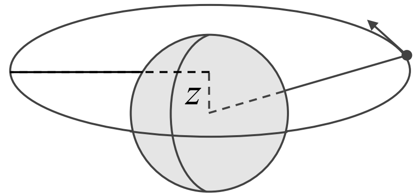
Intense Cherenkov Radiation from a Particle Rotating About a Dielectric Ball Along a Non-equatorial Orbit



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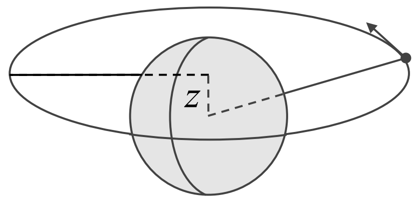
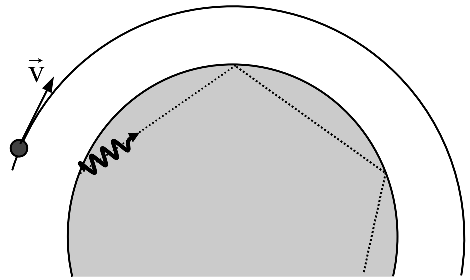
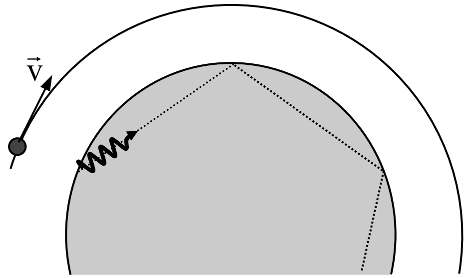


I. Introduction and the aim of the work

Consider radiation from a relativistic particle revolving about a dielectric ball.



In case of short distances of particle from the ball surface in addition to the synchrotron radiation (SR) the relativistic particle may generate the Cherenkov radiation (CR) inside the ball.



The revolving ralativistic particle may, at separate high harmonic, generate CR tens of times more intense than CR from the same particle revolving in a continuous, infinite and transparent medium.

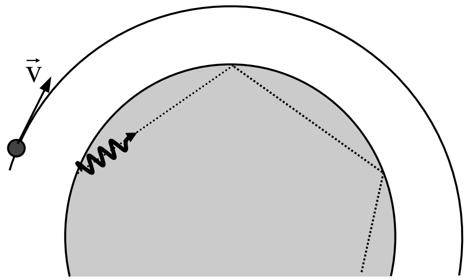
The theoretical substantiation of this effect and its visual explanation are given in 2006-2009.

[L.Sh. Grigoryan, H.F. Khachatryan, S.R. Arzumanyan, M.L. Grigoryan, Nucl. Instr. and Meth. **B252**, 50 (2006).

L.Sh. Grigoryan, H.F. Khachatryan, S.R. Arzumanyan, M.L. Grigoryan, Presentation at the 34th Intern. Conf. “Infrared, Millimeter and Terahertz Waves”, Busan, Korea, Sept. 21-25, 2009.

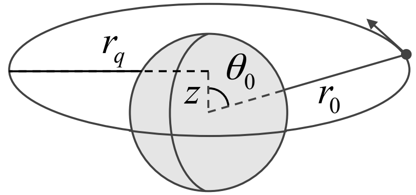
The aim of the report

(1)
A nonrelativistic electron revolving about the ball maid of strontium titanite may generate CR tens and even hundred of times more intense than CR from the same particle revolving in a continuous, infinite and transparent medium.



(2)
This radiation is generated at the first harmonic.

II. Statement of the problem



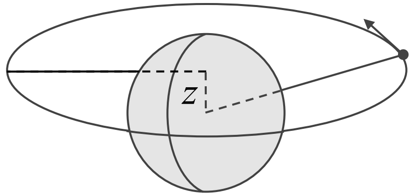
A relativistic charged particle uniformly rotating about a dielectric ball.

The problem parameters

$$E_q \qquad r_q = r_0 \sin\theta_0 \qquad r_0$$

$$z = r_0 \cos\theta_0 \longleftrightarrow \theta_0$$

$$r_b \qquad \varepsilon_b \qquad \mu_b$$



It is convenient to introduce a dimensionless quantity

$$W_k / h\nu_k \equiv n_k$$

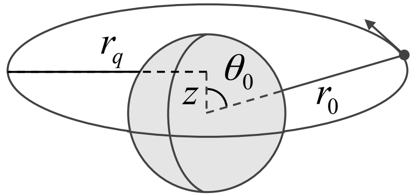
W_k is the energy of radiation generated during one turn of the particle about of ball

ν_k is the frequency of emitted radiation energy of corresponding electromagnetic wave quantum.

k is the number of corresponding harmonic

n_k is the “number of electromagnetic field quanta” emitted during one revolution period of particle

$$n_k(E_q, r_0, \theta_0, r_b, \varepsilon_b)$$



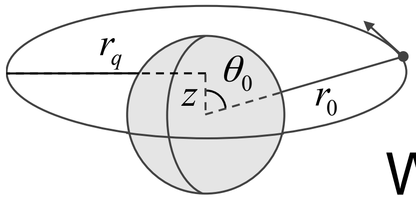
We are derived the expressions for calculation of the number of quanta

$$n_k(E_q, r_0, z, r_b, \varepsilon_b)$$

generated per revolution period,

They are based on exact solutions of Maxwell equations with due regard for dielectric losses of energy within the ball material.

III. Numerical results and discusions



We shall assume:

$$\varepsilon_b = 232(1 + 0.0001i)$$

(strontium titanite in frequency range ~1 GHz) and

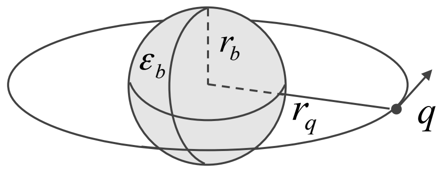
$$r_b = 1cm$$

The magnetic permeability of the ball material is taken to be 1.

We shall confine ourselves to the consideration of electron radiation at a first harmonic .

$$k = 1.$$

III.1. *The case of equatorial orbit*

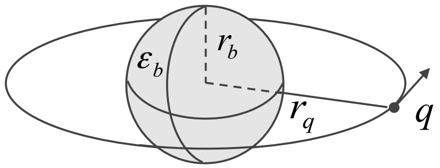


$$z = 0$$

$$\varepsilon_b = 232(1 + 0.0001i) \qquad \mu_b = 1$$

strontium titanite.

$$r_q = 1.05\, r_b \qquad k = 1.$$



$$\varepsilon_b = 232(1 + 0.0001i)$$

$$r_q = 1.05\, r_b$$

$$k = 1.$$

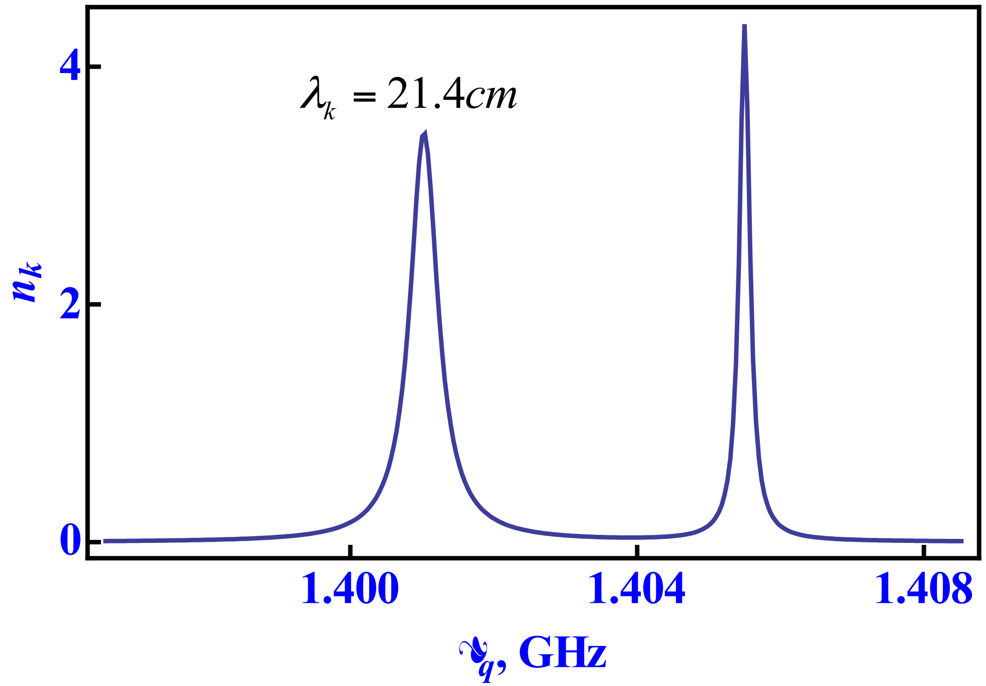


Fig.1. The number of photons n_k emitted during one turn of electron versus of the rotation frequency nu_q

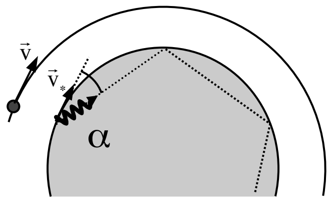
$$\boxed{1 \le n_k(\nu_q) \le 4}$$

$$n_k(\infty) = 0.027$$

Tens and hundred of times larger values of n_k are possible in comparison with the case of infinite and continuous matter.

III.2 *The reason of radiation amplification*

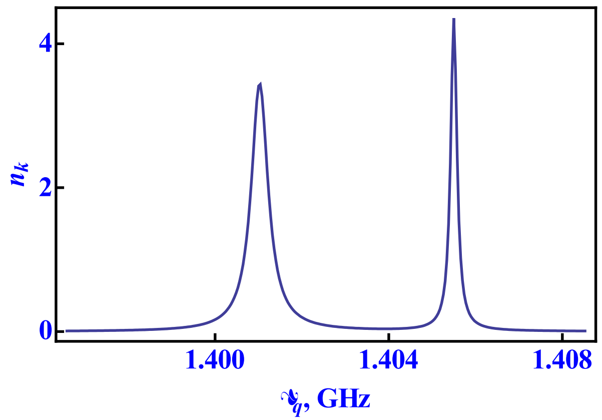
If the electron rotates about a ball, then in addition to the synchrotron radiation it may also generate Cherenkov radiation. Its rise is attributed to the fact that the field coupled with the relativistic electron partially penetrates the ball and rotates together with the particle.



If the Cherenkov condition is satisfied

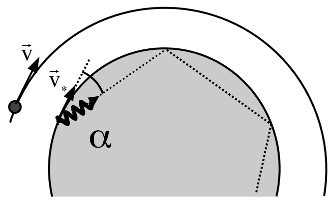
$$v \geq c / \sqrt{\varepsilon_b'}$$

for the velocity of particle and the material of ball, then CR is generated inside the ball.



$$n_k(\infty) = 0.027$$

In general, the influence of ball on radiation from the particle is small and radiation differs slightly from synchrotron radiation. However, in some specific cases (two peaks in Fig.1) the electron may generate n_k >1 quanta of electromagnetic field during one rotation period.

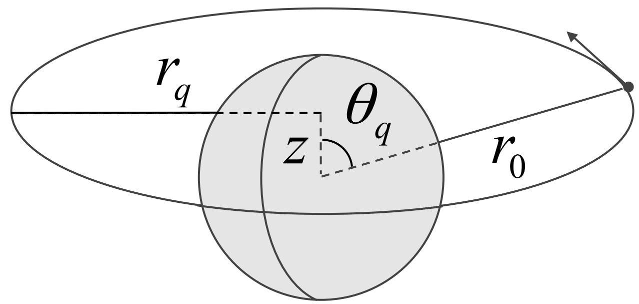


High power radiation rises due to the fact that **electromagnetic oscillations of Cherenkov radiation** induced by the particle along its entire trajectory **are partially locked inside the ball and are superimposed in nondestructive way** [3].

III.3. *The case of non-equatorial orbit*

The electron rotates with the resonant frequency

$$\nu_q = 1.401 GHz$$



It's trajectory moves away from the equatorial plane of ball:

$$0 \le z \le 1.05\, r_b$$

Case 1

$$r_q = 1.05\, r_b \qquad E_q = 25\, keV$$

$$1.05\, r_b \le r_0(z) \le 1.15\, r_b$$

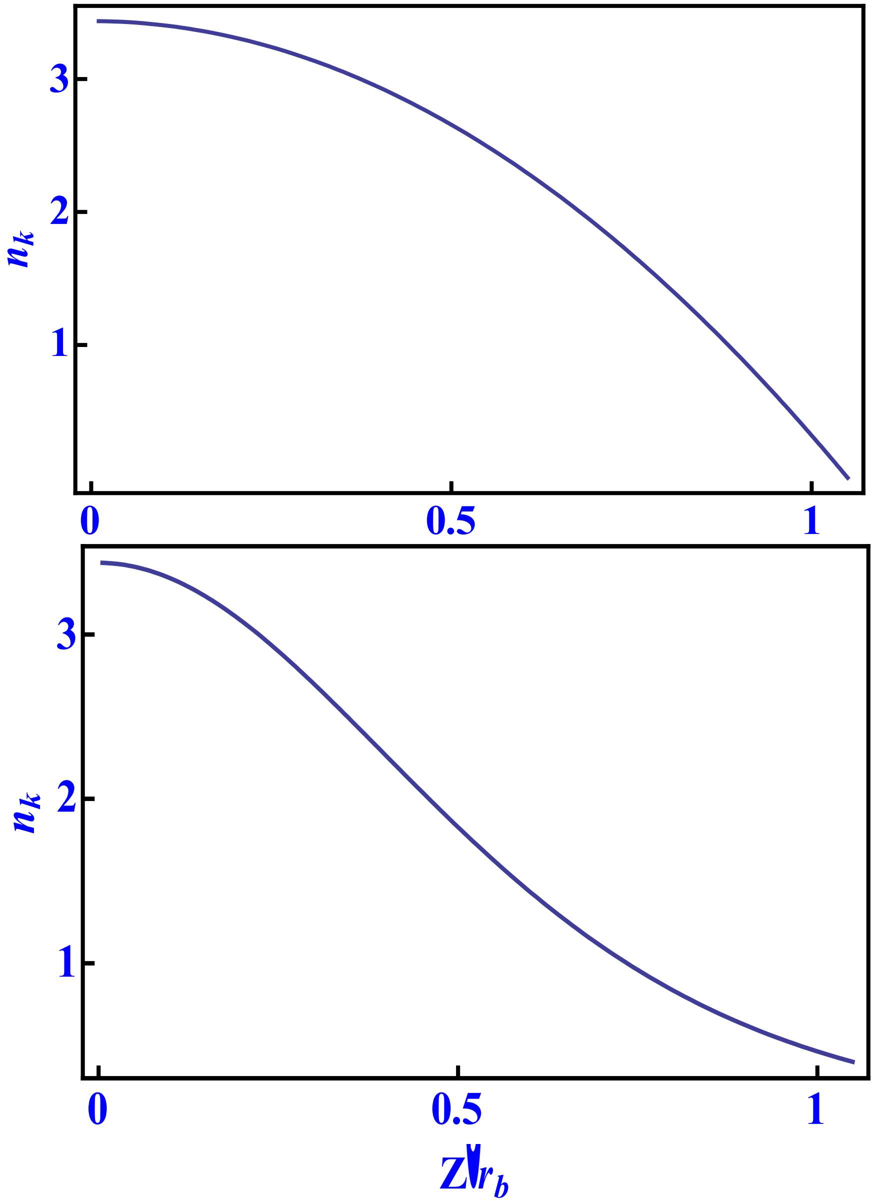
Case 2

$$r_0 = 1.05\, r_b$$

$$1.05 r_b \ge r_q(z) \ge 0$$

$$25 keV \ge E_k(z) > 0$$

Fig.2,3. The number of quanta generated per revolution of electron about a dielectric ball.



$r_q = 1.05\, r_b$ $\quad$ $E_q = 25\, keV$

$1.05\, r_b \le r_0(z) \le 1.15\, r_b$

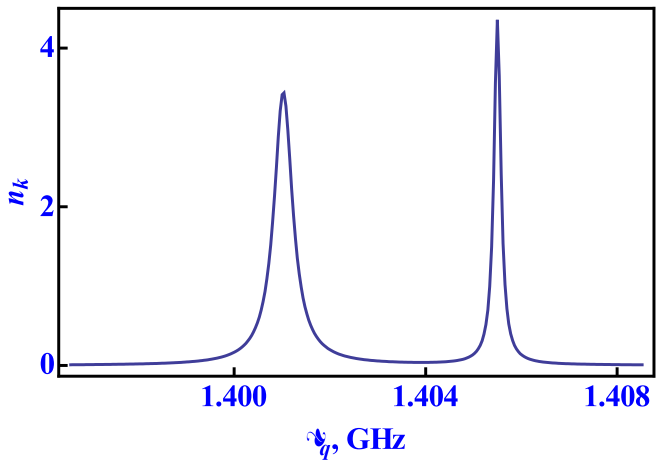
$\nu_q = 1.401 GHz$

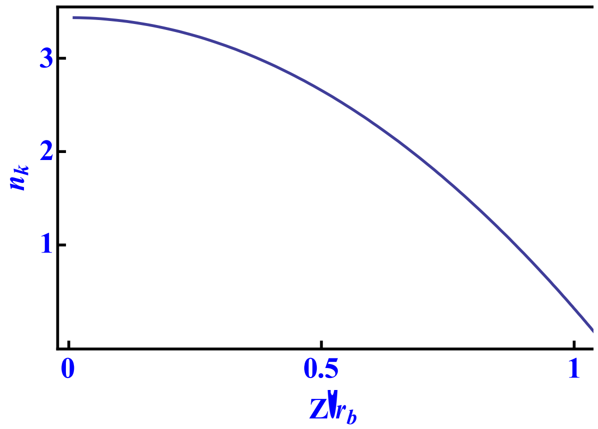
$$1 \le n_k(z) \le 4$$

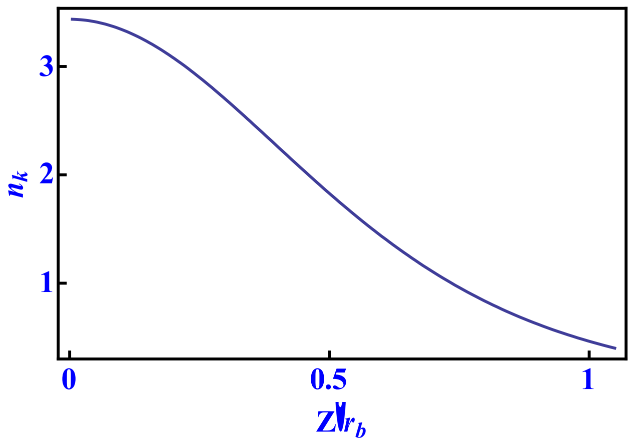
$n_k(\infty) = 0.03$

$r_0 = 1.05\, r_b$ $\quad$ $1.05 r_b \ge r_q(z) \ge 0$

$25 keV > E_k(z) > 1 keV$







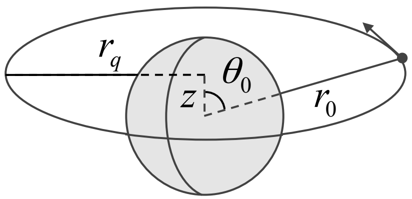
From Figs 1-3 it follows:

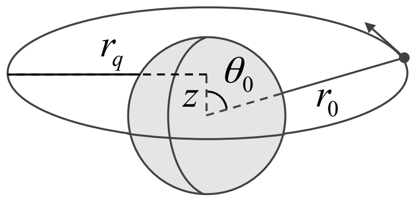
1) Large values

$$1 \leq n_k \leq 4$$

$$n_k(\infty) = 0.027$$

are possible if the rotation frequency of an electron takes on a separate (resonant) value: $\nu_q = 1.401 GHz$





2)
The radiation from particle remains intensive for the following sizeable variations of electron parameters:

$$n_k \geq 0.1$$

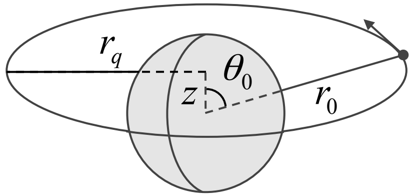
(a) electron energy: $5KeV \leq E_q \leq 25KeV$

(b) the distance of the electron orbit plane from the ball centre

$$0 \leq z / r_b \leq 0.7$$

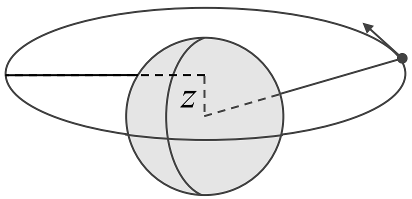
(c) the distance between the electron and ball centre:

$$0.05 \leq l / r_b \leq 0.14$$



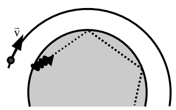
3),
The intensity of resonant radiation is very sensitive function of ball radius and the permittivity of ball material.

This fact may be **useful for applications**, e.g., for detection of external weak influences (acoustic waves)..



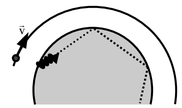
IV. Conclusions

1) In our report the Cherenkov radiation from an electron uniformly revolving along a non-equatorial orbit about a dielectric ball is investigated under the assumption that the ball is made of strontium titanate.



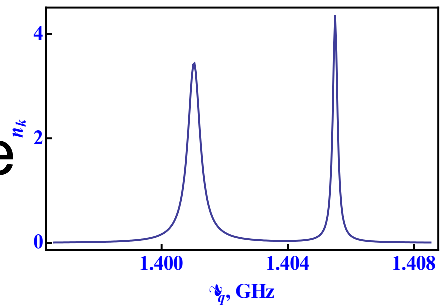
2) Expressions for calculation of the number of electromagnetic field quanta generated per revolution of electron about a dielectric ball are derived.

3) The results of numerical calculations testify that:



a)
at the revolution of particle at comparatively small distances from the ball surface, the Cherenkov radiation may be generated inside the ball material;

b)
The nonrelativistic electron rotating at the resonant frequency about the strontium titanate ball generates at the first harmonic several quanta of CR (per one revolution about a ball).



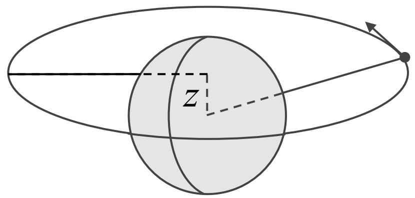
$$\nu_q = 1.401 GHz$$

$$n_k(\infty) = 0.027 << n_k \le 4 \quad :$$

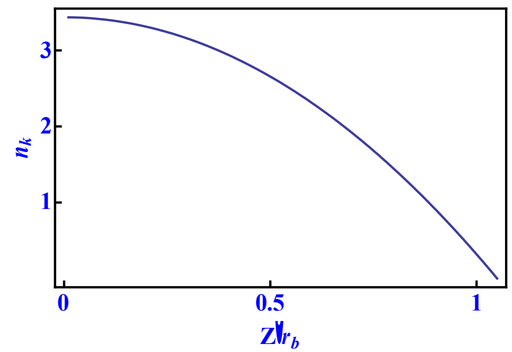
c)

The radiation from particle remains intensive

$$n_k(\infty) = 0.027 << n_k \leq 4$$



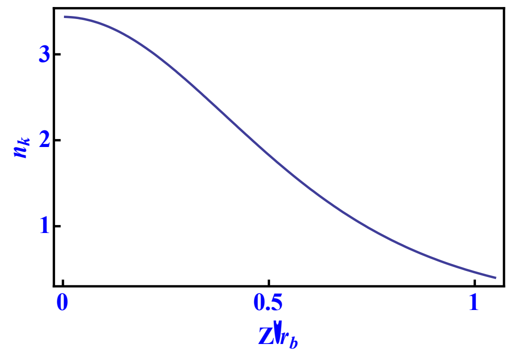
for the following sizeable variations of electron parameters:



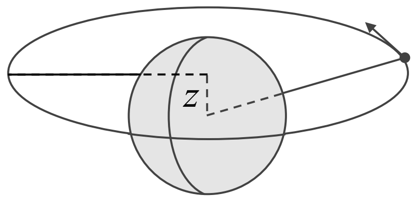
- the electron energy:

$$25\,keV > E_k > 5\,keV$$

- the distance z of the electron orbit plane from the ball centre.



- the distance between the electron and ball centre.



Thank you indeed for your attention

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