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Features of the Transition Radiation of the Electron in the Vacuum Ultraviolet Range

A. S. Kubankin

Laboratory of Radiation Physics, Belgorod State University, ul. Pobedy 85, Belgorod, 308015 Russia

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Abstract—The transition radiation (TR) of an electron in the vacuum ultraviolet range near the direction of total quantum reflection from the medium-vacuum interface has been investigated. The effect of a substantial increase (tens times) in the TR angular density has been predicted. The substantial dependence of lightness of this effect on the susceptibility of the dielectric target, the exit angle, and the energy of the emitting electron has been found.

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INTRODUCTION

The transition radiation appears when the charged particle crosses the interface of the media with different values of dielectric susceptibility $\varepsilon(\omega)$ ($\varepsilon(\omega) = \varepsilon'(\omega) + i\varepsilon''(\omega)$) ($\omega$ is the emitted quantum energy) and has been well theoretically and experimentally studied [1]. The TR angular distribution of a nonrelativistic charged particle normally crossing the medium-vacuum interface indicated the strong effect of the relation between $\varepsilon'(\omega)$ and $\varepsilon''(\omega)$ on the maximum of the angular distribution [2]. The maximum of angular distribution was found to coincide with the angle of total internal reflection of light from the interface at $\varepsilon''(\omega) = 0$ and the maximum has a greater value than for the cases when $\varepsilon''(\omega) \neq 0$. The position of the maximum of the TR angular distribution of nonrelativistic particles is determined only by the quantities $\varepsilon'(\omega)$ and $\varepsilon''(\omega)$.

For nonrelativistic electrons, the energy of the emitting particle defines the amplitude of the maximum of the TR angular distribution, and depending on the direction of the electron momentum, the shape of the distribution insignificantly varies near the position specified by the normal momentum orientation relative to the interface. The TR case for the weakly relativistic particle when the Coulomb field becomes deformed, and the position of the maximum of the TR angular distribution becomes sensitive not only to the quantities $\varepsilon'(\omega)$ and $\varepsilon''(\omega)$, but also to the energy of the emitting particle is of most interest. For the TR case of the weakly relativistic electrons, the vacuum ultraviolet range, where the relation between $\varepsilon'(\omega)$ and $\varepsilon''(\omega)$ can take different values and the TR spectral-angular characteristics will be different, is of most interest.

The TR of relativistic electrons in the soft X-ray range (in the described case the relation $\varepsilon'(\omega) \approx 1 \gg \varepsilon''(\omega)$ is always fulfilled) for small angles of incidence of an emitting electron onto the medium-vacuum interface was studied in [3] and it was shown that the TR yield can increase when an emitting relativistic particle moves at the angle of order of the angle of total internal radiation reflection from the interface. The TR of relativistic electrons is near the angles $\gamma^{-1} \ll 1$ relative to the direction of the electron momentum (γ is the Lorentz factor of an emitting particle). The possibility of a sharp increase in the TR angular density will be demonstrated below for the case of grazing incidence of weakly relativistic electrons onto the medium-vacuum interface and it will be shown that the growth mechanism differs from that considered in [3].

Then, in the work, the theoretical investigation of the TR properties of electrons in the vacuum ultraviolet range is carried out for different target orientations relative to the momentum of the emitting electron. To calculate the spectral-angular TR characteristics the experimental dependences $\varepsilon'(\omega)$ and $\varepsilon''(\omega)$ are used [4]. The relativistic scheme of units $\hbar = c = 1$ is used in the calculations.

THEORETICAL ANALYSIS

Consider the TR formed for the rectilinear transit of a weakly relativistic particle through the medium-vacuum interface in the geometry presented in Fig. 1. We write the expression for the radiation amplitude using the data in [1]. For convenience of the further analysis we present the amplitude as the sum of two vector terms being in mutually perpendicular planes

$$\mathbf{A}^{TR} = \left(\mathbf{e}_{\perp} - n_{\perp}\frac{\mathbf{n}_{\parallel}}{n_{\parallel}^2}\right)A_1 + \mathbf{e}'A_2, \qquad (1)$$

where $n_{\perp}$ and $n_{\parallel}$ are the components of $\mathbf{n}$ ($n_{\parallel}^2 = n_x^2 + n_y^2$), $\mathbf{e}' = \dfrac{[\mathbf{n}_{\parallel}\mathbf{e}_{\perp}]}{n_{\parallel}}$, $\mathbf{e}_{\perp}$ is the unit vector along the normal to the plane of medium surface

$$A_1 = \frac{e}{\pi}\frac{n_\perp V_\perp}{n_\parallel}\frac{\chi}{(1-\mathbf{n}_\parallel\mathbf{V}_\parallel)^2 - n_\perp^2 V_\perp^2} \times \frac{1}{1-\mathbf{n}_\parallel\mathbf{V}_\parallel - V_\perp\sqrt{n_\perp^2+\chi}} \times \frac{V_\perp\sqrt{n_\perp^2+\chi}(n_\parallel^2 - \mathbf{n}_\parallel\mathbf{V}_\parallel) - n_\parallel^2(1-V_\perp^2-\mathbf{n}_\parallel\mathbf{V}_\parallel)}{n_\perp(1+\chi)+\sqrt{n_\perp^2+\chi}}, \quad (2a)$$

$$A_2 = \frac{e}{\pi}\frac{n_\perp V_\perp}{n_\parallel}\frac{\chi}{(1-\mathbf{n}_\parallel\mathbf{V}_\parallel) - n_\perp^2 V_\perp^2} \times \frac{1}{1-\mathbf{n}_\parallel\mathbf{V}_\parallel - V_\perp\sqrt{n_\perp^2+\chi}}\frac{n_y V_\perp n_x}{n_\perp + \sqrt{n_\perp^2+\chi}}. \quad (2b)$$

Consider the spectral-angular radiation distribution in the reaction plane containing $\mathbf{V}$ and $\mathbf{e}_\perp$.

$$\omega\frac{dN_1}{d\omega d\Omega} = \frac{e^2}{\pi^2}\frac{n_\perp^2 V_\perp^2}{n_\parallel^2}\frac{\chi'^2+\chi''^2}{((1-\mathbf{n}_\parallel\mathbf{V}_\parallel)^2 - n_\perp^2V_\perp^2)^2}\frac{1}{(1-\mathbf{n}_\parallel\mathbf{V}_\parallel - V_\perp\tau')^2 + V_\perp^2\tau''^2} \times \frac{(V_\perp\tau'(n_\parallel^2 - \mathbf{n}_\parallel\mathbf{V}_\parallel) - n_\parallel^2(1-V_\perp^2-\mathbf{n}_\parallel\mathbf{V}_\parallel))^2 + V_\perp^2\tau''^2(n_\parallel^2-\mathbf{n}_\parallel\mathbf{V}_\parallel)^2}{(n_\perp(1+\chi')+\tau')^2 + (n_\perp\chi''+\tau'')^2}, \quad (3)$$

$$\tau' = \frac{1}{\sqrt{2}}\sqrt{\sqrt{(n_\perp^2+\chi')^2+\chi''^2} + n_\perp^2 + \chi'}, \quad \tau'' = \frac{1}{\sqrt{2}}\sqrt{\sqrt{(n_\perp^2+\chi')^2+\chi''^2} - n_\perp^2 - \chi'}.$$

It should be noted that three multipliers enter into (3) which are significant to investigate the dependence of the TR characteristics on the parameters of the task and the individual consideration of them is necessary.

The denominator of the first multiplier in (3) defines the narrowing of the cone of the TR angular distribution by virtue of the Coulomb field transformation of an emitting particle in vacuum

$$((1-\mathbf{n}_\parallel\mathbf{V}_\parallel)^2 - n_\perp^2V_\perp^2)^2. \quad (4)$$

The denominator of the second multiplier in (3) defines the effect of the Coulomb field transformation of an emitting particle in a target on the TR angular properties.

$$(1-\mathbf{n}_\parallel\mathbf{V}_\parallel - V_\perp\beta')^2 + V_\perp^2\beta''^2. \quad (5)$$

The denominators in (4) and (5) define the position of TR maxima formed by virtue of the Coulomb field transformation of electron for relativistic velocities. For $\chi'(\omega) > 0$ Eq. (5) is resonant and defines the position of the spectral-angular maximum for the Vavilov-Cherenkon radiation. The denominator of the third multiplier in (3) defines the position of the maximum for the angular radiation distribution formed by virtue of the total quantum reflection from the medium-vacuum interface and was described in detail in [2]

$$(n_\perp(1+\chi')+\beta')^2 + (n_\perp\chi''+\beta'')^2. \quad (6)$$

It is easy to show that only the denominator in (6) enters into the expression for the spectral-angular TR distribution of non-relativistic electrons ($V \ll 1$), and the form of the angular radiation distribution is determined by the quantities $\chi'(\omega)$ and $\chi''(\omega)$ only

$$\omega\frac{dN_1}{d\omega d\Omega} = \frac{e^2}{\pi^2}(\chi'^2+\chi''^2)\frac{n_\perp^2 n_\parallel^2 V_\perp^2}{(n_\perp(1+\chi')+\beta')^2 + (n_\perp\chi''+\beta'')^2}. \quad (7)$$

The maxima of the angular distribution are near the angle of total internal reflection determined by the equality $\cos(\Theta) = \sqrt{-\chi'}$ and their position does not depend on the orientation of the momentum of the emitting electron.

It is convenient to represent (3) by the angular variables in the form of the product of two functions

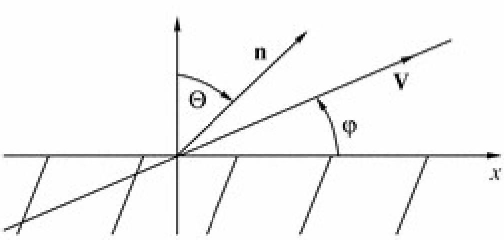

Fig. 1. Geometry of radiation process: **V** is the velocity of an emitting electron, **n** is the unit vector along the direction of emitted quantum propagation.