Experimental study of the Σ-nucleon system through the reaction ^{2}H$(K, \pi)\Sigma N$

M. May, R. E. Chrien, H. Palevsky, and R. Sutter
Brookhaven National Laboratory, Upton, New York, 11973

S. Dytman, D. Marlow, P. Pile, and F. Takeutchi
Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213

M. Deutsch
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

R. Cester*
Princeton University, Princeton, New Jersey 08540

S. Bart, E. Hungerford, T. M. Williams, L. S. Pinsky, and B. W. Mayes
University of Houston, Houston, Texas 77004

R. L. Stearns
Vassar College, Poughkeepsie, New York 12601
(Received 7 August 1981)

We report $\Sigma^- n$ mass spectra for the reaction ^{2}H$(K^-, \pi^+)\Sigma^- n$ at $\theta_{K\pi}=20°$, momentum transfer $q=294$ MeV/c. Upper limits on formation cross sections are given and appear to rule out the existence of Σ^- neutron bound states. In addition, a missing mass spectrum for the reaction ^{2}H$(K^-\pi^-)X$, $\theta_{K\pi}=4°$, $q=134$ MeV/c ($X=\Sigma^+ n$, $\Sigma^\circ p$, or Λp), is shown and discussed.

[NUCLEAR REACTIONS Σn mass spectrum, Σ neutron bound states, (K, π) reaction on deuterium, Λp mass spectrum.]

Charge conservation forbids the conversion of Σ^-+neutron to any Λ+nucleon charge state and hence a bound state of $\Sigma^- n$, if it exists, decays only by the weak interaction. The existence of such states was first discussed by Pais and Treiman.[1] $\Sigma^- n$ belongs to the same SU(3) multiplet[2] [27] as nn, which is almost bound in the $^1S_0$ state. For the $\Sigma^- n$ system, the potentials of Nagels, Rijken, and de Swart[3] indicate weak repulsion in the triplet state and attraction in the singlet state, though not strong enough to bind. However, this potential is based on scanty low energy hyperon- nucleon scattering data and so should not be taken as conclusive. Several experimental searches[4,5] for $\Sigma^- n$ bound states have been performed without definitively resolving the issue. Previous experiments were most sensitive to the triplet spin states where binding is least likely. We therefore have maximized singlet formation in our experiment. We have studied the reaction ^{2}H$(K^-, \pi^+)\Sigma^- n$ using 800-MeV/c K^- mesons. The positive pions were detected at 20° with respect to the incident kaon direction resulting in a momentum transfer of 294 MeV to the $\Sigma^- n$ system. The large momentum transfer was chosen to enhance the probability of spin flip. Using the KN partial wave amplitudes of Gopal *et al.*[6] we estimate that $\Sigma^- n$ was formed 12% in the singlet and 88% in the triplet spin states.

The experiment was performed at the Brookhaven National Laboratory Alternating Gradient Synchrotron in the Low Energy Separated Beam I. The beam contains 10^5 negative kaons in a pulse of 1-s duration, repeated every 2.5 s. Kaons compose 7% of the total flux. Kaons are distinguished from pions, which constitute the major contaminant in the beam, by a Cerenkov counter with a lucite radiator, and by time of flight over an 8-m path.

The momentum of the kaon and the pion are measured event by event using two focusing magnetic spectrometers. The kaon spectrometer brings the beam to a momentum dispersed focus at the target using a system of one dipole and four quadrupole magnets. The trajectory of the kaon is measured before and after the magnetic system using multiwire proportional chambers with 1-mm wire spacing. The precision of the momentum determination is 2×10^{-3} full width at half maximum (FWHM). The useful flux of kaons at the target is approximately 10^4 per pulse. The momentum of the pion is measured in a similarly constructed spectrometer which can rotate to an angle of 35° with respect to the beam direction. The use of a thick (3 g/cm^2) liquid deuterium target was the major contribution to the energy resolution. The overall energy resolution was 4 MeV FWHM in the $\Sigma^- n$ missing mass. The cross sections measured in this experiment have an overall normalization uncertainty of ±20%. Because the reaction involves charge exchange as well as strangeness exchange, the data are very free of background and most events satisfying the fast trigger requirements are genuine. The details of the spectrometer and particle identification methods have been described previously.[7]

Figure 1 shows the $\Sigma^- n$ mass spectrum in the bound state region. The data correspond to a flux of 19×10^8 K^- mesons. Due to a malfunction of the cryogenic system, for a subset of these data corresponding to 8.5×10^8 K^-, there was a 10% contamination of liquid hydrogen in the target. However, because of the kinematics of the reactions, the hydrogen does not contribute a signal in the mass region of Fig. 1.

The data (Fig. 1) show no evidence for bound states. To calculate an upper limit for the rate of formation of bound states in the region between 0- and 6-MeV binding energy we have used the data with binding greater than 10 MeV for a background subtraction. A precise knowledge of the location of threshold is crucial for this experiment. A measurement of Σ^- production on hydrogen enabled us to correct for any offsets in the energy scale. We estimate an uncertainty in the absolute energy scale of ±0.5 MeV.

Table I gives the cross section limits obtained at

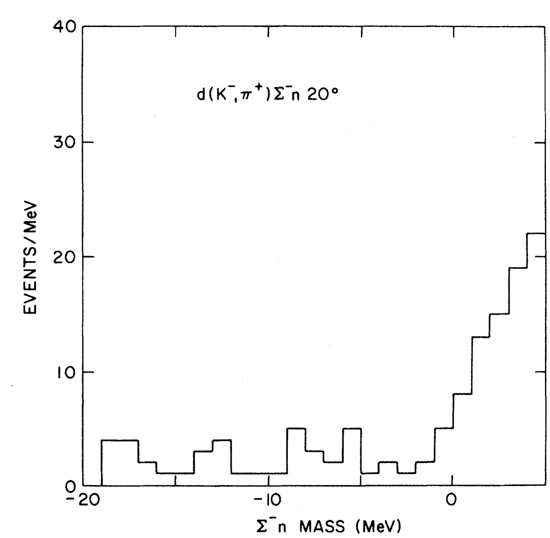

FIG. 1. Σ^- neutron mass spectrum in bound state region for the reaction $^2H(K^-,\pi^+)\Sigma^- n$, $\theta_{K\pi}=20°$, momentum transfer $q=294$ MeV/c. Zero corresponds to $M_{\Sigma^-}+M_n$. The sensitivity is 0.15 μb/sr event.

TABLE I. Upper limit for production of $\Sigma^- n$ bound states in the reaction $K^- d\to(\Sigma^- n)\pi^+$ for kaon momentum 800 MeV/c and $\theta_{K\pi}=20°$.

Binding energy (MeV)	Upper limit μb/sr 95% confidence level
0	2.9
2	1.4
4	1.8
6	2.0

the 95% confidence level. We can set an upper limit of 2.9 μb/sr for the production of $\Sigma^- n$ bound states near zero binding energy.

Using a plane wave impulse approximation, we estimate that if a bound state exists it should have been produced at a level of 6 μb/sr for a singlet bound state and 44 μb/sr for a triplet bound state. The factors which enter into this estimate are as follows:

(a) The laboratory cross section for Σ^- production on a free proton taken[6] to be 0.68 μb/sr at this incident momentum and angle.

(b) The probability of spin flip taken to be 12%.

(c) The probability of binding calculated in a plane wave impulse approximation using Hulthen wave function for the deuteron and for the $\Sigma^- n$ state. We have assumed 100-keV binding energy for the $\Sigma^- n$ and for this case, the probability is 0.071. Note that the production cross section estimate grows roughly as the square root of the binding energy of the state.

Figure 2 shows the mass spectrum for the subsample of the data with no hydrogen contamination in the target. These data contain singlet and triplet final states in a ratio of 1:7.7.

Figure 3 shows the missing mass spectrum for the reaction $^2H(K^-,\pi^-)X$ where X can be $\Sigma^0 p$, $\Sigma^+ n$, or Λp. The data were taken at $\theta_{K\pi}=4°$, $q=135$ MeV/c. Background events not associated with the deuterium target could not be completely eliminated from the spectrum. The spectrum of background was measured by taking data with the deuterium target empty and is drawn as a dashed line in the figure. Since the data contain three final state channels, an analysis is difficult without supplementary information. The *Fermi averaged* cross sections[8] for $p(K^-,\pi^-)\Sigma^+$ and $n(K^-,\pi^-)\Sigma^0$ are in a ratio of 1:2.5 indicating the predominance of the $\Sigma^0 p$ final state over the $\Sigma^+ n$ final state. The contribution of Λp final state to the data is substantial only in the vicinity of $\Sigma^+ n$ threshold. An enhancement in the cross section for $^2H(K^-,\pi^-)\Lambda p$ at Λp mass within an MeV of $\Sigma^+ n$ threshold was first observed by Dahl.[9] The enhancement,[10] which has a width of less than 6

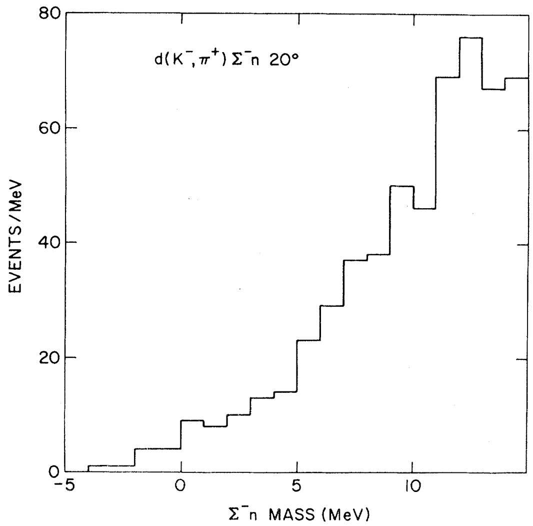

FIG. 2. Σ^- neutron mass spectrum in continuum region for the reaction $d(K^-,\pi^+)\ \Sigma^- n\,\theta_{K\pi}=20°$ momentum transfer $q=294$ MeV/c. Zero corresponds to $M_{\Sigma^-}+M_n$. The sensitivity is 0.2 μb/sr event.

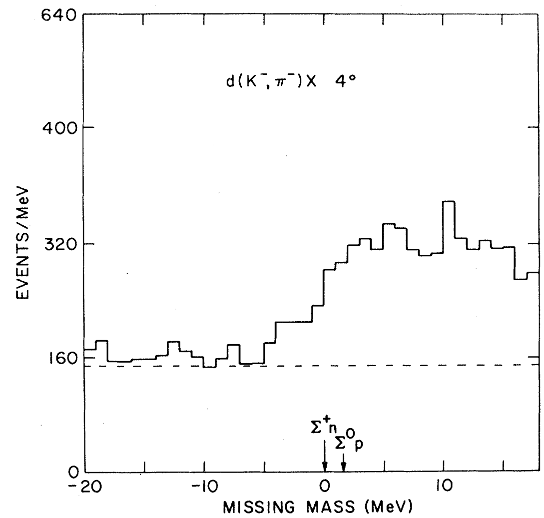

FIG. 3. Missing mass spectrum for the reaction ^{2}H$(K^-,\pi^-)X$ taken at $\bar{\theta}_{K\pi}=4°$, momentum transfer $q=135$ MeV/c. X can be $\Sigma^0 p$, $\Sigma^+ n$, or Λp. Zero corresponds to $M_{\Sigma^+}+M_n$. The sensitivity is 0.22 μb/sr event. The dashed line shows the level of background measured with the deuterium target empty.

MeV and a laboratory cross section of 80 mb/sr at the kinematics of our reaction, has been interpreted[11] as either a $\Sigma^+ n$ virtual bound state or a cusp. The enhancement probably accounts for excess of events in our data just below $\Sigma^+ n$ threshold.

In conclusion, upper limits on formation cross section have been presented which appear to rule out the existence of $\Sigma^- n$ bound states. Continuum ΣN mass distributions have been measured which contain information on the ΣN final state interaction. However, additional data at other angles would be required to resolve the interaction into singlet and triplet spin components.

We wish to thank R. H. Dalitz for advice and encouragement during the data taking and for discussions which clarified the meaning of our results. Discussions with A. Gal were also of great assistance. We thank the staff of the AGS for their cooperation during the experiment. Research has been performed under Contract No. DE-AC02-76-CH00016 with the U.S. Department of Energy.

*Currently at the University of Torino, Turin, Italy.

[1]A. Pais and S. B. Treiman, Phys. Rev. 107, 1396 (1957).
[2]R. J. Oakes, Phys. Rev. 111, 2239 (1963).
[3]M. M. Nagels, T. A. Rijken, and J. J. deSwart, Phys. Rev. D 15, 2547 (1977); *ibid.* 20, 1633 (1979).
[4]O. Dahl, N. Horwitz, D. Miller, and J. Murray, Phys. Rev. Lett. 4, 428 (1960).
[5]R. A. Burnstein, W. C. Cummings, D. L. Swanson, and V. R. Veirs, Phys. Rev. 177, 1945 (1969).
[6]G. P. Gopal, R. T. Ross, A. J. Van Horn, A. C. McPherson, E. F. Clayton, T. C. Bacon, and I. Butterworth, Nucl. Phys. B119, 362 (1977).
[7]R. E. Chrien, M. May, H. Palevsky, R. Sutter, P. Barnes, S. Dytman, D. Marlow, F. Takeutchi, M. Deutsch, R. Cester, S. Bart, E. Hungerford, T. M. Williams, L. S. Pinsky, B. W. Mayes, and R. L. Stearns, Phys. Lett. 89B, 31 (1979).
[8]C. B. Dover (private communication).
[9]O. I. Dahl, N. Horwitz, D. H. Miller, J. J. Murray, and P. G. White, Phys. Rev. Lett. 6, 142 (1961).
[10]O. Braun, H. J. Grimm, V. Hepp, H. Stroebele, C. Thoel, T. J. Thouw, F. Gandini, C. Kiesling, D. E. Plane, and W. Wittek, Nucl. Phys. B124, 45 (1977).
[11]R. H. Dalitz, in *Proceedings of the International Conference on Nuclear Physics, Berkeley, California, 1980,* edited by R. M. Diamond and J. Rasmussen (North-Holland, Amsterdam, 1981), see discussion p. 1026.