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Scattering of Ultrashort Electromagnetic Pulses on Atomic Systems

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Abstract

The Advanced Ultra-Short-Pulse Theory discovered strong non-linear and even resonance like features while absolute values of the scattering probabilities are enhanced up to 1-2 orders of magnitudes. This opens up new possibilities to investigate atomic structure and also to access characteristic parameters of a complex surrounding medium.

Keywords: ***Electromagnet; Ultra-Short Pulse Theory; Magnitudes***

Introduction

Modern technologies of ultrashort electromagnetic pulse (USP) generation *via* Higher-Harmonics in plasmas allow to access VUV and soft X-ray spectral ranges in femto- and even atto-second domain while X-ray Free Electron Laser (XFEL) radiation sources permit the USP generation in an even broader frequency range [1-5]. The term “ultrashort” implies that the scattering probability is not proportional to the pulse duration, an assumption almost exclusively applied in standard atomic physics theory and atomic kinetics. However, more invoked theory shows that one has to consider the total probabilities for the entire pulse duration instead of probabilities per unit time (resulting, e.g. from standard quantum mechanical perturbation theory). Numerical calculations discover that for USP the scattering probability is a non-linear function of the pulse duration,

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develops maxima and minima while absolute values may change up to 1-2 orders of magnitude. It is therefore of particular interest to investigate the transition regime from the total scattering probability to the standard probability per unit time in dependence of the pulse duration itself.

For the application of the Advanced Ultra-Short Pulse Theory (AUSPT) we consider the radiative scattering probabilities on atomic systems that develop resonance-like features (peaks and dips) in their dynamical polarizabilities. Such features are generally encountered for neutral atoms with many electron shells [6] and even in highly charged ions in plasmas with strong resonance transitions [7].

The scattering probability for total time of USP action is given by (atomic units are used: $e = m_e = \hbar = 1$) [8]:

$$W_{sc}(\tau,\omega) = \frac{c}{4\pi^2}\int_0^\infty \sigma_{sc}(\omega')\frac{|E(\omega',\omega,\tau)|^2}{\omega'}d\omega' \qquad (1)$$

Where c is the velocity of light, $\sigma_{sc}(\omega')$ is the scattering cross section at frequency ω', $E(\omega',\omega,\tau)$ is Fourier transform of electric field strength in the pulse, ω and τ are carrier frequency and pulse duration, respectively. The scattering cross section is expressed in terms of the atomic dynamic polarizabilty $\beta(\omega')$ of the target:

$$\sigma_{sc}(\omega') = \frac{8\pi}{3}\frac{\omega'^4}{c^4}|\beta(\omega')|^2 \qquad (2)$$

The frequency dependence of the dynamic polarizabilty shows resonance-like features that in turn result in non-linear dependences of the scattering probabilities on pulse duration. FIG. 1 presents two typical examples, namely scattering of atto- and femto-second pulses on neutral aluminum atoms (left) and on hydrogen-line potassium ions (right). The calculations demonstrate the strong non-linear dependence (including maxima and minima) of the scattering probability W_{SC} (left) and, (right) more than an order of magnitude enhanced scattering probability (see flash) for atto-second pulses compared to standard theory (dotted line).

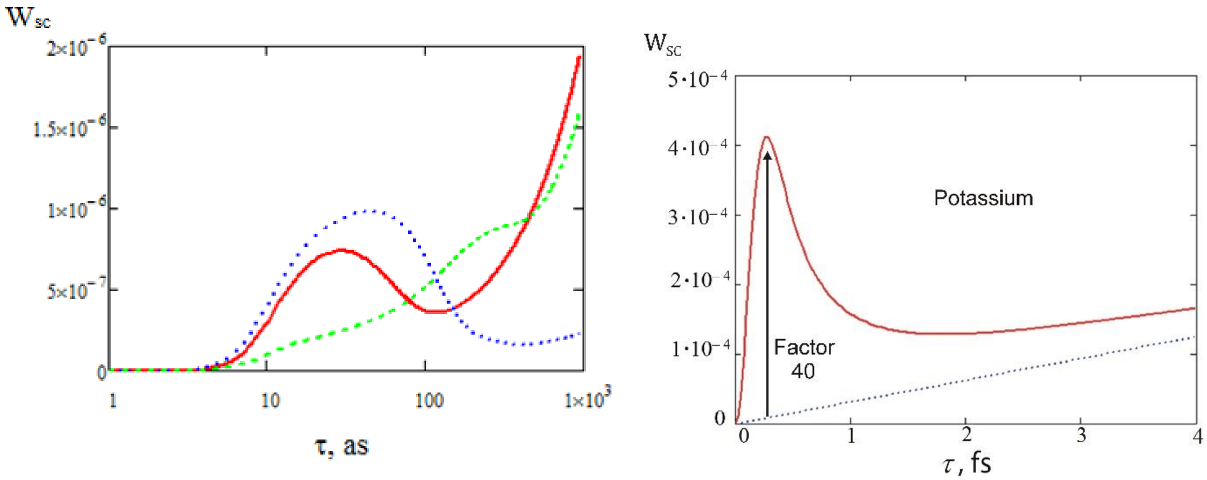

FIG. 1. **(Left) Total scattering probability of USP on aluminum atoms as a function of pulse duration for different carrier frequencies: solid line – ω=60 eV, dotted line – ω=65 eV, dashed line – ω=70 eV (for the latter case the scattering probability is multiplied by a factor 0.2 for better demonstration); (Right) scattering probability on H-like ions in plasma with Z=19 in dependence of the pulse duration, electron temperature is kT=1 keV. Solid line-calculations using AUSPT according Eq. (1), dotted line-long pulse limit.**

Conclusion

In conclusion the Advanced Ultra-Short-Pulse Theory discovered strong non-linear and even resonance like features while absolute values of the scattering probabilities are enhanced up to 1-2 orders of magnitudes. This opens up new possibilities to investigate atomic structure and also to access characteristic parameters of a complex surrounding medium.

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