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Capture of K^--Mesons by Deuterium and Hyperon-Nucleon Interaction

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THE study of K-meson capture in hydrogen and deuterium can provide valuable information not only concerning the properties of K-mesons but also concerning the interactions between hyperons and nucleons. In particular, it may be possible to answer the question about the existence of bound states of a hyperon-nucleon system. Examples of such reactions (occurring with conservation of "strangeness"[1] and, consequently, possessing large cross sections) are

1) $K^- + d \to \Lambda + n + \pi^\circ$,	1') $K^- + p \to \Lambda + \pi^\circ$,
2) $K^- + d \to \Lambda + p + \pi^-$,	2') $K^- + n \to \Lambda + \pi^-$,
3) $K^- + d \to \Sigma^- + n + \pi^+$,	3') $K^- + p \to \Sigma^- + \pi^+$,
4) $K^- + d \to \Sigma^+ + n + \pi^-$,	4') $K^- + p \to \Sigma^+ + \pi^-$,
5) $K^- + d \to \Sigma^\circ + n + \pi^\circ$,	5') $K^- + p \to \Sigma^\circ + \pi^\circ$,
6) $K^- + d \to \Sigma^\circ + p + \pi^-$,	6') $K^- + n \to \Sigma^\circ + \pi^-$,
7) $K^- + d \to \Sigma^- + p + \pi^\circ$,	7') $K^- + n \to \Sigma^- + \pi^\circ$.

As definite examples we shall consider reactions 3 and 3'.

Assuming that the hyperon has spin 1/2, the amplitude of reaction 3' will in general be of the form

$$A = a + \mathbf{b}\vec{\sigma}, \tag{1}$$

where a and $\mathbf{b}$ are functions of the K- and π-meson momenta; of k and p and of the spin of the K-meson, if this amplitude exists. The differential cross section of this reaction, averaged over the spins of the heavy particles, is

$$d\sigma = (|a|^2 + |b|^2)\, d\Omega. \tag{2}$$

If we consider the formation of π^+-mesons near the upper limit of their energy spectrum in reaction (3) we have for the corresponding cross section in the momentum approximation[2]

$$d\sigma = \left| \int \psi_f^*(\vec{\rho}) \exp\{i\vec{\varkappa}\vec{\rho}\}\, \psi_0(\vec{\rho})\, d\vec{\rho} \right|^2 \frac{d\mathbf{f}}{(2\pi)^3}\, d\Omega, \tag{3}$$

$$\vec{\varkappa} = \frac{M_1}{M_1 + M_2}(\mathbf{k} - \mathbf{p}).$$

Here M_1 and M_2 are the nucleon and hyperon masses and $\mathbf{f}$ is their relative momentum. Averaging over the spins of the baryons, we obtain

$$d\sigma = \{|a|^2 + {}^2/_3 |b|^2) |I_t|^2 + {}^1/_3 |b|^2 |I_s|^2\} (2\pi)^{-3} f^2\, df\, d\Omega_f\, d\Omega. \tag{4}$$

Here

$$I_{t,s} = \int \varphi_f^{(t,s)*}(\vec{\rho}) \exp\{i\vec{\varkappa}\vec{\rho}\}\, \varphi_0(\vec{\rho})\, d\vec{\rho}.$$

Taking

$$\varphi_0 = \sqrt{\alpha/2\pi}\; \frac{e^{-\alpha\rho}}{\rho}, \tag{5}$$

$$\varphi_f^{(t,s)} = \exp\{i\mathbf{f}\vec{\rho}\} - (e^{-2i\delta_{t,s}} - 1)\frac{e^{-if\rho}}{2if\rho},$$

where $\delta_{t,s}$ is the S-phase in the triplet and singlet states of the hyperon-nucleon system, we obtain (after integrating over all directions)

$$\begin{aligned} \int |I_{t,s}|^2 d\Omega_f = 8\pi\alpha \Big\{ & \frac{4\pi}{[\alpha^2 + (\varkappa - f)^2][\alpha^2 + (\varkappa + f)^2]} \\ & + \frac{\pi}{2(\varkappa f)^2} \ln \frac{\alpha^2 + (\varkappa - f)^2}{\alpha^2 + (\varkappa + f)^2} \\ & \times \Big[\sin 2\delta_{t,s} \Big(\operatorname{arctg}\frac{\varkappa + f}{\alpha} + \operatorname{arctg}\frac{\varkappa - f}{\alpha} \Big) \\ & - \sin^2\delta_{t,s} \ln \frac{\alpha^2 + (f + \varkappa)^2}{\alpha^2 + (f - \varkappa)^2} \Big] \\ & + \frac{\pi}{(\varkappa f)^2} \sin^2\delta_{t,s} \Big[\Big(\operatorname{arctg}\frac{\varkappa + f}{\alpha} + \operatorname{arctg}\frac{\varkappa - f}{\alpha} \Big)^2 \\ & + \frac{1}{4} \Big(\ln \frac{\alpha^2 + (\varkappa + f)^2}{\alpha^2 + (\varkappa - f)^2} \Big)^2 \Big] \Big\}. \end{aligned} \tag{6}$$

When we make use of the relationship

$$E_0 = \sqrt{\mu^2 + k^2} - (M_2 - M_1) \tag{7}$$

$$= \sqrt{m^2 + p^2} + \frac{(\mathbf{p} - \mathbf{k})^2}{2(M_1 + M_2)} + \frac{M_1 + M_2}{2M_1M_2} f^2,$$

Eqs.(4) and (6) give the pion distribution near the upper limit of the spectrum. Assuming $\cot\delta_{t,s} = -\beta_{t,s}/f$ and considering mesons whose energy differs from the upper limit by an amount of the order β^2/M, we obtain

$$d\sigma = \frac{\alpha}{\pi \varkappa_m^2}\left[\frac{M_1M_2}{2(M_1 + M^2)}\right]^{1/2}\left(1 + \frac{w_m}{M_1 + M_2}\right) \tag{8}$$

$$\times \left\{\frac{|a|^2 + {}^2/_3|b|^2}{\varepsilon_t + [E_0 - w - (w^2 - m^2)/2(M_1 + M_2)]} + \frac{{}^1/_3|b|^2}{\varepsilon_s + [E_0 - w - (w^2 - m^2)/2(M_1 + M_2)]}\right\}$$

$$\times \sqrt{E_0 - w - \frac{w^2 - m^2}{2(M_1 + M_2)}}\, dw.$$

Here $\epsilon_{t,s} = \beta^2_{t,s}\,(M_1 + M_2)/2M_1M_2$ and $\varkappa_m$ and w_m are the limiting values of $\varkappa$ and $w = \sqrt{m^2 + p^2}$ (for $f = 0$). According to (8), the pion energy distribution near the upper limit of the spectrum has two sharp peaks whose position and width is determined by ϵ_t and ϵ_s. An experimental investigation of this process in hydrogen and in deuterium would enable us to determine these important quantities as $|a|$ and $|b|$.

If bound states of the nucleons and hyperons exist there will be discrete lines in addition to the continuous portion of the pion energy spectrum. We obtain as the corresponding cross sections

$$d\sigma_t = \left(|a|^2 + \frac{2}{3}|b|^2\right) 2\frac{\sqrt{\alpha\beta_t}}{\varkappa}\,\mathrm{arctg}\,\frac{\varkappa}{\alpha + \beta}, \tag{9}$$

$$d\sigma_s = \frac{1}{3}|b|^2 2\frac{\sqrt{\alpha\beta_s}}{\varkappa}\,\mathrm{arctg}\,\frac{\varkappa}{\alpha + \beta_s}.$$

In connection with the capture of a K^-–meson from the K-shell or from the continuous spectrum, but with emission of a pion at a small angle with relation to the K-meson momentum, certain conclusions can be reached regarding the magnitudes of a and b (see the Table). Here P_K and S_K are the parity and spin of the K-meson; P_Y is the parity of the hyperon relative to the nucleon.

For the study of the interactions between Ξ-particles and nucleons we can use the reactions

$$K^- + d \to K^+ + \Xi^- + n, \quad K^- + d \to K^0 + \Xi^- + p$$

along with the corresponding reactions with protons. These reactions are impossible in connection

P_y \ S_k, P_k	0^+	0^-	1^+	1^-
+1	$a = 0$	$b = 0$	$a \neq 0$, $b \neq 0$	$a = 0$
—1	$b = 0$	$a = 0$	$a = 0$	$a \neq 0$, $b \neq 0$

with the capture of K^--mesons from the K-shell because of the energy threshold.

We note in conclusion that the interaction between nucleons and hyperons could also be studied by investigating the energy spectrum of K-mesons in reactions such as[3]

$$p + p \to \begin{cases} p + \Lambda + K^+ \\ p + \Sigma^+ + K^0 \end{cases} \text{или } p + n \to \begin{cases} n + \Lambda + K^+ \\ n + \Sigma^+ + K^0 \\ p + \Sigma^- + K^+ \end{cases}$$

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Spectra of Neutrons Produced by Bombarding Light Nuclei with 14 mev Deuterons

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In the previous work of our laboratory[1] it was found that the spectra of neutrons, produced by bombarding tritium and deuterium with 14 mev deuterons, are not monchromatic. Besides the neutron groups, corresponding to the production of