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Title
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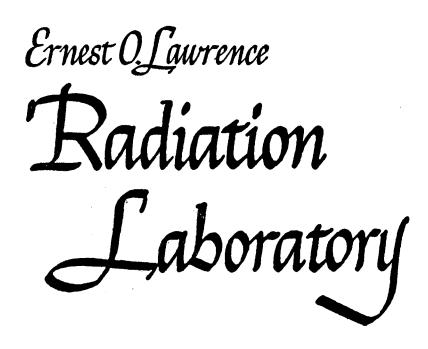**Permalink**

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In a recent communication, Day, Snow, and Sucher predicted that K^- mesons when stopped in liquid hydrogen or deuterium would be captured from high-lying S atomic orbitals of the K^--p or K^--d system.[1] They found that the Stark-effect mixing of angular-momentum states induced by the strong electric fields experienced by the neutral K^--p or K^--d system as it passed within the Bohr orbitals of other atoms of the liquid allowed rapid capture through the S-wave K-nucleon interaction. Their prediction has been used to draw important conclusions about the properties of hyperons[1] and the nature of the low-energy, S-wave K-nucleon interaction.[2] In addition, estimates indicate that Stark-effect mixing determines the course of the antiproton annihilation reaction at rest.[3] Because of the wide applicability of the prediction, an experimental test is highly desirable. The obvious experiment of looking for K-shell x-rays when K^- mesons are stopped in liquid H_2 or D_2 is technically difficult and probably will not be done in the near future.

It may be noted that several of the K^--d capture reactions are sensitive to the orbital angular momentum of the K^--d system. This is implied for example in the calculations of Pais and Treiman[4] and Day and Snow[5] on the Σ^-n-hyperfragment production rate. Their work shows that if the bound Σ^-n system existed and its characteristics were known,

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the production rate for stopped K^- mesons would provide a clear determination of the orbital from which capture occurs. It is the purpose of this note to point out that the K^--d orbital angular momentum determines the rates for another class of reactions that is more accessible experimentally, the nonmesic capture reactions in deuterium,

$$K^- + d \rightarrow \Sigma^- + p \qquad (1a)$$

$$\Sigma^0 + n \qquad (1b)$$

$$\Lambda + n , \qquad (1c)$$

where the rate for reaction (1a) is twice that for (1b) by charge independence. We shall confine our attention to reaction (1a) since it is easily recognized in a deuterium-filled bubble chamber and is known to occur at a rate of $\sim 0.7\%$ when stopped K^- mesons are captured.[6] For K^- capture at rest, the center-of-mass momentum of the Σ_p system is 511 Mev/c, and production is inhibited unless the K^- is absorbed while the two nucleons are within a distance $\sim 0.4(10^{-13})$cm. The small size of this effective interaction volume implies that the rate for (1a) will be $\propto |\phi_{nS}(r=0)|^2$ or $\propto |\nabla\phi_{nP}(r=0)|^2$ depending upon the atomic orbital from which capture occurs. On the other hand, mesic absorption can occur over the entire volume of the deuteron and will proceed through the S-wave K^--nucleon interaction for capture from either S or P atomic orbitals.[5] Therefore, if capture occurs predominantly from S-orbitals as predicted by Day, Snow, and Sucher, the fraction of nonmesic absorptions observed at rest and inflight must be a continuous and slowly varying function of K^- momentum.

Making the explicit assumption that the behavior of the nonmesic

transition amplitude is determined by the centrifugal barrier in the

initial state, and that only S- and P-wave absorption is important at low

momentum, we have[7]

$$\Gamma_{nm}(q) = (A + Bq^2)\, pcN\,. \tag{2}$$

Here q is the center-of-mass momentum of the initial K^--d system

in units of $\mu_{Kd}c$ where μ_{Kd} is the K^--d reduced mass and c the

velocity of light; p is the final center-of-mass momentum measured in

units of its threshold value, $p_0 = 511$ Mev/c ; and N is the atomic

density of liquid deuterium.   The quantities A and B are to be determined

from measurement of the in-flight production cross sections.   The capture

rate from nS or nP orbitals may then be estimated by using

$$\Gamma_{nm}^{nS} = cA \left|\, \phi_{nS}(r=0) \,\right|^2 \tag{3a}$$

$$\Gamma_{nm}^{nP} = cB\, (\hbar/\mu_{Kd}c)^2 \left|\, \nabla\phi_{nP}(r=0) \,\right|^2 \tag{3b}$$

Since the absolute transition rate cannot be measured, Eqs. (3a) and

(3b) must be compared with the mesic absorption rate. To obtain the latter,

we assume that the absorption rate in deuterium is essentially the sum of the

absorption rates for the free neutron and proton.[8] The mesic absorption

rate from an nℓ orbital is then given by

$$\Gamma_n^{n\ell} = 4\pi c\, (\hbar/\mu_{Kp}c)\, \left(\frac{b_0+3b_1}{2}\right) \left\langle \left| \phi_{n\ell}(r) \right|^2 \right\rangle_{av}\,, \tag{4}$$

where μ_{Kp} is the reduced K^--p mass, and the average over the nucleon

density distribution is evaluated by using the Hulthén form for the deuteron

wave function.   The quantities b_0 and b_1 are the imaginary parts of the

T = 0 and T = 1 zero-energy scattering lengths evaluated by Dalitz and Tuan.[9] Dividing Eqs. (3a) and (3b) by Eq. (4), we obtain for the fraction of nonmesic absorptions from S or P atomic orbitals:

$$R^S(0) = 0.123 \ (10^{26}) \ A \qquad (5a)$$

$$R^P(0) = 0.0241 \ (10^{26}) \ B. \qquad (5b)$$

At present, only the fraction of nonmesic absorptions occurring at rest is known. Since either Eq. (5a) or (5b) should essentially account for the observed value, R(0) ≃ 0.007, A and B may be determined and corresponding lower limits for $\Gamma_{nm}(q)$ estimated from Eq. (2). To obtain lower limits for the fraction of nonmesic absorptions expected in flight, $\Gamma_{nm}(q)$ may be divided by the mesic absorption rate as given by

$$\Gamma_m(q) \simeq qc \left(\frac{\sigma_0 + 3\sigma_1}{2} \right) N, \qquad (6)$$

where σ_0 and σ_1 are the absorption cross sections for the T = 0 and T = 1 states of the K⁻-p system.[9] Typical results are listed in Table I for the two assumptions of S- or P-orbital capture at rest.

Table I

Lower limit for fraction of nonmesic absorptions expected in flight when K⁻ capture at rest occurs from either S or P atomic orbitals.

K⁻ laboratory momentum (Mev/c)	S-orbital capture	P-orbital capture
50	0.007	0
200	0.019	0.016
300	0.017	0.032

The ease with which the experiment can yield a definitive result depends upon the extent to which A is not equal to B in Eq. (2). In the analogous reaction $\pi^+ + d \rightarrow p + p$ B is much greater than A because of the anomalously small S-wave, π-nucleon interaction. In the present case, the S-wave, K^--nucleon interaction is very large, and if A is much greater than B, a measurement of low statistical accuracy would indicate that ordinary collisional and radiative de-excitation mechanism were inadequate to account for the observed nonmesic rate at rest.

FOOTNOTES

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

2. R. H. Daltiz and S. F. Tuan, The Phenomenological Representation of K^--Nucleon Scattering and Reaction Amplitudes, EFINS-56-63, submitted to Annals of Physics.

3. Bipin Desai, Proton-Antiproton Annihilation in Protonium, UCRL-9014, January 5, 1960, to be published in the Physical Review.

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

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

6. Data of N. Horwitz, D. Miller, and J. Murray, reported by L. Alvarez at the Ninth Annual International Conference on High Energy Physics, Kiev, Russia, 1959.

7. The general properties for such a transition amplitude have been discussed by K. A. Brueckner and K. M. Watson Phys. Rev. $\underline{86}$, 923 (1952) and K. M. Watson Phys. Rev. $\underline{88}$, 1163 (1952) in connection with the reaction $p+p \rightarrow \pi^+ + d$.

8. It may be expected that final-state interactions will redistribute the reaction products among the available final states but will not seriously affect the absolute transition rate. T. B. Day, G. A. Snow, and J. Sucher in Univ. of Maryland Technical Report 167, March 1960 have estimated the effects of multiple scattering on the absorption rate at 200 Mev/c K^- laboratory momentum and found them to be small.

9. At zero and 200 Mev/c, the necessary parameters for the $T = 0$ and $T = 1$ absorption channels were taken from reference 2 for the experimentally preferred (a+) and (b+) solutions. At 300 Mev/c, we used the σ_0 and σ_1 absorption cross sections of P. Norden, R. Tripp,

A. Rosenfeld and F. Solmitz reported by L. Alvarez at the Ninth

International Conference on High Energy Physics, Kiev,

Russia 1959.