Polarization of electromagnetic radiation emitted during planar channeling of electrons and methods for measuring it

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(Submitted 2 July 1991)
Pis'ma Zh. Eksp. Teor. Fiz. **54**, No. 5, 263–265 (10 September 1991)

Calculations suggest an experiment which might be carried out to polarize photon beams, and to measure this polarization, for applications in high-energy physics.

1. Aside from the results obtained by a Tomsk group[1] at an electron energy $\epsilon \approx 1$ GeV, there are no experimental or theoretical data on the polarization P of the electromagnetic radiation emitted by channeled particles. We have accordingly calculated P as a function of $x = \omega/\epsilon$ (ω is the energy of the emitted photon) in the constant-field approximation of Ref. 2, using the equations for synchrotron radiation.[3] We will discuss methods for measuring P at energies $\omega > 200$ GeV.

2. During planar channeling in a parabolic potential of the planes, $V(y) = V_0 y^2$, an electron is subjected to an electromagnetic field E, and the parameter χ in the synchrotron-radiation theory is $\chi = \gamma E/E_0 = 4\gamma(V_0/m)(\lambda_e/d_p)y = 3.023 \times 10^{-8} \times y V_0$ (eV)$/d_p$(Å), where V_0 is the depth of the potential well, y is the distance from the plane in units of half the distance between planes (d_p), $E_0 = 1.32\times 10^{16}$ V/cm, $\gamma = \epsilon/m$, and $\lambda_e = 1/m(\hbar = c = 1)$. Using the equations of the quantum theory of synchrotron radiation, and taking an average over y, we find the following expression for the degree of linear polarization $P = (I_\perp - I_\parallel)/(I_\perp + I_\parallel)$ in the model of Ref. 2:

$$P = \frac{1}{I_0}\int_0^1 dy W(y) K_{2/3}(u),$$

$$I_0 = \int_0^1 dy W(y)\left[(2 + x^2/(1-x))K_{2/3}(u) - \int_u^\infty K_{1/3}(s)ds\right]. \qquad (1)$$

Here $I_\perp(\omega)$ and $I_\parallel(\omega)$ are the intensities of the synchrotron radiation with polarization respectively perpendicular and parallel to the plane of the trajectory, $u(y) = 2x/3(1-x)\chi(y)$, $K_\nu(\mu)$ is the modified Bessel function, and $W(y)$ is the distribution function of the channeled electrons.[4] In the derivation of (1) the following assumptions were used: (a) The fraction of the electrons which are channeled is[4] $D = 1$. (b) Scattering (dechanneling) is ignored. (c) The polarization P is independent of the cutoff parameter L in the model of Ref. 2. Expression (1) is valid at electron energies above a certain ϵ_t, whose values for the (110) plane of diamond, Si, Ge, and W crystals are 20.5, 19.0, 10.9 and 4.5 GeV, respectively. Figure 1 shows P as a function of x for the diamond (110) plane at various values of ϵ. Over a broad x interval there is a high degree of polarization P. The direction of the polarization is normal to the (110) plane, in agreement with synchrotron radiation.

3. The old, tested methods are not practical for measuring P at $\omega > 200$ GeV. Working from the properties of birefringence in crystals,[3,5,6] we will discuss here a modification of methods[7,8] which have been proposed for coherent pair production.

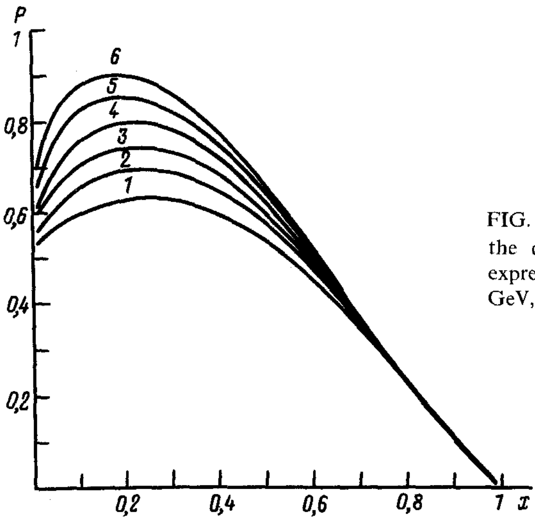

FIG. 1. Degree of polarization P versus $x = \omega/\epsilon$ for the diamond (110) plane. 1–6—Calculated from expression (1) for $\epsilon = 1000, 400, 200, 100, 40$, and 20 GeV, respectively.

a) Method of one thick crystal. A beam of γ rays, produced by the method described above, with a known polarization P and an intensity $I(\omega,0)$, passes through an analyzer crystal of thickness t. The intensities $I_\perp(\omega,t)$ and $I_\parallel(\omega,t)$ are measured. These intensities correspond to the two orientations in which a plane, say, the (110) plane, is respectively perpendicular and parallel to the plane of the polarization P. From the expression[3,7] for the decrease in the beam intensity as a function of the angle between P and the crystal plane we then find

$$P=(r-1)/[(r+1)\tanh(RWt)], \tag{2}$$

where $r=I_\perp(\omega,t)/I_\parallel(\omega,t)$, $R=(W_\perp-W_\parallel)/(W_\perp+W_\parallel)$, $W=(W_\perp+W_\parallel)/2$, and $W_{\perp,\parallel}$ are the photon absorption coefficients for the two orientations. Measuring r, and using the theoretical values[3,5,6] of R and W, we can thus determine P.

b) Method of two thick crystals. The quantities r_1 and r_2 are measured by method a) in two crystals, with thicknesses t_1 and $t_2=2t_1$. The degree of polarization is then found from

$$P=\left[2\frac{r_2+1}{r_2-1}\frac{r_1+1}{r_1-1}-\left(\frac{r_1+1}{r_1-1}\right)^2\right]^{-1/2}. \tag{3}$$

This method has the advantage that P can be determined even if we do not know theoretical values of R and W; calculations of these quantities involve approximations and difficulties.[3,5,6]

c) Method of one thin crystal. The numbers ($N_{\perp,\parallel}$) of e^+e^- pairs for the orientations specified above are measured in the process of pair production in the strong fields of crystal planes.[3,5,6] The polarization is determined from the measured asymmetry and the theoretical value of R, with the help of the known expression. In contrast with the coherent pair production discussed in Ref. 8, pair production in the model of strong crystal fields is predominant at photon energies $\omega>200$ GeV, and there is no restriction that only symmetric pairs be detected.

In summary, experiments can be carried out to test this approximation and the results of this paper at the SPS, the Tevatron, and the future colliders SSC and UNK, where electron beams with $\epsilon>200$ GeV will be available.

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Translated by D. Parsons