SU8707537

Preprint ЕФИ-891 (42)-86

ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ
ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ

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PRODUCTION OF QUASIMONOCHROMATIC BEAMS OF γ - QUANTA BY K - IONIZATION OF RELATIVISTIC IONS

ЦНИИатоминформ

ЕРЕВАН-1986

Նախնատիպ ԕФИ-891(42)-86

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ԳԱՄՄԱ-ՔՎԱՆՏՆԵՐԻ ՔՎԱԶԻՄՈՆՈՔՐՈՄԱՏԻԿ ՓՆՋԵՐԻ ՍՏԱՑՈՒՄԸ ՌԵԼՅԱՏԻՎԻՍՏԻԿ ԻՈՆՆԵՐԻ K-ԻՈՆԱՑՈՒՄՈՎ

Ցույց է տրված, որ ռելյատիվիստիկ իոնների K-իոնացումով, որն առաջանում է կամ նրանց և լազերային ֆոտոնների ճակատային ընդհարման և կամ էլ նրանց բարակ բյուրեղների միջով անցնելու հետևանքով, կարելի է ստանալ γ-քվանտների քվազիմոնոքրոմատիկ փնջեր: Հաշվված են այդպիսի γ-փնջերի անկյունային և սպեկտրալ բաշխումները, ինչպես նաև գնահատված է նրանց ինտենսիվությունը:

Երևանի ֆիզիկայի ինստիտուտ

Երևան 1986

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ЕФИ-89I(42)-86

K.A. ISPIRIAN, M.K. ISPIRIAN

PRODUCTION OF QUASIMONOCHROMATIC BEAMS OF γ - QUANTA BY K - IONIZATION OF RELATIVISTIC IONS

It is shown that by K-ionization of relativistic ions produced either by their head on collision with laser photons, or during their passage through thin targets, one may obtain quasimonochromatic beams of γ - quanta. The angular and spectral distributions of such γ - beams are calculated as well as some estimates of their intensity are carried out.

Yerevan Physics Institute
Yerevan 1986

Препринт ЕФИ-891(42)-86

К.А.ИСПИРЯН, М.К.ИСПИРЯН

ПОЛУЧЕНИЕ КВАЗИМОНОХРОМАТИЧЕСКИХ ПУЧКОВ γ - КВАНТОВ К - ИОНИЗАЦИЕЙ РЕЛЯТИВИСТСКИХ ИОНОВ

Показано, что К - ионизацией релятивистских ионов, вызванной или их столкновением с навстречу летящими лазерными фотонами, или же их прохождением через тонкие мишени, можно получить квазимонохроматические пучки γ - квантов. Вычислены угловое и спектральное распределения и произведены оценки интенсивности таких γ - пучков.

Ереванский физический институт
Ереван 1986

At present quasimonochromatic beams of X-rays and γ-quanta, produced by means of high energy electrons, find wide application in various fields of science and technology. Still in 1973 K.A.Ispirian and A.T.Margarian have suggested [1] a method for production of such beams by colliding relativistic ions with $\gamma = E/M = (1-\beta^2)^{-1/2} \gg 1$ with laser photons of energy ω_1 where $h = c = 1$, E , M and β are the energy, mass and velocity of the ions, respectively. The essence of the method [1] is in the following. In the case of head on collision in the rest frame of the ion (IS) the photon energy increases up to $\omega_1' = 2\gamma\omega_1$ due to the Doppler effect, and if $\omega_1' = \omega_{ij}$ where ω_{ij} is the energy of any allowed transition between two atomic or nuclear level of the ion, it takes place resonance scattering (absorption and emission) of the photon. Due to the Lorentz transformation from IS to the laboratory frame (LS) the scat - tered photons, having almost isotropical angular distribution in IS are emitted mainly under small angles $\theta \sim 1/\gamma$ with respect to the ion momentum, and their energy ω_2 in LS reaches up to $\omega_{2max} \approx 4\gamma^2\omega_1$. The total cross section of such transformation of a beam of soft photons into a beam of hard γ-quanta is equal to $\sigma \approx (10^{-15} - 10^{-17})$ cm^2 and $(10^{-25} - 10^{-27})$ cm^2 for ω_{ij} lying in the optical (including

UV) and X-ray regions, respectively.

In connection with the fact that in the nearest future suitable beams will be available [2] the interest to the method [1] grows rapidly. So in 1981 it has been published the work of B.I.Goryachev [3] in which the excitation of the nuclear levels of the ions passing through thin targets by the pseudo-photons of the target nuclei has been considered, while the work of N.G.Basov et al [4].published in 1985 has been devoted to the excitation of the ion atomic levels by laser photons. Recently S.M.Darbinian et al.[5] have calculated the polarization, angular and spectral distributions of the scattered photons.

This work is devoted to investigation of the production of γ - beams by relativistic ions K-ionization occuring either by photoeffect called out by laser photons flying against them, or by collision with atoms of the target through which the ions pass. In the case of the method under consideration, compared with the case of resonance scattering on atomic levels [1,4] , there are no necessity of fine "tuning" $2\gamma\omega_1=\omega_{ij}$ and hard requirement to monochromaticity of the colliding beams, while compared to the case of excitation of nuclear levels [1,3], the cross sections are larger.

First consider the K -ionization of ions colliding with laser photons. In the energy region where the K -ionization cross section is large, i.e. when $\omega_1'=2\gamma\omega_1 \geqslant I$, where $I=me^4Z^2/2$ is the ionization energy of the main level of hydrogenlike atoms (approximately equal to K -edge), Z is the atomic number of the ion nucleus, the K-shell photo-effect cross section is expressed by the well known Stobbe formula [6] which in the limit $\omega_1' \to I$ gives:

$$\sigma_K \approx 9.67 \cdot 10^6 \sigma_T / Z^2 \qquad (1)$$

where $\sigma_T = 6.65 \cdot 10^{-25}$ cm^2 is the Thomson cross section.

Now by the method [7] let us estimate the K-ionization cross section for the relativistic ions passing through thin target of matter with atomic number Z_T. In IS fluxes of electrons and nuclei of the target atoms fall on the ion in rest and therefore on its K-electrons. For the values of the impact parameter $\beta \geqslant R$, where R is the sum of the radii of the K-shells of the ion and target atom the fields of the electrons and nuclei of the target atoms screen particularly or completely each other: therefore, the contribution of the region $\beta \geqslant R$ into K-ionization is small. For $\beta \leqslant R$ [8] with an accuracy up to terms of the order of $I/\gamma m_e$, independly of mass and spin the K-ionization cross section by a particle with unit charge is equal to $\sigma \approx 1.5 \sigma_T m_e / I$. As in many models assuming that each electron and nucleus of the target atoms calls out ion K-ionization independently each from other we obtain

$$\sigma_K \approx 1.5 Z_T (Z_T + 1) \sigma_T m_e / I \,. \qquad (2)$$

After the K-ionization with cross section (1) or (2) has taken places an another electron of the same ion fills in the vacant K-shell during times of order of $\gamma \tau_0$ where $\tau_0 \sim 10^{-14}$ sec is the lifetime of K-vacancy, and the ion emits a characteristic quantum of the lines K_α, K_β ... with a total cross section $\sigma^{tot} = C_K \sigma_K$ where C_K is the fluorescense yield. Assuming that in IS the energies of all the lines are equal each to other and equal to $\omega_2' \approx E_{K_\alpha}$, and using the relation

$$\omega_2 = E_{K_\alpha}/[\gamma(1-\beta\cos\theta)] \; ; \quad \omega_{2max} = (1+\beta)\gamma E_{K_\alpha} \; , \qquad (3)$$

one may write out the following angular and taking into account (3), spectral distribution for the produced γ - quanta in LS:

$$d\sigma(\theta) = \frac{C_K \sigma_K}{2\gamma^2} \, \frac{\sin\theta \, d\theta}{(1-\beta\cos\theta)^2} \; ; \quad d\sigma(\omega_2) = \frac{C_K \sigma_K}{2\beta\gamma} \, \frac{d\omega_2}{E_{K_\alpha}} \, . \qquad (4)$$

For $\theta \ll 1$ ($\gamma \gg 1$) denoting $u = \gamma\theta$; $x = \omega_2/\omega_{2max} = (1+u^2)^{-1}$,

$$d\sigma(u) = C_K \sigma_K (1+u^2)^{-2} du^2 \; ; \quad d\sigma(x) = C_K \sigma_K \, dx \, . \qquad (5)$$

For single collision of two pulses of $\sim 10^{10}$ oxygen ions with $\gamma \approx 182$ and of $\sim 10^{20}$ photons from argon laser with ω_1 = 2,4 ev (the length and cross section of both pulses are $\sim 10^{-6}$ sec and ~ 1 cm^2 while the length of their interaction volume $\sim 10^2$ cm or after single passage of the above mentioned ion pulse through an aluminium target of thickness of $\sim 10^{-4}$ cm one obtains $\sim 10^7$ γ - quanta with $\omega_{2max} \approx 315$ KeV. As in the cases [1,3-5] the use of collimators with opening angles of the order $\sim 1/\gamma$ will provide the necessary monochromaticity $\Delta\omega_2/\omega_2 \approx (2 - 20)\%$ of the beams of these γ -quanta without great losses.

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The manuscript was received 2 April 1986

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(на английском языке, перевод автора)

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Технический редактор А.С.Абрамян

Подписано в печать II/УI-86г. ВФ-05568 Формат 60х84/16
Офсетная печать.Уч.изд.л. 0,5 Тираж 299 экз.Ц. 8 к.
Зак.тип.№ 365 Индекс 3624

Отпечатано в Ереванском физическом институте
Ереван 36, Маркаряна 2

индекс 3624

ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ