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UPPER LIMIT FOR PRODUCTION OF Σ^-n HYPERFRAGMENTS BY K⁻ CAPTURE IN DEUTERIUM

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UPPER LIMIT FOR PRODUCTION OF Σ⁻n HYPERFRAGMENTS BY K⁻ CAPTURE IN DEUTERIUM[◇]

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Recently, Gondolfi et al. reported evidence for the existence of a bound state of the $\Sigma^- n$ system.[1] Pais and Treiman had already suggested that such a system might be produced when K^- mesons were captured in deuterium.[2] They assumed that the $\Sigma^- n$ would form a deuteron-like structure bound in either the ^1S or ^3S state and used an impulse-type model to estimate the relative rates for the processes

$$K^- + d \rightarrow \Sigma^- n + \pi^+ \tag{1}$$

$$K^- + d \rightarrow \Sigma^- + n + \pi^+ \tag{2}$$
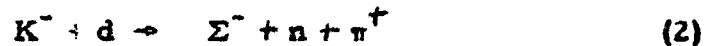
for both odd and even K-Σ parities. Day and Snow have pointed out that the strong S-wave K^--nucleon interaction will dominate the capture process from either S or P atomic orbitals and have extended the calculations of Pais and Treiman to the latter case.[3] Typical values calculated for the fraction of all Σ^- productions leading to the formation of the bound state are summarized in Table I.

Table I

Probability for formation of a Σ^-n with binding energy E_b when a K^- meson is captured in deuterium <u>via</u> the S-wave K-nucleon interaction.

K-Σ parity	Σ^-n bound state	S-orbit capture[a]		P-orbit capture[b]	
		$E_b = 0.1$ Mev	$E_b = 0.5$ Mev	$E_b = 0.1$ Mev	$E_b = 0.5$ Mev
−	^3S	0.20	0.37	0.03	0.06
	^1S	forbidden		0	0
	^3S	0.13	0.25	0.02	0.04
	^1S	0.07	0.13	0.01	0.02

[a]Reference 2.

[b]Reference 3.

In order to determine the relative rates for reactions (1) and (2),
we are examining 2100 Σ^-(n) productions obtained during two exposures of
the Alvarez 15-in. deuterium chamber to the separated 450-Mev/c K$^-$ beam.
Of the Σ^-(n) productions, 85±5% result from K$^-$ absorptions at rest. Thus
far we have analyzed in detail 227 events in which the Σ^-(n) came to rest
and was captured via the reactions Σ^-(n) + d $\rightarrow$ Λ (or Σ^0) + n + n (+n).[4]
For the three cases giving best fits when these events are interpreted as
examples of reaction (1), the probabilities for exceeding the observed values
of χ^2 were 30%, 10%, and 1%. From this result it is concluded that the
fraction of Σ^- productions leading to formation of the bound state is < 1%.

Day, Snow, and Sucher have argued that it is extremely likely that
K$^-$ mesons, when stopped in liquid H_2 or D_2, are captured from high-lying
S orbitals.[5] If their prediction is correct and if the existence of the Σ^-n is
confirmed, the present result can be consistent with the calculations of Pais
and Treiman only if

(a) the binding energy of the Σ^-n is exceedingly small ($\lesssim$ 5 kev)
or

(b) the K$^-$-Σ parity is odd so that reaction (1) is forbidden by
conservation of angular momentum and parity.

In the absence of any special mechanism, the usual de-excitation
processes for the K$^-$-D atom (collisional Auger effect and radiation) will lead
to population of the 2P atomic orbital from which a large fraction of K$^-$'s will
undergo direct nuclear capture. Since the hyperfragment rates are suppressed
by a factor ~ 10 (see Table I), no strong conclusion could then be drawn from
the present experiment.

EXPERIMENTAL

The following considerations lead us to believe that the $\Sigma^-(n)$ capture events are more favorable than decay events for correct identification of hyperfragments:

(a) Ross has examined the interactions of Σ^- hyperons produced by absorption of stopped K^- mesons in hydrogen.[6] He finds that more than 95% of the Σ^- captures occur at rest. Therefore, it may be assumed that the present analysis is effectively limited to events in which the $\Sigma^-(n)$ does not interact (or decay) before traveling its full range. If reaction (1) is produced by a stopped K^-, the Σ^-n will be colinear with the π^+ and have a range of $2.43\pm.05$ mm. Since the diameter of such a heavily ionizing stub is ~ 0.3 mm, the usefulness of the colinearity requirement would decrease rapidly if the shorter path lengths of the decay events were included in the analysis.

(b) The distribution in the $\Sigma^--\pi^+$ included angle for reaction (2) peaks at $180°$, and many events in which the Σ^- decays within 2.5 mm of the production vertex would be indistinguishable from those of (1). Therefore, the present requirement of unique range provides a strong additional criterion for correct identification.

(c) No corrections are necessary for (i) events in which the $\Sigma^-(n)$ range is poorly determined because of emission of a decay pion at a small angle or (ii) colinear Σ^-'s produced by a K^- absorption in the hydrogen contamination of the bubble chamber.

The film coordinates of all tracks associated with the Σ^--capture events were punched onto IBM cards with the LRL measuring projector and the tracks were spatially reconstructed by means of suitable IBM programs. The distribution in range and included angle for the reconstructed events (with included angle greater than 140 deg and Σ^- range between 1 and 6 mm) is shown in Fig. 1. There is no evidence for the expected concentration of

evento in the region expected for hyperfragmento. Ao a check on the machine meaouremento, all evento were re-examined on the ocanning projector and obviouoly noncolinear evento rejected. For the remainder, the $\Sigma^-(n)$ wao aoounmed to be colinear with the π^+ oo that the meaoured valueo of the π^i dip and azimuthal angleo (determined to ± 0.5 deg) could be uoed to calculate the lengtho expected on the film for a range of 2.43 mm. Comparioon of calculated lengtho with direct meaouremento on the film gave reoulto conoiotent with the χ^2 eotimateo deduced from the machine meaourements.

The oignificance of the present meaourement dependo upon the probability P_c that a Σ^-n will come to reot and be captured. Thio quantity may be written

$$P_c = \exp[-\Gamma_b(T_1 + T_2 + T_c^D)],\qquad(3)$$

where Γ_b io the decay rate for the bound Σ^-, T_1 io the proper time from production to the time the Σ^-n hao olowed down to a velocity $v/c = 0.05$ (the approximate lower limit for the validity of the uoual range-momentum relation), T_2 io the time from $v/c = 0.05$ to initial capture by a D_2 molecule and T_c^D io the time from molecular capture to nuclear aboorption.

Snow hao ohown that if charge independence io valid, the Σ^-n will probably be bound by leoo than 0.5 Mev.[7] Dalitz and Liu have argued that for ouch loooely bound oyotemo, the major modificationo in decay rateo ohould arioe from the change in phaoe opace available and from the operation of the Pauli principle in the final otate.[8] Uoing Eq. (3.3) given in their paper, we have eotimated the magnitude of theoe effecto. Since the S- and P-channel decay amplitudeo for the free Σ^- are not known, reouito for Γ_b are given in Table II for the extreme caoeo.

Table II

Decay rate of $\Sigma^- n$ relative to the free Σ^-. The $\Sigma^- n$ was assumed to be bound by 0.5 Mev.

| Amplitude for | Bound state of $\Sigma^- n$ | |
| Σ⁻ decay into | | |
S and P channels	^1S	^3S
$S \neq 0; P = 0$	1.28	0.94
$S = 0; P \neq 0$	0.94	1.04

Integration of the range-momentum relation yields

$T_1 = 0.99 \times 10^{-10}$ sec. Wightman has estimated T_2 for particles of various

masses;[9] a slight extrapolation of his results gives $T_2 = 0.19 \times 10^{-10}$ sec.

Because of the complexity of the de-excitation process, no reliable estimate

is available for T_c; however, some orientation may be gained by consideration

of a related process. An equation analogous to Eq. (3) may be used to

calculate the capture rate for Σ^- hyperons produced by K^- absorption in

hydrogen. The observed capture rate is obtained with

$T_c^H = (0.10 \pm .25) \times 10^{-10}$ sec. [10] To relate this result to the present situation,

we make the rough assumption that the mass dependence is not worse than

that characteristic of energy loss to electrons by collision,[11] i. e.

$$T_c^D \simeq (\mu_D/\mu_H)T_c^H \simeq (0.2 \pm .5) \times 10^{-10} \text{ sec,}$$

where $\mu_D(\mu_H)$ is the reduced mass of the $\Sigma^- n\text{-}d(\Sigma^- \text{-}p)$ systems.

Under the above assumption, Eq. (3) gives $P_c = 0.32^{+.17}_{-.11}$ for the

most unfavorable case ($K^-\text{-}\Sigma$ parity even, $\Sigma^- n$ bound in the ^1S state). Using

this value, we estimate that if the fraction of Σ^- productions leading to the

bound state were 1‰, 6^{+3}_{-2} $\Sigma^- n$ capture events should have been observed.

Since the entire distribution of events is completely consistent with all

Σ^-'s being produced via reaction (2), and since at most, one event can

reasonably be interpreted as a hyperfragment production, it is probable that

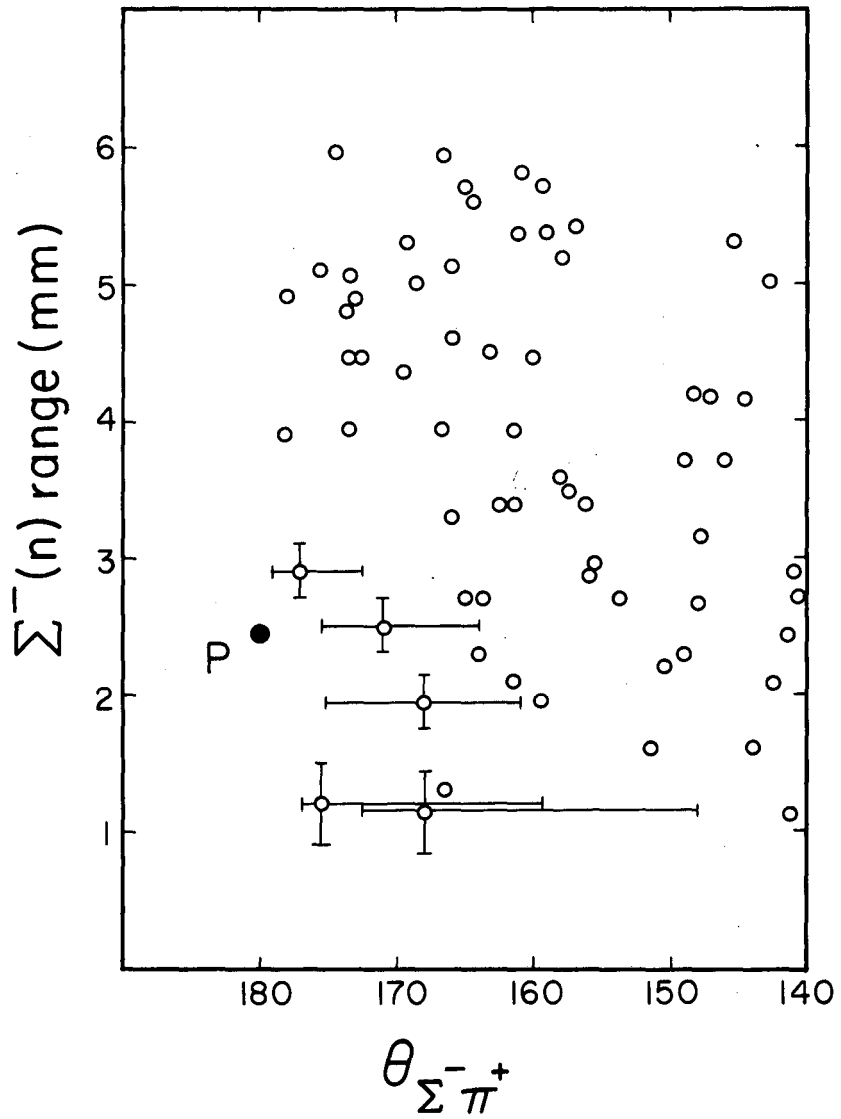the branching ratio for reaction (1) is substantially less than 1‰.

FOOTNOTES

1. E. Gondolfi, J. Heughebaert, and E. Quercigh, Nuovo cimento XIII, $\underline{4}$, 2436 (1959).

2. A. Pais and A. B. Treiman, Phys. Rev. $\underline{107}$, 1396 (1957).

3. T. B. Day and G. A. Snow, Phys. Rev. Letters $\underline{2}$, 59 (1959).

4. O. Dahl, N. Horwitz, D. Miller, and J. Murray, Phys. Rev. Letters $\underline{4}$, 77 (1960).

5. T. B. Day, G. A. Snow, and J. Suchar, Phys. Rev. Letters $\underline{3}$, 61 (1959).

6. Ronald R. Ross, Bull. Am. Phys. Soc., Ser. II, $\underline{3}$, 335 (1958).

7. George A. Snow, Phys. Rev. $\underline{110}$, 1192 (1958).

8. R. H. Dalitz and L. Liu, Phys. Rev. $\underline{116}$, 1312 (1959).

9. A. S. Wightman, Phys. Rev. $\underline{77}$, 521 (1950).

10. For the free Σ^- decay rate we used $\Gamma_b = (0.642 \pm .039) \times 10^{10}/\text{sec}$, the weighted average of the values measured in associated production experiments. These values were reported by Prof. Luis W. Alvarez at the Ninth International Conference on High Energy Physics, Kiev, USSR (1959). The preliminary value, $0.099 \pm .007$, for the Σ^- capture rate was kindly supplied by Drs. Rosenfeld, Solmitz, and Tripp of our group.

11. This is the mass dependence determined by Wightman for T_2 (Ref. 9). Fermi and Teller (Phys. Rev. $\underline{72}$, 406 (1947) obtain a similar mass-dependence for particles losing energy by electronic collisions after capture into high-lying atomic orbitals in solids.

FIGURE LEGEND

Fig. 1. Measured range <u>vs</u> $\Sigma^-(n)-\pi^+$ included angle for reactions (1) and

(2). The angle and range required for a Σ^-n hyperfragment are

designated by P. Typical measurement errors are indicated for the

six closest events.

Fig. 1

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