Chapter 1

POLARIZATION BREMSSTRAHLUNG EFFECT
IN PARTICLE COLLISIONS

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1.1. Introductory Remarks

The electromagnetic radiation from charged particles is a traditional topic of
physical research, at least since the end of the last century. The production of radi­
ation requires the interaction of a charged particle with matter or with an external
field. Various kinds of radiation can result from these interactions, including
bremsstrahlung, Cerenkov, transition, synchrotron, and undulator radiation [1].
Here we hope to emphasize one fundamental property of radiation in a medium,
specifically the important role played in transition and Cerenkov radiation by the
variable polarization induced by a charge in a medium. The question of the role of
polarization effects in such fundamental phenomena as bremsstrahlung arises natu­

ally.

Until quite recently, bremsstrahlung was a phenomenon that seemed to have
been exhaustively studied, both theoretically and experimentally, and formed a
rather extensive branch of modern physics. It is, therefore, all the more surprising
that a whole class of effects associated with radiation in particle collisions, which
appears simultaneously with "traditional" bremsstrahlung, has clearly been left out.
In some cases, this new effect is inseparable from the traditional effect and may
dominate it under certain conditions. This effect can be referred to as polarization
bremsstrahlung in particle collisions.
1.2. Elementary Concepts of "Traditional" Bremsstrahlung in the Static Field of a Charge

Here we begin by recalling the basic features of the traditional mechanism for bremsstrahlung.

Particle collisions involve the slowing down (or acceleration) of the particles. During a collision between a light particle and a heavy one, it is primarily the light particle which is accelerated and emits radiation. If the incident particle is nonrelativistic, then the spectral distribution of the energy radiated in a single collision event is determined by the classical formula [2,3] for dipole radiation

\[ W_\omega = \frac{8\pi\epsilon_0^3}{3\sigma^2} (r_\omega)^2 = \frac{8\pi\epsilon_0^4}{3\sigma^4 m_0^2} (F_\omega)^2 = \frac{8\pi\epsilon_0^4 e^4}{3\sigma^4 m_0^2} \left( \frac{r}{r^3} \right)_\omega^2, \]

where \( W_\omega \) is the energy radiated over the entire duration of the collision in the frequency interval \( d\omega \); \( \epsilon_0 \) is the charge and \( m_0 \) is the mass of the light particle; \( r_\omega \) is the Fourier component of its acceleration; and \( F_\omega \) is the Fourier component of the field of the heavy particle, whose charge is given by \( e_i = Ze \) (the charge on the electron is \( -e \)).

The simplest case is that in which the particles pass by one another at distances large enough that the trajectory of the incident particle undergoes little change. The shortest distance between an incident particle and a heavy particle, if the trajectory of the incident particle were not perturbed, is usually referred to as the impact parameter \( \rho \). For long-range (distant) encounters, we can neglect the change in the trajectory when calculating the acceleration of the incident particle in the field of a heavy charge. Then

\[ r^2 = \rho^2 + \nu_0^2 \rho^2, \]

where \( \nu_0 \) is the velocity of the incident particle. Evidently, when the particles pass by one another at a distance \( \rho \), radiation at frequencies lower than \( \nu_0/\rho \) will be emitted. Then the Fourier component \( (\rho/r^3)\omega \) in Eq. (1.1) is constant and equal to \( \rho/\pi
\nu_0^2 \). This represents radiation with a "white" spectrum (i.e., the spectral distribution of the radiant energy is independent of frequency).

The term "bremsstrahlung" appeared after the work of Stokes and Sommerfeld [4] who explained the continuous "white" x-ray spectrum observed when cathode rays were slowed down in the material of an anticathode. In this case, of course, we are speaking of radiation from a flux of particles interacting with a target, rather than of radiation in individual collision events. Each of the incident particles encounters a sequence of motionless heavy particles along its path. If the particle density in this target is \( n_i \) per cubic centimeter, then the spectral power of the radiation is given by the spectral energy density of a single particle, \( W_\omega \), multiplied by \( n_i 2\pi \rho d\rho \nu_0 \). Here it is assumed that the incident particle radiates at each heavy particle independently. This means that the scattering centers are