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A b s t r a c t

It is shown that the particles with different spin projections on the direction of a magnetic field are spatially separated when the electrons with energy of up to hundreds of GeV are passing through a megagauss magnetic field.

In the present paper we want to draw attention to the possibility of obtaining the polarized electrons at ultrahigh energies with the use of strong magnetic field. The effect becomes already noticeable when $\chi \sim 0,05$ (a parameter $\chi = \frac{H}{H_0}\frac{\varepsilon}{m}$, H is the magnetic field, $H_0 = \frac{m^2}{e} = 4,41 \cdot 10^{13}$ Oe, ε is the energy of an electron, m is its mass). At the electron energy $\varepsilon = 250$ GeV (secondary beams of accelerators FNAL, CERN II) the magnetic field $H \sim 4$ MG is necessary to obtain $\chi \sim 0,05$. At present, megagauss fields of that kind in small volumes and for a short time (not shorter than transit-time of particles) are obtained by the explosive means. Similar devices - magnetic converters - have been thoroughly discussed (see, for example /1/). The method under consideration essentially broadens the possibilities of magnetic converters since both photons (whose maximum of the spectral distribution for $\chi \lesssim 1$ lies at $\omega \sim \varepsilon\chi$) and secondary electrons can be used in these converters, what is of importance, especially if one takes into account the complexity of producing the electrons at ultrahigh energies.

The electron distribution function $\rho_{\zeta}(\varphi, \varepsilon, t)$ with respect to the deviation angle φ in a magnetic field and the energy ε at the depth t is determined by the kinetic equation. We shall be interested in the distribution with respect to the angle φ depending on the polarization of an electron ζ (the direction of a magnetic field is the axis of the spin quantization, $\zeta \equiv \zeta_H = \pm 1$). As in the paper /2/ by the present authors, let us find the distribution moments, making use of the probabilities of the process with the spin terms (see ref./3/)

and confining ourselves to the lowest order in χ in which the phenomenon reveals. In this approximation we neglect the spin-flip transitions what means, in particular, that the number n_ζ of particles having an appropriate projection ζ is conserved.

Let us define

$$u(\zeta, n, K) \equiv \int \frac{\rho_\zeta(\varphi, \varepsilon, t)\, \varphi^n \varepsilon^K}{\varepsilon_0^K n_\zeta} d\varphi\, d\varepsilon \qquad (1)$$

The first two terms of the expansion $u(\zeta, n, K)$ in powers of χ

$$u(\zeta, n, K) = u^{(0)}(\zeta, n, K) + \chi_0 u^{(1)}(\zeta, n, K) + \dots \qquad (2)$$

satisfy the system of equations

$$\frac{du^{(0)}(\zeta, n, K)}{dz} = -K u^{(0)}(\zeta, n, K) + n\beta u^{(0)}(\zeta, n-1, K-1)$$

$$\frac{du^{(1)}(\zeta, n, K)}{dz} = -K u^{(1)}(\zeta, n, K+1) + n\beta u^{(1)}(\zeta, n-1, K-1) +$$

$$+ K\left(b + c(K+1)\right) u^{(0)}(\zeta, n, K+2) \qquad (3)$$

where $z = t\,\frac{I_0}{\varepsilon_0}$, $I_0 = \frac{2}{3}\alpha m^2 \chi_0^2$ is the classical intensity of the radiation, ε_0 is the initial energy $(\chi_0 \equiv \chi(\varepsilon_0))$, $\beta = \frac{eH}{I_0}$, $b = 4c + \frac{3}{2}\zeta$, $c = \frac{55}{32\sqrt{3}}$

In what follows we shall need the expressions for the mean value φ: $\langle\varphi\rangle_\zeta \equiv u(\zeta, 1, 0)$; the dispersion of a distribution over φ: $\Delta^2 = \langle\varphi^2\rangle_\zeta - \langle\varphi\rangle_\zeta^2$ and of the mean energy $\langle\varepsilon\rangle$:

$$\langle\varphi\rangle_\zeta = \frac{\beta z(z+2)}{2}\left[1 - \frac{2\chi_0 b}{z(z+2)}\left((z+1)L - z\right)\right]$$

$$\Delta^2 = \frac{2}{3}\beta^2 c\, z^3 \chi_0$$

$$\langle\varepsilon\rangle = \frac{\varepsilon_0}{1+z}\left[1 + \frac{\chi_0}{1+z}\left(bL + \frac{2cz}{1+z}\right)\right] = \varepsilon_0 u(\zeta, 0, 1) \qquad (4)$$

where $L = \ln(1+z)$. From the formula (4) it is seen that the particles, having different projections ζ deviate at different angles, namely:

$$\langle\varphi\rangle_{\zeta=-1} - \langle\varphi\rangle_{\zeta=+1} = 3\beta\chi_0\left[(z+1)L - z\right] \equiv 2\varphi_1 \qquad (5)$$

and the distribution width given by the equation (4) does not depend on the value ζ. This means that the particles with a different polarization are spatially separated.

From the known moments of the distribution one can, in principle, reconstruct the distribution function. However, we have, in fact, only a few first terms of the expansion of the distribution moments in powers of χ_0. In such a situation the problem of reconstruction of the distribution function proves to be sufficiently "delicate" and the analysis of the kinetic equations is required; the authors are going to discuss this question elsewhere. For simple estimations we make use here of the Gaussian distribution function of the same type as in /2/:

$$\rho_\pm = n_\pm \frac{1}{\sqrt{2\pi\Delta^2}} \exp\left\{-\frac{(\varphi - \varphi_0 \pm \varphi_1)^2}{2\Delta^2}\right\} \qquad (6)$$

where $2\varphi_0 = \langle\varphi\rangle_+ + \langle\varphi\rangle_-$, $\rho_+ \equiv \rho_{\zeta=+1}$, etc. Then the degree of the beam polarization for particles deviating at the angle larger than α is given by the expression

$$\xi := \frac{\int_{\alpha}^{\infty} d\varphi \left[\rho_-(\varphi) - \rho_+(\varphi) \right]}{\int_{\alpha}^{\infty} d\varphi \left[\rho_-(\varphi) + \rho_+(\varphi) \right]} \tag{7}$$

In particular, for $\alpha = \varphi_0$ we get

$$\xi = \frac{2}{\sqrt{\pi}} \int_0^{\delta} dz\, e^{-z^2} \equiv \varphi(\delta) \tag{8}$$

where

$$\delta = \frac{\varphi_1}{\sqrt{2\Delta^2}} = 1.3\sqrt{\chi_0}\, f(z), \quad f(z) = \frac{(z+1)\ln(1+z) - z}{z^{3/2}} \tag{9}$$

$f(z)$ is the smooth function, in the maximum when z_m = 7.6, f_m = 0,52; and $f(0,5)$ = 0.31, $f(1)$ = 0.39, $f(2)$ = 0,46. Note that the energy of a particle at the depth z (see (4)) is $\varepsilon \sim \frac{\varepsilon_0}{1+z}$.

For χ = 0,1 (χ = 0,05) we have from (8) the degree of polarization ξ = 0,18 (ξ = 0,13) when z = 1 and ξ = 0,21 (ξ = 0,15) when z = 2. A relatively small degree of polarization is due to the fact that the electron distribution with ζ = 1 and ζ = - 1 are greatly overlapped and when $\alpha = \varphi_0$ all the secondary particles are actually used. To obtain the beam of particles with a larger polarization it is necessary to select the particles whose deviation angle significantly differs from φ_0. For instance, for $\alpha = \varphi_0 + \varphi_1 + \sqrt{2}\Delta \equiv \alpha_1$ we have ξ = 0,43 (ξ = = 0,31) when z = 1, and ξ = 0,49 (ξ = 0,37) when z = 2; in this case, 11% (12%) of particles deviate at the angle larger than α_1 when z = 1 and z = 2. Moreover, with such a selection the collinearity requirements for the initial particle momenta become less stringent and the formation of a beam of secondary particles is simplified (in the above examples the difference of the angles $\alpha_1 - \varphi_0 \sim 10^{-3}$). Note that if z = 1 the path length in a magnetic field is about 1.6 cm when ε = 250 GeV and χ = 0,05.

Above we have restricted ourselves to the first order of the expansion in powers of χ. It is interesting to know what changes will occur when taking into account the following terms of the expansion. In the order χ^2 the radiative polarization mechanism will begin to work; due to this mechanism the degree of polarization of the beam as a whole at the chosen values of χ and z turns out to be significant, attaining $\sim$ 0,1. So, it is seen that it is desirable to consider the polarization phenomenon in the following orders in χ. In this case, it should be borne in mind that the change of a picture of the phenomenon in the order χ^2 is not at all exhausted by the allowance for the radiative polarization. The careful study of this question proves to be technically quite complicated and will be discussed elsewhere.

R e f e r e n c e s

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