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ЦЕНТРАЛЬНЫЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ ИНФОРМАЦИИ И ТЕХНИКО-ЭКОНОМИЧЕСКИХ ИССЛЕДОВАНИЙ ПО АТОМНОЙ НАУКЕ И ТЕХНИКЕ

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SUPPRESSION OF MULTIPLE SCATTERING AT PLANAR CHANNELING OF NEGATIVE PARTICLES

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ПОДАВЛЕНИЕ МНОГОКРАТНОГО РАССЕЯНИЯ ПРИ ПЛОСКОСТНОМ КАНАЛИРОВАНИИ ОТРИЦАТЕЛЬНЫХ ЧАСТИЦ

Теоретически показано, что при плоскостном каналировании отрицательных частиц значительная доля пучка испытывает пониженное многократное рассеяние по сравнению со случаем с неориентированной мишенью. Эта аномалия многократного рассеяния сохраняется до больших глубин.

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SUPPRESSION OF MULTIPLE SCATTERING AT PLANAR CHANNELING OF NEGATIVE PARTICLES

It is shown that at planar channeling of negative particles a considerable portion of the beam undergoes depressed multiple scattering as compared to the case of nonoriented target. This anomaly of multiple scattering is preserved up to large depths.

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Until presently the main attention in investigating the channeling of negative particles was given to axial channeling and its comparison to positive particles (see [1]). The spectra of radiation on channeling of relativistic electrons have also been intensively investigated. In the present paper we consider in detail the anomaly of multiple scattering of high energy electrons ($E \geqslant 100$ MeV) at planar channeling. For this energy the classical approximation is valid.

To describe the channeling of electrons we will use the parabolic approximation for the potential

$$U(y) = -U_0 \left(1 - (y/\ell)\right)^2 \qquad (1)$$

where U_0 is the depth of the potential well, and $2\ell = d_p$ is the spacing of lattice planes.

The probability to find a particle in this or that region of the transverse plane is given by the formula

$$dW(y) = \frac{2dt}{T} = \frac{\sqrt{2m}\, dy}{T\sqrt{\varepsilon_\perp - U(y)}} \qquad (2)$$

where $\varepsilon_\perp$ is the transverse motion energy counted from the edge of the well. The period of oscillation T is then defined by the formula

$$T = d_p \sqrt{\frac{2m}{U_0}}\; \nu \ln\left(\frac{\sqrt{U_0} + \sqrt{\varepsilon_\perp + U_0}}{\sqrt{|\varepsilon_\perp|}} \right) \qquad (3)$$

where m is the particle mass, $\nu = 1$, if $\varepsilon_\perp \geqslant 0$, $\nu = 0.5$.

As is seen, for the value of the transverse energy near the edge of the potential well the period strongly increases. In other words, particles hang about the classical turning point just there where the density of nuclei is the lowest. The group of particles with small transverse energies rushes by the region of the maximum density of nuclei at a maximum velocity. Due to thermal oscillations the nuclei are located near the plane in the vicinity of the order of the thermal oscillation amplitude u, which is much smaller than the spacing of lattice planes. The time spent by the channeled particles with $\varepsilon_\perp \approx 0$ in this region decreases as compared to the nonoriented target

$$\varkappa = \frac{\sqrt{U_0/(\varepsilon_\perp + U_0)}}{\ln\left(\frac{\sqrt{U_0} + \sqrt{\varepsilon_\perp + U_0}}{\sqrt{|\varepsilon_\perp|}} \right)} \qquad (4)$$

times. The beam of channeled particles may be divided into two groups. The first group with small $|\varepsilon_\perp|$ undergoes weak multiple scattering. Namely this group will be considered below. The second group of strongly bound electrons $\varepsilon_\perp \sim -U_0$, on the contrary, undergoes strong multiple scattering on nuclei as well as strong simple Rutherford scattering which has been considered in detail earlier [1].

Consider first the decrease in the mean square angle of multiple scattering on nuclei.

Let $\gamma_N = \delta\theta_K^2 / \delta\theta_a^2$ be the ratio of the mean square angle of multiple scattering on nuclei in a crystal and in an amorphous target. The multiple scattering on nuclei is approximately proportional to their local density. At this condition

$$\gamma_N = \frac{ZL'}{ZL'+L''} \int_0^{y_m} \rho_N(y)\, dW(y)\,, \tag{5}$$

where y_m is the turning point, $\rho_N(y)$ is the nuclei distribution in amplitudes of thermal oscillations, Z is the nucleus charge, $L' = \ln 184.15\, Z^{-1/3}$, $L'' = \ln 1194\, Z^{-2/3}$

$$\rho_N(y) = \frac{d_p}{\sqrt{2\pi}\, U_1} \exp\left(-y^2/2U_1^2\right) \tag{6}$$

Since $d_p/U_1 \gg 1$, the integral (5) may be calculated by the method of steepest descent provided $y_m \gg U_1$, i.e. $\varepsilon_\perp \gg -U_0$. Then $\gamma_N = ZL'\varkappa(ZL'+L'')^{-1}$. For the particles in the very bottom of the potential well with $\varepsilon_\perp \approx -U_0$, for which $y_m < U_1$, from (5) an $\gamma_N \approx ZL' d_p(\sqrt{2\pi}\, U_1 (ZL'+L''))^{-1}$ fold amplification of scattering on nuclei is obtained as compared to the amorphous target. To calculate the multiple scattering on electrons, one should replace in (5) $\rho_N(y)$ by $\rho_{el}\alpha L''/ZL'$ where $\rho_{el}(y)$ is the distribution of electrons in the transverse plane, $\alpha = 0{,}5$ is the separation factor of the ionization loss for contributions of short- and long-range collisions [2]. This distribution may be obtained from the potential according to Poisson's equation. For the parabolic potential it is independent of y, i.e. in this approximation the multiple scattering on electrons remains unchanged.

Figure [illegible] presents the values of γ_{el} and $\gamma_S = \gamma_{el} + \gamma_N$. Points denote the same values computed by the formula (5) using Molier's potential at the channeling of electrons by the crystal planes (110). As is seen, calculations by the formula (4) are in a good agreement with the numerical calculation in the region of transverse energies for which suppression of scattering occurs.

Using the value $\varepsilon_\perp$ at which the value of $\gamma_S = \gamma_{el} + \gamma_N$ becomes less than a unit, one may find the portion of the beam of particles undergoing depressed multiple scattering. At a normal beam incidence on the crystal it is $\sim 50\%$.

Let us estimate the approximate thickness of the crystal till which this effect may occur. Let us use for a crude estimate the approximation of the monotonous increase in the transverse energy first proposed by Lindhard [2], which is approximately valid in the region of strong dependence of γ_S on the transverse energy and gives the lower boundary of depth at which most particles from this region will arrive. This region covers approximately the range $-0.3\,U_0 \leq \varepsilon_\perp \leq 0.5\,U_0$. The specific thickness at these assumptions is

$$L_c = \frac{1}{K} \int_{x_1}^{x_2} \frac{dx}{\gamma_S}$$

[illegible] $\delta \Theta_a^2 / \delta z$, $x = \varepsilon_\perp / U_0$, $x_1 = -0.3$, $x_2 = 0.5$. For example [illegible] at $E = 4.5$ GeV for diamond at channeling along the axis (110). The integral value for the parabolic approximation is (universally) equal to 1.8[illegible]. Hence $L_c = 0.2[illegible]$ mm. The given estimate overstates dechanneling. We have developed [illegible] use approximation method for estimate [illegible]

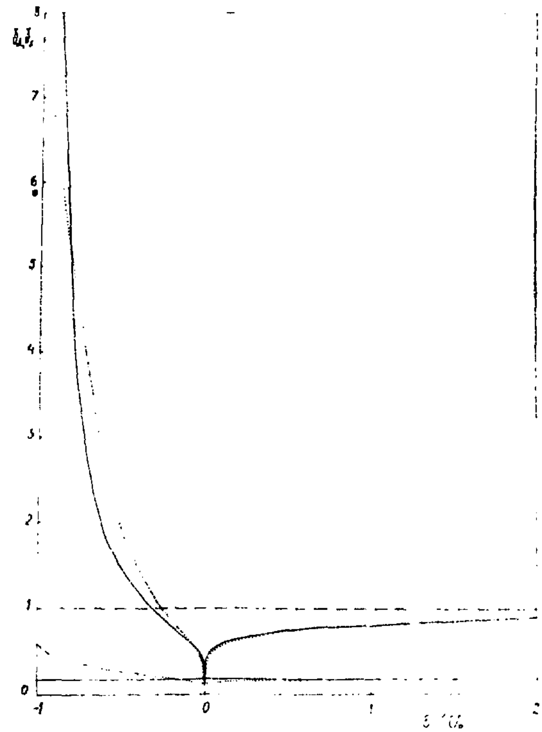
[illegible] the fact that the [illegible] ta after each reflection from the plane at a given intial transverse momentum has been assumed to be Gaussian with a mean square spread

$$\frac{\Delta P_{\perp}^{2}}{\Delta z} = \frac{2E}{c^{2}} U_{o} K \gamma_{s}$$

We have later on performed integration with a distribution in the initial momenta of incident particles. By means of the obtained distribution functions we have calculated for the thickness L the per cent of particles f with transverse energies which undergo substantial depression of multiple scattering ($-0.3\, U_o \leqslant \varepsilon_{\perp} \leqslant 0.5\, U_o$). The results obtained are plotted in the table.

L (μm)	0	100	500	1000	2000	4000
f %	50	68.5	48.9	30.3	23.7	17.4

Thus, up tc considerable thickness a noticeable per cent of particles are observed that undergo depressed multiple scattering. This effect has been first noticed apparently in the experiment [3].



Values of γ_{el} (curve 1) and γ_s (curve 2). Points denote the same values computed by the formula (5) at the channeling of electrons by diamond planes (110). The dotted line denotes the value of γ_s for an amorphous target.

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