Unruh radiation in linear colliders and in collisions of TeV electrons with intense laser beams

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The intensity of Unruh radiation is calculated and the possibility of its observation in the passage of electrons through strong constant magnetic fields and in the field of a circularly polarized plane wave is discussed.

1. Almost simultaneously with the appearance of papers by Hawking[1] there appeared three papers[2–4] which showed that a body moving with acceleration a' in its instantaneous rest frame (IRF) finds itself in a bath of thermal radiation with a temperature $T = a'/2\pi k$ (the Unruh effect), where k is the Boltzmann constant ($\hbar = c = 1$). The importance of the phenomenon has led in recent years to the appearance of many papers devoted to an understanding of the phenomenon,[5] how it might manifest itself,[6,7] and the experimental detection of the effect.[8,9] At the same time, Ref. 10 has put in doubt the very idea of the Unruh thermal bath, underlining the importance of an experimental verification of the effect. In particular, in Ref. 9 it was shown that in the strong fields of crystalline axes and planes channeled particles undergo large transverse accelerations $a'_\perp$ in their IRF and, on the basis of Unruh's ideas, the properties of the Unruh radiation of the channeled particles in the laboratory frame, which arises as a result of Compton scattering of the Planck spectrum were theoretically investigated.

In the present study we have calculated the intensity of the Unruh radiation, which is generated by TeV electrons in a constant magnetic field and also in a laser radiation field, and we compared it with the intensity of the radiation of competing processes.

2. Let an electron pass through a uniform magnetic field with initial velocity β perpendicular to the field. The transverse (with respect to the direction of motion of the electron) acceleration in the IRF is then $a'_\perp = \gamma eH/m\beta$ ($\gamma = E/m$, where m and E are the mass and energy of the electron) and $kT/m = \gamma eH/2\pi m^2\beta = 3.606\times 10^{-15}$ $\gamma H(G)$. Departing from the Planck distribution of the photon density for the Unruh bath with given temperature T and using the differential Compton scattering cross sections in the IRF, one can calculate the spectral distribution of the Unruh radiation in the laboratory frame. To do this, it is only necessary to substitute the value of T in Eqs. (2) and (3) of Ref. 9. The dependence of the intensity per unit pathlength, $xdN/dldx$, in 2 uniform magnetic field and of the accompanying synchrotron radiation calculated on the basis of the standard classical and quantum formulas, on $x = \omega_2/E$ (ω_2 is the energy of the radiated quantum) and on H are shown in Figs. 1a and 1b. As can be seen from Fig. 1a, the spectra of the Unruh radiation extend into the region $x > 1$. This result is connected with the presence of high frequencies in the Planck spectrum in the IRF. It can also be seen that the intensity of the Unruh

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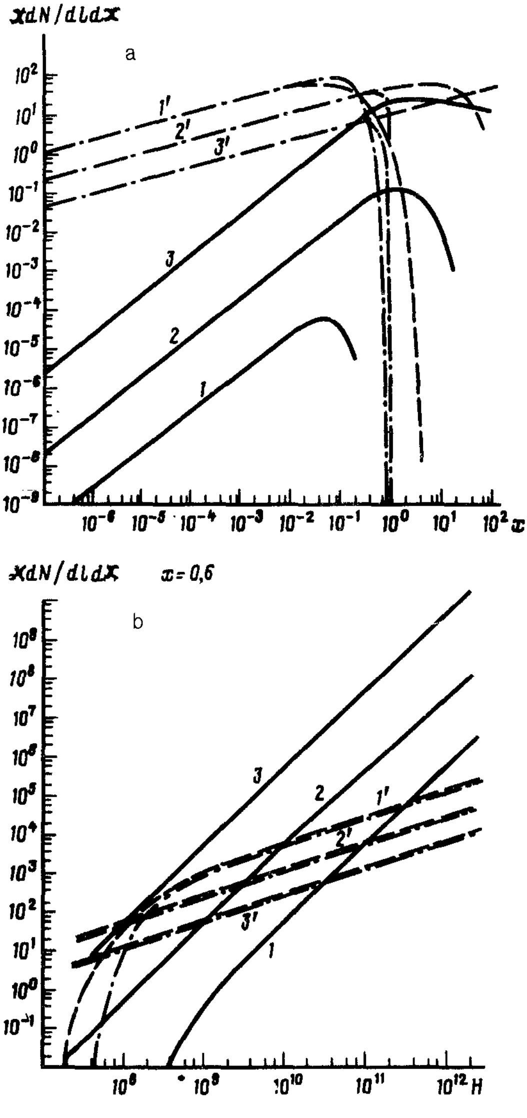
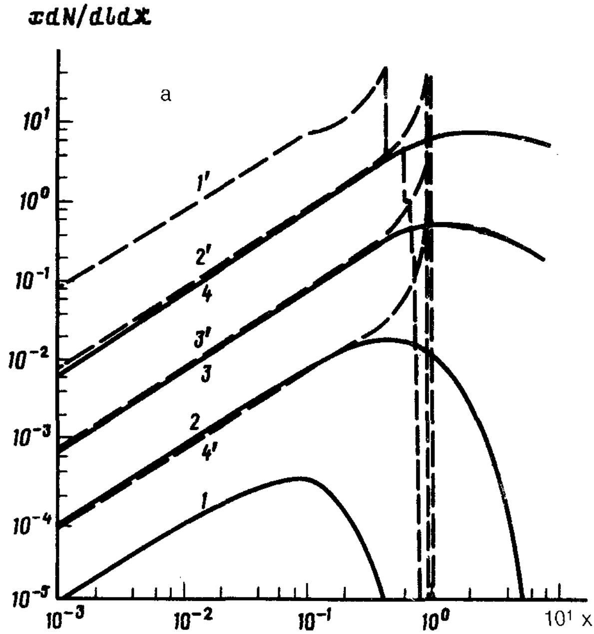


FIG. 1. Dependence of $xdN/dldx$ on x at $H = 5\times10^7$ G (a) and on H at $x = 0.6$ (b). The solid curves are the Unruh radiation, the dashed and dot-dashed curves are the synchrotron radiation calculated according to the classical and the quantum formulas, respectively, at $\gamma = 10^5$, 10^7, and 10^9 (curves 1, 1′, 2, 2′, and 3, 3′, respectively).

radiation at $H = 5\times10^7$ G is almost linearly proportional to γ and begins to exceed the intensity of the synchrotron radiation only when $\gamma \gtrsim 10^9$. Consequently, we can conclude that in the projecting linear colliders *TLC, JLC* and *CLIC* (and also *SLC*) it is impossible to observe Unruh radiation when the fields (created by the bunches of particles) through which the particles of the colliding beam must pass are much less



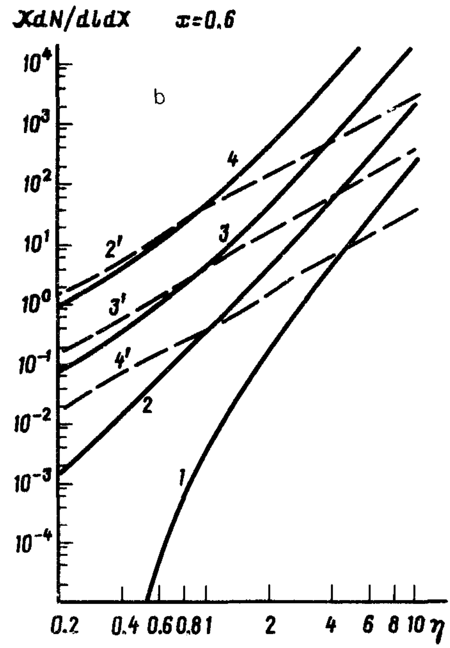


FIG. 2. Dependence of $xdN/dldx$ on x at $\omega = 1.18$ eV and $\eta = 0.4$ (a) and on η at $x = 0.6$ (b). The solid curves are the Unruh radiation, and the dashed curves are the radiation in a laser beam field at $\gamma = 10^5$, 10^6, 10^7, and 10^8 (curves 1, 1′, 2, 2′, 3, 3′, and 4, 4′, respectively).

than 5×10^7 G.[1)] At present, this type of mechanism of formation of Unruh radiation can take place only in cosmic objects, e.g., in pulsars, in which $H\gg10^7$ G.

3. Now let the electron pass through the electromagnetic field of a circularly polarized plane wave. The motion of the electron has been well studied in this case and it can be shown that in the IRF $a'_\perp=2\omega\gamma\cdot\eta\sqrt{1+\eta^2}$, where ω is the frequency, and $\eta=e\varepsilon/m\omega$ (ε is the amplitude of the field). Consequently, $kT/m=(\gamma\omega/\pi m)\eta\sqrt{1+\eta^2}$.

The calculated dependences of the intensity per unit pathlength, $xdN/dldx$, of the Unruh radiation, and also of the accompanying radiation of the electron in the wave,[11] on x and η are shown in Figs. 2a and 2b. Curve 1′ in Fig. 2a was calculated according to formulas for the radiation of an electron in the field of an intense laser beam[11] to the fifth harmonic, and curves 2′, 3′, and 4′ in Figs. 2a and 2b were calculated according to the simple Compton backscattering formulas (in order not to crowd the figure). As can be seen from Fig. 2a, at $\eta=0.4$ the intensity of the Unruh radiation is equal to, or even greater than, the intensity of the competing background for $\gamma\gtrsim10^7$, i.e., at the energies of the *SSC*.

Thus, in spite of the fact that we have left out a number of factors (e.g., the finiteness of the interaction region), the above results nevertheless show that the development of laser and accelerator technology should make it possible in the near future to investigate the Unruh effect, along with the nonlinear effects of quantum electrodynamics[13] if its theoretical underpinnings[2–4] are valid. The existence of the region $x>1$ in the spectra possibility indicates that these ideas require further theoretical and experimental study such as we have proposed here.

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[1)] In a private communication Professor R. Palmer informed us that a variant of the e^+e^- supercollider (1 to 5 TeV) is now being considered. This supercollider will have a bunch structure that can produce fields as strong as $H\gtrsim10^9$ G.

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