Siberian Branch of Russian Academy of Science
BUDKER INSTITUTE OF NUCLEAR PHYSICS

V. N. Baier and V. M. Katkov

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V. N. Baier and V. M. Katkov

Budker Institute of Nuclear Physics,
630090 Novosibirsk, Russia

Abstract

The effect of radiative damping of transverse oscillations of positrons in planar channel of a crystal is considered in realistic conditions when multiple scattering of positrons on atomic electrons is taken into account.

1 Introduction

An influence of the radiation reaction on particle motion in a system with a strong transverse focusing is now under active study (see [1]-[3] and references therein). One of a possible realization of such system is the planar channeling of positrons, where positrons are moving in the superstrong microscopic focusing field formed by crystalline planes. Existence of phenomenon of radiation damping of transverse oscillation of positrons in was found nearly two decades ago [4].

2 Damping of a transverse energy

In [4] motion of particle in oscillatory transverse potential well $U(x) = \dfrac{kx^2}{2}$ was considered under influence of the force of radiative braking as it is given in [5]. The set of equations was derived:

$$\begin{aligned} \ddot{x} + a\dot{x} + \frac{kx}{m\gamma} = 0, \\ \dot{\gamma} + \frac{ka}{mc^2}\gamma^2 x^2 = 0, \end{aligned} \tag{1}$$

where x is the transverse coordinate, $\gamma = \dfrac{\varepsilon}{mc^2}$ is the Lorentz factor of the positron, $a = \dfrac{2ke^2}{3m^2c^3}$, below we will put $c = \hbar = 1$.

Averaging over particle oscillations in a channel (over "fast" variables) one obtains

$$\begin{aligned} \dot{\varepsilon}_\perp + a\varepsilon_\perp + \frac{a}{4m}\varepsilon_\perp^2\gamma = 0, \\ \dot{\gamma} + \frac{a}{m}\gamma^2\varepsilon_\perp = 0, \end{aligned} \tag{2}$$

where $\varepsilon_\perp$ is the transverse energy of the particle. This set contains "slow" variables only. It coincides with the set obtained in [3] by two different methods and given in terms of γ and $J_x = \varepsilon_\perp/\omega$, where $\omega = \sqrt{k/m\gamma}$ is the oscillation frequency.

Solution of this set (see [3]) is

$$\begin{aligned} \varepsilon_\perp(t) = \frac{\varepsilon_\perp(0)e^{-at}}{R^{1/5}(t)}, \quad \gamma(t) = \frac{\gamma(0)}{R^{4/5}(t)}, \\ R(t) = 1 + \frac{5}{8}\varrho_0(1 - e^{-at}), \end{aligned} \tag{3}$$

where $\varrho_0 = \dfrac{2\varepsilon_\perp(0)\gamma(0)}{m}$. If one introduce so called multipolarity parameter $\varrho = 2\gamma^2\overline{v_\perp^2}$, where $\overline{v_\perp^2}$ is a mean square of the transverse velocity (when $\varrho \ll 1$ the radiation is dipole, when $\varrho \gg 1$ the radiation is of magnetic bremsstrahlung nature, the case $\varrho \sim 1$ is intermediate one and many harmonics of radiation is essential), then $\varrho = \dfrac{2\varepsilon_\perp(t)\gamma(t)}{m}$ and ϱ_0 is the initial value of this parameter.

When $at \ll 1$, one has

$$\begin{aligned} \varepsilon_\perp(t) &= \frac{\varepsilon_\perp(0)}{R_1^{1/5}(t)}, \quad \gamma(t) = \frac{\gamma(0)}{R_1^{4/5}(t)}, \\ R_1(t) &= 1 + \frac{5}{8}\varrho_0 at, \end{aligned} \tag{4}$$

so that the transverse energy and total energy initially damp with power laws in the case when $\varrho_0 \gg 1$. However, exponential damping factor in the transverse energy becomes more important for longer time (distance). When $at \gg 1$, one has

$$\begin{aligned} \varepsilon_\perp(t) &= \frac{\varepsilon_\perp(0)e^{-at}}{R_2^{1/5}}, \quad \gamma(t) = \frac{\gamma(0)}{R_2^{4/5}}, \\ R_2 &= 1 + \frac{5}{8}\varrho_0, \end{aligned} \tag{5}$$

Exponential damping factor in (3), (5) can be written in the form $\exp(-l/l_a)$, where l is the length of the way of the particle in crystal. The characteristic damping length l_a for plane (110) in different crystals is given in Table 1 along with distance between planes d_{pl} and depth of the potential well U_0. Note that the length l_a is quite close to the standard radiation length L_{rad} in corresponding media and only for diamond l_a is a few times shorter than L_{rad}.

Form of the transverse potential for planar channeling of electrons is very different from oscillator potential and atomic nuclei are situated in the middle of the channel, so that multiple scattering of electrons is amplified comparing with amorphous medium. The transverse potential for positrons is more similar to oscillator one and positrons in channel are moving mostly far from atomic nuclei, so that multiple scattering of positrons is diminishing comparing with amorphous medium. So, only the case of channeling of particles with positive charge is interesting from the point of view of damping of the transverse oscillations of a particle moving in a planar channel. Although in real crystals the planar potential is quite different from the oscillator one and a spread of frequencies of motion of a positron in a channel is order of one [6], nevertheless consideration of damping in the oscillator potential is a very useful model importance of which is connected with existence of the exact analytical solution.

3 Damping process with multiple scattering included

The only interesting situation is the case when positrons are moving far from the crystalline planes, when the main scattering process is a scattering on atomic electrons. Connected with this scattering increment of the transverse energy is (see [6], Sec. 10):

$$\frac{\Delta\varepsilon_\perp}{\Delta l} = \frac{\varepsilon}{2}\frac{\Delta\vartheta_s^2}{\Delta l}, \tag{6}$$

where ϑ_s^2 is the mean value of the square of x-component of the angle of the multiple scattering of a positron. An interaction of a positron with atomic electrons can be split into two parts. The first contribution into the square of angle of the multiple scattering gives scattering on electrons situated inside planes forming planar channel in which positron is moving. The maximal momentum transfer follows from a condition that positron should not go out of the channel and minimal momentum transfer is defined by maximal remoteness of positron from atomic plane:

$$\begin{aligned} q_{max}^2 &= 2\varepsilon U_0 = \varrho_p m^2, \quad q_{min} = \frac{1}{d_{pl}}, \\ \frac{q_{max}^2}{q_{min}^2} &= \varrho_p \frac{d_{pl}^2}{\lambda_c^2} \sim \varrho_p 10^5, \end{aligned} \tag{7}$$

where U_0 is the depth of the transverse potential well in which channeling occurs, d_{pl} is the distance between neighbor planes, $\lambda_c = \dfrac{1}{m} = \left(\dfrac{\hbar}{mc}\right)$ is the electron Compton wavelength, $\varrho_p = \dfrac{2\varepsilon U_0}{m^2}$. In the region $q \geq q_{min}$ one can consider scattering as a scattering on free electrons and its cross section is defined, within logarithmic accuracy, by local density of atomic electrons $n(x)$ depending on positron coordinate $x(1/q < d_{pl})$. So, we have for the square of angle of the multiple scattering following expression:

$$\frac{\Delta\vartheta_s^2}{\Delta l} == \frac{4\alpha^2 n(x)}{\varepsilon^2}\int\limits_{q_{min}}^{q_{max}} \frac{q_x^2 d^2 q}{q^4} = \frac{2\pi\alpha^2 n(x)}{\varepsilon^2}\ln\frac{q_{max}^2}{q_{min}^2}, \tag{8}$$

where $\alpha = e^2 = 1/137,\ q^2 = q_x^2 + q_y^2$. Note that ratio $\frac{q_{max}^2}{q_{min}^2}$ and consequently the square of angle of the multiple scattering does not depend on a particle's mass. Now we compare the square of angle of the multiple scattering of relativistic protons moving in a planar channel with expression for ionization losses (stopping power) in a corresponding amorphous medium:

$$\left(\frac{\delta\varepsilon}{\delta l}\right)_{am} = \frac{4\pi\alpha^2 n_{am}}{m}\left(\ln\left(\frac{2\gamma_M m}{\omega_0}\right) - \frac{1}{2}\right), \tag{9}$$

where $\gamma_M = \frac{\varepsilon}{M}$, M is the proton mass, and $\omega_0^2 = \frac{4\pi n_{am}}{m}$ is the plasma frequency, n_{am} is the mean density of electrons in an amorphous medium. Taking into account that

$$\frac{\omega_0}{m} = \sqrt{\frac{4\pi\alpha n_{am}}{m^3}} \sim \sqrt{Z}10^{-5}, \quad \frac{2\gamma_M}{\sqrt{Z}} = \frac{2\varepsilon U_0}{MU_0\sqrt{Z}} \sim \varrho_p, \tag{10}$$

and comparing eqs.(7)-(8) with eqs. (9) - (10) we find that

$$\frac{\Delta\vartheta_s^2}{\Delta l} \simeq \frac{m}{2\varepsilon^2}\left(\frac{\delta\varepsilon}{\delta l}\right)_{am}\frac{n(x)}{n_{am}}. \tag{11}$$

Use the expression (11) for calculation of the dechanneling length for protons with energy $10\ GeV \leq \varepsilon \leq 200\ GeV$ moving in (110) or (111) channels in Si gives a result which agree satisfactory with experimental data [7].

The contribution of electrons situated outside planes which are forming the channel under consideration (contribution of long distances, $x \geq d_{pl}$) into mean square of the angle of multiple scattering has a form

$$\begin{aligned} \frac{\Delta\vartheta_s^2}{\Delta l} == \frac{4\alpha^2 n_{am}}{\varepsilon^2}\int\limits_{\omega_0}^{1/d_{pl}}\frac{q_x^2 d^2 q}{q^4} = \frac{2\pi\alpha^2 n_{am}}{\varepsilon^2}\ln\frac{1}{\omega_0^2 d_{pl}^2}, \\ \omega_0^2 d_{pl}^2 \simeq \frac{4\pi\alpha Z d_{pl}^2}{d_{pl}^3 m} = 4\pi\alpha Z\frac{\lambda_c}{d_{pl}} \simeq Z\cdot 10^{-4}. \end{aligned} \tag{12}$$

The total contribution of the both short and long distances into the increment of the transverse energy is

$$\frac{\Delta\varepsilon_\perp}{\Delta l} = \frac{\pi\alpha^2}{\varepsilon}\left(n_{am}\ln\left(\frac{10^4}{Z}\right) + n(x)\ln(\varrho_p 10^5)\right). \tag{13}$$

Ratio r_c of contribution of long distances to contribution of short distances is given in Table. When high energy particle ($\gamma\omega_0 \geq I_{max},\ I_{max} \sim Z^2\cdot 10\ eV,\ \omega_0 \sim \sqrt{Z}\cdot 10\ eV, \gamma \geq Z^{3/2}$) traverses an amorphous medium, density $n(x)$ should be substituted by n_{am}. So, the sum of contributions of the both short and long distances into mean square of the angle of multiple scattering has a form

$$\frac{\Delta\vartheta_s^2}{\Delta l} = \frac{2\pi\alpha^2}{\varepsilon^2}n_{am}\left(\ln\left(q_{max}^2 d_{pl}^2\right) + \ln\frac{1}{d_{pl}^2\omega_0^2}\right) = \frac{2\pi\alpha^2}{\varepsilon^2}n_{am}\ln\frac{q_{max}^2}{\omega_0^2}. \tag{14}$$

Ionization losses of a high energy particle per unit length are

$$\left(\frac{\delta\varepsilon}{\delta l}\right)_{am} = 2\frac{\varepsilon^2}{2m}\frac{\Delta\vartheta_s^2}{\Delta l} = \frac{2\pi\alpha^2}{m}n_{am}\ln\frac{q_{max}^2}{\omega_0^2}. \tag{15}$$

The last expression coincides, within logarithmic accuracy,with known formula for ionization losses (see, e.g., [8]).

For the oscillatory potential $U(x) = kx^2/2$ (which describes either averaged characteristics of one-parametric potential, or a motion of the particle near a bottom in any potential well), one has from the Poisson's equation

$$n(x) = \frac{k}{4\pi\alpha} = \frac{2U_0}{\pi\alpha d_{pl}^2} = const.$$

To proceed with inclusion of multiple scattering into set of eq.(2), we use eqs.(12) and (13) and the last equation, which are self-consistent for the oscillatory potential. Besides, when one uses eqs.(12) and (13), it is necessary to substitute $q_{max}^2 \to 2\varepsilon\varepsilon_\perp$ (or $\varrho_p \to \varrho$), since in the case when increment of the transverse energy $\Delta\varepsilon_\perp \gg \varepsilon_\perp$ in one interaction act (time of scattering is much shorter than the period of motion) one can not describe motion in the terms of classical trajectory.

TABLE Parameters of the potential for the plane (110)
and characteristics of damping and antidamping processes

Crystal	T(K)	$d_{pl}, 10^{-8}cm$	U_0, eV	l_a, cm	A	β_0	η	r_c
C_d	293	1.26	23	2.3	1.7	9	6.8	1.1
Si	293	1.92	23	5.5	2.6	10.6	7.3	1.5
Ge	293	2.00	40	3.4	3.2	11.1	7.5	1.6
W	293	2.24	130	0.33	4.1	11.8	7.7	1.7

Furthermore, an analysis below shows that within adopted accuracy (logarithmic accuracy) one can put in equations of motion that $\varrho = 1$ in an argument of a logarithm. As a result we obtain

$$\begin{aligned} &\dot{\varepsilon}_\perp + a\varepsilon_\perp + \frac{a}{4m}\varepsilon_\perp^2\gamma - \frac{b}{\gamma} = 0, \\ &\dot{\gamma} + \frac{a}{m}\gamma^2\varepsilon_\perp = 0, \end{aligned} \tag{16}$$

where

$$b = \frac{k\alpha}{4m}\left(\ln 10^5 + A\ln\frac{10^4}{Z}\right), \quad A = n_{am}\frac{\alpha\pi d_{pl}^2}{2U_0}.$$

Values of A (expression for A is valid for crystal structures $fcc_{(d)}, bcc$) for some crystals are given in Table.

It is convenient to rewrite the set (16) in terms of functions $\gamma(t)$ and $r(t) = \varepsilon_\perp(t)\gamma(t)$ in which the set is simplified considerably:

$$\begin{aligned} &\dot{r} + ar + \frac{5ar^2}{4m} - b = 0, \\ &\dot{\gamma} + \frac{a}{m}\gamma r = 0, \end{aligned} \tag{17}$$

It is seen that the first equation of this set contains function $r(t)$ only and this is a differential equation with separable variables, solution of which is straightforward. With found function $r(t)$ one can integrate the second equation of the set (17). Solution of the set can be presented in the form

$$\begin{aligned} &\varrho(t) = \frac{2r(t)}{m} = \frac{4}{5}\frac{G(t)}{F(t)}, \\ &\varepsilon_\perp(t) = \frac{4\varepsilon_\perp(0)}{5\varrho_0}\frac{G(t)}{F^{1/5}(t)(2\eta)^{4/5}}\exp\left(\frac{2}{5}(\eta-1)at\right), \\ &\gamma(t) = \gamma(0)\left(\frac{2\eta)}{F(t)}\right)^{4/5}\exp\left(-\frac{2}{5}(\eta-1)at\right), \end{aligned} \tag{18}$$

where

$$\begin{aligned} &F(t) = \beta_1 - \beta_2 e^{-a\eta t}, \quad \beta_1 = 1 + \eta + \frac{5}{4}\varrho_0, \quad \beta_2 = 1 - \eta + \frac{5}{4}\varrho_0, \\ &G(t) = \beta_1(\eta-1) + \beta_2(\eta+1)e^{-a\eta t}, \quad \eta = \sqrt{1 + 5\frac{b}{ma}}. \end{aligned} \tag{19}$$

The value of the parameters for some usable crystals is given in Table. When the multiple scattering is turned off ($\eta = 1$), one returns to the solution (3).

Now we will proceed with qualitative analysis of the set (17) which we rewritten in the form:

$$\begin{aligned} &\frac{d\varrho}{dT} + \varrho + \frac{5\varrho^2}{8} - 2\beta = 0, \\ &\frac{d\gamma}{dT} + \frac{\gamma\varrho}{2} = 0, \end{aligned} \tag{20}$$

where $T = at$, we introduce

$$\beta = \frac{3}{8}\left(\ln(\varrho 10^5) + A\ln\frac{10^4}{Z}\right), \quad \beta_0 \equiv \frac{b}{ma} = \frac{3}{8}\left(\ln(10^5) + A\ln\frac{10^4}{Z}\right). \tag{21}$$

Parameters β_0 for some usable crystals are shown in Table. So, in this analysis we take into account that β is logarithmically depend on energy. When $\varrho_0 \gg 1$ and $T \ll 1$ one can neglect terms $\varrho - 2\beta$ in the first equation (20) since value of ϱ is still large at $T \ll 1$. Then we have set

$$\frac{d\varrho}{dT} + \frac{5\varrho^2}{8} = 0, \quad \frac{d\gamma}{dT} + \frac{\gamma\varrho}{2} = 0, \tag{22}$$

solution of which is

$$\begin{aligned} &\varepsilon_\perp(T) = \frac{\varepsilon_\perp(0)}{R_1^{1/5}(T)}, \quad \gamma(t) = \frac{\gamma(0)}{R_1^{4/5}(T)}, \quad \varrho = \frac{\varrho_0}{R_1(T)}, \\ &R_1(T) = 1 + \frac{5}{8}\varrho_0 T. \end{aligned} \tag{23}$$

It coincides with (4) where multiple scattering is neglected.

When $T \sim \dfrac{1}{\sqrt{\beta}}$ from (23) one has that $\varrho \sim \sqrt{\beta}$. In this situation all terms in the first equation in (20) is of one order and multiple scattering is turned on. In this case with a good accuracy we have $\beta \simeq \beta_0$. With further increase of T function ϱ tends to its stationary value

$$\frac{d\varrho_s}{dT} = 0, \quad \varrho_s + \frac{5\varrho_s^2}{8} - 2\beta = 0, \quad \varrho_s \simeq \frac{4}{5}\left(\sqrt{1 + 5\beta_0} - 1\right). \tag{24}$$

Note, that for crystals we considered (diamond, Si, Ge, W) for plane (110) one has $\varrho_s \simeq 5$ and one can neglect dependence β on ϱ, ($\beta \simeq \beta_0$). In this region of T the total energy decreases exponentially $\gamma(T) \propto \exp(-\varrho_s T/2)$ and the transverse energy increases exponentially since the value $\varrho = \dfrac{2\gamma\varepsilon_\perp}{m}$ remains constant.

In the opposite case when $\varrho_0 \ll 1$ value of $\varrho + \dfrac{5}{2}\varrho^2$ remains small compared with 2β until $T \sim 1/\sqrt{\beta}$. In this case one can neglect damping effects (terms $\propto \varrho,\ \varrho^2$) and function ϱ varies only due to multiple scattering:

$$\frac{d\varrho_s}{dT} - 2\beta_0\left(1 + \frac{\ln\varrho}{C}\right) = 0, \tag{25}$$

where $C = 25$ for diamond and $C = 31$ for W. Solving this equation by the method of successive approximations we find after the first step

$$\varrho(T) \simeq 2\beta_0 T\left(1 + \frac{\ln(2\beta_0 T + \varrho_0) - 1}{C}\right) + \varrho_0. \tag{26}$$

At $\varrho_0 \ll T \le 1/\sqrt{\beta}$, $\varrho(T) \simeq 2\beta_0 T$ is independent of the initial value ϱ_0 and (with logarithmic accuracy) is defined by value β_0. With T increase the function ϱ attains value of the order of $\sqrt{\beta}$ and one has to take into account all the terms in set (20) and we have situation discussed above: $\varrho \to \varrho_s$, the total energy decreases exponentially, while transverse energy increases exponentially.

So, we have shown that with logarithmic accuracy (this is just the accuracy we could calculate β) one can neglect by the dependence of $\beta(\varrho)$ and put $\beta = \beta_0$.

Solutions (18) of the set (17) are illustrated also in Fig.1 and Fig.2. The ratio $\dfrac{\varepsilon_\perp(T)}{\varepsilon_\perp(0)}$ vs $T = at$ is given in Fig.1. The curve 1 in (a), (b) and (c) present the case $\eta = 1$ when the multiple scattering is turned off. These curves show damping of the transverse energy and coincide, naturally, with results of [3]. However, the multiple scattering changes the situation drastically. For low ϱ_0 the transverse energy is increasing from the very beginning, while for $\varrho_0 = 100$ the transverse energy first decreasing but starting from $T \sim 1$ it ceases decrease and begin to increase. So, under this condition decrease of the transverse energy is possible in a very short interval of $T = at$ and only when ϱ_0 is enough high. The ratio $\dfrac{\gamma(T)}{\gamma(0)}$ vs $T = at$ is given in Fig.2. Here one can see that in absence of multiple scattering the total energy first decreasing (for high ϱ_0) and than tends to some constant, while the multiple scattering causes unlimited decrease of the total energy. So, the behavior of curves in figures illustrates numerically the results of the above qualitative analysis.

4 Behavior of a positron beam as a whole

Using the results obtained we can analyze a behavior of a positron beam entering into the oriented crystal at different energies. At low energy the condition $\varrho_0 \ll 1$ is fulfilled for all the particles of the

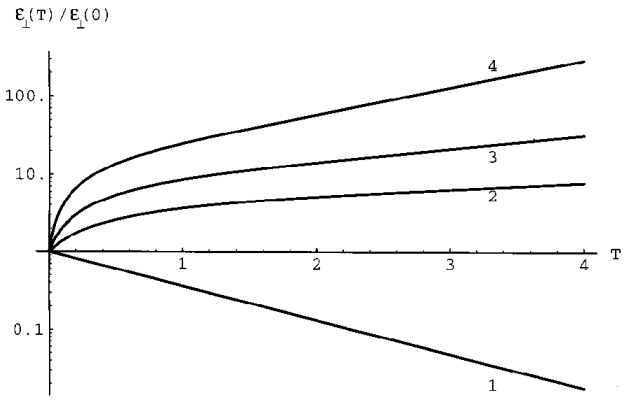
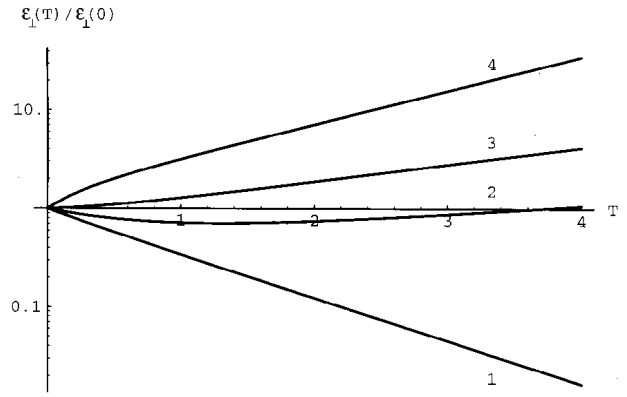
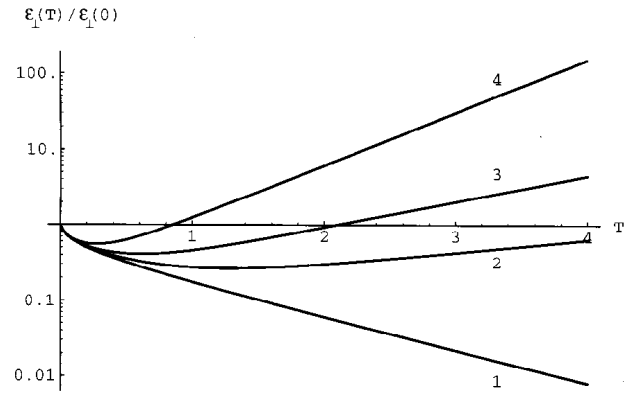


Fig.1. Ratio $\frac{\varepsilon_\perp(T)}{\varepsilon_\perp(0)}$ vs $T = at$ for different values of parameter ϱ_0.

(a) For $\varrho_0 = 0.1$ curve 1 is for $\eta = 1$ when the multiple scattering is turned off; curves 2,3,4 are for $\eta = 1.5, 2, 3$ respectively.



(b) Same for $\varrho_0 = 1$.



(c) Same for $\varrho_0 = 100$ but curves 1,2,3,4 are for $\eta = 1, 2, 3, 5$ respectively.

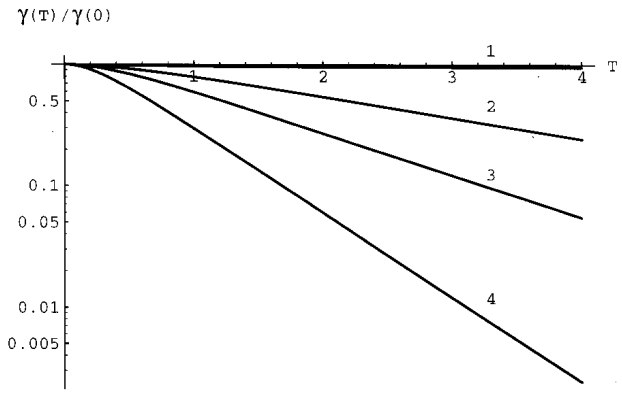
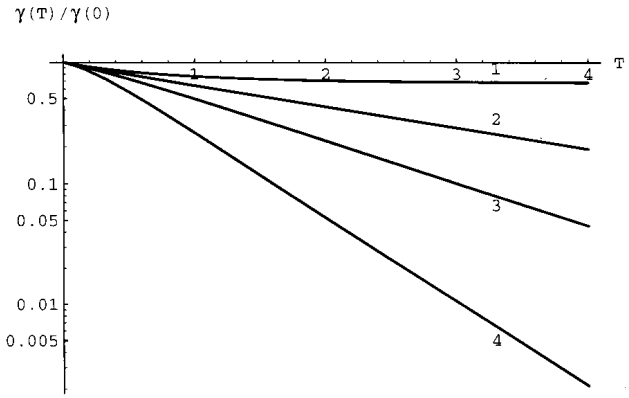
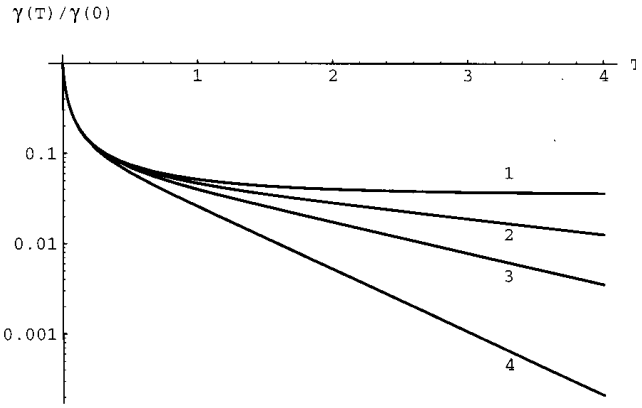


Fig. 2. Ratio $\frac{\gamma(T)}{\gamma(0)}$ vs $T = at$ for different values of parameter ϱ_0.

(a) For $\varrho_0 = 0.1$ curve 1 is for $\eta = 1$ when the multiple scattering is turned off; curves 2,3,4 are for $\eta = 2, 3, 5$ respectively.



(b) Same for $\varrho_0 = 1$.



(c) Same for $\varrho_0 = 100$.

beam ($\varrho_0 \leq \varrho_p \ll 1$). In this case positrons quit the channel during a time which is much shorter than the radiation damping time ($\sim 1/a$) and in this case one can neglect radiation damping. Indeed, the characteristics dechanneling time t_d is (see eqs.(25), (26))

$$\varepsilon_\perp = \frac{\beta_0 a m^2}{\varepsilon} t_d = U_0, \quad t_d = \frac{\varepsilon U_0}{\beta_0 a m^2} = \frac{\varrho_p}{2\beta_0 a} \ll \frac{1}{a}. \tag{27}$$

At high energy when $\varrho_p \gg 1$ the initial distribution of positrons over ϱ_0 for oscillator potential has a form (see eq.(9.24), [6])

$$dN(\varrho_0) = \frac{d\varrho_0}{\sqrt{\varrho_0}} \frac{1}{2\sqrt{\varrho_p}}. \tag{28}$$

Let us consider a fraction of positrons with $\varrho_0 \leq 1$. This portion of positrons is small:

$$N(\varrho_0 \leq 1) = \int_0^1 dN(\varrho_0) = \frac{1}{\sqrt{\varrho_p}}. \tag{29}$$

This is particles moving well inside a channel with energy $\varepsilon_\perp \leq \frac{U_0}{\varrho_p} \ll U_0$. As one can see from the above analysis, during a time $t \sim \frac{1}{a\sqrt{\beta_0}}$ all the particles of this group acquire a value $\varrho \simeq \varrho_s$, while the energy of particles diminishes slightly. Later on the transverse energy increases

$$\varepsilon_\perp \sim U_0 \frac{\varrho_s}{\varrho_p} \exp(\varrho_s a t/2) \tag{30}$$

and during a time $t \sim \frac{2}{\varrho_s a} \ln \varrho_p$ positrons of this group go out of channel. So, the total dechanneling time of this fraction is

$$t_d \sim \left[\frac{1}{\sqrt{\beta_0}} + \frac{5 \ln \varrho_p}{2(\sqrt{1+5\beta_0}-1)} \right] \frac{1}{a} \tag{31}$$

The main fraction of positrons possesses large $\varrho_0 \sim \varrho_p$. In it positrons first loses energy during a time $t \sim \frac{1}{a\sqrt{\beta_0}}$ with some decrease of $\varepsilon_\perp$:

$$\gamma \sim \frac{\gamma(0)}{\varrho_p^{4/5}}, \quad \varepsilon_\perp \sim \frac{U_0}{\varrho_p^{1/5}}, \tag{32}$$

and then dechanneling takes place during a time t according to

$$\varepsilon_\perp \sim \frac{U_0}{\varrho_p^{1/5}} \exp(\varrho_s a t/2) \sim U_0, \quad t \sim \frac{2}{\varrho_s a} \frac{\ln \varrho_s}{5}. \tag{33}$$

The total dechanneling time for this fraction is

$$t_d \sim \left[\frac{1}{\sqrt{\beta_0}} + \frac{\ln \varrho_p}{2(\sqrt{1+5\beta_0}-1)} \right] \frac{1}{a}. \tag{34}$$

The analysis above was performed in frame of classical electrodynamics. As it is known ([6]), quantum effect govern by the parameter $\chi_c = \frac{\varepsilon U_0}{dm^3}$. Since quantum effects in radiation are turned on rather early, value $\chi_c \geq 0.1$ can be considered as a boundary of quantum region. From this estimate one has that quantum effects become significant starting from energy $\varepsilon \sim 60\ GeV$ in tungsten and $\varepsilon \sim 600\ GeV$ in silicon. We neglect also a diffusion of the transverse energy in scattering process. Both these effects could be considered in a consistent way using distribution function of channeled particles only.

5 Conclusion

An idea to use particle channeling in oriented crystals in accelerator technique is very attractive one. However, it appears that even in ideal conditions there is the damping of transverse oscillations without loss of the total energy only in the case $\varrho_0 \ll 1$, otherwise particle loses its total energy along with damping of transverse oscillations. Inclusion of the interaction of the channeling particle with atomic electrons

deteriorates the situation drastically. Damping of rather limited scale is possible only in the case $\varrho_0 \gg 1$ in a very narrow interval of time. Otherwise we have antidumping: the transverse energy is increasing while total energy is decreasing. Furthermore, we don't take into account scattering of positrons on fluctuations of a planar potential, which can contribute essentially when positrons are moving close to atomic planes, and connected with this scattering radiation.

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