Three-photon ionization of He^+ by the 13th harmonic of a Ti:Sapphire laser

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Abstract: We numerically show that the three-photon ionization of He^+ by 13th harmonic pulses of a Ti:Sapphire laser is suitable for the observation of a third-order nonlinear optical effect in the XUV region.

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The recent progress in the high-order harmonic generation technique has enabled the production of high-power XUV pulses. The generation of 13th-harmonic pulses ($\lambda = 62.3\,\mathrm{nm}$) of a Ti:Sapphire laser with an output energy as high as 4.7 μJ has recently been reported [1]. When we focus such a pulse to an area of $10\,\mu\mathrm{m}^2$, its average intensity may reach $10^{15}\,\mathrm{W/cm}^2$. With such an intensity, *the high-field physics in the XUV range* is now within reach.

In this study, we perform numerical experiments of three-photon ionization of He^+. Why He^+? Because He^+ is easy to prepare from He, e.g., by optical field ionization. Its $1s-2s$ transition (40.8 eV) is close to the two-photon resonance of the 13th harmonics of a Ti:Sapphire laser. Moreover, from a theoretical point of view, the exact solution can be delivered for this hydrogenlike system. Our results show that this process is an attractive candidate for the observation of a third-order nonlinear optical effect and even above-threshold ionization in the XUV range.

We solve the time-dependent Schrödinger equation in length gauge using the Peaceman-Rachford method [2], and evaluate the ionization yield as the number of electrons absorbed by the mask function at the outer radial boundary.

Figure 1 shows the yield of He^{2+} obtained by a Gaussian 13th- and 15th- harmonic pulse with a duration T (FWHM) of 10 fs and a peak intensity $I_{\max}$ of $10^{14}\,\mathrm{W/cm}^2$ as a function of wavelength λ. We can see a prominent peak at $\lambda = 60.7\,\mathrm{nm}$, which corresponds to the two-photon resonance with the $1s-2s$ transition. Such a 13th harmonic is obtained from a fundamental wavelength of 789 nm. This lies well within the spectral range of a Ti:Sapphire laser, thus posing no additional experimental difficulty. The He^{2+} yield exceeds 10^{-3} for a wavelength around 60.7 nm. This is sufficiently high to be observed experimentally, and is higher than the value expected for two-photon ionization by a 27th harmonic pulse [3].

Figure 2 shows the yield of He^{2+} obtained by a Gaussian 13th-harmonic pulse with $\lambda = 60.7$ nm and $T = 10$ fs as a function of peak intensity $I_{\max}$. While the yield begins to saturate at $I_{\max} > 10^{14}\,\mathrm{W/cm}^2$, it may reach 24% at a peak intensity of $10^{15}\,\mathrm{W/cm}^2$. Figure 3 shows the electron energy spectrum for the case of a Gaussian 13th-harmonic pulse with $\lambda = 60.7$ nm, $T = 10$ fs, and $I_{\max} = 10^{15}\,\mathrm{W/cm}^2$. We can see a small but clear signature of above-threshold ionization around 27 eV.

In conclusion, we propose two-photon resonant three-photon ionization of He^+ as an attractive candidate for the realization of a third-order nonlinear optical effect in the XUV region, with its high yield and possibility of above-threshold ionization.

References

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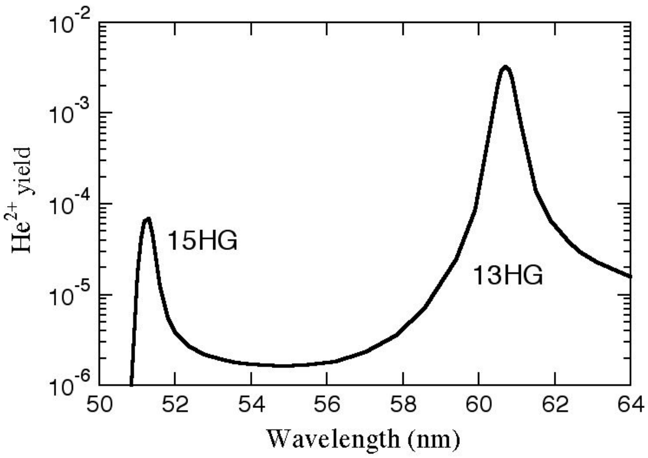

Fig. 1: Yield of He^{2+} vs. wavelength λ of a Gaussian 13th- and 15th-harmonic pulse with a pulse duration of 10 fs and $I_{\max} = 10^{14}\,\mathrm{W/cm}^2$.

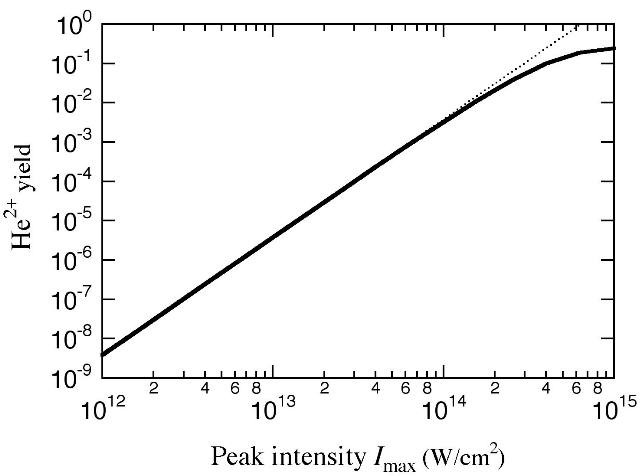

Fig. 2: Yield of He^{2+} vs. peak intensity $I_{\max}$ of a Gaussian 10fs-13th-harmonic pulse ($\lambda = 60.7$ nm). Solid line: numerical results. Dotted line: fitting $\propto I_{\max}^3$.

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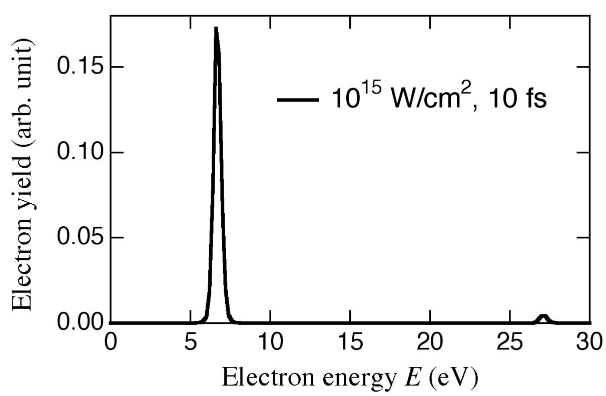

Fig. 3: Energy spectrum of ejected electrons for the case of a Gaussian 10fs-13th-harmonic pulse with $\lambda = 60.7$ nm and $I_{\max} = 10^{15}$ W/cm^2.