DECAY $\pi \to \mu + \nu$ IN THE FIELD OF A PLANE ELECTROMAGNETIC WAVE WITH ALLOWANCE FOR THE POLARIZABILITY OF THE PION

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UDC 539.12:530.145

The process $\pi \to \mu + \nu$ in the field of a plane electromagnetic wave is investigated with allowance for the complex structure of the pion. Exact values are obtained for the probability of pion decay in circularly and elliptically polarized fields. Pion structure effects become observable for $\chi \sim 5$, where $\chi = e\sqrt{(F_{\mu\nu}p_\nu)^2}/m^3$.

The role of quantum effects in an external electromagnetic field poses a timely problem in connection with the application of lasers as sources of high-power electromagnetic radiation, the investigation of phenomena involving the transmission of high-energy particles through crystals, and the study of astrophysical fields. An external electromagnetic field is known to affect the probabilities of decay of elementary particles [1], which, in turn, exhibit a strong dependence on the decay energy. As an example, for small values of $\chi = e\sqrt{(F_{\mu\nu}p_\nu)^2}/m^3$ the probability of the decay

$$\pi \to \mu + \nu \tag{1}$$

increases, and the probability of

$$\pi \to e + \nu \tag{2}$$

decreases [2]. The method of exact solutions is used in studying elementary particle decays in external fields, because it is applicable to fields of any strength. In the case of particle motion in a magnetic field, inasmuch as vacuum is stable, it is even possible to investigate field strengths H above the critical value $H_{cr} = 4.41 \cdot 10^{13}$ G (there is now evidence of the possible existence of fields with $H \sim 10^{18}$ G in the depth of pulsars).

The decay (1) has been investigated previously [2, 3] for a point pion in electromagnetic fields with different polarizations. However, the pion is known to have a quark structure and is not a point particle. This attribute shows up in its behavior in an external magnetic field. The additional characteristic associated with the structure of the particle is taken into account by introducing the electric and magnetic polarizability coefficients of the composite particle [4]. For large field strengths approaching 10^{17} G, phenomena associated with the nonpoint character of the particle can provide contributions of the order of several percent to the probability of neutron beta decay [5].

We now derive an expression for the probability of the decay (1), based on the exact solution of the wave equation for a scalar particle with polarizability in the field of a plane electromagnetic wave [6].

The amplitude of the process (1), written in the contact approximation of the Weinberg–Salam–Glashow model, has the form

$$A = \frac{G}{\sqrt{2}} f_\pi \cos\theta_c \int d^4x \Psi_\pi P_\pi^\alpha \tilde{\Psi}_\mu \gamma_\alpha (1 + \gamma_5) \Psi_\nu,$$

where $P_\pi^\alpha = i\partial_\alpha - eA_\alpha$ is the kinetic momentum of the pion, G is the Fermi constant, θ_c is the Cabibbo angle, f_π is a parameter with the units of mass, which takes the virtual strong interactions of the pion into account, and Ψ_j is the wave function of the j-th particle in the external field ($j = \pi, \mu, \nu$).

We begin the analysis with the case of a circularly polarized electromagnetic wave, because the resulting probability expressions are simpler. In this case the external electromagnetic field has the form

State University, Grodno. Institute of Physics, Academy of Sciences of the Belorussian SSR. Translated from Izvestiya Vysshikh Uchebnykh Zavedenii, Fizika, No. 12, pp. 65-68, December, 1991. Original article submitted July 30, 1991.

0038-5697/91/3412-1101$12.50

$$A_\sigma = a_{1\sigma}\cos\varphi + \varepsilon a_{2\sigma}\sin\varphi, \tag{3}$$

where $\varphi = (kx)$; $\varepsilon = +1$ or -1 for right- or left-hand polarization of the wave, respectively. The following relations also hold:

$$(\kappa a_1) = (\kappa a_2) = (a_1 a_2) = \kappa^2 = 0,$$
$$(a_1)^2 = (a_2)^2 = a^2.$$

The wave functions of particles in the field (3) are given by the expressions

$$\Psi_\pi = \frac{1}{\sqrt{2q_0}}\exp\left\{i\left[x_\sigma q_\sigma + \frac{e}{(\kappa p)}[(pa_1)\sin\varphi - \varepsilon(pa_2)\cos\varphi]\right]\right\};$$

$$\Psi_\mu = \left[1 + \frac{e\hat{\kappa}\hat{A}}{2(\kappa p')}\right]u(p')\exp\left\{i\left[x_\sigma q'_\sigma + \frac{e}{(\kappa p')}[(p'a_1)\sin\varphi - \varepsilon(p'a_2)\cos\varphi]\right]\right\};$$

$$\Psi_\nu = u(l)\exp\{ix_\sigma l_\sigma\},$$

where q_σ and q'_σ are the quasimomenta of the pion and muon, respectively, and are given by the expressions

$$q_\sigma = p_\sigma - \left[\frac{e^2a^2}{2(\kappa p)} - \frac{(\alpha+\beta)(\kappa p)a^2}{2m}\right]\kappa_\sigma; \quad q'_\sigma = p'_\sigma - \frac{e^2a^2}{2(\kappa p')}\kappa_\sigma,$$

where p_σ, p'_σ, and ℓ_σ are the 4-momenta of the pion, muon, and neutrino, respectively, and α and β are the dipole and magnetic polarizability coefficients of the pion, for which the following values have been obtained experimentally [7]:

$$\alpha + \beta = (1{,}4 \pm 5{,}5)\cdot 10^{-4}\ \mathrm{F\cdot m^3}.$$

Summation over the polarizations and integration with respect to the momenta of the final particles yield an expression for the total pion decay probability:

$$W_\varepsilon = \frac{G^2 f_\pi^2 m^2 m'^2}{8\pi q_0}\sum_{s>s_0}\int_0^{u_s}\left\{\left[\Delta - \frac{(\alpha+\beta)\chi^2 m^3}{e^2}\right]J_s^2(z) + \frac{x^2u}{2}[J_{s-1}^2(z) + J_{s+1}^2(z) - 2J_s^2(z)] + \right.$$
$$\left. + \varepsilon\left(\frac{x^2us}{z} - \frac{\chi z}{s}\right)J_s(z)[J_{s-1}(z) - J_{s+1}(z)]\right\}\frac{du}{(1+u)^2}, \tag{4}$$

where m and m' are the pion and muon masses, respectively, $\Delta = 1 - (m'/m)^2$, and

$$s_0 = \frac{x[-\Delta + (\alpha+\beta)\chi^2 m^3/xe^2]}{2\chi};$$

$$u_s = \left[x\Delta + 2s\chi - \frac{(\alpha+\beta)\chi^2 m^3 x}{e^2}\right] \Big/ x(1 - \Delta + x^2); \tag{5}$$

$$z^2 = \frac{x^4 m'^2 u(u_s - u)(1+x^2)}{\chi^2 m^2}, \quad x = \frac{ea}{m}.$$

For $x \ll 1$ (arbitrary χ) the most sensitive quantity to the structure of the pion is the sum $W_1 + W_{-1}$ of the decay probabilities in left- and right-hand polarized electromagnetic fields.

A comparison of Eq. (4) and the expression for the decay probability of a point pion shows that the effects of its structure become significant for

$$\frac{(\alpha+\beta)\chi^2 m^3}{e^2} \sim 10^{-2},$$

i.e., for $\chi \sim 5$. In high-power lasers χ attains values of the order of unity. We see, therefore, that in order to study the complex structure of the pion under laboratory conditions, it is more promising to consider reactions such as

$$\pi^\pm \to \pi^0 + e^\pm + \nu,$$

which takes place with a smaller energy release than the process (1), so that its field sensitivity is higher [2].

The expressions for the decay probabilities are far more complicated in elliptically and linearly polarized fields. For example, in the case of a linearly polarized wave we have

$$W = \frac{G^2 f_\pi^2 m^2 m'^2}{16\pi^2 q_0} \sum_{s>s_0} \int_0^{2\pi} d\varphi \int_0^{u_s} \left\{ \Delta A_0^2 + ux^2 \left[A_1^2 - A_0 A_2 \left[1 - \frac{(\alpha+\beta)\chi^2 m^3 u}{x^2 e^2} \right] \right] \right\} \frac{du}{(1+u)^2},$$

where

$$A_n(s\beta\tau) = \frac{1}{2\pi} \int_{-\pi}^{\pi} \cos^n\theta \exp[f(\theta)]\, d\theta;$$

$$\beta = e\left[\frac{(ap)}{(\kappa p)} - \frac{(ap')}{(\kappa p')}\right], \quad \tau = -\frac{e^2 a^2}{8}\left[\frac{1}{(\kappa p')} - \frac{1}{(\kappa p)} - \frac{(\alpha+\beta)(\kappa p)}{me^2}\right];$$

$$f(\theta) = i(\beta\sin\theta - \tau\sin 2\theta - s\theta);$$

is the angle between the (κ, q') and (κ, a) planes in the center-of-mass system, and s_0, u_S, and z are obtained from the corresponding expressions for a circularly polarized wave by making the substitution $(\alpha + \beta) \to (\alpha + \beta)/2$.

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MONITORING ENVIRONMENTAL ELECTROMAGNETIC FIELDS.
1. REMOTE-SENSING METHODS

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UDC 550.3+551.5

This paper discusses monitoring electromagnetic fields (natural and artificial) in the atmosphere. Methods are described for remote sensing of the atmosphere and surface in order to examine static and alternating electromagnetic-energy fluxes in the biosphere.

1. PURPOSES

Static and alternating electromagnetic fields occur in various frequency ranges and with various origins in the environment.

Academician Vernadskii observed that "electromagnetic fields surround us, always and everywhere, without interruption, which are eternally changing and colliding and involve radiations with various wavelengths" [1]. Electromagnetic fields are factors that have influenced the evolution of all living nature. They are particularly important because of their effects on the gas and aerosol components of the biosphere and thus influence the ecological setting. Electromagnetic radiations in various ranges govern not only the behavior of all members of the biosphere but also the evolution of them on various scales in space and time.

Biomedical research on atmospheric electromagnetism is important because of the levels of natural and industrial electromagnetic fields, which have various effects on biological systems. The levels of these fields in the atmosphere make it necessary to estimate the permissible levels in the radio frequency and optical ranges in the interests of safety. During recent decades, advances in power engineering and data-transmission systems have increased

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Translated from Izvestiya Vysshikh Uchebnykh Zavedenii, Fizika, No. 12, pp. 69-79, December, 1991. Original article submitted September 6, 1991.