ЛАБОРАТОРИЯ ТЕОРЕТИЧЕСКОЙ ФИЗИКИ

ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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Abstract

The electromagnetic transition $\Lambda \to \Sigma^\circ$ which is interesting in investigating possibilities of experimental determination of the Σ° particle life time and of testing charge independence for strange particles (reactions $\Lambda + He^4_2 \to \Sigma^\circ + He^4_2$, $\Lambda + d \to \Sigma^\circ + d$) is considered.

A part of the matrix element corresponding to the electromagnetic transition $\Sigma^\circ \to \Lambda + \gamma$ can be written in the form[1]:

$$\bar{u}(p_\Lambda)\,[\,f(k^2)\,\sigma_{\mu\nu}k_\nu + g(k^2)\,k_\mu + h(k^2)\,\gamma_\mu]\;a_\pm\;u(p_\Sigma)$$

$$k = p_\Lambda - p_\Sigma$$

$a_\pm = 1$ or γ_5 depending upon the relative parity of Σ° and Λ . Owing to the gauge invariance the term $g(k^2)\,k_\mu$ does not contribute and $h(0) = 0$. The probability of the decay is thus determined by the only quantity f, possessing dimension of the magnetic moment.

The direct methods of measurement of the lifetime of Σ° (by decay distance) can turn out to be inapplicable because the lifetime of the Σ° particle is very short :

$$\frac{1}{\tau} = \frac{f^2\omega^3}{\pi}\,, \quad \omega = \frac{M^2_\Sigma - M^2_\Lambda}{2M_\Sigma}\,, \hbar = c = 1,\; \frac{e^2}{4\pi} = \frac{1}{137}$$

i.e. $\frac{1}{\tau} = 4\cdot 10^{18}\left(\frac{f}{\mu_0}\right)^2$ sec^{-1}, $\quad \mu_0 = \frac{e}{2M}$

M being the nucleon mass. $\left(\frac{\hbar}{\tau} \approx 3\left(\frac{f}{\mu_0}\right)^2 \text{ kev}\right)$

The evaluation of the quantity f similar to those of the magnetic moments of hyperons in the paper[2] yields $f \approx 2\,\mu_0$, if we assume the coupling constants in interaction of π- mesons with hyperons and the cutoff momentum to be similar as in the case of the interaction of π - mesons with nucleons.

From reversibility considerations it follows that the transition $\Lambda \to \Sigma^\circ$ for small k^2 ($k^2 \lesssim m^2_\pi$) is determined by the same quantity as the decay, since $f(k^2) \approx f(0)$, $h(k^2) \approx 0$. To define the lifetime of Σ° it is natural therefore to use an inverse transition which can be carried out in the interaction of the Λ- particle with electron and the Coulomb field of a nucleus. This idea is similar to that of Primakoff on the determination of the lifetime of π° meson[3]. Such possibility of determination of the lifetime of Σ° has been pointed out also by I.Y.Pomeranchuk and I.M.Shmushkevich[4]* .

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Since in collisions of Λ particle with nucleons the transition $\Lambda \to \Sigma^\circ$ is possible owing to strong interactions, the cross section on nucleon being about 10^{-26}, see[5], then it would be most natural to use the Λ - particle excitation in colliding with electron. The corresponding differential cross section

$$d\sigma = 2\alpha f^2 \frac{dk}{k} = \alpha f^2 \frac{dT}{T}, \quad \alpha = \frac{1}{137}$$

$T = \frac{k^2}{2m_e}$. is the energy transferred to the electron if in the beginning it was at rest. However , the threshold of the reaction $\Lambda + e \to \Sigma^\circ + e$ is about 170 BeV. Differential cross section for the excitation of the Λ- particle in the point Coulomb field is

$$d\sigma^{(\pm)} = Z^2 \alpha f^2 S(\pm) \frac{dk}{k} = Z^2 \alpha f^2 S(\pm) \frac{p_\Lambda p_\Sigma}{k^2} d\cos\Theta$$

$$\cos\Theta = \frac{\vec{p}_\Lambda \vec{p}_\Sigma}{p_\Lambda p_\Sigma}, \quad S^{(\pm)} = 1 + \beta_\Lambda \beta_\Sigma \cos\Theta - \frac{2(\bar{k}\cdot\bar{p}_\Lambda)(\bar{k}\,\bar{p}_\Sigma)}{k^2 \mathcal{E}_\Lambda \mathcal{E}_\Sigma} \mp \frac{m_\Lambda m_\Sigma}{\mathcal{E}_\Lambda \mathcal{E}_\Sigma}$$

$$\beta_\Lambda = \frac{p_\Lambda}{\mathcal{E}_\Lambda}, \quad \beta_\Sigma = \frac{p_\Sigma}{\mathcal{E}_\Sigma}$$

All the quantities are in the Lab.sys., ($\pm$) correspond to the $\pm$ relative parity of Λ and Σ°. For the case of a nucleus it is necessary to introduce the multiplier $F^2(k^2)$ into the expression for $d\sigma$, where $F(k^2)$ is the formfactor of the nucleus which can be determined from experiments on the scattering of electrons on the nucleus.

By introducing the quantity $\delta = p_\Lambda - p_\Sigma / p_\Lambda = (M_\Sigma - M_\Lambda) M_\Lambda / p^2_\Lambda$ and assuming that $\delta << 1$, $\beta_\Lambda = \beta_\Sigma = \beta$ it is easy to obtain for small angles (just these angles give the main contribution into the cross section) the following formulas :

$$d\sigma^{(+)} = Z^2 \alpha f^2 \beta^2 \frac{\Theta^2 d\Theta^2}{(\delta^2 + \Theta^2)^2}$$

$$d\sigma^{(-)} = Z^2 \alpha f^2 [\Theta^2 + \delta^2(1-\beta^2)] \frac{d\Theta^2}{(\delta^2 + \Theta^2)^2}$$

From the formulas obtained it is seen that $\frac{d\sigma}{d\Theta^2}$ ($\frac{d\sigma}{d\Theta^2} = \pi \frac{d\sigma}{d\Omega}$) has a sharp peak for $\Theta \approx \delta$ with the width $\sim\delta$ and the total cross section increases slowly (logarithmically).

$$\left(\frac{d\sigma}{d\Theta^2}\right) = Z^2 \alpha f^2 / 4\delta^2$$

increases fast with the energy increase of the Λ- particle and can in principal exceed (for $\Theta \sim \delta$) the cross section of the transition $\Lambda \to \Sigma^{\circ}$ owing to strong interactions. It is not difficult to evaluate the corresponding energy of the Λ-particle. We assume that the strong transition $\Lambda \to \Sigma^{\circ}$ is connected to the exchange by quanta with the rest mass m. Then it is easy to obtain that $(d\sigma)_{strong} = \sigma_o \frac{p^2_\Lambda}{m^2} \frac{d\Theta^2}{(1+\frac{p^2_\Lambda \Theta^2}{m^2})^2}$

where σ_o being the total cross section. It is natural to assume that σ_o does not change strongly with the energy increase and remains of the geometric order / $\sigma_o \sim 2\pi A^{2/3} 10^{-26}$ cm^2 /. Under these assumptions it turns out that $d\sigma$ (electromagnetic) becomes of the order of $d\sigma$ (strong) for $p_\Lambda \sim 20$ BeV, $\Theta \sim 10^{-4}$ and for $Z = 90$, $A = 200$; the recoil nuclear energy in this case is ~ 50 ev. (We assumed $f = 2\mu_o$, $m = 2m_\pi$).

It is possible however to decrease strongly the contribution from strong interactions if we choose as a target nuclei with equal number of neutrons and protons ($I_3 = 0$), since for the system Z with the definite isotopic spin I and $I_3 = 0$ the transition $\Lambda + Z \to \Sigma + Z$ is forbidden if the isotopic spin invariance takes place. The presence of Coulomb forces leads to the fact that the nucleus states are not exact eigenstates of $\hat{I}^2$, i.e. there are admixtures of states with other I. From this point of view He^4_2 and deuterium are most suitable. For He^4_2 it can be assumed that $|He^4_2\rangle = |I = 0\rangle + \gamma|I = 1\rangle$. A rough estimation gives $|\gamma|^2 \lesssim 10^{-3}$.

If we restrict ourselves to the really measurable angles $\Theta \sim 0{,}5^{\circ}$ which corresponds to $p_\Lambda \sim 3$ BeV and to the recoil energy $\sim 0{,}2$ MeV then when $|\gamma|^2 \lesssim 10^{-3}$ we obtain for He^4_2 by analogy with the evaluation made above:

$$\frac{\left(\frac{d\sigma}{d\Theta^2}\right)_{electromagnetic}}{\left(\frac{d\sigma}{d\Theta^2}\right)_{strong}} \gtrsim 1$$

(in evaluating we do not take into account the interference. But it is easy to write a general expression for $d\sigma$ too). Thus, under the conditions indicated it is possible in principle to separate experimentally the electromagnetic transition, through the cross sections $\sim 10^{-30}$ cm^2 have to be measured.

Besides the coherent strong transition considered non-coherent processes, for example $\Lambda + He^4_2 \to He^3_2 + n + \Sigma^{\circ}$ will occur. By choosing events with the low-energy nucleus recoil we can decrease the contribution of these processes. Furthemore, the angular dependence for such processes will be comparably smooth, as in the case of bremsstrahlung of the Λ- particle. The latter can be apparently neglected.

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References

1. G.Feldman and T.Fulton. Nucl.Phys. 8, 106 (1958).
2. W.G.Holladay. Phys.Rev. 115 , 1331 (1959).
3. H.Primakoff. Phys.Rev. 81 , 899 (1951). A.V.Tollestrup et al. Proceeding of the 1960 Rochester Conference.
4. I.Y.Pomeranchuk and I.M.Shmushkevich (in print). Nucl.Phys.
5. M.Cresti et al. Phys.Rev.Lett. 2, 174 (1959).