of the plane of polarization. The interaction, which has been observed from currents of a few amperes up to large currents, is also being studied for the onset of the conversion from damped Alfvén waves to propagating helicons.

The author is grateful to Dr. J. K. Galt for originally suggesting this topic of investigation. He is indebted also to Dr. S. J. Buchsbaum for many valuable discussions, to Dr. G. A. Baraff for comments on the theory, and to Dr. G. E. Smith in cooperation with whom the large power-dissipation feature of the experiment was developed. It is a pleasure also to acknowledge the technical assistance of W. A. Nordland.

[1]D. J. Bartelink, Bull. Am. Phys. Soc. 8, 205 (1963).
[2]J. Bok and P. Nozières, J. Phys. Chem. Solids 24, 709 (1963).
[3]R. D. Larrabee and M. C. Steele, J. Appl. Phys. 31, 1519 (1960); M. Glicksman, Phys. Rev. 124, 1655 (1961).

PROPERTIES OF Ξ HYPERONS*

D. Duane Carmony,† Gerald M. Pjerrou, Peter E. Schlein, William E. Slater, Donald H. Stork, and Harold K. Ticho
Department of Physics, University of California at Los Angeles, Los Angeles, California
(Received 12 March 1964)

In a study of interactions initiated by 1.80- and 1.95-GeV/c K^- mesons in the Lawrence Radiation Laboratory 72-in. hydrogen bubble chamber, a total of 356 Ξ^- hyperons was observed. Table I shows the pertinent reactions, the number of events observed at each momentum, and the total cross sections. The observation of the Λ from Ξ^- decay was required for the identification of reactions (a) and (b); the decay Λ was also observed in all but 24 examples of reaction (c). The cross sections are based on a τ count and were corrected for neutral Λ decays.

The Ξ^- mean life was computed by means of a maximum likelihood procedure in which each event was assigned an a priori probability

$$P(x)=N\exp(-x/L_{\Xi})\times\{\exp(-y_0/L_\Lambda)-\exp[-y_1(x)/L_\Lambda]\},\quad(1)$$

consistent with the requirement that the Λ be seen. Here $L_i=m_i/(p_i\tau_i c)$, m_i, p_i, and τ_i being respectively the mass, momentum and mean life of particle i; x is the decay distance of a given Ξ^-, y_0 the minimum accepted Λ decay distance and $y_1(x)$ the maximum or the chamber wall. Because of the curvature of the Ξ^- track, the normalization N had to be calculated numerically by the requirement

$$\int_{x_0}^{x_1}P(x)dx=1;$$

x_0 and x_1 are, respectively, the smallest and largest accepted Ξ^- flight path. The evaluation of the maximum likelihood yielded

$$\tau_{\Xi^-}=(1.77\pm0.12)\times10^{-10}\text{ sec},$$

essentially independent of cut-offs, provided $x_0>0.5$ cm. The mean life determination does not depend sensitively on τ_Λ; $d\tau_\Xi/d\tau_\Lambda\approx0.04$. The result is in good agreement with other determinations.[1,2]

Regardless of the Ξ^- spin J, the helicity of the Λ from Ξ^- decay[3] in the Ξ^- rest frame is $\alpha=2\,\mathrm{Re}(A_{J-1/2}A_{J+1/2}^*)$ where A_L is the normalized amplitude for Ξ decay into a $\Lambda\pi$ system of orbital angular momentum L; $|A_{J-1/2}|^2$

Table I. The number of Ξ^- production events at each momentum.

Final state \ Momentum	1.80 GeV/c Number	1.80 GeV/c Total cross section (μb)	1.95 GeV/c Number	1.95 GeV/c Total cross section (μb)
(a) Ξ^-K^+	99	113 ± 12	88	99 ± 11
(b) $\Xi^-K^+\pi^0$	21	24 ± 5	20	23 ± 5
(c) $\Xi^-K^0\pi^+$	71	59 ± 7	57	52 ± 7

$+|A_{J+1/2}|^2 = 1$. Accordingly, the Λ decay distribution function is given by $(1+\alpha\alpha_\Lambda\hat{\Lambda}\cdot\hat{p})/2$ where $\hat{\Lambda}$ is the Λ direction in the Ξ^- rest frame, $\hat{p}$ is the proton direction in the Λ rest frame, and α_Λ is the Λ asymmetry parameter; as determined by Cronin and Overseth,[4] $\alpha_\Lambda = +0.62 \pm 0.07$. For the sample of 356 Ξ^-, the best fit value of $\alpha\alpha_\Lambda$ is

$$\alpha\alpha_\Lambda = -0.41 \pm 0.10.$$

Combining recent results for this quantity,[1] the worldwide average is $\alpha\alpha_\Lambda = -0.30 \pm 0.04$. This yields $\alpha = -0.48 \pm 0.08$ for the best estimate of α independent of the Ξ spin, J.

Recently, a method for the determination of J has been proposed[5] which is based on a ratio of moments of the transverse and longitudinal polarizations of the decay Λ. Specifically, for moments which need not vanish for $J=\frac{1}{2}$, this method gives

$$(2J+1) = \frac{[\langle\hat{p}\cdot\hat{n}\times\hat{\Lambda}\rangle^2 + \langle\hat{p}\cdot\hat{\Lambda}\times(\hat{n}\times\hat{\Lambda})\rangle^2]^{1/2}}{(1-\alpha^2)^{1/2}|\langle\hat{p}\cdot\hat{\Lambda}\hat{n}\cdot\hat{\Lambda}\rangle|} \qquad (2)$$

where $\hat{n} = (\hat{k}\times\hat{\Xi})/|\hat{k}\times\hat{\Xi}|$ is the normal to the production plane in the Ξ^- rest frame and $\langle\,\rangle$ represents an average of the enclosed experimental quantity.[6] Substituting in (2) and using the worldwide spin-independent value of $\alpha = -0.48 \pm 0.08$, the data at the two momenta combined yield

$$(2J+1) = 1.53 \pm 0.88.$$

This result is consistent with $J=\frac{1}{2}$ but 2.8 standard deviations removed from $J=\frac{3}{2}$. Because of the skewness of the distribution function of $(2J+1)$ the discrimination against $J=\frac{3}{2}$ is actually equivalent to 3.1 standard deviations.

With the spin J established to be $\frac{1}{2}$, the distribution function of the unit vectors $\hat{\Lambda}$ and $\hat{p}$ is

$$W(\Lambda,p) = \tfrac{1}{4}\{1 + \alpha\alpha_\Lambda\hat{\Lambda}\cdot\hat{p} + \overline{P}[\alpha\hat{n}\cdot\hat{\Lambda} + \alpha_\Lambda\hat{p}\cdot(\hat{\Lambda}\hat{n}\cdot\hat{\Lambda} + \beta\hat{n}\times\hat{\Lambda} + \gamma\hat{\Lambda}\times(\hat{n}\times\hat{\Lambda}))]\} \qquad (3)$$

where $\overline{P}$ is the mean polarization of the Ξ^- along $\hat{n}$. The parameters α, β, and γ are defined by (3); in terms of normalized transition amplitudes they are

$$\alpha = 2\,\mathrm{Re}(A_0^*A_1),$$
$$\beta = 2\,\mathrm{Im}(A_0^*A_1),$$
$$\gamma = |A_0|^2 - |A_1|^2. \qquad (4)$$

Since $\alpha^2+\beta^2+\gamma^2=1$, the parameters which were used in the fit to (3) were α and φ where

$$\beta = (1-\alpha^2)^{1/2}\sin\varphi, \quad \gamma = (1-\alpha^2)^{1/2}\cos\varphi. \qquad (5)$$

The mean polarizations at 1.80 and 1.95 GeV/c, $\overline{P}_{1.80}$ and $\overline{P}_{1.95}$, were also regarded as adjustable parameters. As a result of a maximum-likelihood fit to (3), we find $\overline{P}_{1.80} = 0.49 \pm 0.16$, $\overline{P}_{1.95} = 0.77 \pm 0.24$,

$$\alpha = -0.62 \pm 0.12, \quad \varphi = 54° \pm 25°.$$

It is important to recognize that while α and φ are essentially uncorrelated, β and γ are correlated strongly. This is illustrated in Fig. 1 which shows lines of constant β and γ in the α-φ space. The present results and other determinations[1] (converted to α and φ), shown in the figure, do not appear to be in good accord.

Some properties of Ξ^0 hyperons were determined in the same exposure by a study of reactions

$$K^- + p \to \Xi^0 + K^0, \qquad (A)$$
$$\to \Xi^0 + K^+ + \pi^-. \qquad (B)$$

In both, the decay Λ had to be observed; in (A), the K^0 decay had to be seen as well; in (B), the K^+ was required to have a momentum <600 MeV/c such that it could be distinguished from a π^+ by

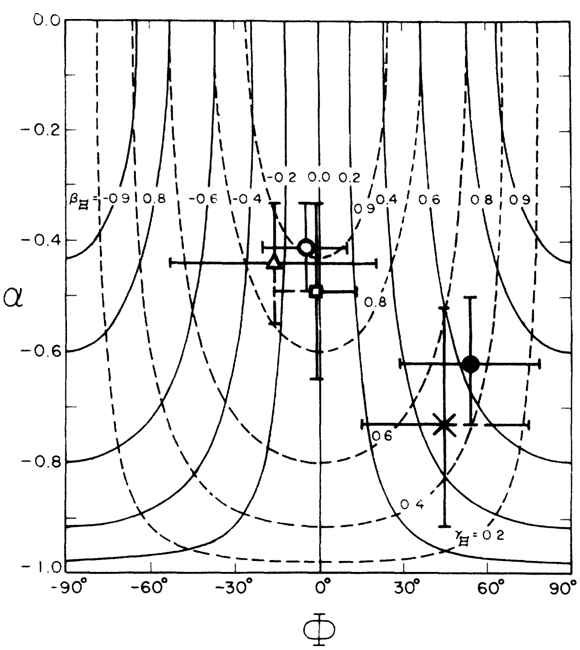

FIG. 1. Ξ^- decay asymmetry parameters α and φ; ● this experiment; × Schneider, reference 1; ○ Alvarez et al., reference 1; △ Jauneau et al., reference 1; □ Connolly et al., reference 1.

ionization. This last requirement eliminated a large background of $\Lambda\pi^+\pi^-2\pi^0$ events. With these detection criteria, 27 examples of each reaction were found. These events were tested to determine whether they could be due to the pion contamination in the incident kaon beam: 4 events of type (A) also fit Σ^0K^0 and 5 events of type (B) also fit $\Sigma^0\pi^-K^+$.

The 45 unambiguous Ξ^0 events were fitted kinematically for various assumed Ξ^0 mass values and the best Ξ^0 mass was obtained by χ^2 minimization. To reduce the chance of systematic errors the same fitting procedure was used on 150 Ξ^-K^+ events by withholding from the computer all information concerning the Ξ^- and the decay π^- tracks after correcting the Λ direction for the rotation of the Ξ^- track in the magnetic field. The resulting mass difference was

$$(m_{\Xi^-} - m_{\Xi^0}) = +6.1 \pm 1.6 \text{ MeV}.$$

This result is in good agreement with the value of 6.8 ± 1.6 MeV observed by Jauneau et al.[7] It also agrees with the prediction[8] of SU(3) symmetry,

$$(m_{\Xi^-} - m_{\Xi^0}) = (m_{\Sigma^-} - m_{\Sigma^+}) - (m_n - m_p)$$
$$= +6.7 \pm 0.4 \text{ MeV}.$$

At the incident momenta used here, the trajectories of the Ξ^0 and its decay Λ are colinear within 5°. Therefore no attempt was made to determine the decay point of the Ξ^0. Instead, the distance z from the Ξ^0 production point to the Λ decay point was used in the Ξ^0 mean life determination. In the maximum-likelihood fit, the probability of a given z was taken to be

$$Q(z) = M[\exp(-z/L_\Xi) - \exp(-z/L_\Lambda)]/(L_\Xi - L_\Lambda) \quad (6)$$

with the normalization constant M given by

$$\int_{z_0}^{z_1} Q(z)dz = 1;$$

z_0 and z_1 are respectively, the minimum and maximum acceptable values of z. The maximum-likelihood procedure yielded

$$\tau_{\Xi^0} = (3.5^{+1.0}_{-0.8}) \times 10^{-10} \text{ sec}$$

when $\tau_\Lambda = 2.5 \times 10^{-10}$ sec was used. The method used here is such that $d\tau_{\Xi^0}/d\tau_\Lambda \approx -1$. Ambiguous events were assigned a probability p of being a Σ^0 event and a probability $(1-p)$ of being a Ξ^0 event. As p was varied from 0.1 to 0.5, the Ξ^0 mean life varied by less than 0.3×10^{-10} sec. The uncertainty in p was included in the quoted error.

The distribution of the total time T between Ξ^0 production and Λ decay is shown in Fig. 2. The mean life is insensitive to z_0. However, if z_1 is made short enough such that events with $T > 12 \times 10^{-10}$ sec are rejected, then the mean life falls to 2.6×10^{-10} sec. Only one of the three events with $T > 12 \times 10^{-10}$ sec was missed on one of the two scans. The detection efficiency for events with large z was therefore sufficiently good such

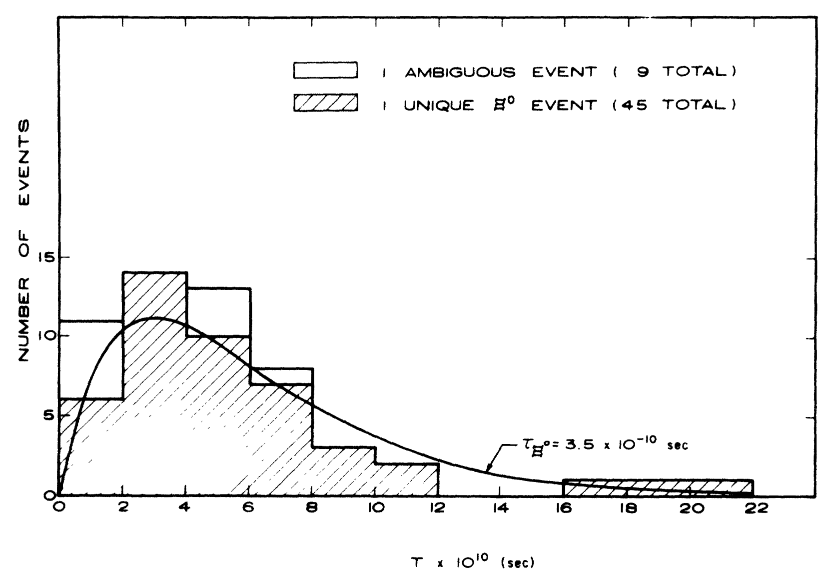

FIG. 2. Time distribution between the production of the Ξ^0 and the decay of its decay Λ.

that their rejection does not appear justifiable. Their effect on the mean life is large, of course. The ratio of the decay rates of Ξ^0 and Ξ^- reported in this work is $0.51^{+0.15}_{-0.12}$. The $|\Delta I| = \frac{1}{2}$ rule predicts $\frac{1}{2}$ for this ratio. Other recently reported values of the Ξ^0 mean life are $(3.8^{+1.0}_{-0.7}) \times 10^{-10}$ sec by Jauneau et al.[7] and $(2.5^{+0.4}_{-0.3}) \times 10^{-10}$ sec by Hubbard et al.[2]

We wish to thank the hydrogen bubble chamber group at the Lawrence Radiation Laboratory and, in particular, Professor L. W. Alvarez, for their continuing friendly cooperation. We acknowledge gratefully many helpful discussions with Professor N. Byers, Professor M. Gell-Mann, and Dr. S. Fenster. Finally, we thank our scanners for their painstaking work.

---

*Work supported in part by the U. S. Atomic Energy Commission.

†Now at the University of California, San Diego, La Jolla, California.

[1]H. Schneider, Phys. Letters 4, 360 (1963); L. W. Alvarez, J. P. Berge, J. R. Hubbard, G. Kalbfleisch, J. Shafer, F. T. Solmitz, M. L. Stevenson, and S. Wojcicki (private communication); L. Jauneau, D. Morellet, U. Nguyen-Khac, A. Rousset, J. Six, H. H. Bingham, D. C. Cundy, W. Koch, M. Nikolić, B. Ronne, O. Skjeggestad, H. Sletten, A. K. Common, J. J. Esten, C. Henderson, C. M. Fisher, J. M. Scarr, R. H. Thomas, A. Haatuft, R. Møllerud, and K. Myklebost, Proceedings of the Siena International Conference on Elementary Particles, Siena, Italy, 1963 (unpublished); P. L. Connolly, E. L. Hart, G. Kalbfleisch, K. W. Lai, G. London, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, M. Goldberg, M. Gundzik, J. Leitner, and S. Lichtman, Proceedings of the Siena International Conference on Elementary Particles, Siena, Italy, 1963 (unpublished). These reports, along with portions of this work, have been reviewed by H. K. Ticho, Proceedings of the Conference on the Fundamental Aspects of Weak Interactions, Brookhaven National Laboratory, Upton, N.Y., September 1963 (unpublished).

[2]J. R. Hubbard, J. P. Berge, G. R. Kalbfleisch, J. B. Shafer, F. T. Solmitz, M. L. Stevenson, G. Wojcicki, and P. G. Wohlmut, University of California Radiation Laboratory Report No. UCRL-10819 (unpublished); and (to be published).

[3]T. D. Lee and C. N. Yang, Phys. Rev. 109, 1755 (1958).

[4]J. W. Cronin and O. E. Overseth, Phys. Rev. 129, 1795 (1963).

[5]N. Byers and S. Fenster, Phys. Rev. Letters 11, 52 (1963).

[6]M. Ademollo and R. Gatto, Phys. Rev. 133, B531 (1964).

[7]L. Jauneau, D. Morellet, U. Nguyen Khac, P. Petiau, A. Rousset, A. H. Bingham, D. C. Cundy, W. Koch, M. Nikolić, B. Ronne, O. Skjeggestad, H. Sletten, F. W. Bullock, A. K. Common, M. J. Esten, C. Henderson, F. R. Stannard, J. M. Scarr, J. Sparrow, A. G. Wilson, A. Halsteinslid, and R. Møllerud, Proceedings of the Siena International Conference on Elementary Particles, Siena, Italy, 1963 (unpublished).

[8]S. Coleman and S. L. Glashow, Phys. Rev. Letters 6, 423 (1961).

OBSERVATION OF $f^0 \to 2\pi^0$ †

L. Sodickson, M. Wahlig, I. Mannelli,* D. Frisch, and O. Fackler
Laboratory for Nuclear Science and Department of Physics,
Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received 2 April 1964)

In a recent Letter, Frazer et al.[1] proposed that the f^0 meson is the neutral member of a 1^- triplet of which the $B^\pm$ mesons are the charged members. As one experimental test, they suggested looking for the decay mode $f^0 \to 2\pi^0$. If this decay mode exists, the spin of the f^0 must be even and the proposal cannot be correct.

We have observed the $f^0 \to 2\pi^0$ decay mode and conclude that the f^0 has even spin and positive parity. This agrees with earlier indications,[2] recently reinforced by Lee et al.[3]

We observe $f^0 \to 2\pi^0$ decays from forward-going f^0's produced in liquid hydrogen in the reaction $\pi^- + p \to f^0 + n$ at an incident pion momentum of 10 GeV/c. The four product gammas from $f^0 \to 2\pi^0 \to 4\gamma$ make showers in a 14-plate (5 radiation lengths) brass spark chamber. The spark chamber detects only those gamma rays produced within ±14° of the beam direction, and is protected by a scintillation counter which vetoes charged particles. Almost all of the remaining solid angle is covered by counters made up of alternate layers of lead and scintillator, which veto gamma rays as well as charged particles. This system is thus designed to be triggered only by events which yield only neutrals in the forward direction. This apparatus was used in high-energy $\pi^- + p \to \pi^0 + n$ elastic charge-exchange scat-