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# High-order harmonics and isolated-attosecond pulse generation of Three-Dimensional H atom by UV-assisted chirped fields

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**Abstract.** By solving the time-dependent Schrödinger equation (TDSE) accurately with time-dependent generalized pseudospectral (TDGPS) method, we theoretically investigated the high-order-harmonic generation (HHG) from three dimensional (3D) Hydrogen atom in ultraviolet (UV)-assisted chirped fields. When a 128 nm UV pulse is added on a chirped fundamental field, the HHG spectra is greatly broadened and enhanced, which is quite similar as the HHG from H atom initially prepared in the first excited state in the chirped field only. Besides, the HHG of H atom in the combination of a chirped fundamental field and a 256 nm UV pulse case is also investigated. The HHG process is illustrated by the semi-classical three-step model and the time-frequency analysis. The ionization probability and electron wavepacket as functions of time are also calculated to further illustrate this phenomenon. Furthermore, we also discuss the influence of time delay between the chirped fundamental field and the 128 nm UV pulse on HHG process. Finally, by superposing the harmonics in the range of 200th-260th order, an isolated attosecond pulse with a duration of about 64 as can be generated.

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**Key words**: High-order harmonic generation, generalized pseudospectral method, UV-assisted chirped fields, attosecond pulse

## 1 Introduction

With the development of laser technique, the ultrafast electron dynamics of atoms and molecules leads to a series of nonlinear nonperturbative phenomena, and attracts much

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interest in ultrafast science and technology [1, 2, 3]. In particular, high-order harmonic generation (HHG), which occurs during the process of laser pulses interact with atoms or molecules, has been studied for more than two decades [4, 5, 6]. It is still a rapid growing field because of its potential to generate coherent light sources in ultraviolet to extreme ultraviolet (XUV) range and generating attosecond pulse. The HHG process can be well understood by the well-known semi-classical three-step model [7, 8, 9]: an electron first tunnels out of a Coulomb potential barrier suppressed by the field and moves away from the parent ion; then the freed-electron is pulled back and accelerated when the laser field direction is reversed; finally it recombines with the parent ion and emits a harmonic photon. In the past few years, many efforts have been paid to broaden the bandwidth of HHG by controlling the ionization process, including the employment of high-energy IR field [10, 11], multicolor fields [12, 13, 14, 15], Terahertz (THz) field [16, 17], static field [18, 19], the macroscopic propagation effect [20, 21], spatially inhomogeneous field [22, 23, 24] and chirped field [25, 26]. Generally, the intensity of HHG is decreased by using chirped laser pulse. Furthermore, many methods have been investigated to enhance intensity of HHG, including the coherent superposition of ground state and excited states in atoms [27, 28], adding an ultraviolet (UV) pulse [29, 30], or a noise field [31], and the two-cell harmonic generation effect [32]. Due to the high energy of photons, a UV pulse can facilitate the electronic transition of ground state [33, 34], and naturally acts as a trigger to increase the contributions of special electron paths [35, 36, 37]. Recently, Li *et al.* [38] have presented an efficient method to generate an ultrashort isolated 26 as pulse. Feng *et al.* [39] theoretically achieved an isolated 40 as pulse of He atom by means of the combination of a two-color chirped pulse and an ultrashort ultraviolet pulse.

In this paper, we investigate the extension and enhancement of HHG from three dimensional (3D) H atom in UV-assisted chirped fields by solving time-dependent Schrödinger equation (TDSE) accurately with time-dependent generalized pseudospectral (TDGPS) [40, 41] method. The corresponding time-frequency and three-step model are also presented to explain the difference between the chirped field only case and the combination of chirped fundamental field and a 128 nm UV pulse case. We also demonstrate the ionization probability and electron wavepacket as functions of time to further illustrate this phenomenon.

## 2 Model

In this paper, the interaction between laser pulse and H atom can be obtained by numerically solving 3D TDSE in spherical coordinates ($x=r\sin\theta\cos\varphi$, $y=r\sin\theta\sin\varphi$, and $z=r\cos\theta$), and the laser field is linearly polarized along the z axis. The 3D TDSE is given by (in atomic units (a.u.)):

$$i\frac{\partial\psi(r,t)}{\partial t}=\hat{H}\psi(r,t)=[\hat{H}_0+\hat{V}(r,t)]\psi(r,t). \tag{1}$$

Here, $\hat{H}_0$ is the unperturbed Hamiltonian of H atom and V is the Coulomb potential