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COHERENT PECULIARITIES IN RADIATIVE INTERACTION OF MULTICHARGE NANO-CLUSTERS AND SUCH OBJECTS DIAGNOSTIC

Preprint of SINP MSU - 2007 -3/824

MOSCOW 2007

PACS: 78.70-g; 78.70Ck; 79.90 +t

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COHERENT PECULIARITIES IN RADIATIVE INTERACTION OF MULTICHARGE NANO-CLUSTERS AND SUCH OBJECTS DIAGNOSTIC

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Abstract

Coherent peculiarities of X-ray bremsstrahlung radiation in particular polarization bremsstrahlung radiation (PB) and coherent traditional bremsstrahlung radiation (BR) generated in fast multi-charge cluster interaction with a medium one are considered. Some new coherent PB and BR effects connected with the mutual screening in clusters contained positive and negative charged particles and transformations of X-ray spectra are indicated that may be used in nano-object diagnostic.

В.К.Гришин

ОСОБЕННОСТИ КОГЕРЕНТНОГО РЕНТГЕНОВСКОГО ИЗЛУЧЕНИЯ ВЗАИМОДЕЙСТВУЮЩИХ МНОГОЗАРЯДНЫХ НАНОКЛАСТЕРОВ И ДИАГНОСТИКА ПОДОБНЫХ ОБЪЕКТОВ

Препринт НИИЯФ МГУ - 2007 - 3/824

Аннотация

Анализируется особенности когерентного рентгеновского тормозного излучения при взаимодействии многозарядных нано-объектов - быстрого и неподвижного кластеров . Аналитически исследуются поляризационное тормозное излучение (ПТИ) быстрых зарядов на электронах неподвижного кластера и традиционное тормозное излучение (ТИ) быстрых электронов на тяжелых зарядах этого кластера. Указаны ПТИ- и ТИ-эффекты, обусловленные взаимным экранирующим действием разноименных зарядов, и трансформация спектров излучения, что необходимо использовать при диагностике нано-объектов.

1 Introduction

At present diverse kinds of matter with new structures are lively discussed. In particular, the special interest is caused by matters containing various "macro - micro" objects as fullerenes, hetero-fullerenes, nanotubes, composite structures and so on in connection with wide perspectives of their application. Among others, note their extremely various probable using in medicine, by development of superconducting materials, in motor oil industry etc. Such objects have large sizes (up to ten of nm) and complex structures. Evidently, it is very important to discover and identify these objects.

Like a single fast charge, fast multi-charge objects are participating in bremsstrahlung processes of X-ray radiation in a matter. It is necessary to note here two mechanisms of X-ray radiation by a fast charge which are important for the following consideration: traditional bremsstrahlung radiation (BR) on atomic nucleus and polarizing bremsstrahlung radiation (PB) on atomic electrons of the matter [1-3]. Therefore BR and PB observation allows to obtain separately a different information about nuclei and electrons distributions in interacting objects.

Besides, there are some additional facts. In general , X-ray radiation is a dispersion of the electromagnetic field of all the charges participating in the emission process (see below). By virtue of opposite charges of electrons and nuclei in complex clusters , some new effects appear in PB and BR. So it is possible to expect a essential suppression of X-ray radiation in low-frequency range, and here it can be shown only in a high-frequency range. The suppression character must be directly connected with the interacting particle distribution.

Finally, it is important to underline also that because of the average distances between particles in a fast cluster and a structured matter (including a motionless cluster) are comparable, new coherent effects can be observed in X-ray radiation processes. All the mentioned facts are very interesting for possible applications to nano-structure diagnostics.

2 Analytical description of X-ray radiation

Now we want to present an analytical approach which is used below for the description of X-ray radiation processes considered here.

2.1 Polarization bremsstrahlung radiation (PB)

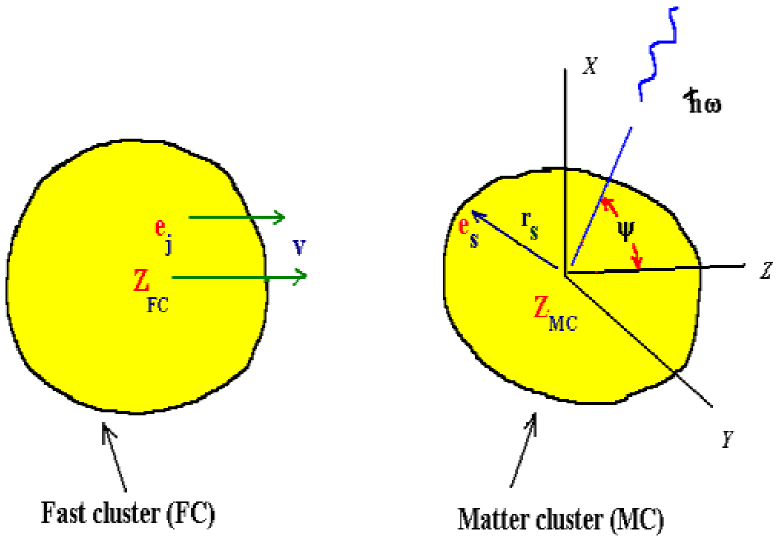

Figure 1: Scheme of multi-charge fast cluster (FC) and multi-charge matter cluster (FC) interaction in X-ray radiation process.

As noted, polarizion radiation (PB), including its kinds, can be described as a dispersion of own electromagnetic field of a fast charge on matter electrons [1,3 § 33] . Consider a case when the fast cluster (FC) is interacting with a matter cluster (MC), see Fig.1 where the geometry of this interaction is illustrated. FC contains a nucleus with the positive charge $e\,Z_{FC}$ and Z_e electrons (in general $Z_{FC} \neq Z_e$; in Fig.1 only one of FC electrons is indicated; $j = 1, 2, .., Z_e$).

Here the Cartesian coordinates are used with the z axis parallel to FM velocity $\vec{v}$. The center of the Cartesian coordinates coincids with the point where the FC nucleus is crossing MC . The summary FC electric field is dispersed by each of matter cluster electrons , and photon with the frequency ω is emitted in the $(x, z)-$ plane under an angle ψ. Following known procedures [4,5], it is possible to receive the spectral- angular density of a coherent PB energy

$$\frac{d^2\, W_\omega}{d\,\omega\, d\,\Omega} = \frac{e^6}{8\,\pi\, m^2\, c^3\, v^2}\, F_{eff} \tag{1}$$

where W_ω is the spectral radiation density with the frequency ω in an element $d\,\Omega$ of the solid angle. Factor

$$F_{eff} \,=\, \frac{v^2}{e^2} \,<|\sum_{s=1}^{Z_{MC}} \,\left[\mathbf{n}'\,\mathbf{E_s}\right] exp(-i\,\mathbf{q}_\omega\,\mathbf{r_s})\,|^2> \tag{2}$$

where Z_{MC} is the number of MC electrons, $\vec{n'}$, is the radiation unit vector.

Vector $\vec{E_s}$ is the spectral amplitude of the summary FC electric field calculated for the frequency ω in the point $\vec{r_s}$ for each MC electron.

The summary FC electric field is a sum of FC particle fields

$$\vec{E}_{FC} \,=\, \vec{E}\,(Z_{FC}) \,-\, \sum_{j=1}^{Z_e} \vec{E}(e_j) \tag{3}$$

The electric field of each FC particle can be presented as a wave package termed as the package of virtual photons [6,7]. The electric field cross component (only field cross component, which is axial-symmetric with respect to the fast particle trajectory, is indicated below due to an action of the field axial component is much less) has Fourier's component

$$E_\omega \,=\, G\,\zeta\,K_1(\zeta)/(\pi\,b\,v)\,; \qquad \zeta \,=\, (\omega\,b)/(\gamma\,v) \tag{4}$$

where b is the perpendicular distance from particle trajectory (i.e. it is impact parameter with respect to a MC electron), $G \,=\, -e$ for the FC electrons, and $G \,=\, e\,Z_A$ for the FC nucleus, K_1 is modified Hankel's function, γ is relativistic factor of the cluster particles. We propose that the FC velocity is much more than the velocities of particle relative movements in this object.

The quantity E_ω remains approximately constant up to $\zeta \,\simeq\, 1$, and then it sharply decreases. Wave vectors in the package are $\vec{k}_\omega \,=\, \vec{v}\,\omega/v^2$ where the unit vector $\vec{n}$ is directed along the z axis.

The vector $\vec{q_\omega} \,=\, \vec{k'}_\omega - \vec{k}_\omega$. Here $\vec{k'_\omega}$ is the wave vector of the real photons emitted along $\vec{n}$, $(\vec{q_\omega}\,\vec{r_s}) \,=\, q_1\,x_s \,+\, q_3\,z_s$ where

$$q_1 \,=\, \omega\,sin\,\psi/c \qquad q_2 \,=\, 0\,, \qquad q_3 \,=\, \omega(1\,/v \,-\, cos\,\psi/c) \tag{5}$$

Brackets <> in relation (2) mean averaging over the spatial distribution of MC electrons.

Note field description (1) is corresponding to a charge motion in the vacuum. In a matter, field is undergoing some changes due to a screening action by the matter. But let us be limited to a case of poorly relativistic particles in the fast cluster (that is very natural for heavy nuclei) when the relativistic factor γ of FC particles and region of radiation frequencies ω satisfy to condition $\omega^2 > \gamma^2 \omega_o^2$ where ω_o is the plasma frequency of matter ($\hbar\omega_o \simeq$ 30-40 eV). In this case the screening action is reduced.

Then in dipole approximation (we take in account that dispersed phonon energies exceed the binding energies of matter electrons essentially) the factor F_{eff} of the coherent PB is determined as

$$F_{eff} = Z_{eff}^2 \, S_o^2 \, cos^2\psi \tag{6}$$

where

$$Z_{eff} = (Z_{FC} - Z_e \, \Phi_e) \tag{7}$$

$$S_o = \Big(\int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} \frac{x \, sin(q_x \, x) \, cos(q_z \, z)}{x^2 + y^2} \, \zeta \, K_1(\zeta) \, \rho \, (\vec{r}) d\vec{r} \Big)^2 cos^2\psi \tag{8}$$

with $d\vec{r} = dx \, dy \, dz$, and

$$\zeta = \frac{\omega \sqrt{x^2 + y^2}}{\gamma \, v}. \tag{9}$$

Factor Φ_e in relation (7) is a result of averaging over all the positions of FC electrons. At first approximation, proposing that the cluster electron distribution is spherically symmetric with respect to the cluster nucleus, we obtain

$$\Phi_e = \frac{1}{(1 + (q_1 \, R_{FC}/3)^2)^2} \tag{10}$$

where R_{FC} is the mean radius of the fast cluster electron distribution. Finally, $\rho(\vec{r}_s)$ is the MC electron density distribution [1].

2.2 Bremsstrahlung radiation(BR)

The same method of virtual photons is rather useful to description of ordinary bremsstrahlung radiation (BR) (by the way, this approach has a big "age" [8]) and realization of a comparative analysis. Following to [3], BR by the fast charge on a nucleus is a dispersion (in own system K' of reference for the fast charge with correction $\vec{v} \longrightarrow -\vec{v}$) of electromagnetic field of nucleus by charge which in the K' system has no propagation velocity.

[1]Here we are applying a continuous distribution as a result of averaging over motions of matter electrons. Besides, we neglect an incoherent PB component which is relatively small in multi-particle systems.

Thus BR in the K' system is described by the "inverse" formulas for BR ($FC \longrightarrow MC$). In particular, returning to the laboratory coordinate system K we see two important facts: screening effect by MC electrons and traditional narrowing of BR radiation cone. The latter is described by the formula

$$sin\psi \, = \, \frac{sin\psi'}{\gamma \, (1 \, + \, v \, cos\psi'/c)} \tag{11}$$

where ψ and ψ' are the radiation angles in K and K' systems.

3 Results and Discussion

The analytical description obtained allows to carry out a versatile consideration of discussed radiating processes. We can note some important moments. Different particles are participating in PB and BR processes: in PB - all the charges of fast cluster and only the matter cluster electrons, in BR - all the matter cluster charges and only the fast cluster electrons. Therefore in both PB and BR are observed a complex dependence of the mutual electrons-nucleus charge screening in both clusters on the emitted photon energies. However it is possible to see different screening effects in PB and BR processes. So Fig.2 is presented the dependence of main PB parameter

$$Z_{eff}^2 \, = \, (Z_A \, - \, Z_e \, \Phi_e)^2$$

on the photon energy. We see the full charge suppression in the low photon energy at $Z_A \, = \, Z_e$ when $\Phi_e \, \rightarrow \, 1$. The same effect can be noted in BR, but it is created by all the MC charges (see also $[\, 3, \S \, 28])$. Note also, that BR and PB relative contribution in a total X-ray yield depend on the radiation angle. So coherent PB and BR have minima at $\psi \, = \, \pi/2$ and $\psi' \, = \, \pi/2$, respectively. But in the whole, BR prevails for small angles while PB becomes dominant for the big angles of an emission including the back hemisphere.

Total contribution of all the factors in PB is illustrated in Fig. 3 . Note here is manifested also that the quantity of F_{eff} depend on both longitudinal and cross distribution of particles. Their contributions are determined by two parameters: longitudinal and cross lengths $L_{long} \, = \, \pi/q_3$ and $L_{\perp} \, = \, \pi/q_1$, respectively.

Thus the consideration performed is confirming that PB and BR can be used for versatile study of nano-object structure.

The author is very thankful to N. N. Nasonov and N.F.Shulga for helpful discussions of the obtained results. The present work was supported by grants of President of Russian Federation "Science School", N 5365.2006.2 and RFBR, NN 05-02-17648, 06-02-16714.

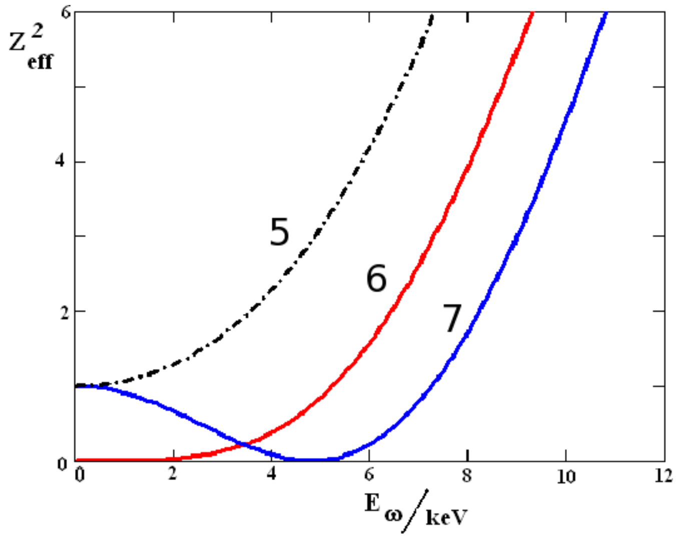

Figure 2: Mutual charge screening in clusters interaction for different energies of PB photons. $Z_{eff}^2 = (Z_{FC} - Z_e\,\Phi_e)^2$ is the square of the effective charge number of fast cluster in PB. Nucleus charge $Z_{FC} = 6$, electron number $Z_e = 5, 6, 7$, respectively, $\psi = \pi/4$, $R_{FC} = 0.05\,nm$. Limit $Z_{eff}^2 \longrightarrow Z_{FC}^2 = 36$ at $E_\omega \geq 20keV$. Ranges $E_\omega < 2{-}3keV$ for $Z_e = Z_{FC}$ and $E_\omega < 5, keV$ for $Z_e = Z_{FC} + 1$ are zones of coherent PB suppression.

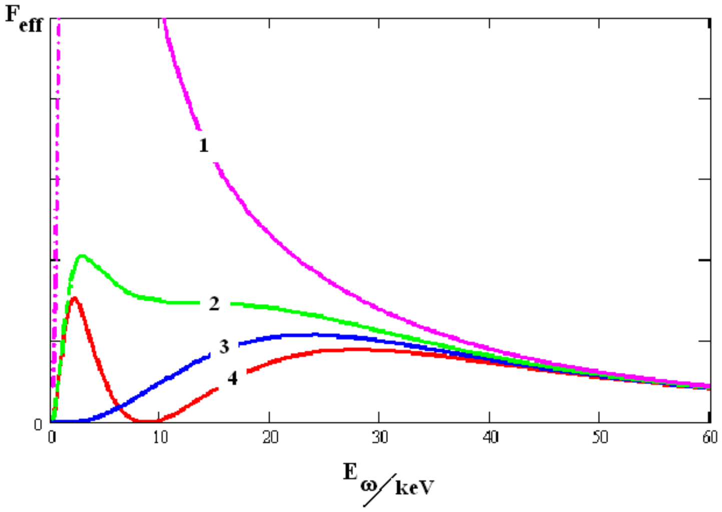

Figure 3: Influence of screening effect on factor F_{eff} (arb. un.) for different charge state of fast cluster in dependence on photon energy. Faster cluster - atom and ion of carbon C ($Z_{FC} = 6$), matter cluster - silicon atom Si ($Z_{MC} = 14$). Curves 1,2,3,4 correspond to carbon state C^{+3}, C^{+1}, C^{0}, C^{-1}, respectively. Here $\gamma = 1.1$, $\psi = p/4$.

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Препринт НИИЯФ МГУ - 2007 - 3/824

Работа поступила в ОНТИ 18.04.2007.