined from observing the production and decay of these particles in a spark-chamber experiment. We measure the lifetime of the $\Lambda^0$ to be $(2.31\pm0.10)\times10^{-10}$ sec and that of the $K_1^0$ to be $(0.86\pm0.04)\times10^{-10}$ sec. These values are compared with recently published values in Tables III and IV.

TABLE IV. Recently published values of the $K_1^0$ lifetime.

| Author | $K_1^0$ lifetime in $10^{-10}$ sec |
|---|---|
| Garfinkel[a] | 0.90±0.05 |
| Alexander *et al.*[b] | 0.86±0.03 |
| This experiment | 0.86±0.04 |

[a] A. F. Garfinkel, Nevis Report 104, 1962 (unpublished).
[b] G. Alexander, S. P. Almeida, and F. S. Crawford, Jr., Phys. Rev. Letters **9**, 69 (1962).

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