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# IDENTIFICATION OF NANO-OBJECTS IN SUBSTANCES BY USING OF X-RAY ELECTRON RADIATION

V.K.Grishin, Institute of Nuclear Physics of Lomonosov State University, Moscow, Russia*

## *Abstract*

Application possibility of X-ray electron emission for identification of such macro-micro objects as fullerenes , nanotubes and so on is discussed. A kind of X-ray relativistic electron emission - polarization bremsstrahlung radiation (PB) is considered. PB rises as result of fast charge interaction with media atomic electrons. Due to this, PB depends very strongly on media structure. Therefore spectra of PB in a media containing macro-micro objects reflex structural characteristics of last ones. In particular, as it is manifested on examples of fullerenes $C_{60}$, $C_{60}@C_{240}$, $C_{60}@C_{240}@C_{540}$ , PB spectra contain the low-frequence coherent peak and series of oscillations which give the valuable information about single- or multilayers fullerene structures. Note the PB intensity depends weakly enough on observation angles that permits to pick up PB signal from traditional bremsstrahlung radiation and to facilitate measurement conditions.

## INTRODUCTION

At present the possibilities of different varieties of polarization bremsstrahlung (PB) radiation for the diagnostics of matter structure are actively considered. In particular, the special concern is caused by matters containing different ”macro - micro” objects as fullerenes, hetero-fullerenes, nanotubes, composite structures and so on in connection with perspectives of their wide application [1-3].

Detection of such objects and their structure features can be researched with application of PB by accelerated electrons. Really, properties of PB, which is generation by interaction of fast charges with atomic electrons, directly depend on features of their distribution in matter. As a result, PB mirrors the character of interatomic interaction in matter, including a reaction to presence of mentioned structure elements. It is very important PB depends slowly on the radiation angle, and this fact permits to select the optimum condition for PB experimental observation. Meanwhile the ordinary bremsstrahlung radiation (BR) is directed strongly along the incident electron trajectory. Due to this, BR is not considered below. Let’s to demonstrate it on the example of fullerenes.

The most widespread kind of fullerene has ball-shaped forms (although some fullerenes have more rare form like a cubic one) composed from several tens and hundreds of atoms which dispose in surface with single or multilayer structures. The sizes fullerenes are much more than sizes of separate atom (so, the radius of fullerene $C_{60}$ is 0.35 nm, and radius of atom of carbon is less than 0.1 nm).

The major features of PB on fullerenes, permitting to select this radiation from PB of an environment, should be watched in the range of photon energies below 3 - 5 keV (see below). Therefore, the wave lengths of emitted photons exceed distances between atoms in fullerene structures. In a first approximation it is possible to present fullerenes as a sphere with homogeneous distribution of all atomic electrons.

In this representation, PB property can be forecast outgoing from following physical approach. Let PB of a electron passing through a fullerene be watched under a given angle. For photons of high energies, the intensity of PB is sum of photons emitted on separate atomic electrons. But in the mentioned above range of photon energies, PB gets a coherent character where the process of radiation covers large number of atomic electrons. Therefore PB intensity increases proportionally to quadrate of number of coherent electrons.

Simultaneously, in PB will be watched some interference effects. If the phase differences of photons emitted in a given direction from different regions of fullerene become to be multiple of $\pi$, the collective radiation intensity will be either weakened or magnified. In total, the oscillations of intensity should be watched in PB spectra.

At last, in the range of photons energy where length of radiation becomes more than fullerene radius (i.e. in range 1-1.5 kev) the coherent process of PB will cover all fullerene electrons that should be accompanied by sharp rise of the radiation intensity.

The estimated analysis which has been carried out in the author’s work [4] confirms as a whole the predictions made above. Nevertheless, more detailed consideration which results are stated below, brings a number of the important specifications, allowing to make a substantiated conclusion about a reality of PB use for diagnostics of nano-objects.

## ANALYTIC ESTIMATIONS

Let’s apply here the PB analytical description as a dispersion of the electromagnetic field of the incident electrons on atomic electrons of matter [5,6]. Consider the follow scheme, see Fig. 1.

A fast electron passes through a fullerene at some distance $|\mathbf{t_e}|$ from its center . The Cartesian coordinates are used with the $z$ axis parallel to the electron velocity $\mathbf{v}$. The electron coordinates are $\mathbf{t_e} = (t_x, t_y, 0)$,

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[*] grishin@depni.sinp.msu.ru

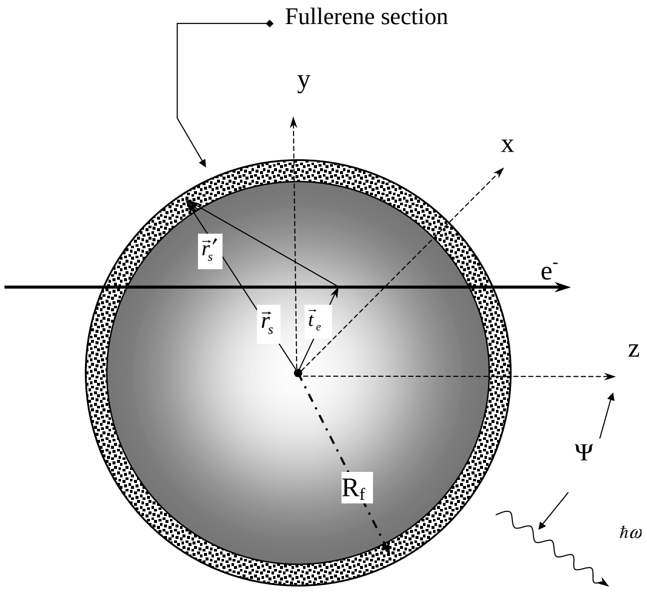

Figure 1: Scheme of fast electron-fullerene PB interaction.

$\mathbf{r_s} = (x_s,\, y_s,\, z_s)$, $\mathbf{r'_s} = (x'_s,\, y'_s,\, z_s)$.

Using the proposed approach it is possible to receive the estimate of PB intensity in the form [7,8]:

$$\frac{d^2\, W_\omega}{d\,\omega\, d\,\Omega} = \frac{e^4}{8\,\pi\, m^2\, c^3}\; F_{eff} \qquad (1)$$

where $W_\omega$ is the spectral density of radiation with the frequency $\omega$ in an element of the solid angle $d\,\Omega$. The formfactor

$$F_{eff} \; = <|\sum_{s=1}^{Z_f} \left[\mathbf{n}'\,\mathbf{E}_{\omega,\,\mathbf{s}}\right] exp(-i\,\mathbf{q}_\omega\,\mathbf{r'_s})\,|^2> \qquad (2)$$

where $Z_f$ is the total number of fullerene electrons, vector $\mathbf{q}_\omega = \mathbf{k}'_\omega - \mathbf{k}_\omega$, $\mathbf{k}_\omega$ and $\mathbf{k}'_\omega$ are the wave vectors of an incident wave and dispersed one along $\mathbf{n}'$ at an angle $\Psi$ with respect to the $z$ axis, $\mathbf{r'_s} = \mathbf{r_s} - \mathbf{t_e}$ are radius-vectors of fullerene electrons. Place vector $\mathbf{k}'_\omega$ in the $(x\,, y\,-)$plane. Then $q_x = \omega\, sin\Psi/c$, $q_z = -\omega\,(1 - \beta\,\cos\Psi)/v$ where $\beta = v/c$ due to $k_\omega = \omega/v$ and $k'_\omega = \omega/c$.

The vectors $\mathbf{E}_{\omega,\,\mathbf{s}}$ in the vector products at the relation (2) are the incident electron fields calculated in the positions for each matter electrons. Therefore the $\mathbf{E}_{\omega,\,\mathbf{s}}$ values have different values $\rho_s$ of the impact parameter: $\rho_s^2 = x_s'^2 + y_s'^2$ ). Practically here we can take in account only the field cross component (which is axial symmetric; field axial component is much less for relativistic particles). According to [9], at first approximation

$$E_{\omega,s} = \frac{e}{\pi\,\rho_s\,v}$$

at $\frac{\omega\,\rho_s}{\gamma\,v} < 1$ and $E_{\omega,s} \sim 0$ at the opposite condition.

At last, brackets $<>$ mean that it is necessary to average the whole expression over the distribution of fullerene electrons and over all possible values of the parameter $\mathbf{t_e}$.

Evidently the factor $F_{eff}$ represents the sum of fullerene electrons contribution to the process of PB radiation. Therefore, it is the coherence parameter of the PB process. It is possible to predict some important peculiarity of PB by analyzing of $F_{eff}$. At the limit, $F_{eff}$ is proportional to $Z_f$ for $q_\omega \to \infty$ (i.e. the radiation frequency is very high). Here the PB process has an incoherent character.

On the contrary, at the region of low frequency radiation, the quantity of $F_{eff}$ is determined by a sum of two competing processes . First, due to the wave length of radiation is becoming larger than the fullerene diameter, all the fullerene electrons can emit coherently and the radiation amplitude may increase very sharply (in limit up to $Z_f^2$!). Second, self-suppressing of radiation at $\omega \to 0$ owing to mutual anti-polarity of the incident particle field components proportional to $Z_f^2$ for $q_\omega \to 0$. So it is possible to expect occurrence of sharp low-frequency peak PB of relativistic electrons on fullere.

To estimate expected PB effects, it is possible to apply (for our approximation) a continuous distribution of fullerene electron density $n\,(\mathbf{r})$ in the form

$$n\,(\mathbf{r}) = \sum_{k=1}^{m} Z_k\, exp\Big(-g_k^2\,(\sqrt{x^2\,+\,y^2\,+\,z^2}{-}R_k)^2\Big)/N_m \qquad (3)$$

where $m$ is the number of fullerene layers with electron numbers $Z_k$ and radii $R_k$, parameters $g_k$ determine the layer thicknesses. The factor $N_m$ is normalizing of $n$.

## RESULTS AND DISCUSSION

Some results of numerical calculation of the reduced formfactor $F_{eff}/Z_f^2$ magnitude as functions of dispersed (i.e. radiated) photon energy are represented in Fig. 2,3 where PB on single- and multilayer structures are analyzed.

The fullerene $C_{60}$ as an example of a single-layer configuration is considered ( m = 1 in the relation (3), $Z_f = 360$, the fullerene radius $R_f = 0.35$ nm, all electrons are concentrated in a thin surface layer, i.e. $1/g_1 << R_f$).

The dependence of the reduced formfactor magnitudes on the photon energy at radiation angles $\psi_1 = \pi/4$, and $\psi_2 = \pi\, 3/4$ is demonstrated in Fig.2.

Peculiarities of PB on multi-layer fullerene are indicated in Fig.3. The fullerenes $C_{60}$ (m=1 in the relation (5)), $C_{60}\,@\,C_{240}$ (m=2), and $C_{60}\,@\,C_{240}\,@\,C_{540}$ (m=3) for the approximation $1/g_{1,2,3} << R_f$ [10] are considered. $Z_1 : Z_2 : Z_3 = 1 : 4 : 9$, and $R_1 : R_2 : R_3 \simeq 1 : 2 : 3$. Here interference effects of the signals from different layers and a common shift of the main PB coherent peak to lower frequencies can be observed.

It is necessary to note that the coherent signal is sharply decreased in the photon energy range of some hundreds of eV. This PB self-suppression is a result of the opposite action of all components of the incident electron field.

We see that the analytical testing confirms the initially made physical predictions. Let's to indicate that the quan-

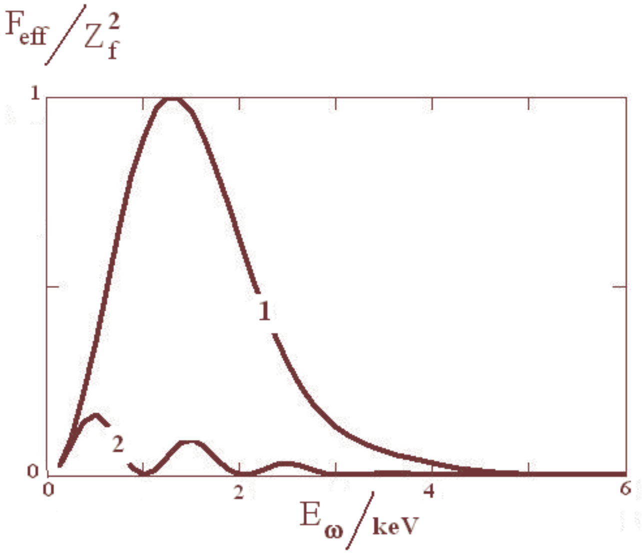

Figure 2: Reduced formfactor $F_{eff}/Z_f^2$ (arb.un.)for PB on fullerene $C_{60}$ as function of the photon energy for different angles of radiation. Curves $1,\ 2,$ correspond to $\psi_1 = \pi/4$ and $\psi_2 = 3\pi/4$, respectively. The relativistic factor of the incident electron is assumed to be $\gamma = 100$.

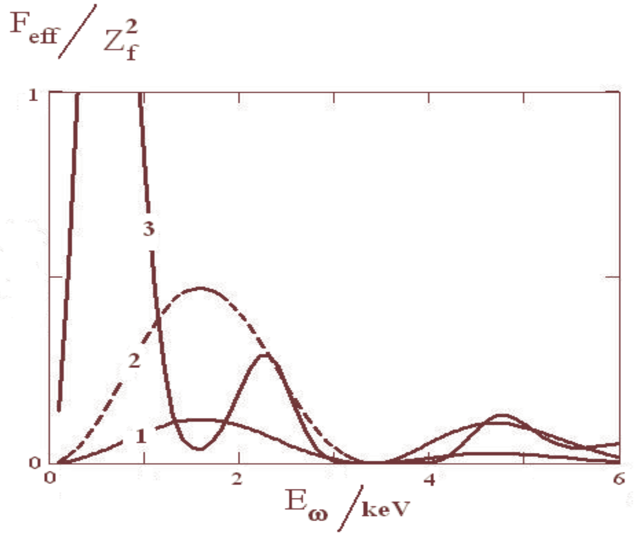

Figure 3: Reduced formfactor $F_{eff}/Z_{f2}^2$ (arb.un.) for PB on fullerenes $C_{60}$, $C_{60}@C_{240}$ and $C_{60}@C_{240}@C_{540}$ as function of PB photon energy at $\psi = \pi/4$, (curves $1,\ 2,\ 3$, respectively). $Z_{f2}$ is the electron number in fullerene $C_{60}@C_{240}$. The relativistic factor of the incident electron is assumed to be $\gamma = 100$.

tity $Z_f^2$ for fullerenes is very large. Therefore PB intensity on fullerenes exceeds that of amorphous environment considerable. This allows to identify fullerenes by PB. Note one important PB detail. The results obtained depend rather slow on the energy of incident electrons if a condition (see (1)) is been kept for photon energies about 5 keV need for to touch a coherent effects. The latter may occur if electron energies surpass several MeV.

Finally, one can conclude that using of PB X-ray radiation has wide perspectives of experimental investigation of not only fullerenes but also another nano-objects [11] since PB on such matter should reveal all peculiarities obtained in this work.

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