Suppression of radiation in an amorphous medium and in a crystal

N. F. Shul'ga and S. P. Komin

Physicotechnical Institute, Ukrainian Academy of Sciences
(Submitted 12 December 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **27**, No. 2, 126–128 (20 January 1978)

A new effect of suppression of the radiation of fast particles in an amorphous medium is predicted and differs greatly from the Landau-Pomeranchuk effect. The possibility of observing this effect for particles channeling in an amorphous medium or in a crystal is discussed.

PACS numbers: 41.90.+e, 61.80.Mk, 61.40.−a

1. The Landau-Pomeranchuk theory[1] of the effect of multiple scattering on the radiation of relativistic particles in an amorphous medium is valid if the target thickness greatly exceeds the zone in which the radiation is formed.

In the present paper we consider the bremsstrahlung of fast particles in a plate whose thickness T is much smaller than the radiation-formation zone z_{eff}.[1)] It is shown that at $T \gtrsim Lm^2/\epsilon_s^2$, where L is the radiation length, m is the particle mass, and $\epsilon_s^2 = 4\pi 137 m^2$, and at freqnencies ω exceeding the characteristic frequencies of the transition radiation, a radiation-suppression effect sets in that is substantially different from the Landau-Pomeranchuk effect. The conditions for the appearance of this effect in an amorphous medium and in a crystal in the course of channeling of particles are described.

 0021-3640/78/2702-0117$00.60 © 1978 American Institute of Physics

2. The energy radiated by a particle moving along a trajectory $\mathbf{r}(t)$ in the frequency interval $(\omega,\omega+d\omega)$ is determined in classical electrodynamics by the formula[1]

$$\frac{dI}{d\omega} = \frac{e^2}{4\pi^2}\int |\mathbf{k}\times\mathbf{I}|^2 dO, \tag{1}$$

where dO is the solid-angle element in the direction of the wave vector $\mathbf{k}$, and

$$\mathbf{I} = \int_{-\infty}^{\infty} dt\, e^{i[\omega t - \mathbf{kr}(t)]}\frac{d}{dt}\frac{\mathbf{v}(t)}{\omega - \mathbf{kv}(t)} \tag{2}$$

Since fast particles are scattered in a medium predominantly through small angles, in first-order approximation the velocity vector can be represented in the form $\mathbf{v}(t)\approx\mathbf{v}(1-v_{\perp}^2/2)+\mathbf{v}_{\perp}(t)$, where v is the velocity of the incident particle and $\mathbf{v}_{\perp}(t)$ are the components of $\mathbf{v}(t)$ in a plane perpendicular to $\mathbf{v}$. The angle θ of particle scattering by the plate is connected with $\mathbf{v}_{\perp}(t)$ by the relation $\theta=v_{\perp}(\infty)/v$. The mean squared scattering angle is $\bar{\theta}^2=\epsilon_s^2T/\epsilon^2L$.

With increasing energy, the zone $z_{\text{eff}}\sim\min[\epsilon^2/m^2\omega;(\epsilon/\epsilon_s)\sqrt{L/\omega}\,]$ in which the radiation is formed increases, so that at sufficiently large ϵ the condition $z_{\text{eff}}\gg T$ can always be satisfied. In this case we can set the exponential in the integrand of (2) equal to unity and integrate in (1) over the solid angle. Then

$$\frac{dI}{d\omega} = \frac{2e^2}{\pi}\left\{\frac{2\xi^2+1}{\xi\sqrt{\xi^2+1}}\ln(\xi+\sqrt{\xi^2+1}) - 1\right\}, \tag{3}$$

where $\xi=\epsilon\theta/2m$. We see that the emission spectrum (3) depends substantially on the ratio of the scattering angle θ to the characteristic radiation angle m/ϵ. If $\bar{\theta}^2\ll(m/\epsilon)^2$, then formula (3), after averaging over the particle scattering angles θ with a Gaussian distribution, leads to the Bethe-Heitler result[2]

$$\frac{dI}{d\omega} = \frac{2e^2}{3\pi}\frac{\epsilon_s^2 T}{m^2 L}. \tag{4}$$

On the other hand, if $\bar{\theta}^2\gg(m/\epsilon)^2$, i.e., $\epsilon_s^2T/m^2L\gg1$, then

$$\frac{dI}{d\omega} = \frac{4e^2}{\pi}\ln\frac{\epsilon_s^2 T}{m^2 L}. \tag{5}$$

The emission spectrum in this case, in contrast of the Bethe-Heitler result (4) and the Landau-Pomeranchuk result[1,2]

$$\frac{dI}{d\omega} = \frac{2e^2}{\pi}\frac{\epsilon_s T}{\epsilon L}\sqrt{L\omega} \tag{6}$$

is practically independent of the target thickness, of the particle energy, and of the emitted-photon frequency. The condition for the appearance of the Landau-Pomeranchuk effect, $T\gg z_{\text{eff}}$ and $\epsilon^2\epsilon_s^2/m^4L\omega\gtrsim1$, differ from the conditions of the effect considered by us, $T \ll z_{\rm eff}$ and $\epsilon_s^2 T/m^2 L \gtrsim 1$, and therefore the spectral distributions (5) and (6) are also different. According to (5), the radiation intensity from a unit path traversed by the particle in the plate decreases with increasing T, i.e., the radiation is suppressed in this case.

A characteristic feature of the considered effect is the weak dependence of the emission spectrum on the number of particle collisions with the atoms of the medium. We note that a similar phenomenon was observed recently in an investigation of the interaction between high-energy hadrons and heavy nuclei. The gist of the phenomenon is that the cross sections, multiplicity, and other characteristics of the processes are practically independent of the number of nucleons in the nucleus.[5]

3. The question of radiation from fast particles that channel through a crystal has been extensively discussed of late.[6,7] We shall show that under channeling conditions there is also a suppression of the radiation, analogous to that considered above, and this effect occurs at a much lower energy in a crystal than in an amorphous medium. This makes it possible to observe the suppression effect at energies attainable with modern accelerators, $\epsilon \gtrsim 10$ GeV.

The channeled particle deviates periodically from the direction of the initial motion by an angle $\theta = \theta_c$, where θ_c is the critical channeling angle,[8] and the particle scattering takes place over a length $\sim R/\theta_c$ (R is the screening radius of the atom). In the case of axial channeling $\theta_c = \sqrt{2Ze^2/\epsilon a}$, where a is the lattice constant. If the condition $Z_{\rm eff} \gg R/\theta_c$ is satisfied, then the energy radiated by the particle as it interacts with a chain of crystal atoms placed along the channel axis is also determined by formula (3), in which it is necessary to put $\xi = \epsilon\theta_c/2m$. Thus,

$$\frac{dI}{d\omega} \approx \frac{2e^2}{\pi} \begin{cases} 2Ze^2\epsilon/3m^2 a, & \theta_c \ll m/\epsilon \quad (7a) \\ \ln(2Ze^2\epsilon/m^2 a), & \theta_c \gg m/\epsilon \quad (7b) \end{cases}$$

These formulas show that at $\theta_c \sim m/\epsilon$ a substantial change takes place in the character of the radiation from the channeled particle—the linear dependence of the spectrum (7a) on ϵ gives way with increasing energy to the weaker logarithmic dependence (7b). From the conditions for the applicability of formulas (5) and (7b) it follows that in an amorphous medium the effect of suppression of the radiation sets in at an energy $\epsilon \sim m^2\sqrt{\omega L}/\epsilon_s \gg m^2 a/Ze^2$ much higher than in particle channeling.

The authors thank A.I. Akhiezer, E.L. Feinberg, M.L. Ter-Mikaelyan, P.I. Fomin, and V.F. Boldyshev for useful discussions of the questions touched upon in the article.

[1)]In the earlier investigations of radiation from fast particles in a thin plate, the principal attention was paid to the influence of different factors on the transition radiation.[2-4]

[1]L.D. Landau and I.Ya. Pomeranchuk, Dokl. Akad. Nauk SSSR **92**, 535, 735 (1953).
[2]M.L. Ter-Mikaelyan, Vliyanie sredy na élektromagnitnye protsessy pri vysokikh energiyakh (Effect of Medium on Electromagnetic Processes at High Energies), Izd. Akad. Nauk Arm. SSSR, Erevan, 1969.

[3]V.E. Pafomov, Trudy Fiz. Inst. Akad. Nauk SSSR **44**, 28 (1969).
[4]G.M. Garibyan, and Ya.Shi, Zh. Eksp. Teor. Fiz. **70**, 1627 (1976) [Sov. Phys. JETP **43**, 848 (1976)].
[5]Yu.P. Nikitin, I.L. Rozental', and F.M. Sergeev, Usp. Fiz. Nauk **121**, 3 (1977) [Sov. Phys. Usp. **20**, 1 (1977)].
[6]M.A. Kumakhov, Zh. Eksp. Teor. Fiz. **72**, 1489 (1977) [Sov. Phys. JETP **45**, 781 (1977)].
[7]A.I. Akhiezer, V.F. Boldyshev, and N.F. Shul'ga, Dokl. Akad. Nauk SSSR **236**, 830 (1977) [Sov. Phys. Dokl. **22**, 569 (1977)].
[8]J. Lindhard, Mat.-Fyz. Medd. Dan Vid. Selsk. **34**, No. 14 (1965).