PASSAGE OF POSITIVELY AND NEGATIVELY CHARGED PARTICLES THROUGH STRAIGHT AND BENT NANOTUBES

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Passage of high-energy charged particles through oriented crystals and nanotubes is investigated. It is shown that the particle passage through crystals and nanotubes may to be described in the same manner. The possibility of positively and negatively charged particle deflection by bent nanotube due to axial channelling phenomenon is demonstrated. Computer simulation results for relativistic charged particle beam passage through straight and bent nanotubes are presented.

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1. INTRODUCTION

In 90th it were discovered new periodical structures – carbon nanotubes (see [1,2] and refs. herein). Nanotubes are long cored cylinders with about 1 nm diameter. The nanotube surface is formed by periodically situated carbon atoms. In [3-9] it was paid attention to the fact, that for particle passage through nanotubes there are possible effects similar to effects under particle passage through crystal near one of it axis. There are, in particular, channelling, rainbow scattering and orbiting of particles.

Special interest for the fast charged particle interaction with a crystal has process of the particle passage through a bent crystal, when the effective beam deflection effect is possible. It was paid attention ([10]) to the possibility of such effect, while plane channelling of positively charged particles in bent crystal was studied.

In [11,12] it was paid attention to another possibility of the relativistic beam deflection deals with a charged particle multiple scattering by atomic strings of a bent crystal. The effect takes place both for positively and negatively charged particles [12-14]. The computer simulation program for the beam passage through straight and bent crystals was developed in [12-14]. This program is based on crystal presentation as aggregate of atomic strings.

In present paper passage of fast charged particles through straight and bent nanotube is studied. The possibility of positively and negatively charged particle deflection by a bent nanotube due to axial channelling phenomenon is shown. Computer simulation results for particle passage through nanotube with account both coherent and incoherent effects in scattering are presented.

2. BEAM DEFLECTION AND SPLITTING UNDER SCATTERING BY CRYSTAL ATOMIC STRINGS

The motion of a fast charged particle near the crystallographic axis (z-axis) is determined mainly by the continuous string potential, which is the crystal potential averaged along the z-axis [15,16]. In such potential, particles may perform finite (channelling) as well as infinite (over-barrier) motion in the plane orthogonal to the z-axis. In a straight crystal the multiple scattering of over-barrier particles by atomic strings results in so-called donut scattering effect, when the particle scattering over azimuthal direction sufficiently exceed the scattering in radial direction (see for instance [16]).

In [13] it was shown that in a bent crystal the beam deflection as whole is possible. It is due to both channelling and donut scattering mechanisms [14]. Together with the effect of beam deflection, for particle motion near the crystal axis the beam splitting effect is possible [11,14]. In [14] it was shown, that the splitting effect is a result of donut scattering too. For detailed investigation of particle passage in a straight and bent crystal the computer simulation program was developed [12-14]. In this program the particle interaction with a crystal is based on the particle interaction with atomic strings, which compound the crystal. Computer simulation results confirm the possibility of the beam deflection and splitting under it passage through a bent crystal near crystallographic axis [8,12-14].

3. PARTICLE CHANNELING AND DECHANNELING IN NANOTUBE

Nanotubes can be represented (see for instance [1,7]) as an aggregate of carbon atom strings, which situated in parallel to nanotube axis. Such geometry lead to formation of deep two-dimensional potential hole with minimum in centre of nanotube. The value of the potential barrier for protons is about 100 eV in this case (see Fig. 1,2 of [7]). Thus, similarly to the channelling phenomenon in crystals, the channelling phenomenon is possible too for the particle motion along nanotube axis. Because of potential hole shape, positively charged particles perform channelling inside nanotube along it axis, while negatively charged particles perform channelling near nanotube surface. Like to the crystal case, incoherent scattering of particles by thermal vibrations of atoms and by an electron subsystem of nanotube lead to the particle dechannelling. The investigation of these effects can to be realised on base of the computer simulation method, which was developed for investigation of the particle passage through crystals [14]. Fig. 1 presents results of computer simulation for channelling and dechannelling processes of charged particles in nanotubes.

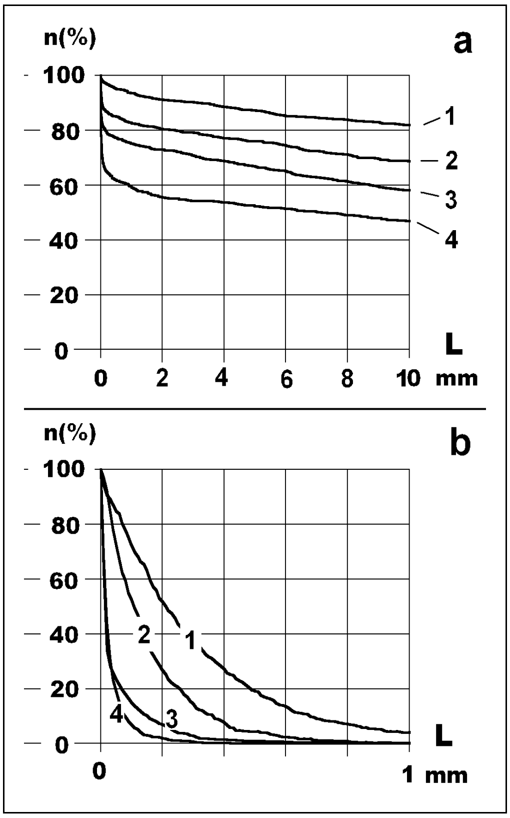

Fig. 1. *Channelling fraction with nanotube length for the beam passage through straight and bent nanotubes along nanotube axis. Particle energy is* $\varepsilon = 10$ *GeV. (a) protons: (1,2)–nanotube (10,1), (3,4)–nanotube (10,0); (b)* π^- *pions: (1,3) – straight nanotube, (2,4) – bent nanotube with bending radius R = 10 cm. Simulation statistics is 1000 particles*

The Fig. 1 shows that the dechannelling lengths of positively charged particles in nanotubes exceed sufficiently that for negatively charged particles. It deals with the fact that the positive particle channelling is inside nanotube far from it surface, while the channelling of negative particle is directly in the region of thermal vibrations of nanotube atoms and in the region of high electron density. From Fig. 1 it is seen, that the particle fraction in channel depends of nanotube curvature and it geometry (definition of nanotube indexes see for instance in [2]).

4. BEAM DEFLECTION UNDER AXIAL CHANNELING IN A BENT NANOTUBE

In a bent nanotube those particles, which perform the axial channelling, will follow axial channel bend similarly to the particle plane and axial channelling in a bent crystal. Deflection condition based on the fact, that axial channel is not destroyed by crystal bend (same as for bent crystal planar channel case [10,17])

$$R > R_c = \frac{\varepsilon}{U_H}\cdot\frac{a}{2}, \qquad (1)$$

where R_c is the radius of the critical bend, ε is the particle energy, a is the width of the potential well, U_H is its depth and R is the bending radius of nanotube.

For particle motion near crystal axis the value of U_H is of the order of several eV, that limits the possibilities of such deflection mechanism. In nanotubes U_H ~100 eV and according to (1), the critical radius of nanotube bending for proton beam with 10 GeV energy is R_c ~ 4 cm (such bending is not a problem for nanotubes).

Figs. 2, 3 present horizontal profiles for positively and negatively charged particles after passage through bent nanotube.

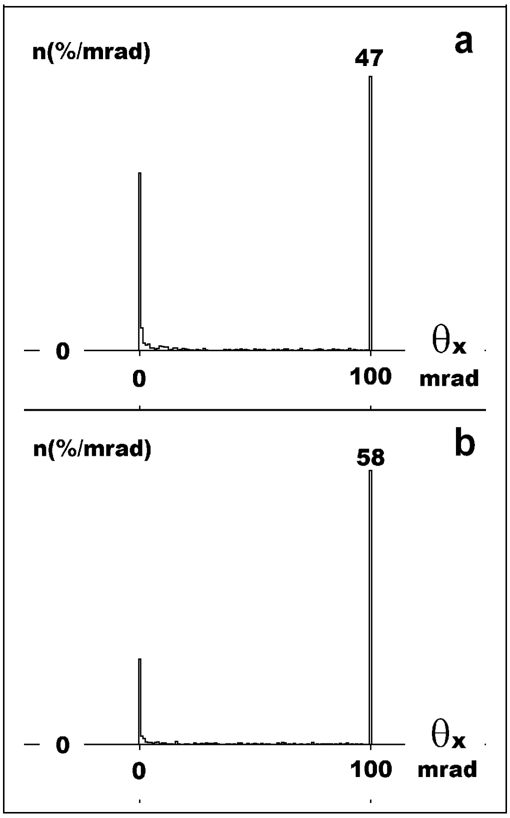

Fig. 2. *The horizontal profile of the proton beam with energy 10 GeV after passage through the bent nanotube with thickness L = 1 cm and curvature radius R = 10 cm. (a) nanotube (10,0); (b) nanotube (10,1). Numbers above right peaks correspond to fraction of particles, which were deflected to whole angle of nanotube bend (in % of beam particles, which were initially captured by the nanotube channel). The simulation statistics is 1000 particles*

Particle deflection is due to channelling mechanism. Thus channelling fractions of Fig. 1 determine fractions of deflected particles. In this case the deflection angle θ_R for particle bending by nanotube is

$$\theta_R = \frac{L}{R}, \qquad (2)$$

where L is the nanotube thickness.

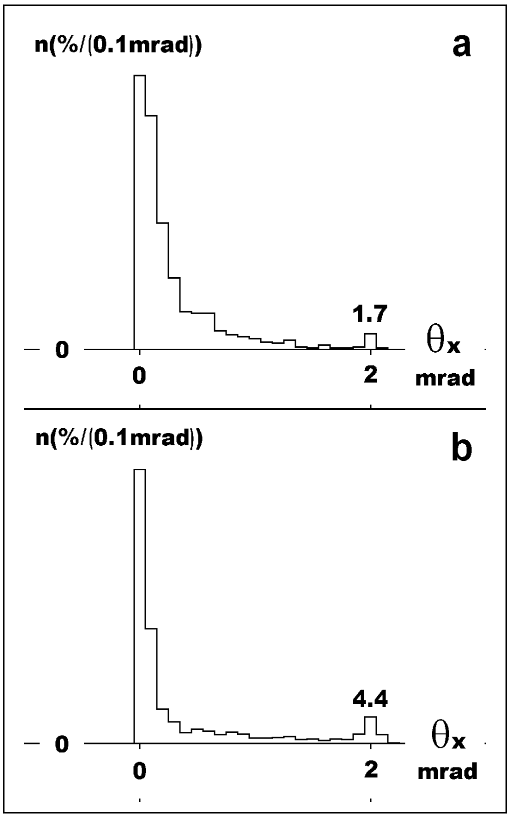

Fig. 3. *Same as on Fig. 2., but for beam of* π^- *pions and nanotube thickness* $L = 200$ μm

Presented simulation results confirm the possibility of large deflection angles of relativistic beams by short nanotubes [8]. As one can see from Figs. 2,3 possible deflection angles for positively charged particles exceed sufficiently that for negatively charged particles. It is due to above noted differences in dechannelling of positively and negatively charged particles. Nevertheless, the efficiency of negatively charged particle deflection by a bent nanotube (Fig. 3) exceeds the efficiency of negatively charged particle deflection by a bent crystal [8,11,14,18].

Thus, nanotube is of sufficient interest as possible instrument for deflection of high-energy beams of positively as well negatively charged particles.

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