N. F. Shul'ga. *Development of electrodynamic processes in space and time at high energy.* Several new effects that may unfold in the interaction of high-energy particles with matter have recently been predicted.

They include, among others, effects of intensive radiation of above-barrier and channeled particles in a crystal, acceleration of electromagnetic-shower development in crystals, amplification and attenuation of radiation intensity, formation of electron-positron pairs, and ionization losses at high energies in thin films of matter (see Refs. 1–3 and their reference lists). It is characteristic of all these processes that they unfold in large regions of space along particle pulses and that the effectiveness of the interaction between the particles and atoms of the medium differs in these regions from the effectiveness of interaction of the particles with isolated atoms. Since the lengths on which the electromagnetic processes develop at high energies may be macroscopic, it is necessary to know what happens on these lengths.

E. L. Feĭnberg[4,5] drew attention to a number of interesting features of the temporal development of the state vector of a system consisting of an electron and a photon after the electron has been scattered through a large angle by an atom. It was shown, for example, that the electron remains in a "semibare" state for a long time after scattering, substantially without its intrinsic normal Coulomb field, and that in subsequent collisions of such an electron with atoms of the medium its radiation is suppressed as compared to the radiation in the case in which the electron has had time to form a field.

The characteristic scattering angles of a relativistic particle in motion through the matter are small. Analysis of the radiation of a relativistic electron in matter indicates in this case that on small-angle scattering the intensity of the radiation from the "semibare" electron in matter may be either higher or lower than the intensity of the radiation in a rarefied medium.[3]

The time interval $\Delta t = 2\varepsilon^2/m^2\omega$ during which the electron is "semibare" increases rapidly with increasing particle energy ε and with decreasing frequency ω of the radiated photon; therefore it is always possible at large enough ε and small ω to satisfy the condition $V\Delta t \gg T$, under which an electron in flight through a layer of matter of thickness T will interact with all atoms of the medium in the "semibare" state. In this case the spectral density of the radiation is determined by the total angle of scattering ϑ of the electron by a plate and does not depend on the shape of the particle's trajectory in the medium[1]:

$$\frac{dE}{d\omega} = \frac{2e^2}{3\pi} \begin{cases} \gamma^2\vartheta^2 & \gamma\vartheta \ll 1, \quad \text{(1a)} \\ 3\ln(\gamma^2\vartheta^2); & \gamma\vartheta \gg 1, \quad \text{(1b)} \end{cases}$$

where e is the electron charge and $\gamma = \varepsilon/m$ (the velocity of light is assumed equal to one). At small angles of scattering of the electron by the plate ($\vartheta \ll \gamma^{-1}$) the interference of waves radiated on stripping and formation of the electron's intrinsic field after scattering becomes significant, so that $dE/d\omega \sim \vartheta^2$ at small angles. But if $\gamma\vartheta \gg 1$, there is practically no interference effect in the radiation; $dE/d\omega$ is then nearly independent of ϑ.

The spectral density of the radiation (1) must still be averaged over the angle distribution of the particles emerging from the plate. In the case of an amorphous medium, the mean-square angle of scattering of a particle by the plate is determined by the relation $\overline{\vartheta^2}_{am} = \bar{\varepsilon}T/\varepsilon^2 L$, where $\bar{\varepsilon} = 4\pi\cdot 137m^2$ and L is the radiation length. In this case, relation (1a) gives with logarithmic accuracy the Bethe-Heitler result for the radiation spectrum of a relativistic particle in an amorphous medium. When a relativistic electron moves in a crystal at a small angle ψ to one of the crystallographic axes, the correlations between successive collisions of the electron with lattice atoms become significant. A result of these correlations is that in a broad range of angles ψ, the mean-square angle of scattering of particles by the crystal greatly exceeds the mean-square scattering angle in an amorphous medium (Ref. 6), $\overline{\vartheta^2} \approx N\overline{\theta^2_{am}}$, where $N = R/\psi d$, R is the screening radius of the atom, and d is the distance between the atoms along the crystal axis. In this case, according to (1a), the intensity of the electron's emission in the crystal will be N times higher than the emission intensity in an amorphous medium. The intensification of the electron's emission in the crystal as compared to the amorphous medium is due to interference of the waves radiated on stripping and formation of the electron's intrinsic field.

The inequality $\gamma^2\overline{\vartheta^2} \ll 1$ is violated as the thickness of the plate increases, and much sooner in a crystal than in an amorphous medium. At $\gamma^2\overline{\vartheta^2} \gg 1$, according to (1b), the emission intensity becomes almost independent of T.[6] This means that when $\gamma^2\overline{\vartheta^2} \gg 1$, the intensity of the radiation is practically independent of the number of particle collisions with atoms of the medium, i.e., the emission (bremsstrahlung in the amorphous medium, coherent emission in a crystal) of relativistic particles is suppressed in a thin layer of matter. A similar effect was observed in the 1970s in a study of the interaction of high-energy hadrons with heavy nuclei (see, for example, Refs. 5 and 7 and the bibliographies included). Thus, it was found that the average multiplicity of the fast particles formed on collisions between hadrons and nuclei is independent of the number of nucleons in the nucleus. Various models have been advanced to describe this effect on the basis of an analysis of the temporal development of hadron-nucleon collisions at high energies (for example, models in which the cross section of subsequent collisions of the particle with nucleons of the nucleus is assumed to be smaller than the cross section in the first interaction event). It is possible to verify in electrodynamics some of the hypotheses that have been advanced in studies of hadron-nucleon collisions at high energies. For example, an analysis of the temporal and spatial development of the emission of relativistic particles in a thin layer of matter indicates that the interaction of the particle with atoms of the medium cannot be considered at the level of independent-collision cross sections within the limits of the coherence length because the collision interference effects are lost. Nor does it appear that this approach can be used in a study of hadron-nucleon collisions at high energies (see also Refs. 5 and 8 in this matter). The appearance of similar relationships in electromagnetic interactions of fast particles with matter and hadron-nucleon collisions at high energies gives hope that the methods used to analyze the temporal development of electromagnetic processes at high energies might be extended to other areas of physics.

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