Energy loss to radiation and pair production due to the Unruh effect in linear colliders

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A manifestation of the Unruh effect in high-energy physics is examined theoretically. It is currently believed that this effect would occur in accelerated systems.

1. According to the Unruh effect (Ref. 1, for example), a body undergoing an acceleration a in its instantaneous proper frame of reference is immersed in a "thermal bath" of photons with a Planckian spectrum with a temperature $T = a/(2\pi k)$, where k is the Boltzmann constant, and $\hbar = c = 1$. If so, the interaction of these photons with an accelerated electron in the laboratory frame should result in the observation of a so-called Unruh radiation, as was shown in Refs. 2–4. It should also result in the production of e^+e^- pairs, as was shown in Ref. 3. On the other hand, it has been established that one of the following three processes will dominate the e^+e^- pair production in linear colliders (Ref. 5, for example), depending on the value of the synchrotron-radiation parameter $\kappa = \gamma H/H_0$, where $\gamma = E/m$ and $H_0 = m^2/e = 4.4\times 10^{13}$ Oe. (a) At $\kappa < 0.6$, the dominant process is $\gamma e \to ee^+e^-$; i.e., the synchrotron-radiation photons create a pair in the field of the oppositely directed bunch at other particles of that bunch. (b) At $0.6 < \kappa < 100$, the dominant process is $\gamma H \to He^+e^-$; i.e., the synchrotron-radiation photons of the first bunch create a pair in the field of the oppositely directed bunch. (c) At $\kappa > 100$, the dominant process is $eH \to Hee^+e^-$; i.e., the particles of one bunch create a pair in the field of the entire oppositely directed bunch.

As part of a search for a new method for observing the Unruh effect, we have carried out a study of a process in which a "virtual" Planckian photon, which arises from an acceleration a in the field H of the oppositely directed bunch, creates an e^+e^- pair, $eH \to Hee^-e^+$, at a particle of the bunch which is at rest, e. This process, which corresponds to process (c) outlined above, outweighs (a) and (b). In the laboratory frame it should be seen as a triplet moving in the forward direction and carrying off some of the energy of the bunch.

2. The number of such pairs and also the number of Unruh-radiation photons which are formed per unit time in the instantaneous proper frame by a photon with an energy ω_1' is

$$\frac{dn_{\gamma,p}}{dt'd\omega_1'} = \frac{dn}{d\omega_1'}\sigma_{\gamma,p}(\omega_1') \, . \qquad (1)$$

Here $dn/d\omega_1'$ is a Planckian spectrum with a temperature T, and $\sigma_{\gamma,p}$ are the total cross sections for Compton scattering and for the reaction $\gamma e \to ee^+e^-$ (Ref. 6). Inte-

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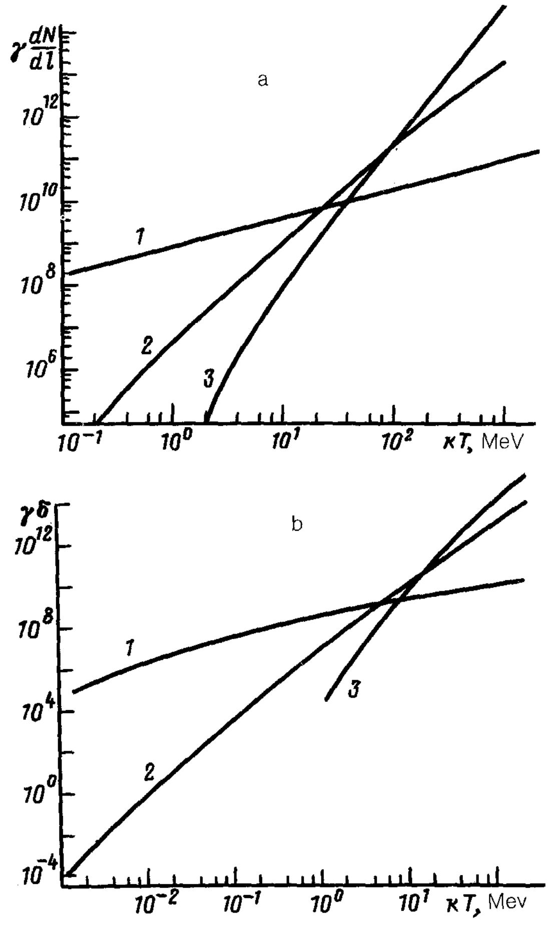

FIG. 1. Curves of (a) $\gamma dN/dl$ and (b) $\gamma d\eta/dl$ versus kT (in MeV) for (curve 2) radiation and (curve 3) e^+e^- pair production by the Unruh mechanism, and also for synchrotron radiation (curve 1). The latter result agrees with the results of Ref. 9.

grating (1) over ω_1' (or over $y=\omega_1'/m$) from 0 and also from $y=4$, and expressing the results per unit length of the colliding bunches in the laboratory frame, we find

$$\gamma\frac{dN_{\gamma,p}}{dl}=1,756\times10^{30}\int\limits_{0;4}^{\infty}\frac{y^2dy}{\exp(my/kT)-1}\sigma_{\gamma,p}(y). \tag{2}$$

Figure 1a shows $\gamma dN/dl$ as a function of kT (in MeV) according to a calculation from (2). We note that kT is related to κ by $kT=e\gamma H/2\pi m=\kappa m/2\pi$. Alternatively, we can write kT (MeV) $=1.84\times10^{-15}\gamma H$ (G) $=8.12\times10^{-2}\kappa$.

3. Figure 1b shows $\eta_p=E_p/E$ and $\eta_\gamma=\omega/E$, i.e., the fractions of the energy which are carried off by the e^+e^- pairs and by the photons in the laboratory frame

(E_p is the total energy of the pair of particles, and ω is the energy of the emitted photon), versus kT (MeV), according to a Monte Carlo calculation.

It follows from Fig. 1, a and b, that after we multiply by γ we obtain universal expressions which are independent of γ. We see the regions along the kT scale (or along the κ scale) in which the various processes are dominant. To find the number of particles which are produced and the value of η for one collision of bunches, we need to multiply the values found from Fig. 1, a and b (for the κ value of the given collider), by the length of the bunch, and we need to divide by γ. Our calculations on processes (a) and (b) show that their contribution is smaller than those of the processes shown in Fig. 1, a and b.

These results thus show that consequences of the Unruh effect could, in principle, be observed at future colliders with large values of κ. Before a quantitative study of an experiment is carried out, however, it will be necessary to incorporate factors such as the effect of variations in H and the edge effect of the bunches, as is done in the case of synchrotron radiation[7] and in the case of ordinary pairs.[8]

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