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An investigation of the Cherenkov X-rays from relativistic electrons

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Abstract

X-ray Cherenkov radiation is studied theoretically for grazing incidence of emitting electrons on thin foils of different materials. The growth of the angular density of emitted photons due to the modification of Cherenkov cone structure is shown. The characteristics of a possible Cherenkov X-ray source are discussed.

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1. Introduction

Cherenkov emission mechanism allows to generate soft X-rays in the vicinity of atomic absorption edges, where the medium refractive index may exceed unity [1]. This theoretical prediction has been experimentally confirmed using 1200 [2], 75 [3] and 5 MeV electron beam [4] and silicon or carbon targets. The high efficiency of possible Cherenkov X-ray source has been best demonstrated in the experiment [4], where the yield $\sim 1\cdot 10^{-3}$ photon/electron has been obtained.

On the other hand the experimental result [3] is of great physical interest since the Cherenkov emission on condition of grazing incidence of an emitting electron on the target's surface was studied in this work. Authors of the work [3] reasoned that the Cherenkov emission yield for grazing incidence can substantially exceed the yield at perpendicular incidence due to the suppression of photoabsorption in the discussed emission process as the main contribution to emission yield for grazing incidence was made from the part of

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emitting electron trajectory placed outside the target near to its surface.

Cherenkov radiation for grazing incidence of electron beam on the target is analyzed in this work as well. We show that the Cherenkov radiation is generated from the part of the particle's trajectory placed inside the target in contrast with conclusion [3]. Nevertheless, the particle's trajectory outside the target plays an important role in the formation of Cherenkov emission yield due to the interference between emission amplitudes corresponding to different parts of the trajectory of emitting particle. Another effect of study is the strong change of the structure of Cherenkov cone taking place for small enough incidence angles. We show a possibility to increase substantially the emission angular density due to the effect in question.

It should be particularly emphasized that only Si and C targets have been used for X-ray Cherenkov photon production. Because of this an analysis of the possibility to generate X-rays in the wide range of emitted photon energies on the basis of Cherenkov radiation from a variety of media is of immediate interest. Such analysis is performed in this work.

A dependence of emission characteristics on the value of grazing incidence angle, electron energy, angular size of a photon collimator is studied in this work as well as an influence of multiple scattering of emitting particles.

2. General expressions

Let us consider an emission from relativistic electrons penetrating a foil of amorphous medium. This task is well known (see for example [5]) so we can use the general results presented in [5]. We are interested in the emission process in soft X-ray range of the emitted photon energy ω, where an influence of photoabsorption is very important. Assuming that the photoabsorption length $l_{\mathrm{ab}} \sim 1/\omega\chi''(\omega)$ (χ'' is the imaginary part of the dielectric susceptibility) is less than the electron path in the target l/φ (l is the thickness of the target, φ is the grazing incidence angle, $\varphi \ll 1$) we use the simple model corresponding to the emission of

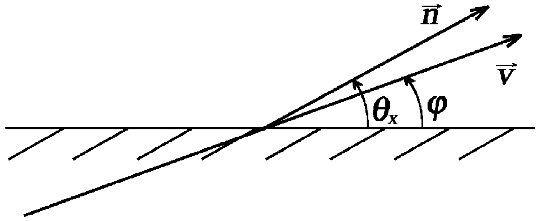

Fig. 1. The geometry of the emission process, **n** is the unit vector to the direction of emitted photon propagation, $\boldsymbol{v}$ is the emitting electron velocity, φ is the incidence angle.

a fast electron flying from semi-infinite absorbing target to a vacuum where the emitted photons are recorded by X-ray detector (see Fig. 1). Since background in the small frequency range under study is determined in the main by transition radiation, we neglect the contribution of bremsstrahlung. In addition to this we consider the emission from electrons moving with uniform velocity $\boldsymbol{v}$, assuming that the value of multiple scattering angle, achievable on the distance of the order of l_{ab}, $\Psi_{\mathrm{ms}} \sim (\epsilon_k/\epsilon)\sqrt{l_{\mathrm{ab}}/L_{\mathrm{R}}}$ ($\epsilon_k \approx 21$ MeV, ϵ is the energy of emitting electron, L_{R} is the radiation length) is small relating to characteristic angle of the Cherenkov cone $\sqrt{\chi'(\omega)}$ (χ' is the real part of the dielectric susceptibility).

Taking into account the above mentioned question we consider the structure of excited electromagnetic fields in a more detailed way in comparison with [5]. In accordance with [5] Fourier-transform of the excited in a vacuum ($x > 0$) transverse electromagnetic field $\mathbf{E}^{\mathrm{tr}}_{\mathbf{k}\omega} = (2\pi)^{-4} \times \int \mathrm{d}t\,\mathrm{d}^3r\,\mathbf{E}^{\mathrm{tr}}(r,t)\mathrm{e}^{\mathrm{i}\omega t - \mathrm{i}\mathbf{k}\cdot r}$ can be presented in the form

$$\mathbf{E}^{\mathrm{tr}}_{\mathbf{k}\omega} = \sum_{\lambda=1}^{2} \mathbf{e}_{\lambda\mathbf{k}} E_{\lambda\mathbf{k}}, \quad \mathbf{e}_{1\mathbf{k}} = [\mathbf{e}_x \cdot \mathbf{k}_\parallel]/k_\parallel,$$

$$\mathbf{e}_{2\mathbf{k}} = [\mathbf{k} \cdot \mathbf{e}_{1\mathbf{k}}]/k,$$

$$E_{\lambda,\mathbf{k}} = \frac{4\pi\mathrm{i}\omega}{k^2 - \omega^2}\mathbf{e}_{\lambda\mathbf{k}} \cdot \mathbf{j}_{\mathbf{k}\omega} + a_{\lambda\mathbf{k}_\parallel}\delta\left(k_x - \sqrt{\omega^2 - k_\parallel^2}\right), \tag{1}$$

where $\boldsymbol{k} = \boldsymbol{k}_\parallel + k_x \mathbf{e}_x$, $\mathbf{e}_x \cdot \boldsymbol{k}_\parallel = 0$, the unknown coefficients $a_{\lambda\mathbf{k}_\parallel}$ are determined by the ordinary boundary conditions for electromagnetic fields at the target's surface and have the form