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HIGH-ENERGY WAVE PACKETS. 'HALF-BARE' ELECTRON

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The evolution in space and time of localized high-energy electromagnetic wave packets, which take place in processes of radiation by ultra relativistic electrons is considered. It is shown that high energies make stabilizing influence on the motion of such packets and that the lengths, within which their dispersion and reconstruction into the packets of diverging waves occurs, can be macroscopic. The electromagnetic field evolution in the process of ultra relativistic electron emission from substance into vacuum is considered. It is demonstrated, that in this case the electron can be in 'half-bare' state with considerably suppressed low frequency Fourier-components of the field around it during long period of time after the emission. It is shown that such state of electron can manifest itself in significant dependence of further ionization energy losses of the electron in thin plate situated in the direction of the particle motion on the distance between the plate and the scattering point.
KEY WORDS: electromagnetic wave packets, ionization energy losses, transition radiation, density effect, 'half-bare' electron

ВЫСОКОЭНЕРГЕТИЧЕСКИЕ ВОЛНОВЫЕ ПАКЕТЫ. «ПОЛУГОЛЫЙ» ЭЛЕКТРОН
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Рассмотрена пространственно-временная эволюция локализованных высокоэнергетических электромагнитных волновых пакетов, имеющих место в процессах излучения ультра релятивистскими электронами. Показано, что высокие энергии оказывают стабилизирующее влияние на движение таких пакетов и что длины, на которых происходит их расплывание и перестройка в пакеты расходящихся волн, могут иметь макроскопические размеры. Рассмотрена эволюция электромагнитного поля в пространстве при вылете ультра релятивистского электрона из вещества в вакуум. Показано, что в этом случае электрон в течение длительного промежутка времени после вылета из вещества может пребывать в «полуголом» состоянии с сильно подавленными низкочастотными компонентами Фурье в окружающем его поле. Также показано, что такое состояние электрона может проявляться в существенной зависимости его последующих ионизационных потерь энергии в тонкой пластинке, расположенной в направлении движения частицы, от расстояния между пластинкой и веществом.
КЛЮЧЕВЫЕ СЛОВА: электромагнитные волновые пакеты, ионизационные потери энергии, переходное излучение, эффект плотности, «полуголый» электрон

ВИСОКОЕНЕРГЕТИЧНІ ХВИЛЬОВІ ПАКЕТИ. «НАПІВГОЛИЙ» ЕЛЕКТРОН
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Розглянуто просторово-часову еволюцію локалізованих високоенергетичних електромагнітних хвильових пакетів, що мають місце у процесах випромінювання ультра релятивістськими електронами. Показано, що високі енергії мають стабілізуючий вплив на рух таких пакетів і що довжини, на яких відбувається їх розпливання і перебудова у пакети розбіжних хвиль, можуть мати макроскопічні розміри. Розглянуто еволюцію електромагнітного поля в просторі при вильоті ультра релятивістського електрона з речовини у вакуум. Показано, що в цьому випадку електрон протягом тривалого проміжку часу після вильоту з речовини може перебувати в «напівголому» стані з сильно заглушеними низькочастотними компонентами Фур'є в оточуючому полі. Також показано, що такий стан електрона може виявлятися в істотній залежності його подальших іонізаційних втрат енергії в тонкій пластинці, розташованій у напрямку руху частинки, від відстані між пластинкою і речовиною.
КЛЮЧОВІ СЛОВА: електромагнітні хвильові пакети, іонізаційні втрати енергії, перехідне випромінювання, ефект густини, «напівголий» електрон

A lot of high-energy physical processes develop within large domains of space along the direction of particle motion (see, for example monographs [1-4] and references in them). In the case of electromagnetic processes the size of these domains can substantially exceed sometimes not only interatomic distances of substance but the size of experimental facility (detectors) as well [1, 2, 4-13]. Essential in this case is the fact that interaction of particles with atoms and experimental facility situated within such domains and outside them can substantially differ. Such situation arises, for example, when considering long-wave radiation in processes of bremsstrahlung and transition radiation by ultra relativistic electrons [14-16]. Therefore, it is necessary to know what happens within such regions and what the peculiarities of evolution of such processes in space and time are. In the present paper we consider the evolution of transition radiation process during relativistic electron emission from dielectric substance into vacuum and manifestation of transformation of electromagnetic field around the particle in this process during further interaction of this electron with matter.

The considered problem is closely related to the problem of study of the behavior of localized high-energy wave packets. Therefore, firstly, we will consider some peculiarities of the behavior of such wave packets drawing special attention to the questions of their stability and reconstruction into the packets of diverging waves. Further we show that the discussed wave packets naturally arise in the process of relativistic electron emission from substance into vacuum.

The consideration is made on the basis of classical electrodynamics. In this case the moving electron is considered as a charge with its own Coulomb field moving together with it. During the electron traversal of the medium-vacuum interface the perturbation of this field occurs. This perturbation is treated here as appearance of a packet of free plane electromagnetic waves, which reconstructs then into a packet of diverging waves of transition radiation. For ultra relativistic particles, however, this does not happen at once. The distance from the interface, within which this process develops, has a name of the coherence length of the transition radiation process [1, 2]. It is $2\gamma^2$ times larger than the length λ of the considered radiated waves (γ is here the electron Lorentz-factor). We show that within this length the field around the electron in vacuum substantially differs from the Coulomb one and the particle exists in so called 'half-bare' state [17, 18] with suppressed low-frequency components of the field around it. It is possible to place thin dielectric plate within this distance from the substance in the direction of the electron motion and consider ionization energy losses of the particle in it. In the present paper it is shown that the electron energy losses in such plate significantly depend on the distance between the plate and the substance, from which the electron is emitted, and are defined by the magnitude of interference between the electron's own Coulomb field and the packet of free waves.

The aim of the paper is to investigate some peculiarities of space-time evolution of the field of high-energy electromagnetic wave packets and to consider the manifestation of such field evolution in the process of relativistic electron ionization energy losses.

HIGH-ENERGY WAVE PACKETS

The general solution of the wave equation can be presented in the form of a wave packet, which spatially disperses in course of time. In semiclassical approximation such packet does not disperse. It moves according to the laws of classical mechanics (see, for example [2, 19]). It is going beyond the semiclassical approximation that leads to the packet dispersion. The high-energy wave packets are of special interest because the speed of their dispersion decreases with the increase of their energy. Let us pay attention to some peculiarities of dispersion of such packets. Significant here is the fact that characteristic features of this dispersion are similar for all fields. Therefore it is sufficient to consider just scalar field.

The general solution of the wave equation

$$\left(\frac{\partial^2}{\partial t^2} - \nabla^2 + m^2\right)\varphi(\vec{r},t) = 0 \tag{1}$$

for a scalar particle with the mass m can be written in the following form of the expansion of the field $\varphi(\vec{r},t)$ over plane waves:

$$\varphi(\vec{r},t) = \int \frac{d^3\kappa}{(2\pi)^3} e^{i(\vec{\kappa}\vec{r}-\omega\, t)} C_{\vec{\kappa}}\ , \tag{2}$$

where $\omega = \sqrt{\vec{\kappa}^2 + m^2}$ and $C_{\vec{\kappa}}$ - are the expansion coefficients. Here and further we will use the system of units in which the speed of light c and the Plank constant $\hbar$ equal unit.

Let us consider the dispersion of the wave packet, which at the initial moment of time coincides with the Gaussian packet modulated by the plane wave with large value of the momentum $\vec{p}$ [2, 20]. Moreover we will assume that the initial widths of the packet $a_{\parallel}$ and $a_{\perp}$ parallel and perpendicular to the particle momentum $\vec{p}$ are different. For such packet at the initial moment of time the field $\varphi(\vec{r},t)$ has the following form:

$$\varphi(\vec{r},t) = \exp\left\{ i\vec{p}\vec{r} - \frac{z^2}{2a_{\parallel}^2} - \frac{\vec{\rho}^2}{2a_{\perp}^2} \right\}, \tag{3}$$

where z and $\vec{\rho}$ are the coordinates parallel and orthogonal to $\vec{p}$. At the moment of time t this packet will be defined by the relation (2) with

$$C_{\vec{\kappa}} = (2\pi)^{3/2} a_{\parallel} a_{\perp}^2 \exp\left\{ -\frac{(p-\kappa_z)^2 a_{\parallel}^2}{2} - \frac{\kappa_{\perp}^2 a_{\perp}^2}{2} \right\}. \tag{4}$$

We can write the obtained expression for the field $\varphi(\vec{r},t)$ in the form