$$A_2 = a\vec{\sigma}\cdot\vec{p}_K + b\vec{\sigma}\cdot\vec{p}_\Lambda + c\vec{\sigma}\cdot\vec{p}_\pi,$$

$$d\sigma_1 = (1/4v)\{|a|^2 p_K^{\,2} + |b|^2 p_\Lambda^{\,2} + 2\,\mathrm{Re}\,(a^*b)\vec{p}_K\cdot\vec{p}_\Lambda + 2\,\mathrm{Im}\,(a^*b)(\vec{p}_K\times\vec{p}_\Lambda)\cdot\vec{\zeta}\}d\rho_F,$$

$$d\sigma_2 = (1/2v)\{|a|^2 p_K^{\,2} + |b|^2 p_\Lambda^{\,2} + |c|^2 p_\pi^{\,2} + 2\,\mathrm{Re}\,[a^*b\,\vec{p}_K\cdot\vec{p}_\Lambda + b^*c\,\vec{p}_\Lambda\cdot\vec{p}_\pi + c^*a\,\vec{p}_\pi\cdot\vec{p}_K] + 2\,\mathrm{Im}\,[a^*b\,(\vec{p}_K\times\vec{p}_\Lambda) + b^*c(\vec{p}_\Lambda\times\vec{p}_\pi) + c^*a\,(\vec{p}_\pi\times\vec{p}_K)]\cdot\vec{\zeta}\}d\rho_F,$$

$$\sigma_1 \sim (1/2v)\,T_1^{\,2}\{0.34\,|b|^2(2\mu Q_1) + [|a|^2 + 0.34\,|b|^2]p_K^{\,2}\},$$

$$\sigma_2 \sim (1/v)\,T_2^{\,2}\{[0.34\,|b|^2 + 0.43\,|c|^2](2\mu Q_2) + [|a|^2 + 0.34\,|b|^2 + 0.43\,|c|^2]p_K^{\,2}\}.$$

The interpretation of data on absorption of K^- mesons in flight at low energies should be less ambiguous than that for absorption at rest. The greatest difficulty would appear to be the small cross sections for reactions (1) and (2).

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*Supported by the National Science Foundation.

[1] L. B. Okun' and I. Ia. Pomeranchuk, J. Exptl. Theoret. Phys. (U.S.S.R.) 34, 997 (1958) [translation: Soviet Phys. JETP 34, 688 (1958)].

[2] See, for example, R. H. Dalitz, Reports on Progress in Physics (the Physical Society, London, 1957), Vol. 20, p. 163, and references contained therein.

POSSIBLE EXPLANATION OF HYPERFRAGMENT SUPPRESSION IN K^--d REACTIONS*

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One of the reactions that can occur when a K^- meson is captured from an atomic orbit about a deuteron is

$$K^- + d \to \Sigma^- + n + \pi^+. \qquad (1)$$

Pais and Treiman[1] have investigated the probability of formation of a bound state of the (Σ^-, n) system, if such a system exists. They concluded that if the (Σ^-, n) binding energy was of the order of a few tenths of a Mev or larger, the probability of bound-state formation via reaction (1) is ~40%, except if the K^- meson were pseudoscalar, and the singlet state of the (Σ^-, n) system is the only bound system.

A re-examination of this problem indicates that there is one important process that was not included in their work; that is, the absorption of the K^- meson from the $2P$ atomic orbit via an s-wave capture process of the type

$$K^- + p \to \Sigma^- + \pi^+. \qquad (2)$$

The rate of this (K^-, p) s-wave capture from the $2P$ orbit is nonvanishing since the deuteron has a finite size and the rate is proportional to the square of the $2P$ orbital wave function evaluated at the position of the proton in the deuteron. Furthermore, a crude estimate of the total absorption rate from the $2P$ orbit by s-wave capture $\Gamma(P, s)$, indicates that it is ~10 times larger than either the $2P \to 1S$ radiative rate $\Gamma(P, \gamma)$ or the $2P$ absorption rate via p-wave capture. It is the purpose of this letter to show that the probability of the formation of the (Σ^-, n) bound state via the s-wave capture process from the $2P$ orbit is one order of magnitude smaller than for the processes considered in PT.

In the following discussion, the notation and approximations of PT are used. These approximations consist in the use of the impulse approximation and two-parameter Hulthén wave functions for the bound states.

Assuming that the K^- meson is pseudoscalar with respect to the (Σ^-, n) system, and that the (Σ^-, n) bound state has spin 1, then, analogous to Eq. (8) of PT, the bound-state transition rate via the s-wave (K^-, p) interaction can be written

$$R_B = \tfrac{2}{3}\pi\,|a|^2 \sum_{m_l} \int \left| y^{m_l} \right|^2 \frac{d\vec{P}_\pi}{(2\pi)^3\,dE}, \qquad (3)$$

where

$$y^{m_l} = \int d\vec{r}\; v_B^{\,*}(\vec{r})\,e^{-i\vec{k}_0\cdot\vec{r}}\,u(\vec{r})\,\psi_{2P}^{\;m_l}(\vec{r}/2). \qquad (4)$$

ψ_{2P} is the K^- wave function in the $2P$ orbit and the other symbols are explained in PT. Since only small values of the argument of ψ_{2P} are important, $\psi_{2P}(\vec{r}/2)$ can be replaced by $\tfrac{1}{2}\vec{r}\cdot\nabla\psi_{2P}(0)$, and the evaluation of R_B is straightforward in terms of the parameters of the bound-state wave functions.

Again in a manner exactly analogous to Eq. (10) of PT, closure is invoked to get for the total transition rate for production into the bound and free states

$$R_F + R_B \cong \tfrac{2}{3}\pi |a|^2 \sum_{m_l} \int I^{m_l} \frac{d\vec{P}_\pi}{(2\pi)^3 dE}, \tag{5}$$

where

$$I^{m_l} = \int d\vec{r}\, |u(\vec{r})|^2 |\psi_{2P}{}^{m_l}(\vec{r}/2)|^2. \tag{6}$$

The ratio $R_B/(R_B+R_F)$ is then easily computed. (The small variation of the pion phase space factor in free production as compared to its value in bound production is ignored.)

The values of the ratio $R_B/(R_B+R_F)$ are plotted in Fig. 1 for several values of the (Σ^-, n) binding energy, ϵ', and for two values of the effective range ρ'. Instead of getting values ~40% for this ratio as found by PT, we find values ~6%. Hence, in the most favorable case of a pseudoscalar K^- meson and a triplet (Σ^-, n) bound state, the ratio of (Σ^-, n) bound to $(\Sigma^- + n)$ free via s-state capture from the $2P$ orbit is only ~6%. If the (Σ^-, n) bound state has spin 0, then this mode of capture gives zero probability for bound-state formation for a pseudoscalar K^- meson. For scalar K^- mesons, and a (Σ^-, n) bound state with spin 0 or 1, the bound-state formation probability will be less than but of the same order of magnitude as the probabilities plotted in Fig. 1 (see discussion in PT).

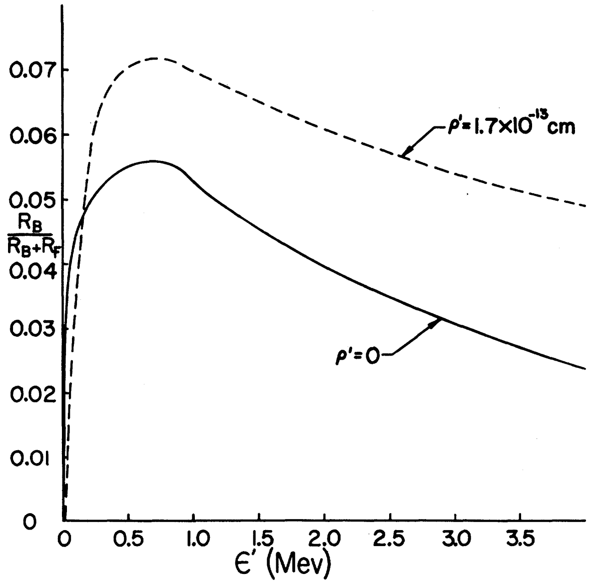

FIG. 1. The ratio of (Σ^-, n) bound-state formation rate to total capture rate from the $2P$ orbit of the (K^-, d) atom via s-wave capture, is plotted as a function of the (Σ^-, n) binding energy, ϵ', for two values of the (Σ^-, n) effective range, ρ'.

The results of the above calculation are significant for the over-all probability of (Σ^-, n) bound-state formation if $\Gamma(P, s)$ dominates the capture process. The much higher values of $R_B/(R_B+R_F)$ as found by PT are still applicable for s-capture from an nS orbit or for p-capture from the $2P$ orbit. (The probability that a K^- meson reach an nS orbit with $n>1$, before reaching the $2P$ orbit is believed to be quite small since the original atomic capture favors high n and consequently high l.) A rough estimate of the absolute magnitude of $\Gamma(P, s)$ can be obtained by using the data presented by Tripp[2] on the cross sections for (K^-, p) absorptions in flight at low energies. Assuming, as is suggested by the energy dependence of the cross sections, that the observed cross sections are mostly s-wave for $P_{K^-} \lesssim 240$ Mev/c, one deduces for the reaction of Eq. (2),

$$2\pi |a|^2 \int \frac{d\vec{P}_\pi}{(2\pi)^3 dE} \cong v_{K^-p}\,\sigma_{\Sigma^-\pi^+} = 23.4\times10^{-17}\ \text{cm}^3/\text{sec}. \tag{7}$$

One then finds

$$R_F + R_B \cong 1.82\times10^{12}\ \text{sec}^{-1}. \tag{8}$$

Hence, $\Gamma(P, s) \gtrsim 5\times10^{12}\ \text{sec}^{-1}$, when one includes the other (K^-, p) capture reactions plus the (K^-, n) s-wave captures. On the other hand, $\Gamma(P, \gamma) = 4.78\times10^{11}\ \text{sec}^{-1}$, so that $\Gamma(P, \gamma)/\Gamma(P, s) \lesssim (1/10)$. This estimate implies that the K^- meson is captured $\gtrsim 90\%$ of the time from the $2P$ orbit before it has a chance to radiate down to the $1S$ orbit.

An estimate of the rate of p-wave capture out of the $2P$ orbit is much more difficult, since the absolute p-wave cross section in (K^-, p) interactions is not known. From analysis of the (K^-, p) cross sections in flight, Jackson et al.[3] have estimated that the capture rate for the reaction $K^- + p \to \Sigma^- + \pi^+$ out of the $2P$ orbit of the (K^-, p) atom is $\lesssim 1\times10^{11}\ \text{sec}^{-1}$. This would imply that in deuterium the transition probability for the reaction $K^- + d \to \Sigma^- + \pi^+ + n$ via p-wave capture from the $2P$ orbit is $\lesssim 2.6\times10^{11}\ \text{sec}^{-1}$. Comparing this estimate with Eq. (8), we find that, for the reaction $K^- + d \to \Sigma^- + n + \pi^+$, the p-wave capture rate from the $2P$ orbit is smaller than the s-wave capture from the $2P$ orbit by a factor $\gtrsim 7$. Much more data on (K^-, p) collisions in flight will be necessary to make the above estimate reliable.

The non-spin-flip amplitude of the p-wave capture process can interfere with the s-wave capture process in the calculation of the probability of formation of the (Σ^-, n) compound. Unfortunately, not enough is known experimentally so as to determine whether this interference is constructive or destructive. Experimentally, Tripp[2] reports no (Σ^-, n) compounds out of 49 events of the type $K^- + d \rightarrow \Sigma^- + n + \pi^+$. The analysis presented here indicates that this experimental result does not as yet exclude the possibility that a (Σ^-, n) bound state exists. Hence a continued, intensive search for such a compound is indicated.

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[*] Supported in part by the U. S. Atomic Energy Commission, while one of the authors (G. A. S.) was in residence at the University of Wisconsin.

[1] A. Pais and S. Treiman, Phys. Rev. 107, 1396 (1957), hereinafter referred to as PT.

[2] R. D. Tripp, 1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (CERN, Geneva, 1958), p. 184.

[3] Jackson, Ravenhall, and Wyld, Nuovo cimento 9, 834 (1958).

IONIZATION OF THE UPPER ATMOSPHERE BY LOW-ENERGY CHARGED PARTICLES FROM A SOLAR FLARE

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Excess ionization of the upper atmosphere at high latitudes following solar flares has been observed on several occasions during the International Geophysical Year, through studies of the absorption of cosmic radio noise. One such event, discussed in this note, occurred on July 29, 1958 following the class 3 solar flare at 03:03 UT.[1] The recordings of the 27.6-Mc/sec cosmic noise received on this date at Thule, Greenland and Barrow and College, Alaska are reproduced in Fig. 1. Identical receiving equipments, consisting of riometers[2] connected to wide beam, vertically-directed Yagi antennas, were used at each station. The dashed curve on each trace shows the strength of the cosmic noise signal that would have been received under undisturbed conditions. The computed values of absorption in decibels are also shown on the respective recordings.

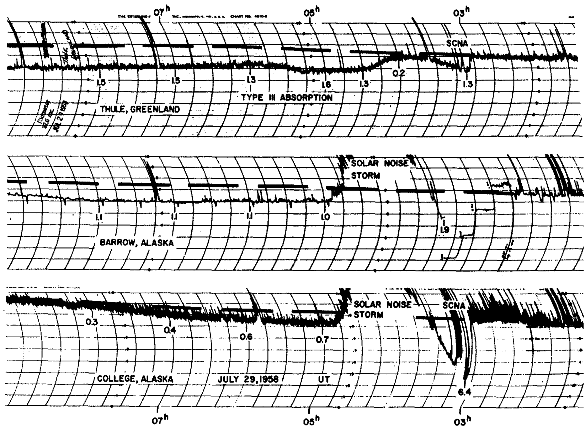

FIG. 1. Cosmic noise absorption on July 29, 1958. The dashed curves show the cosmic noise signal received under quiet conditions at each station; the computed values of absorption in decibels are shown for representative times. A constant amount of interference is present on the Barrow recording and has been included in the Barrow quiet-day curve (the actual cosmic noise level can be seen during the half-hour keying tags of the interfering transmitter).

The sudden cosmic noise absorption (SCNA) coincident with the visible flare is evident on the College and Thule recordings. The Barrow equipment was being calibrated at this time. The SCNA is known to be the result of ionization of the D region by the enhanced ultraviolet and x-ray flux from the flare. The difference in magnitude of the SCNA at College and Thule is a reflection of the greater solar zenith angle at the latter station ($\chi = 83.5°$ at Thule and $\chi = 73.5°$ at College during the peak of the SCNA).

A very intense 27.6-Mc/sec solar noise storm was recorded at College and Barrow which obscured the recovery of the SCNA at those stations. This noise storm was not seen at Thule, through a fortunate combination of large solar zenith angle and orientation of the antenna, which placed the sun in a null of the beam pattern. Thus it is possible to follow the recovery of the SCNA at Thule, and we find that the absorption had decreased to about 0.2 db by 04^h UT.

Approximately sixty-five minutes after the onset of the SCNA the absorption again increased at Thule. We interpret this increase as arising from ionization of the upper atmosphere by charged particles originating at the sun at the