FOCUSING OF NEUTRONS USING NANOTUBES WITH SURFACE CURRENTS

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INTRODUCTION

Neutron polycapillary optics was first suggested by M.A. Kumakhov about 25 years ago. Polycapillary technologies enable creation of neutron diffractometers, spectrometers, reflectometers, microscopes—all with a micron-size focal spot [1,2]. New instruments of neutron optics are portable and highly efficient [2]. So, neutron polycapillary optics makes it possible to create new instruments of scientific research, and allow to use the neutron beams for industrial applications [1-3].

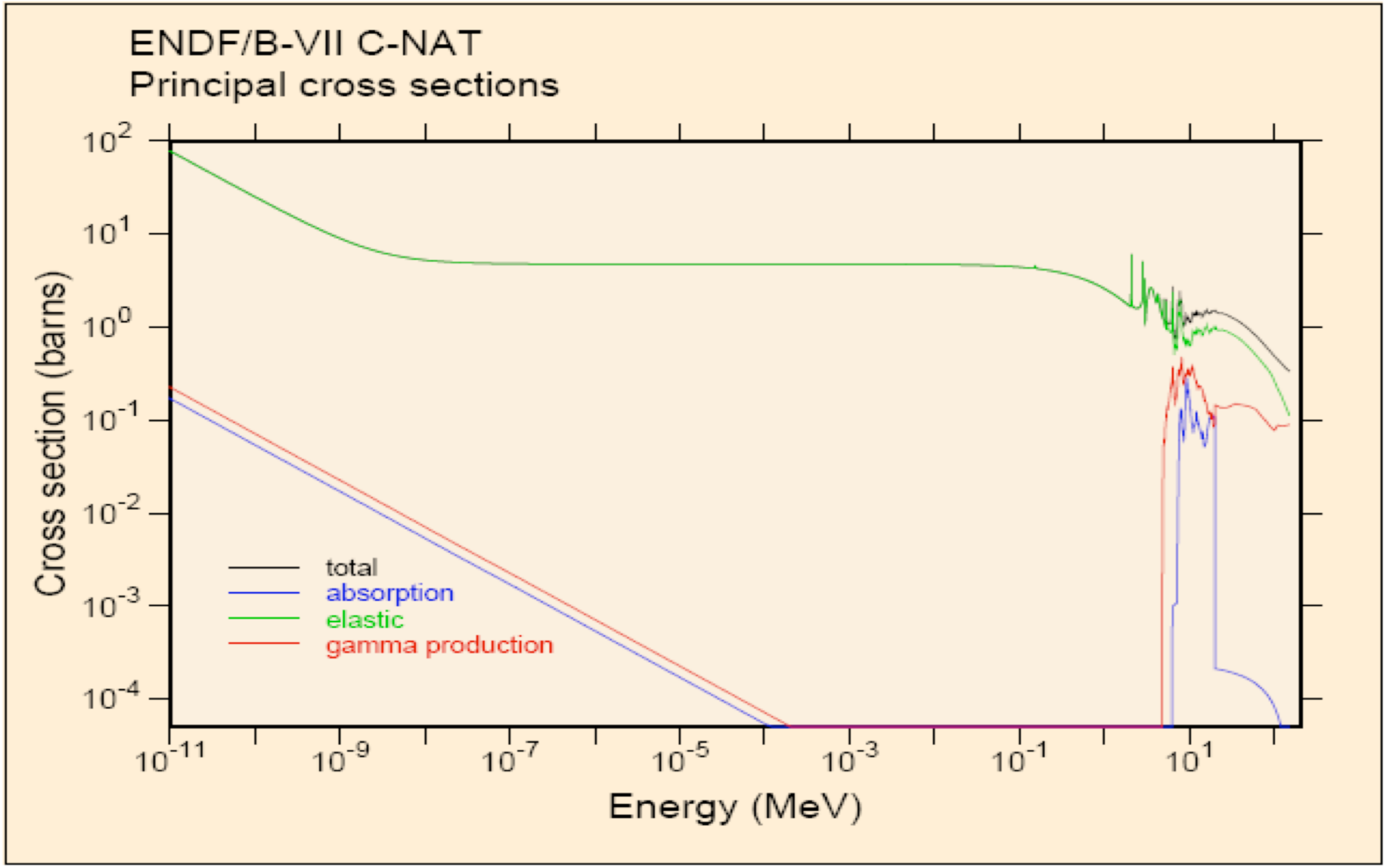
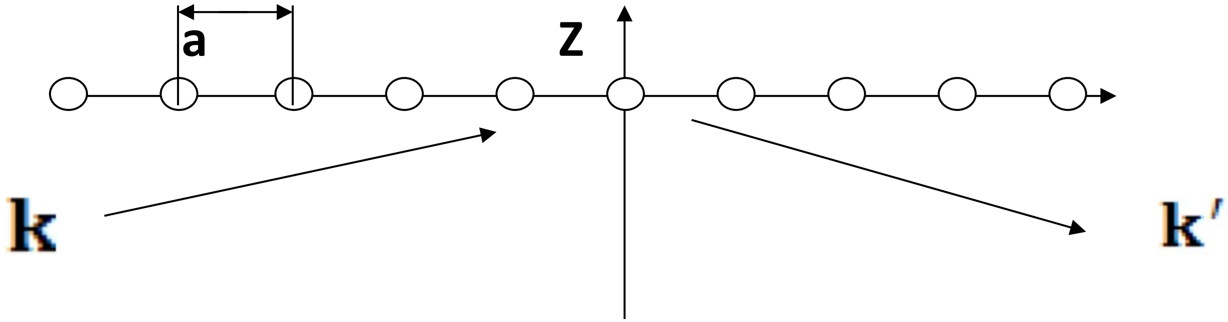


Figure.1. Dependence of cross sections of neutrons from its energy for carbon.



In the Born approximation state of a particle can be described by plane wave:

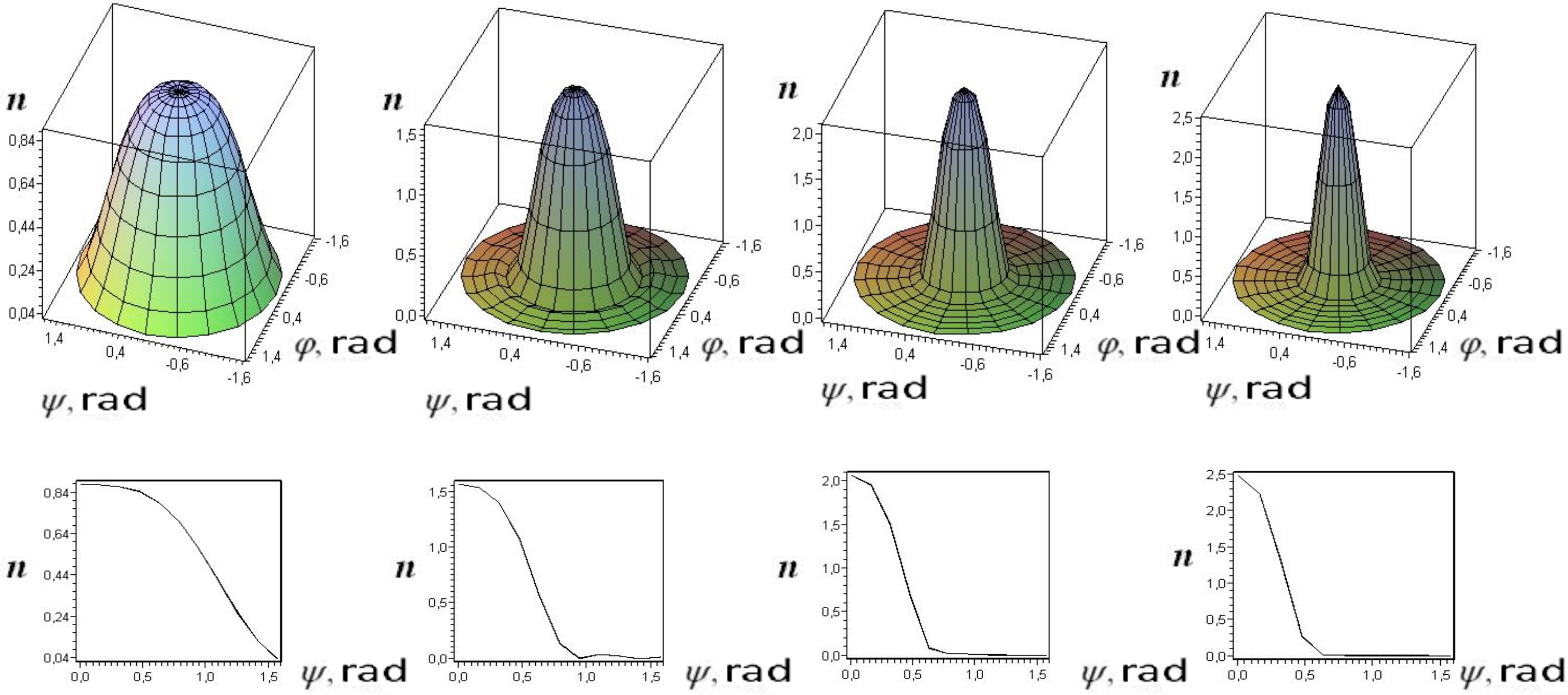
$\left| k \right\rangle = e^{i\vec{k}\vec{x}}$ - Incident wave, $\left| k' \right\rangle = e^{i\vec{k}'\vec{x}}$ -Reflected wave

Interaction Hamiltonian: $H = \sum V\left(x - x_j\right), \qquad j = 1..N$

$$< k'm \,|\, H \,|\, nk > = < m \,|\, \int d^3x e^{i(k-k')x} H \,|\, n >$$

Differential scattering cross section:

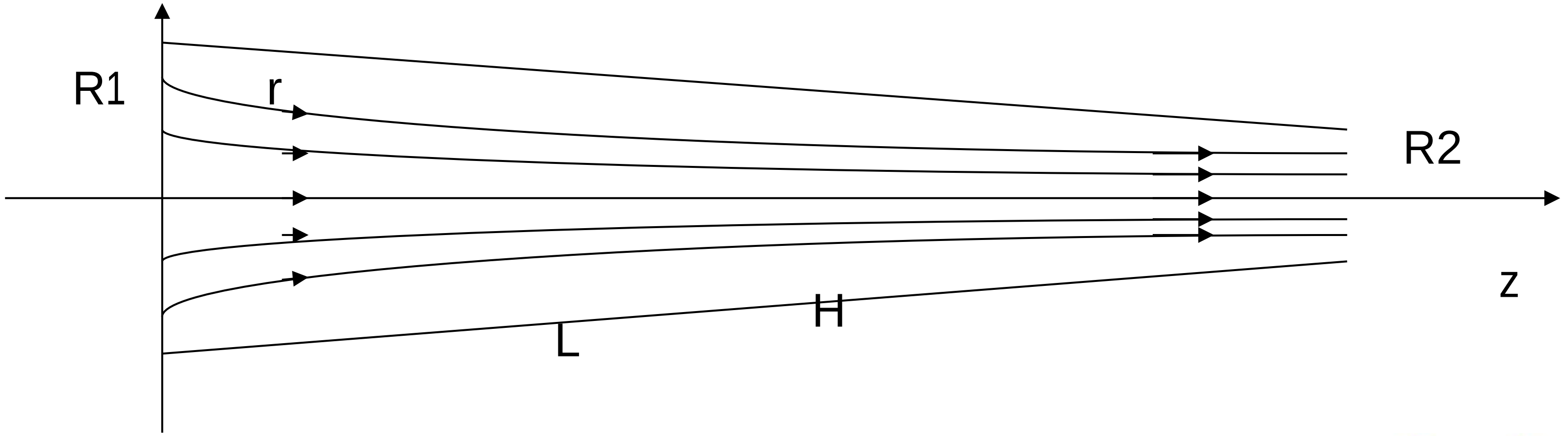
$$\frac{d\sigma}{d\Omega} = \left|\left\langle b \right\rangle\right|^2 \left| \sum_{kl} \exp\left(i(\vec{k} - \vec{k}')\vec{r}_{kl} \right) \right|^2$$



V=2*10^{-5} cm/s V=6*10^{-5} cm/s V=10*10^{-5} cm/s V=14*10^{-5} cm/s

Probability density of the angular distribution of neutrons
and their projections for the different neutron velocities V.

Conical Nanotube



Field inside the nanotubes :

$$R_z = R_1 - \frac{R_1 - R_2}{L} Z$$

$$H_r = \frac{J}{c}\int_0^L\int_0^{2\pi} \frac{(z_0 - z)\sin\varphi}{\sqrt{\left((R(z)\cos\varphi)^2 + (r_0 - R(z)\sin\varphi)^2 + (z_0 - z)^2\right)^3}} d\varphi dz$$

$$H_z = \frac{J}{c}\int_0^L\int_0^{2\pi} \frac{(r_0 \sin\varphi - R(z))}{\sqrt{\left((R(z)\cos\varphi)^2 + (r_0 - R(z)\sin\varphi)^2 + (z_0 - z)^2\right)^3}} d\varphi dz$$

Interaction energy :

$$U = -\vec{\mu}\vec{H}$$

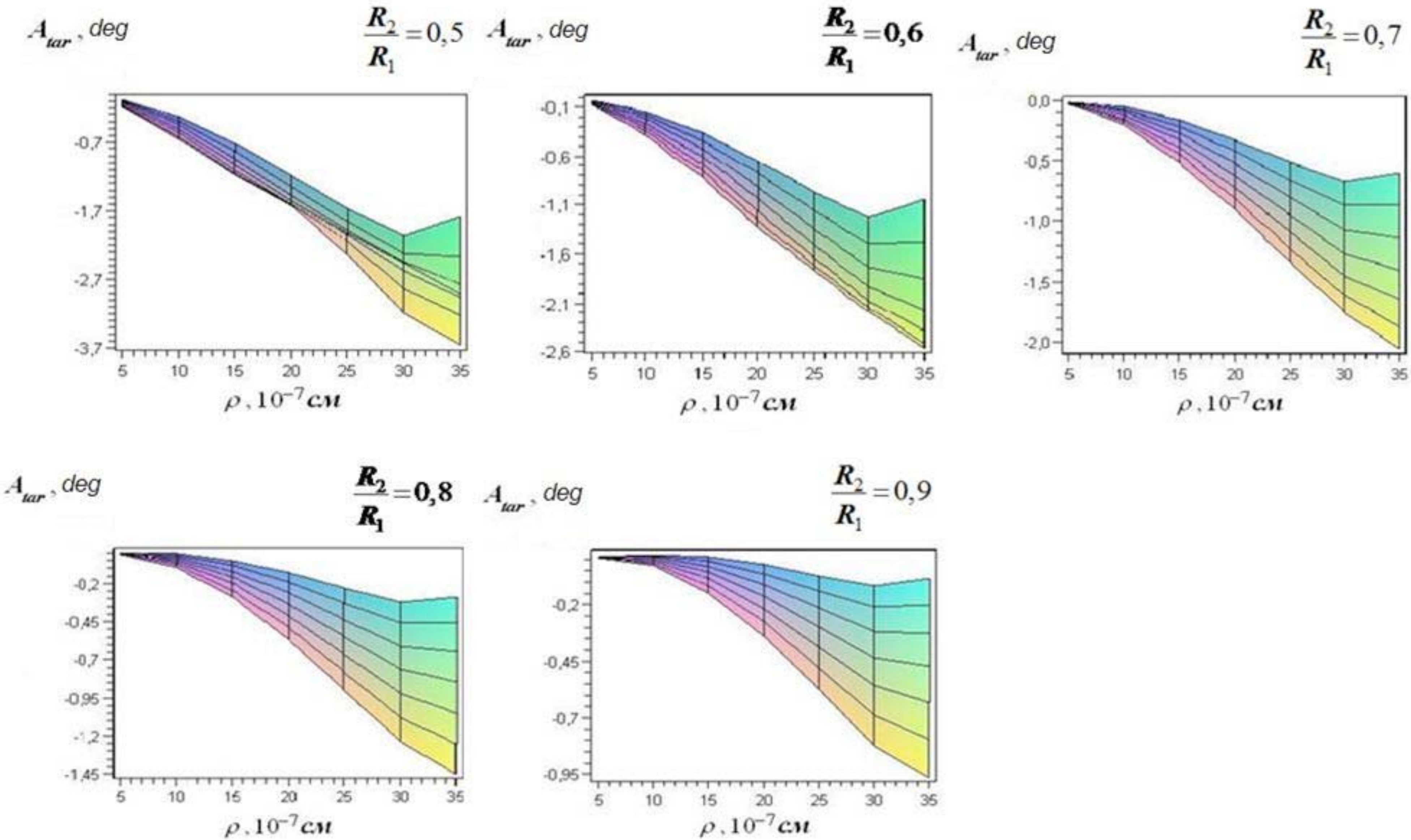


Figure.1. Dependencies of the incidence angles of neutrons on a plane at a distance about the length of the nanotube from its end, from the current density and impact parameters.

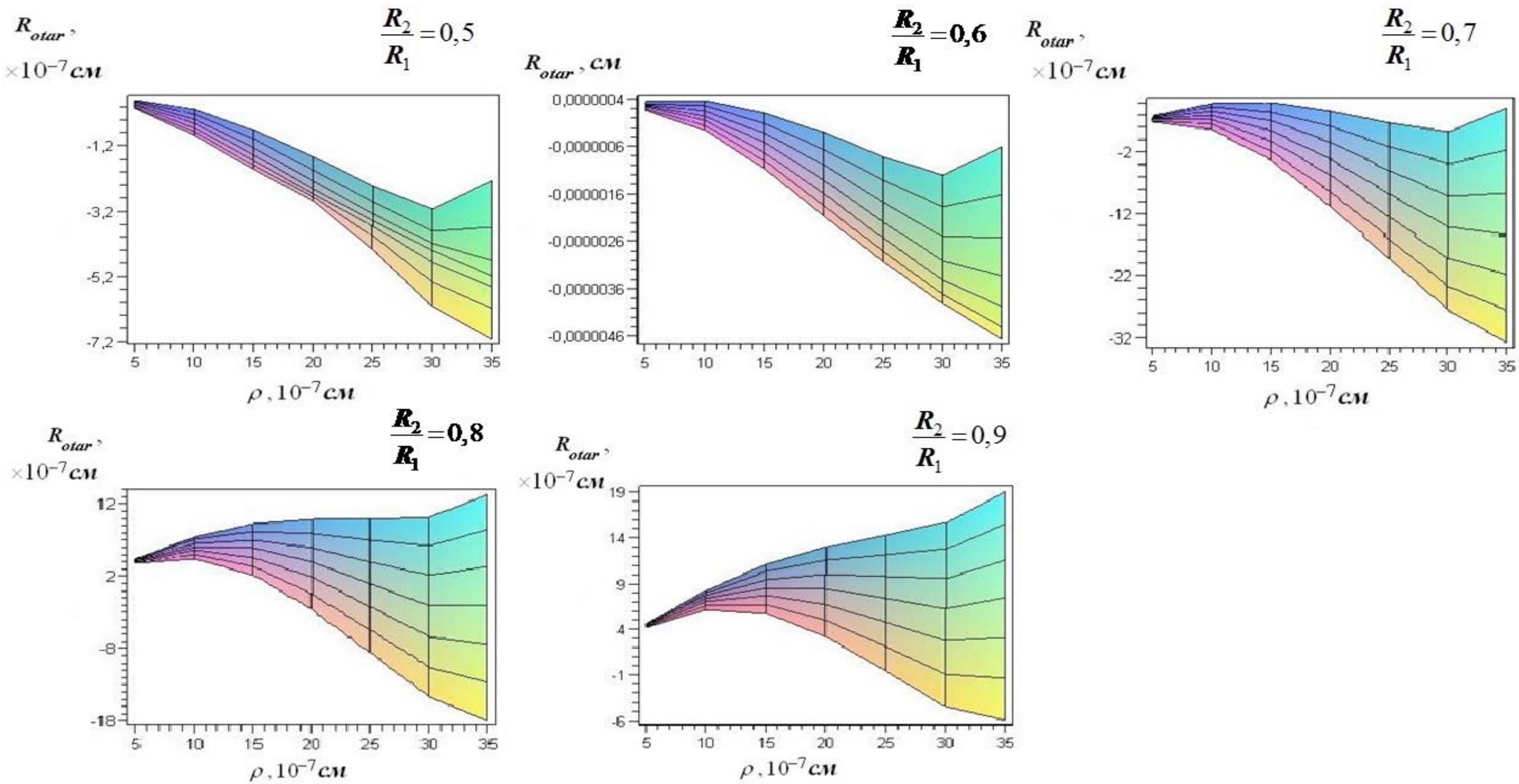
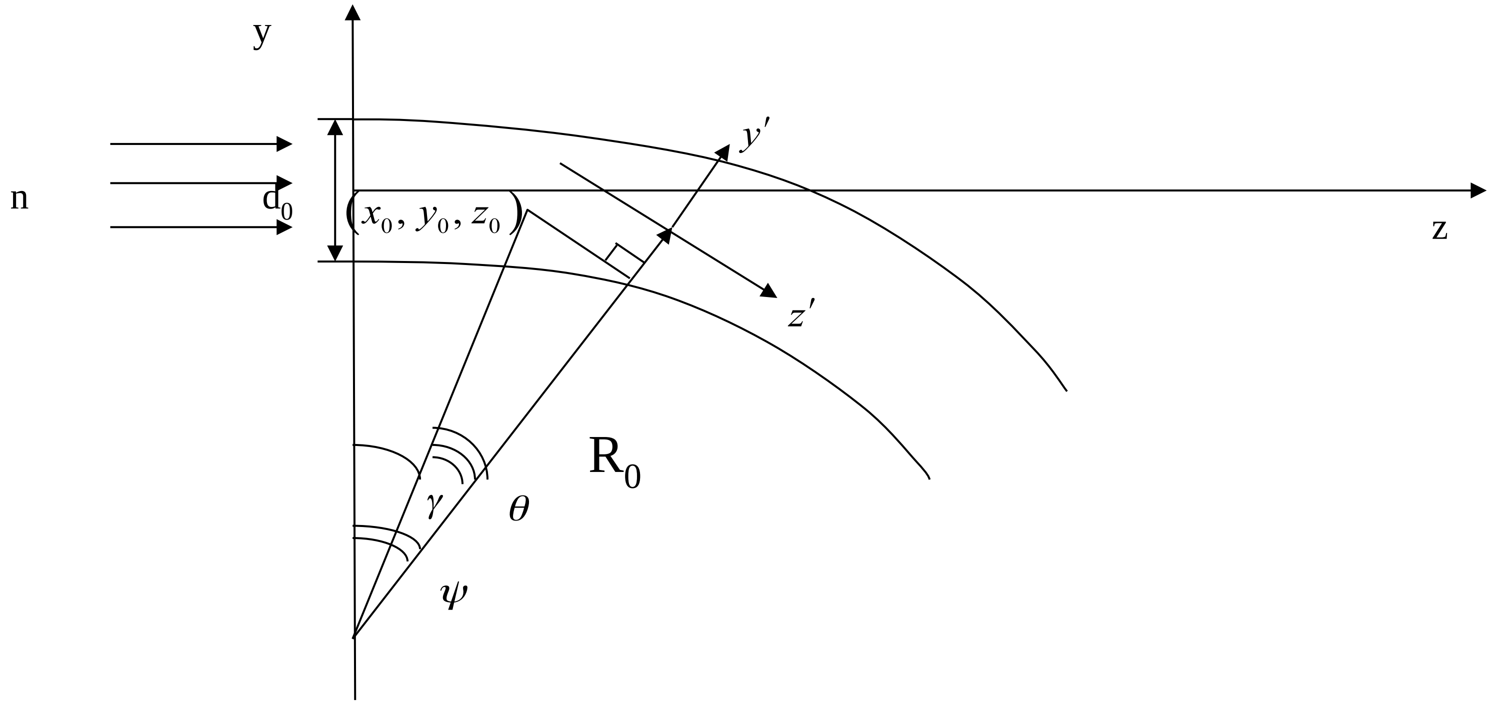


Figure.2. Dependencies of the distances from the axis of the nanotube to the point of contact with the plane at a distance about the length of the nanotube from its end, from the current density and impact parameters.

Curved nanotube



Field inside the nanotube :

$$H_x = \frac{J}{c}\int_0^{\psi_0}\int_0^{2\pi} \frac{\left(\left(y_0 + R_0\right)\sin\psi - z_0\cos\psi\right)\cos\varphi}{\sqrt{\left(\left(x_0 - r_0\cos\varphi\right)^2 + \left(\left(y_0 + R_0\right)\cos\psi + z_0\sin\psi - R_0 - r_0\sin\varphi\right)^2 + \left(\left(y_0 + R_0\right)\sin\psi - z_0\cos\psi\right)^2\right)^3}} d\varphi d\psi$$

$$H_y = \frac{J}{c}\int_0^{\psi_0}\int_0^{2\pi} \frac{\left(\left(y_0+R_0\right)\sin\psi - z_0\cos\psi\right)\cos\psi - \left(x_0\cos\varphi + \left(\left(y_0+R_0\right)\cos\psi + z_0\sin\psi - R_0\right)\sin\varphi - r_0\right)\sin\psi}{\sqrt{\left(\left(x_0 - r_0\cos\varphi\right)^2 + \left(\left(y_0+R_0\right)\cos\psi + z_0\sin\psi - R_0 - r_0\sin\varphi\right)^2 + \left(\left(y_0+R_0\right)\sin\psi - z_0\cos\psi\right)^2\right)^3}}\,d\varphi d\psi$$

$$H_z = \frac{J}{c}\int_0^{\psi_0}\int_0^{2\pi} \frac{\left(x_0\cos\varphi + \left(\left(y_0+R_0\right)\cos\psi + z_0\sin\psi - R_0\right)\sin\varphi - r_0\right)\cos\psi + \left(\left(y_0+R_0\right)\sin\psi - z_0\cos\psi\right)\sin\psi}{\sqrt{\left(\left(x_0 - r_0\cos\varphi\right)^2 + \left(\left(y_0+R_0\right)\cos\psi + z_0\sin\psi - R_0 - r_0\sin\varphi\right)^2 + \left(\left(y_0+R_0\right)\sin\psi - z_0\cos\psi\right)^2\right)^3}}\,d\varphi d\psi$$

$$\nabla U = \mu\left(\frac{\frac{\partial H_x}{\partial x_0}\left|\frac{\partial H_x}{\partial x_0}\right|}{\sqrt{\left(\frac{\partial H_x}{\partial x_0}\right)^2 + \left(\frac{\partial H_y}{\partial y_0}\right)^2}}\vec{i} + \left(\frac{\partial H_y}{\partial y_0}\right)\sqrt{\frac{\left(\frac{\partial H_x}{\partial x_0}\right)^2 + \left(\frac{\partial H_y}{\partial y_0}\right)^2}{\left(\frac{\partial H_x}{\partial x_0}\right)^2 + \left(\frac{\partial H_y}{\partial y_0}\right)^2 + \left(\frac{\partial H_z}{\partial z_0}\right)^2}}\vec{j} + \frac{\frac{\partial H_z}{\partial z_0}\left|\frac{\partial H_z}{\partial z_0}\right|}{\sqrt{\left(\frac{\partial H_x}{\partial x_0}\right)^2 + \left(\frac{\partial H_y}{\partial y_0}\right)^2 + \left(\frac{\partial H_z}{\partial z_0}\right)^2}}\vec{k} \right)$$

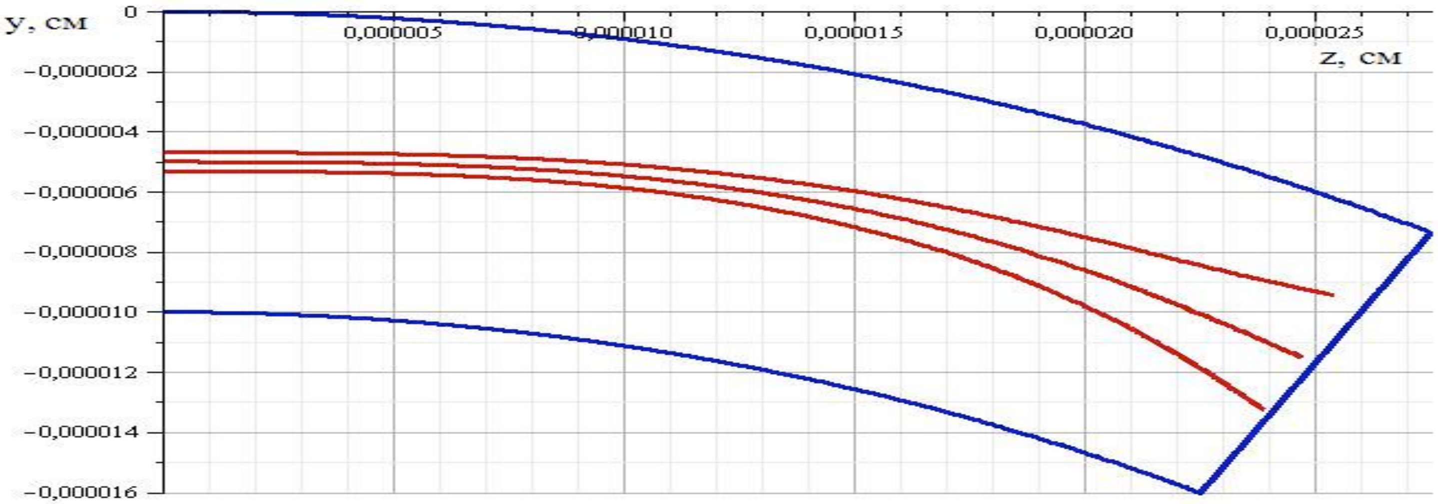


Fig.3. The trajectory of the neutron with speed V=2* 10^5 cm/s
in the bent nanotube.

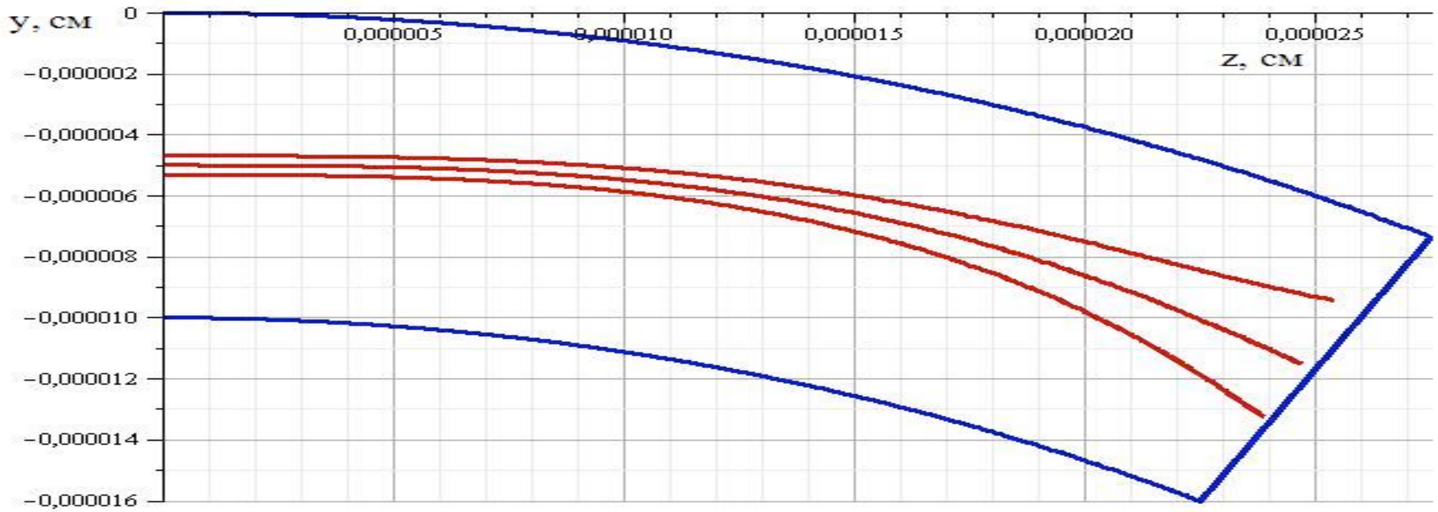


Fig.4. The trajectory of the neutron with speed V=14*10^5 cm/s
in the bent nanotube.

For the nanotubes, which has the dimensions: $r = 50*10^{-7}$ cm, $R=500*10^{-7}$cm, $\psi=\pi/6$, and for different velocities of neutron V calculated surface current density J in a way that the neutron is kept along the curved nanotube. The diameter of the beam was taken $\boldsymbol{d_{II}}=3*10^{-7}$cm.

Table 1.1

V ,$*10^5$ cm/s	J, A/cm	δ
2	586700	6.5994
3	1320000	6.5994
4	2347000	6.5995
5	3667000	6.5995
6	5281000	6.5996
7	7188000	6.5996
8	9389000	6.5996
9	11883000	6.5996
10	14671000	6.5997
11	17751000	6.5997
12	21127000	6.5997
13	24795000	6.5997
14	28754000	6.5997

To determine the dependence of J on V, logarithmic graph Fig.5 was constructed from the relevant data in table 1.1. The factor of proportionality was determined according to the form of the graph:

$$J = 0.00001465 * V^2$$

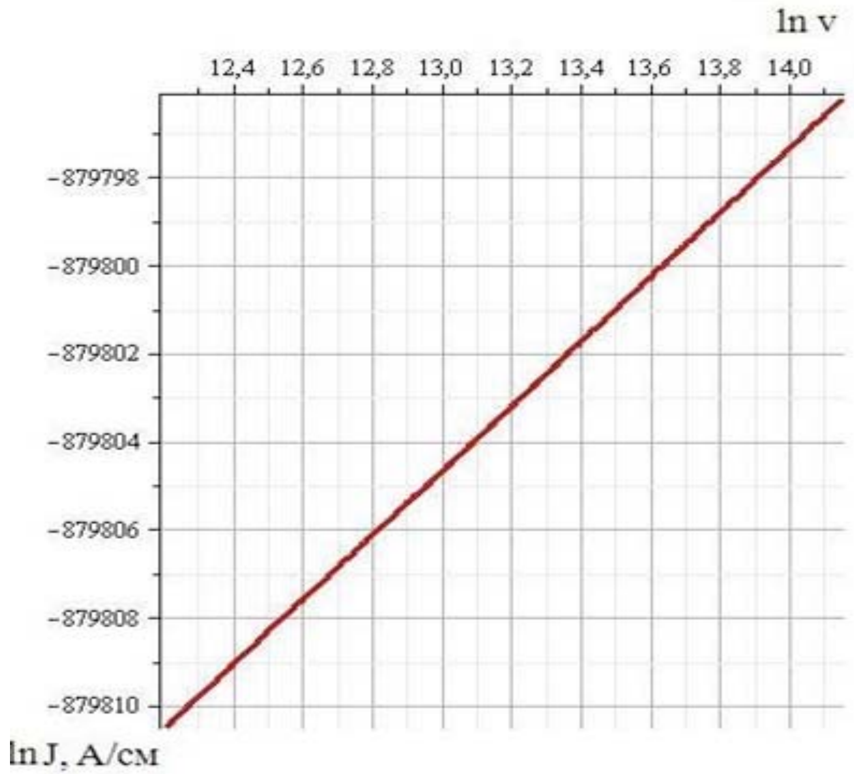


Fig.5. Graph of the logarithmic dependence J from V.

CONCLUSION

In this work the numerical simulation of thermal neutron channeling in the conical and curved nanotubes with large circular surface currents is carried out. The coordinate distribution of neutrons from the impact parameters and the surface current density is obtained. It is demonstrated, that at some conditions the thermal neutrons can be focused on the distances of the order of the tube length from its end. The condition for the retention of neutron along the curved nanotube is defined.

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