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Thomson Scattering of Ultra-short Electromagnetic Wavelet Pulses in Plasmas

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ABSTRACT: The paper is devoted to the theoretical investigation of Thomson scattering of short electromagnetic pulses in plasmas in terms of total probability of the process during all time of pulse action. The calculations are made for the sinus-wavelet pulse. The main attention is given to the dependence of scattering probability upon pulse duration for various scattering angles and for different Debye radius.

Key words: Thomson scattering, short electromagnetic pulse, plasmas

The development of ultra-short pulse (USP) generation technology makes actual the further theoretical investigation of the specific features of pulse-matter interaction [1-3].

As it was shown previously [4] the photo-process induced by USP should be described in terms of the probability during all time of the pulse action *W*, instead of probability per unit time in conventional approach. The expression for *W* in the first order of the perturbation theory has the following form [5]:

$$\frac{dW(\tau,\theta)}{d\Omega}=\frac{c}{4\pi^2}\int_0^\infty \frac{d\sigma_{sc}(\omega',\theta)}{d\Omega}\frac{\left|E(\omega',\tau)\right|^2}{\hbar\omega'}d\omega', \tag{1}$$

here c is light velocity, θ is scattering angle, ω' is current frequency, τ is pulse duration, $d\sigma_{sc}(\omega',\theta)/d\Omega$ is spectral-angular cross section of radiation scattering, $E(\omega',\tau)$ is Fourier transform of electric field strength in the pulse, $d\Omega$ is solid angle in the direction of the pulse scattering.

In the paper [6] the scattering of USP with Gaussian envelope in plasma was studied. The main attention was given to the dependence of scattering probability on the initial phase of the pulse. At the same time in number of publications it was shown that the dependence of the photo-process probability upon pulse duration is one of the important features of USP-matter interaction.

As it's supposed in this paper, the main contribution into the integral (1) comes from the frequency $\omega >> \omega_{pe}$, where ω_{pe} is plasma frequency. Then spectral-angular cross section of Thomson scattering on plasma electron is given by the formula below (in atomic units):

$$\frac{d\sigma_{Th}(\omega,\theta)}{d\Omega}=\frac{1}{2c^4}\frac{\left(1+\cos^2\theta\right)\ \left(2d(\omega/c)\sin(\theta/2)\right)^4}{\left[1+\left(2d(\omega/c)\sin(\theta/2)\right)^2\right]^2} \tag{2}$$

here d is Debye radius.

The cross section (2) describes the radiation scattering on plasma electron with account for screening effect. The detailed derivation of eq. (2) was presented in paper [6].

The spectral dependence of the scattering cross section (2) is shown in Fig. 1 for the different scattering angles and $d = 10^6$ at.u. From this figure someone can conclude that for sufficiently high frequency $\omega >> c/d$ the scattering cross section tends to the free electron case and decreases in opposite limit due to plasma screening.

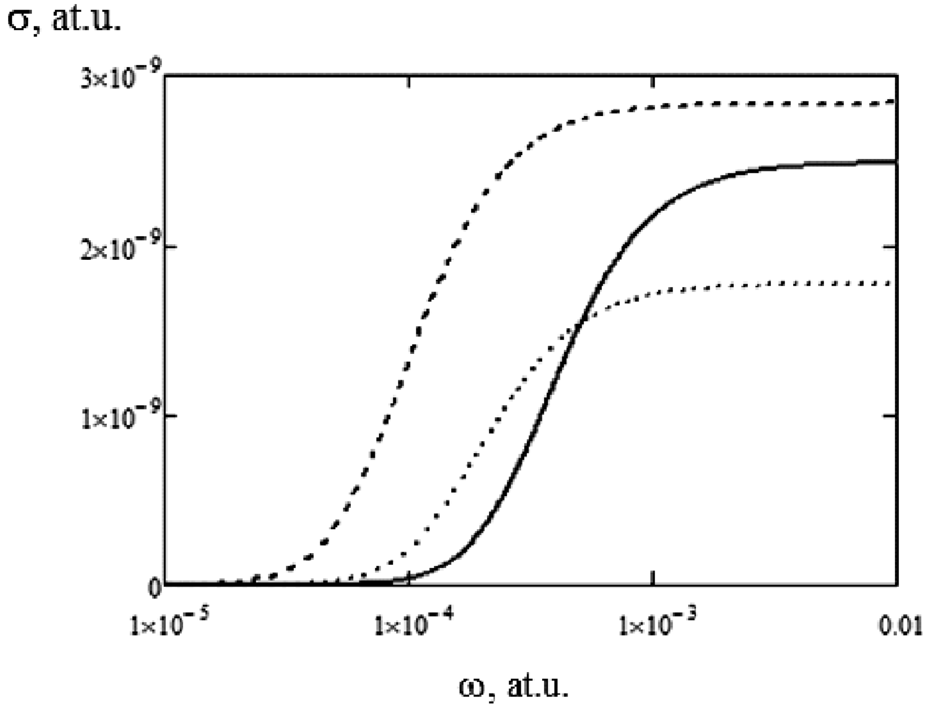

Figure 1: Thomson scattering on electron in plasma ($d = 10^6$ at.u.) for various angles as a function of frequency: solid line – $\theta = \pi/6$; dotted line – $\theta = \pi/3$; dashed line – $\theta = \pi$

Let's consider the scattering probability of short sinus-wavelet electromagnetic pulse. The Fourier transform of sinus-wavelet pulse has the following form (E_0 is the electric field strength amplitude in a pulse):

$$E_s(\omega) = 2\sqrt[4]{\pi}\,\omega\tau^2 E_0 \exp\left(-\omega^2\tau^2/2\right) \tag{3}$$

and it's shown in Fig. 2 for various pulse durations.

The maximum of spectral dependence (3) corresponds to the following frequency: $\omega_{\max} = 1/\tau$, which can be considered as an analog of the carrier frequency of the pulse.

The calculation results according to the formulas (1)-(3) are presented in Fig. 3 and Fig. 4 for normalized scattering probability:

$$Wn = W/E_0^2 \tag{4}$$

The Fig. 3 shows the probability of Thomson scattering of sinus-wavelet pulse as a function of pulse duration for the various scattering angles. As it follows from this figure the function $W(\tau)$ has a bell-curve shape. Its maximum slightly shifts to the longer pulse durations with the further increase of scattering angle.

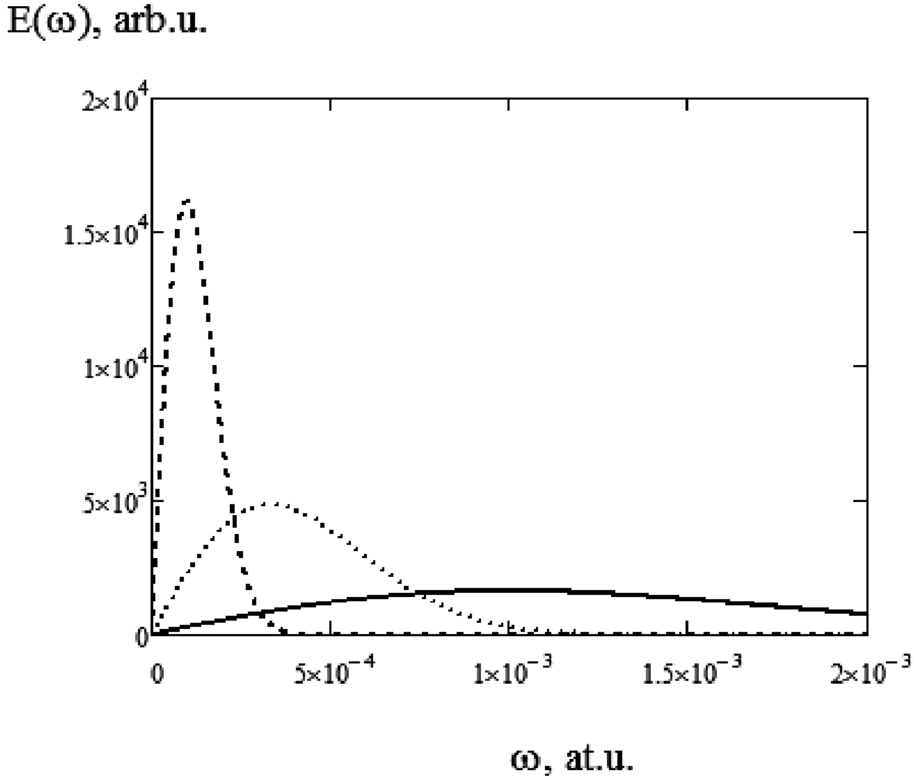

Figure 2: Plots of electric field Fourier transform of sinus-wavelet pulse for different durations: solid line – $\tau = 10^3$ a.u., dotted line – $\tau = 3\times10^3$ a.u., dashed line – $\tau = 10^4$ a.u

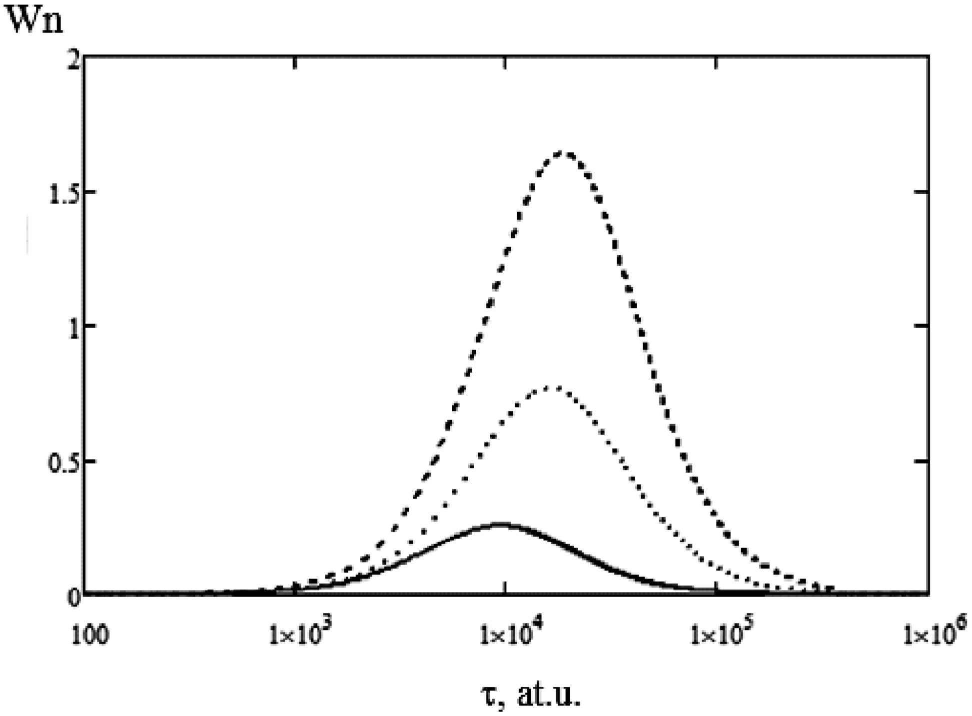

Figure 3: Probability of Thomson scattering of wavelet pulse as a function of pulse duration for various scattering angles ($d = 10^6$ at.u.): solid line – $\theta = \pi/3$; dotted line – $\theta = 2\pi/3$; dashed line – $\theta = \pi$

The Fig. 4 presents the probability of sinus-wavelet pulse back-scattering as a function of pulse duration for the two values of Debye radius.

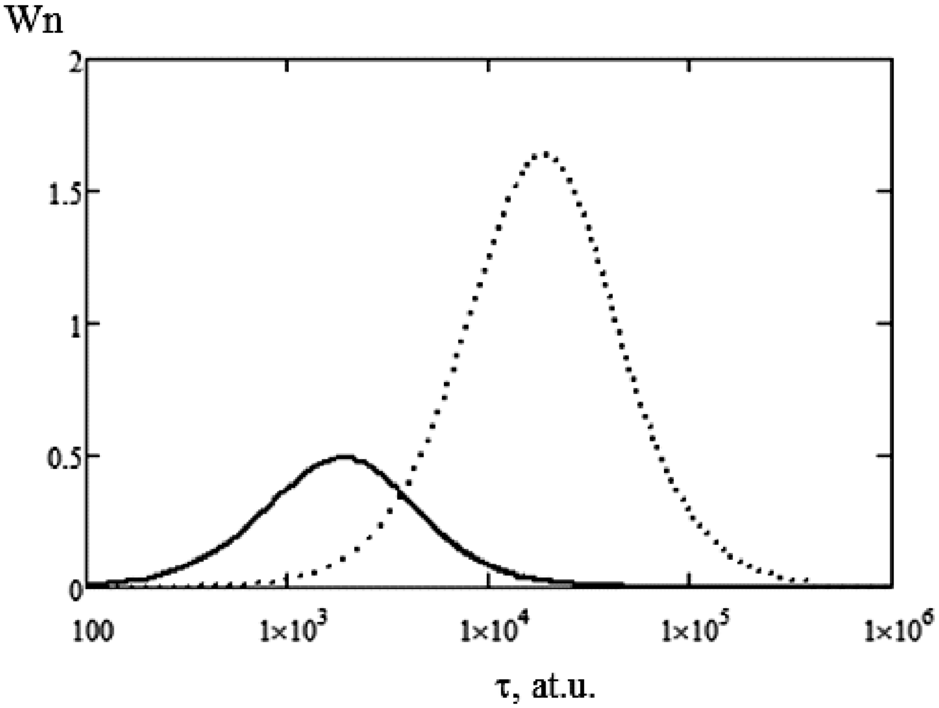

Figure 4: Probability of Thomson scattering of wavelet pulse as a function of pulse duration for various Debye radius and $\theta = \pi$: solid line – $d = 10^5$ a.u.; dotted line – $d = 10^6$ a.u.; the solid line is multiplied by factor 30 for better visibility

In this case the maximum of $W(\tau)$ function shifts significantly to the longer pulse duration with increase of the Debye radius. At the same time the magnitude of the scattering probability maximum also increases.

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