Rev. 98, 693 (1955); H. H. Barschall, Phys. Rev. 86, 431 (1952).

[8]B. Block and H. Feshbach, Ann. Phys. (N.Y.) 23, 47 (1963); R. H. Lemmer, Phys. Letters 4, 205 (1963).

[9]K. Izumo, Prog. Theoret. Phys. (Kyoto) 26, 807 (1961).

[10]A. Bohr, in Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955 (United Nations, New York, 1956), Vol. 2, pp. 151, 220-229; R. W. Lamphere and R. E. Green, Phys. Rev. 100, 763 (1955).

[11]A. K. Kerman, L. S. Rodberg, and J. S. Young, Phys. Letters 11, 422 (1963).

[12]K. K. Seth, Phys. Letters 16, 306 (1965).

ABSORPTION TIME OF NEGATIVE Σ HYPERONS IN LIQUID HYDROGEN*

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(Received 13 September 1965)

The absorption times of negative π and K mesons in liquid hydrogen have been measured.[1-4] The experiments indicate that the absorption times are in the range of $(2-4)\times10^{-12}$ sec. These results are in agreement with the prediction of Day, Snow, and Sucher[5] and the calculations of Leon and Bethe[6] that a "Stark-mixing effect" leads to rapid capture from s states of high principal quantum number n. This model also is expected to hold for any strongly interacting negative particles stopping in liquid hydrogen unless the Stark-mixing phenomenon were strongly mass or spin dependent.

In this note, we report a measurement of the capture time for the hyperon-proton system $-(\Sigma^-,p)$. We find that $T_{\text{expt.}}\sim3\times10^{-12}$ sec, in agreement with the rapid-absorption-mechanism model.

We obtain the data for this determination by observing the decay of Σ^- hyperons in the Saclay 81-cm hydrogen bubble chamber at CERN.[7,8] In particular, the fraction of Σ^- hyperons decaying at rest furnishes the information for obtaining the absorption time.

The reactions which we observe are

$$K^- + p \to \Sigma^- + \pi^+ \quad (K^- \text{ at rest}) \tag{1}$$
$$\qquad \hookrightarrow \pi^- + n,$$

$$n + p \to n + p. \tag{2}$$

An example is shown in Fig. 1.

Reaction (1) alone determines the Σ^- momentum at decay primarily from the Σ^- range information. Near the end of Σ^- residual range, the length measurements are not sufficiently accurate to determine the Σ^- momentum well. In fact, the momentum resolution required for a determination of the Σ^- absorption time by this method requires an improvement of a factor 10. Fortunately, the observation of an associated (n,p) scatter with proton recoil, Reaction (2), gives the added necessary improvement in resolution. A knowledge of the neutron momentum results in a "4C fit"; that is, all the vector momenta at the Σ^--decay vertex are measurable. Therefore, the fit is very sensitive to the Σ^- momentum at decay. In this way we can determine the Σ^- momentum with an accuracy $\sim\pm5$ MeV/c ($\beta=\pm0.004$). In traversing the interval $\beta=0.004$ to atomic capture, theory suggests, the Σ^- hyperon spends a time $\sim2\times10^{-12}$ sec.[9,10] Any Σ^- hyperons that might decay in this short time would form a background to the number of decays at rest.

The film-scanning procedure involved locating (K^-,p) interactions at rest which resulted in Σ^- production and decay. For these events a search was made on two projected views for proton recoils greater than a few bubbles long and within ~7 cm of the Σ^--decay point. Two further restrictions were made on the projected image in order to obtain low-momentum Σ^- decays. One requirement was that the recoil be within a cone of 15° opposite to the decay pion (a Σ^- decay at rest gives rise to a recoil which is colinear with the decay pion). The

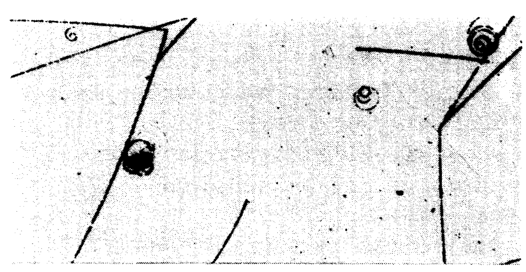

FIG. 1. Photograph of low-momentum Σ^--decay event with (n,p) scatter.

other requirement was that the Σ^- length be greater than 0.5 cm. All events found were checked by a physicist to eliminate kinematically impossible recoils, i.e., those recoils clearly in the backward portion of the 15° cone opposite the decay pion. The surviving events were measured and tested against the hypothesis of Reactions (1) and (2). In this way we identified the low-momentum Σ^- decays in a total sample of approximately 43 700 stopping K^-. Table I is a list of events where $\beta < 0.01$ for the Σ^- at decay. The data given are average values based on two or more measurements. From these data it can be seen that there is a rather clear separation between in-flight and possible at-rest Σ^- decays at $\sim\beta = 0.004$ or $p_{\Sigma^-} \sim 5$ MeV/c. For $\beta < 0.004$, the $\bar{\chi}^2$ for the at-rest fit becomes comparable to $\bar{\chi}^2$ for the in-flight fit, and therefore the in-flight hypothesis cannot be distinguished from the at-rest hypothesis.

The experimental best estimate of the time T_{Σ^-} for Σ^- hyperons to go from $\beta = 0.004$ to nuclear capture is calculated from the relation

$$T_{\Sigma^-} \cong \frac{\tau n_{\Sigma^-}(\beta < 0.004)}{E_f N_{\Sigma^-}(\beta < 0.004) P} = 5\times10^{-12}\ \text{sec},$$

where $\tau = \Sigma^-$ lifetime $= 1.615\times10^{-10}$ sec,[11] $n_{\Sigma^-}(\beta < 0.004) = 5$ = number of Σ^- decays with $\beta < 0.004$ and having recoils satisfying length and distance criteria, E_f = efficiency for finding a recoil $= (80 \pm 10)\%$, $N_{\Sigma^-}(\beta < 0.004)$ = the total number of Σ^- with $\beta < 0.004$, and P = the absolute probability that a neutron will produce a recoil satisfying the length and distance criteria.

The length and distance criteria applied to recoils were that the proton be $\geqslant 0.2$ cm long and that the recoil be within 7 cm of the Σ^--decay vertex. In addition, it was required that all Σ^- have a dip <60°. The absolute probability, P, of finding a proton recoil $\geqslant 0.2$ cm long and within ~7 cm of the Σ^--decay vertex was calculated assuming isotropic (n,p) scattering, an (n,p) scattering cross section of[12] 505 mb at 192.6 MeV/c,[13] and a hydrogen density[14] of 0.0626 g/cm^3. In this way we obtain a probability of 0.10 of finding a recoil.

The scanning efficiency was determined to be $(80 \pm 10)\%$ by a second independent scan of a portion of the film.

The total number, $N_{\Sigma^-}(\beta \leqslant 0.004)$, of Σ^- with $\beta < 0.004$ is obtained from the initial number, 16 500, of Σ^--production events with dip <60°, by using the lifetime and energy-loss theory.

Table I. Data for low-momentum Σ^--decay events.

Frame no.	$\bar{\chi}^2$ at-rest fit	$\bar{\chi}^2$ in-flight fit	Average fit momentum
1 775 412 08	3.2	2.9	0.5
1 765 779 05	6.1	6.1	1.0
1 768 994 08	2.1	21.4	1.6
1 769 032 09	14.3	10.0	2.2
1 766 364 08	5.9	2.9	3.4
1 775 869 11	7.4	1.6	5.7
1 785 168 06	56.7	3.0	7.1
1 787 562 10	14.9	2.8	8.8
1 790 839 02	24.5	1.5	10.3

This number is $\sim 12.5 \pm 1.0\%$ of the initial number of Σ^-.

The experimental result for the Σ^--cascade time in hydrogen is obtained by removing the time required for the Σ^- to go from $\beta = 0.004$ to atomic capture ($\sim 2\times10^{-12}$ sec). This implies a cascade time of $(5-2)\times10^{-12} = 3\times10^{-12}$ sec. This value is comparable to previous experimental determinations for the (π^-,p) and (K^-,p) systems. It also agrees with theoretical predictions of the Σ^--cascade time based on extensions of the "Stark-mixing" transition rates for the (K^-,p) system of Bethe and Leon.[6]

On the other hand, if there were no "Stark-mixing" effects and the Σ^--cascade time was due to Auger and radiative transitions alone, then one would expect a cascade time of $\sim 50\times10^{-12}$ sec, a result which is not in agreement with our observations.

This experiment establishes that the cascade time for the hyperon-proton system, (Σ^-,p), is similar to the cascade times for other lighter strongly interacting particles in hydrogen, i.e., (π^-,p) and (K^-,p). This result strongly suggests that $(\bar{p},p)$ capture should proceed in a similar way with predominant s-wave capture. This implication supplements the experimental result that the particular channel $\bar{p}+p \rightarrow K^0+\bar{K}^0$ is dominated by s-state capture.

Finally, the technique used here, with its superior velocity resolution, offers a means for testing energy-loss theory in the region from $\beta = 0.02$ to $\beta = 0.004$. Previous moderation-time experiments could not check energy-loss theory in this low-velocity region. Our results to date indicate that the observed number of Σ^- decay in the region $\beta = 0.02$ to $\beta = 0.004$ is in excess of the predictions[9,10] (10 instead of 3.8) and may indicate that the theory is not correct in this region. Further work is in progress on this point.

We wish to acknowledge the important contributions of Professor R. G. Glasser, Mr. H. A. Rubin, and Professor B. Sechi-Zorn. In addition, we wish to acknowledge the valuable assistance of Mrs. Mary Resio, Mr. Richard Krider, and our student scanners.

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

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[1]T. H. Fields, G. B. Yodh, M. Derrick, and J. G. Fetkovitch, Phys. Rev. Letters 5, 69 (1960).

[2]J. H. Doede, R. H. Hildebrand, M. H. Israel, and M. Pyka, Phys. Rev. 129, 2808 (1963).

[3]E. Bierman, S. Taylor, E. L. Koller, P. Stamer, and T. Huetter, Phys. Letters 4, 351 (1963).

[4]R. Knop, R. A. Burnstein, and G. A. Snow, Phys. Rev. Letters 14, 767 (1965); M. Cresti, S. Limentani, A. Loria, L. Perruzzo, and R. Santangelo, Phys. Rev. Letters 14, 847 (1965).

[5]T. B. Day, J. Sucher, and G. A. Snow, Phys. Rev. Letters 3, 61 (1959).

[6]M. Leon and H. A. Bethe, Phys. Rev. 127, 636 (1962).

[7]P. Baillon, thesis, University of Paris, 1963 (unpublished).

[8]A description of the beam is given by B. Aubert, H. Courant, H. Filthuth, A. Segar, and W. Willis, in Proceedings of the International Conference on Instrumentation for High-Energy Physics at CERN, edited by F. M. Farley (North-Holland Publishing Company, Amsterdam, 1963).

[9]A. S. Wightman, Phys. Rev. 77, 521 (1950).

[10]T. B. Day, University of Maryland Technical Report No. 175, 1960 (unpublished).

[11]We use the value for the Σ^- lifetime of 1.615×10^{-10} sec, which is the weighted average of the value given in A. H. Rosenfeld et al., Rev. Mod. Phys. 36, 977 (1964); and C. Y. Chang, J. Steinberger, and T. H. Tan, Bull. Am. Phys. Soc. 9, 639 (1964).

[12]J. Marion and T. W. Bonner, Fast Neutron Physics (Interscience Publishers, Inc., New York, 1963), Pt. II, p. 2221, and references contained therein.

[13]This is the momentum of the neutron from a Σ^- decay at rest.

[14]For details of the hydrogen density measurement, see R. A. Burnstein, T. B. Day, B. Kehoe, B. Sechi-Zorn, and G. A. Snow, Phys. Rev. Letters 13, 66 (1964).

[15]B. d'Espagnat, Nuovo Cimento 20, 1217 (1961); R. Armenteros et al., in Proceedings of the International Conference on High-Energy Nuclear Physics, Geneva, 1962, edited by J. Prentki (CERN Scientific Information Service, Geneva, Switzerland, 1962), p. 351; Phys. Letters 17, 344 (1965). C. Baltay et al., to be published.

OBSERVATION OF A PEAK IN $K^- + p \rightarrow \Lambda + \eta$ NEAR THRESHOLD*

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(Received 8 September 1965)

We report here the results of measurements of the cross section for the reaction

$$K^- + p \rightarrow \Lambda + \eta \tag{1}$$

at a number of K^- momenta near the threshold. A sharp peak in the cross section is observed near the threshold. The excitation functions predicted by possible singularities in the reaction matrix are compared with the data.

The examples of Reaction (1) are found among events of the types

$$K^- + p \rightarrow \Lambda + \text{neutral missing mass}, \tag{2}$$

$$K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^0. \tag{3}$$

The events were observed in approximately 150 000 pictures taken at the Brookhaven AGS with the 30-in. hydrogen bubble chamber exposed to a separated K^- beam at five momenta above the threshold for Reaction (1), which occurs at 724.5 MeV/c. The values of these momenta at the center of the bubble chamber were found to be 725, 741, 768, 802, and 820 MeV/c with a beam spread of ±0.7%. These momenta were measured by several methods, including values from $K^- \rightarrow \mu^- + \nu$ decays where the μ^- stops in the chamber and, particularly, the values of K^- momenta computed from the fitted momentum and angle of the Λ in the events interpreted as Reaction (1). (The mass of the η was taken to be 548.7 MeV/c^2.[1]) The measurements are in agreement, the latter being more accur-

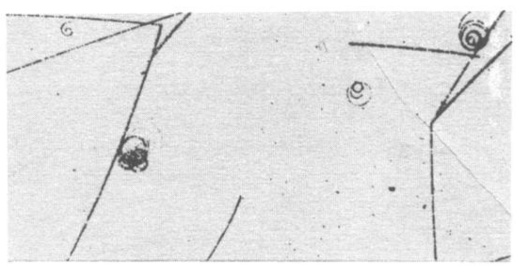

FIG. 1. Photograph of low-momentum Σ^--decay event with (n,p) scatter.