ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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LIMITS FOR A POSSIBLE MAGNETIC MOMENT OF THE K^{o} MESON

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Abstract

According to the experimental data obtained at the synchrophasotron of the Laboratory of High Energies[3], the upper and lower limits of a possible magnetic moment of the K° have been estimated to be $0.04\ \mu_\circ \gtrsim \mu \gtrsim 20\ \mu_\circ$, where $\mu_\circ = \frac{h}{2\pi}\left(\frac{e}{M_k}\right)$.

It has been shown that the values $\mu \geq 20\ \mu_\circ$ lead to an anomalously great cross section for the K° $(\tilde{K}^\circ)$ meson production.

Experimental data available so far indicate that the K° spin is zero. However, as it was noticed by Eberhardt and Good/1/, the problem concerning the K° meson spin cannot be considered as finally solved since more or less arbitrary assumptions of the dynamical nature were used in analyzing the available experimental results*.

Quite a definite conclusion can be made only from the existence of the $K_1^\circ \to 2\pi^\circ$ decay/2/, it follows anambiguously herefrom that the K° spin is even.

Evidently, the K° meson with the nonzero spin should have also a magnetic moment.

In this connection it is interesting to estimate the limits of the magnitude for a possible K° magnetic moment according to the results obtained from the experiment recently performed at the Joint Institute synchrophasotron/3/. Some years ago it was shown by M. Good that if the K° has a magnetic moment, in the passage of the K_2° particles through the magnetic field, there will take place the regeneration of the short-lived K_1° component followed by the decay into 2π mesons/4/.

Indeed, the K_2° particle is a mixture of two states of the K° and anti- K° mesons, for which (according to CPT invariance) for a definite orientation of the K_2° spin, the magnetic moments must have opposite directions with respect to the spin. In the transverse magnetic field H there arises an energy difference $\Delta E = 2m\mu H$ between these states **, which leads to the phase shift between the K° and $\tilde{K}^\circ$. As a result, some of the K_2°'s turn into the K_1°'s and just decay into 2π ***.

In this case the behaviour of the K_1° and K_2° is described by the equations

$$\frac{d\psi_1}{dt} = iM_1\psi_1 - \frac{\lambda_1}{2}\psi_1 - \frac{m\mu H}{h}\psi_2 ,$$

$$\frac{d\psi_2}{dt} = iM_2\psi_2 - \frac{\lambda_2}{2}\psi_2 + \frac{m\mu H}{h}\psi_1$$

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* Taking this circumstance into account, the authors suggested an experiment for determining the K° spin in which no other assumptions are being used but the rules of quantum mechanics and the angular momentum conservation.

** Here m is the spin projection along the direction of the magnetic field (the magnetic quantum number); if the K° spin is 2, then $m = 0, \pm 1, \pm 2$.

*** In the following, this effect will be referred to as 'Good effect' for the sake of brevity.

where M_1, λ_1 and M_2 λ_2 are the masses and the decay constants of the K_1° and K_2° mesons respectively. In solving these equations, we restrict ourselves (just as it was done in[5]) to the first term of expansion since the time of the $K_2^\circ \to K_1^\circ$ transition is great if compared with the lifetime of the K_1° meson ($\frac{2m\mu H}{\hbar} / \lambda_1 << 1$). If we also neglect the strongly dampling exponent term of the order of $\exp(-\lambda_1 t)$ then, for the number of the K_2° mesons at t we get

$$N_{K_2^\circ}(t) = N^{\cdot}_{(t=0)} \exp\{-\frac{\lambda_2}{\gamma} t - \frac{\gamma}{\hbar^2} \frac{\lambda_1(2m\mu H)^2}{(4(M_1-M_2)^2+\lambda_1^2} t\} 1. \qquad (1)$$

As we see from this expression, the K_2° mesons possessing the magnetic moment decay faster in the magnetic field and the second term in the exponent describes the decreasing of the number of the K_2°'s due to their transformation into the K_1°'s. At the same time the ratio of the number of the K_1° decays arising as a result of the 'regeneration') to that of the K_2° decays is

$$\frac{n_{K_1^\circ}}{n_{K_2^\circ}} = \frac{\gamma^2}{\hbar^2} \frac{\lambda_1}{\lambda_2} \frac{(2m\mu H)^2}{(4(M_1-M_2)^2+\lambda_1^2)} \qquad (2)$$

During the analysis of the experimental data[3] it should be taken into account that in the experiment we are considering now the K_2° mesons before arriving at the chamber travel a distance of more than 100 cm in the magnetic field of the accelerator ($H' \approx 10^4$ gauss)*. In this case, as it can be easily seen, the K_2° mesons having a magnetic moment are getting polarized in the direction of the magnetic field.

Indeed, due to the 'Good effect' the K_2° mesons in the states with the magnetic quantum number $m \neq 0$ are gradually transforming into the K_1° mesons in the magnetic field and decay immediately before entering the chamber. As for the states with $m = 0$, they should not be affected by the magnetic field either in the accelerator magnet, or in the analyzing magnet of the chamber as far as the directions of these magnetic fields coincide.

We also assume that in the K° particle production by protons ($E_p \sim 9$ BeV) on the lead nucleus there is no whatever considerable polarization with respect to the plane formed by the momentum of the incident proton and that of the generated K° meson. This assumption is quite reasonable since this plane is not, in general, that of production due to the nucleon motion in a nucleus.

In the experiments pertaining to the 'strange' particle production on nuclei there was not observed a noticeable 'transverse' polarization of hyperons (See, for instance,[6]).

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* The effect of the additional 'clearifying' magnet used in this experiment can be neglected.

Under these conditions the account of the 'polarization' effect of the accelerator magnetic field yields the following expression for the relative number of the K_1° mesons arising and decays in the magnetic field of the chamber

$$\frac{n_{K_1^\circ}}{n_{K_2^\circ}} = \frac{\sum_{m} \gamma^2\hbar^2 \frac{\lambda_1 (2m\mu H)^2}{\lambda_1^2 + 4(M_1 - M_2)^2} \exp\left(-\frac{\gamma}{\hbar^2} \frac{\lambda_1 (2m\mu H')^2}{\lambda_1^2 + 4(M_1 - M_2)^2} \ell/v\right)}{\sum_{m} \lambda_2 \exp\left(-\gamma/\hbar^2 \frac{\lambda_1 (2m\mu H')^2}{\lambda_1^2 + 4(M_1 - M_2)^2} \ell/v\right)} \qquad (3)$$

Here, besides the well-known notations, ℓ is the length of the K_2° range in the magnetic field of the accelerator, v is the velocity of these particles($v \sim 1.7.10^{10}$ cm/sec - for the average K_2° energy of ~ 100 MeV), and $m = 0, \pm 1, \pm 2$

In this experiment among the 600 K_2° decays detected in the chamber ($H \sim$ 15000 gauss) there were observed no $K^\circ \to \pi^- + \pi^+$ decay.

This result enables us, by using formula (3), to estimate the upper limit of the K° magnetic moment which turned out to be $\mu \leq 0.04\ \mu_\circ$ (where $\mu_\circ = \frac{h}{2\pi} \left(\frac{e}{M_K}\right)$ is the K-meson magneton')*

As is seen from formula (3), for a large magnetic moment of the K° meson, $\frac{n_{K_1^\circ}}{n_{k^\circ}}$ is getting smaller since the K_2° mesons with $m = 0$, in the main, enter the chamber.

So, for $\mu > 20\ \mu_\circ$ under the experimental conditions, not a single K_1° decay can be expected among the 600 decays of the K_2°. Evidently, the beam intensity of the K_2° particles striking the chamber will be decreased by a factor of 5 due to the 'Good effect'.

By using the results of [10], we estimate the cross section for the K_2° production at an angle of ~ 100° on the lead nucleus by 9 BeV protons. Assuming that all the accelerated protons interact with the target, we get $\left(\frac{d\sigma}{d\Omega}\right)_{K^\circ} \approx (1-2)$ mb/ sterad .

At the same time the corresponding cross section for the K^+ mesons [11] (recalculated to the lead nucleus and to the corresponding angular interval) was found to be $\left(\frac{d\sigma}{d\Omega}\right)_{K^+} \approx$ (1.5 - 2) mb/sterad**.

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* In the calculations the relative fractions of the neutral decays of K_1° and K were supposed to be equal what does not contradict the available experimental data [7,8]. We also assumed that $|M_1 - M_2| = 0.84\ h\lambda$ [9].

** According to the statistical distributions, this estimate supposes that in the experiment described in [11], more than a half of all the K^+ emitted at 100° were detected.

If the K_2° beam had been weakened because of great μ, then $\left(\frac{d\sigma}{d\Omega}\right)_{K^\circ} = (5 \div 10)\ mb/sterad$ what already contradicts esssentially the data on the K^+ -mesons.*

Thus, the assamption about a large magnetic moment seems unlikely not only in view of general considerations, but also because it leads to an anomalously great cross sections for the $K^\circ (\tilde{K}^\circ)$ meson production.

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* In fact, this descrepancy is still greater since not all the accelerated protons interact with the target.