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YEREVAN PHYSICS INSTITUTE

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NEW MECHANISM FOR UNRUH RADIATION OF  
            
CHANNELED PARTICLES

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ԿԱՆԱԼԱՑՎԱԾ ՄԱՄՆԻԿՆԵՐԻ ՈՒՆԲՈՒԻ ԺԱՌԱԳԱՅՔՄԱՆ ՆՈՐ ՄԵԽԱՆԻԶՄ

Դիտարկված է Ունդուի մտազայթման հայտնաբերման մի նոր եղանակ: Քանի որ կանալացված մասնիկները բյուրեղային առանցքների և հարթությունների ուժեղ դաշտերի ազդեցության տակ ենթարկվում են մեծ ընդլայնական արագացումների, նրանք զտնվում են , , ջերմային մտազայթման քաղնիքում, , , որը ցրվելով առաքվում է որպես իրական ֆոտոններ: Հաշվված են մտազայթման սպեկտրալ բաշխումները և բերված թվային հաշվարկների արդյունքները:

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NEW MECHANISMS FOR UNRUH RADIATION OF  
CHANNELED PARTICLES

A new method for observing the Unruh radiation is considered. Since the channeled particles in the presence of the strong fields of crystallographic axes and planes undergo large transversal accelerations they must be bombarded by the "bath of thermal radiation" which after scattering is emitted as real photons. The results of the theoretical and numerical calculations of the spectral distributions of the produced radiation are given.

Yerevan Physics Institute

Yerevan 1989

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С.М.ДАРБИНЯН, К.А.ИСПИРЯН, А.Т.МАРГАРЯН

НОВЫЙ МЕХАНИЗМ УНРУ ИЗЛУЧЕНИЯ КАНАЛИРОВАННЫХ  
ЧАСТИЦ

Рассмотрен новый способ наблюдения излучения Унру. Поскольку каналированные частицы под действием сильных полей кристаллических осей и плоскостей испытывают большие поперечные ускорения, то они находятся "в бане теплового излучения", которое рассеиваясь испускается в виде реальных фотонов. Вычислены спектральные распределения и приведены результаты численных расчетов.

Ереванский физический институт

Ереван 1969

After the prediction that the black holes may emit Hawking radiation [1], it has been shown [2-4] that any body moving with acceleration  $a$  in its instantaneous rest frame feels a thermal electromagnetic radiation (the so called Unruh effect) with a Planck distribution and temperature  $T = a/2\pi K$ , where  $K$  is the Boltzman constant ( $\hbar = c = 1$ ). At present many works (see [5,6] and references therein) devoted to the understanding of the Unruh radiation have been published. Recently it has been appeared a work [7] in which the author discusses the possibility of observing this radiation using the nonlinear effects in media with fastly varying index of refraction. There is no direct experimental proof of the existence of the Unruh effect mainly due to the absence of possibility for obtaining large values of acceleration,  $a \geq 10^{33} \text{ cm/s}^2$  [8]. Only two observed facts, having other explanations, are interpreted in the works [9,10] as manifestation of Unruh effect.

This work is devoted to the study of the possibility of direct detection of the Unruh radiation of high energy channeled particles undergoing large acceleration in the strong fields of crystallographic axes and planes.

Let us begin by estimating the transversal acceleration  $a_{\perp}$  of a relativistic particle with  $\gamma = E/m = (1 - \beta^2)^{-1/2}$  and moving in a plane channel of a crystal along the direction of  $Z$  axis

(the case of the axial channeling does not change the results essentially). For a parabolic potential  $U = U_0 y^2$  where  $U_0$  is a constant and  $y$  is the distance between the particle and channel axis in units of  $d_p/2$  one obtains  $a_1 = 4U_0 y/m\gamma d_p$  ( $d_p$  is the interplanar distance). In the particle instantaneous rest frame (all physical magnitudes in this frame are primed) which in this case ( $\beta_1 \ll \beta_2$ ) coincides approximately with the so called accompanying frame and moves with velocity  $\beta_2 \approx \beta$  relative to the laboratory frame one obtains

$$a'_1 = a_1 \gamma^2 = 4\gamma \frac{U_0 y}{m d_p}, \quad (1)$$

$$\frac{KT'}{m} = \frac{2}{\pi} \frac{U_0}{m} \frac{\lambda_e}{d_p} \gamma y,$$

where  $\lambda_e = 1/m$  is the electron Compton length. For positrons channeled in the (110) plane of diamond crystal with  $d_p = 1.26 \text{ \AA}$  and  $U_0 = 23 \text{ eV}$  one obtains (for  $y = 1$ )  $a'_1 = 1.3 \cdot 10^{25} \text{ cm/s}^2$  and  $KT'/m = 8.8 \cdot 10^{-8} \gamma$ , i.e. when  $\gamma \approx 10^8$  the acceleration reaches the value  $a'_1 \approx 10^{33} \text{ cm/s}^2$ .

Using the well known spectral densities  $dn'(T')/d\omega'_i$  of the Planck thermal radiation and the differential cross sections  $d\sigma/d\omega'_i$  of the Compton scattering on electron in rest, where  $\omega'_1$  and  $\omega'_2$  are the energies of the incident and scattered photons, after integration over the angles of the isotropic Planck radiation and over  $\omega'_1$  one can derive the spectral-angular distribution of the radiation under investigation in the particle instantaneous rest frame. The limits of integration over  $\omega'_1$

are defined by the Compton effect energy conservation law

$\omega'_2/(1+2\omega'_1/m) \leq \omega'_2 \leq \omega'_1$  . Taking into account that the Plank's photon distribution decreases sharply after the maximum at  $\omega'_2 \sim KT'$

the integration over  $\omega'_1$  one can carry out up to a certain value,

for instance, up to  $\omega'_1 \leq \tilde{\omega}'_1 \sim 10KT'$  . Then for  $0 \leq \omega'_2 \leq \omega'_1 \equiv$

$\equiv \tilde{\omega}'_1/(1+2\tilde{\omega}'_1/m)$  the integration over  $\omega'_1$  is carried out with-

in the limits  $\omega'_2 \leq \omega'_1 \leq \omega'_1/(1-2\omega'_1/m)$  (region I) and for

$\tilde{\omega}'_2 < \omega'_2 \leq \tilde{\omega}'_1$  - within the limits  $\omega'_2 \leq \omega'_1 \leq \tilde{\omega}'_1$  (region II).

One can obtain the spectral-angular distribution in the la-

boratory frame by using the Lorentz transformations  $\omega'_2 =$

$= \gamma \omega_2 (1 - \beta \cos \theta_2)$ ,  $\cos \theta'_2 = (\cos \theta_2 - \beta) / (1 - \beta \cos \theta_2)$  . By integrating the

obtained distribution over the angles  $d\Omega_2 = \sin \theta_2 d\theta_2 d\varphi_2$

one derives the final spectral distribution of the radiation.

Let us note that the limits of the integration over  $\cos \theta_2$  in the region I and II differ from each other depending on the value

of  $\omega_2$  . Without writing the region of very low frequencies

$\omega_2/m < \tilde{\omega}'_1 / \gamma (1 + \beta)$  let us bring the final formulae for

the energetic distribution of the number of the Unruh radiation

photons per unit length of crystal:

for  $\tilde{x}_1/2\gamma^2 \leq x \leq 2\tilde{x}_2$

$$\frac{dN(x, y)}{dl dx} = \frac{d^2}{2\pi \tilde{x}_2 \gamma \beta^2} \left\{ \int_{\tilde{x}_1/x}^{\tilde{x}_2/x} \int_{0.5}^{\tilde{x}_2} \frac{dz}{z} \int_{x_2}^{\tilde{x}_2} \frac{dx_1}{e^{m x_1 / KT'} - 1} \mathcal{F}(x_1, x_2) + (2) \right. \\ \left. + \int_{\tilde{x}_2/x}^{\tilde{x}_1} \int_{x_2}^{\tilde{x}_2} \frac{dz}{z} \int_{x_2}^{\tilde{x}_2} \frac{dx_1}{e^{m x_1 / KT'} - 1} \mathcal{F}(x_1, x_2) \right\} ,$$

for  $2\bar{X}_2 < X \leq 2\tilde{X}_1$

$$\frac{dN(x, y)}{d\ell dx} = \frac{L^2}{2\pi \bar{X}_e \gamma \beta^2} \int_{0.5}^{\tilde{X}_1/x} \frac{dz}{z} \int_{X_2}^{\tilde{X}_1} \frac{dx_1}{e^{mX_1/KT} - 1} \mathcal{F}(X_1, X_2), \quad (3)$$

where

$$X = \omega_2/m\gamma, \quad X_1 = \omega'_1/m, \quad X_2 = \omega'_2/m = Xz,$$

$$\bar{X}_2 = \tilde{X}_1/(1+2\tilde{X}_1), \quad \tilde{X}_1 = \tilde{\omega}'_2/m, \quad \tilde{X}_2 = X_2/(1-2X_2),$$

$$\mathcal{F}(X_1, X_2) = \left( \frac{1}{X_1} - \frac{1}{X_2} \right)^2 + 2 \left( \frac{1}{X_1} - \frac{1}{X_2} \right) + \frac{X_1}{X_2} + \frac{X_2}{X_1}.$$

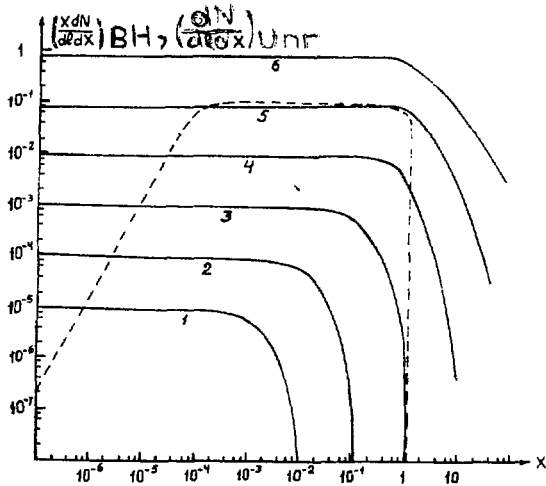
To obtain the real radiation yield it is necessary to average the expressions (2) and (3) over  $y$  using the  $y$ -distribution  $W(y)$  and fraction  $D(\theta_0)$  of the channeled particles [11]. Since these integrations can not be carried out analytically we have performed computer calculations for the (110) plane of diamond crystal when the entrance into crystal  $\theta_0 = 0$  and  $D(0) = 1$ . The results of calculations (see Fig. 1) show that the intensities of radiation via Bethe-Heither and Unruh mechanisms become compatible at very large  $\gamma \sim 10^8$ .

Let us note that the spectra of the radiation under investigation extend behind the values  $X = \omega_2/m\gamma > 1$  which is the consequence of the presence of high frequencies in the Planck's spectrum. Nevertheless the existence of this region of the spectra (though the number of such photons is small and decreases sharply with the increase of  $X$ ) requires further investigation in the sense of the energy conservation law. In conclusion

let us also note that it is possible a similar mechanism for  $e^+e^-$  - pair production only at very large value of  $\chi > 10^7 - 10^8$ .

Figure Captions

Fig. 1. The energy distribution of the radiation per unit length  $\ell$  of a diamond crystal. The entrance angle of the positrons into the crystallographic plane (110) is  $\theta_0 = 0$ .  $\chi = \omega_2 / m\gamma$ . The dotted curve is the bremsstrahlung radiation taking into account the density effect [12]. The solid curves 1 - 6 are the Unruh radiation for  $\gamma = 10^4, 10^5, 10^6, 10^7, 10^8, 10^9$  respectively.



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НОВЫЙ МЕХАНИЗМ УГРУ ИЗЛУЧЕНИЯ КАНАЛИРОВАННЫХ ЧАСТИЦ  
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