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Super Intensity Laser Fields Interacted with Atomic System in Multiphoton Processes: Non-Dipole and Non-Relativistic Effects

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Abstract

As a result of interaction of laser pulses with one-electron atomic systems described that analytic and quantum theory of high harmonic generation by a multiphoton strong-field process. In this study explained that non-relativistic Schrödinger equation and dipole approximation is inconclusive when the single atom interacted with in strong laser field based on simple characterization of multiphoton process. Furthermore, all the calculation discusses how non–dipole influence of order 1/c due to magnetic field component of laser pulse, effects harmonic generation. After that, generation of high order harmonic in single atoms within framework of strong field approximation in semi-classical and quantum mechanical model which have analyzed by the saddle point approximation. In recent years, taking into consideration to the results of this research topic is produced the high harmonic orders as a source of attosecond pulses (10^{-18} seconds) which could investigate for dynamics of electron in atoms. Nowadays, attosecond pulses synthesized by high order harmonic generation have been used as a source in many scientific studies. By this review study, has offered a solution of high harmonic generation, large application and search area that uses new invented optical techniques and energy production.

Keywords: Attosecond pulses, multiphoton process, one-electron atomic systems, photon energy, strong laser field

Multifoton Süreçlerde Atomik Sistem ile Etkileşen Süper Yoğun Lazer Alanları: Dipol ve Rölativistik Olmayan Etkiler

Öz

Bu çalışmada, güçlü alan ile etkileşen bir elektronlu atomik sistemlerde yüksek mertebeden harmonik üretim süreçlerine, kuantum mekaniksel ve analitik çözümler sunulacaktır. Güçlü lazer alanı varlığındaki hesaplamalarda, göreli olmayan Schrödinger dalga denklemi ve dipol yaklaşıklığın bozulduğu multifoton süreçlerin, basit tanımları irdelenmiştir. Manyetik alan bileşenin 1/c mertebesinde olduğu için dipol olmayan etkilerin yüksek mertebeden harmonik üretime katkıları tartışılmıştır. Bunun ardından güçlü alan yaklaşıklığının tanımı ile tek elektronlu atomik sistemler için yüksek mertebeden harmonik üretimin yarı klasik modeli ve tamamen kuantum mekaniksel nicelikleri ele alınmıştır. Güçlü alanda geleneksel olarak 'saddlepoint' yaklaşımı altında uzunluk ayar dönüşümü ile harmonik spektrum için çözümler analiz edilmiştir. Son yıllarda yüksek harmonik üretim için kaynak olan attosaniye atımlar (10^{-18} saniye), elektronların dinamiği için güncel araştırma konusu olmuştur. Günümüzde, yüksek mertebeden harmonik üretim tarafından sentezlenen attosaniye atımları birçok bilimsel çalışmada kaynak olarak kullanılmıştır. Bu derleme çalışma ve sonuçları, atomik fizik teknikleriyle incelenmeye başlanan yüksek mertebeden harmonik üretim, optik ve enerji alanlarında oldukça heyecan verici sonuçlar elde edilen geniş bir uygulama alanına ışık tutmuştur.

Anahtar Kelimeler: Attosaniye atımlar, multifoton süreçler, bir elektronlu atomik sistemler, foton enerji, güçlü lazer alanı

INTRODUCTION

First multiphoton ionization experiments were performed at the beginning of the since 1970s when laser technology has made growing progress. Laser technology has made developing progress when the first multiphoton ionization experiments and application were applied in since 1970s. Today lasers have become indispensable tools for investigating physical processes which is used Nuclear and High Energy Physics, Atomic and Plasma Physics and many different fields (Miloševic et al., 2006; Di Piazza et al., 2012).

Laser-matter interaction is concerned how the atoms, molecules and plasma are interacted to an external light waves. The increasing importance of atom-light interaction is due to unheard of advance in laser technology and

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detection systems (Chirila, 2004). On the other hand, last permanent technological advances are opening of facilities which can be used intense laser radiation to cause or essentially affect physical processes beyond atomic energy scales. The concept of quantum field theory was developed the multiphoton processes how to explain interaction of radiation with matter (Corkum, 1993; Kulander et al., 1993; Yao et al., 1993; Wang et al., 1994; Tong et al., 1997; Saliers et al., 1999; Telnov et al., 1999; Di Piazza et al., 2012).

The selection rules for multiphoton processes are differ from single-photon processes. In dipole, electric transitions including an even number of photons are permitted only between states of identical parity, and involving an odd number of photons are allow between states with different parity. One of the most fundamental applications are base the selection rules for multiphoton processes. Measurement of multiphoton absorption spectrum makes it possible to study by optical methods. In the energy states, which are excited from the ground state is prohibited in single-photon processes (Corkum, 1993; Kulander et al., 1993; Lewenstein et al., 1994; Schafer et al., 1995; Van Linden et al., 1998; Joachain et al., 2003). By the side of single-photon processes, the law of conservation of energy can be satisfied in multiphoton processes when the outgoing transition of an atom from a lower to a higher energy state occurs not only with absorption but also with emission of individual photons. Therefore, multiphoton processes are the basis for the methods used to convert the radiation frequency of lasers and to improve frequency-tunable laser radiation sources. The development to frequency-tunable high-power optical radiation sources also is possible on the source of multiphoton processes (Keldysh, 1964; Burnett et al., 1993; Kulander et al., 1993; Trainham et al., 1993; Mese, 1997; Joachain et al., 2003).

Laser with the discovery of non-linear optical effects that are caused by current intensity. This is just experimental application of the Chirped Pulse Amplification (CPA) technique that it has been feasible to achieve the threshold intensity 10^{14}-10^{15} W/cm^2 related to electric field amplitudes like the Coulomb field in atoms (Piazza et al., 2012).

The laser intensity interaction between the atomic field dramatically alters the dynamics of the electron in atoms and the molecules of which can be utilized to produce extreme ultraviolet (XUV) and high-frequency radiation in the soft X-ray region (HHG) (Krause et al., 1992; L'Huillier et al., 1993; Schafer et al., 1993; Becker et al., 1994; Saliers et al., 1999; Morisson et al., 2000; Scrinzi et al., 2002; Pfeifer, 2004; Mese et al., 2005; Di Piazza et al., 2012;). The most another important laser-atomic interaction is called relativistic regime where the laser optical intensity to the order of 10^{17}-10^{18} W/cm^2. An electron reaches relativistic velocities in such intense, and the precession of electrons in the magnetic field of the laser becomes non-linear function (Milosevic et al., 2002).

The harmonic generation process is defined by a three-step semi-classical model, the first event is electron tunnels out of the area suppressed by the Coulomb potential barrier field when the laser field direction is reversed, the electron returns to the ion and then accelerated, and finally it combines with the ion. The characteristic of the high order harmonic spectrum indicate that the signal intensity has declined for the first low orders, then the densities will remain for many orders in a plateau view and finally the intensity suddenly drops for the highest orders which is called cut-off. While the latest step, an attosecond pulse is emitted (Hentschel et al., 2002; Scrinziet al., 2002; Chang, 2004).

Attosecond pulses are essential tools for analysis and testing of the movement of electron in the atoms. So far, the high-order harmonic generation (HHG) has been the method to produce train or single attosecond pulses (Salieres et al., 1999; Brabecet al., 2000; Bartels et al., 2002).

MULTIPHOTON PROCESSES IN STRONG FIELD

In recent time, advanced laser systems are produce very short pulses, so the peak energy becomes as high as the femtosecond pulse when it is preserving the pulse power. This intensity was obtained until the 10^{19} W/cm^2. Because they have a short of pulses to survive at much higher intensities before ionizing, laser-atom interactions of atoms make it possible to

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completely new regime (Bethe, 1957; Reiss, 1980; Kulander et al., 1996).

Generally, all the bound states except the initial state of the atom is neglected in the strong field approximation (SFA). The wave function is produced as the composition of the quasi-static electric field and bare initial wave function which can describe a motion of electron's wave function (Kulander et al., 1996).

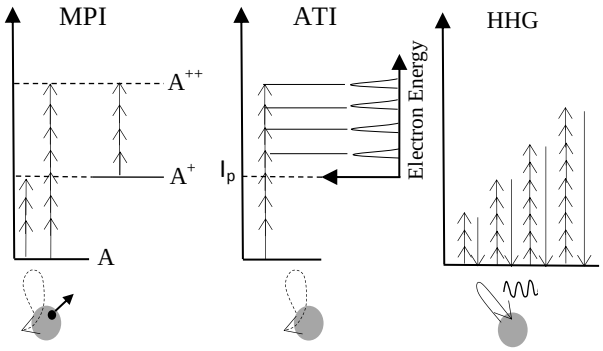

Figure 1. In strong laser fields of atoms to three non-linear process: Multiphoton ionisation (MPI), Above Threshold Ionization (ATI), High Harmonic Generation (HHG) (L' Huillier, 2002)

In 1994, Lewenstein et al., using the saddle-point method and the path integral in quantum mechanics method is called simple man theory (Lewenstein et al., 1994).

Strong field approximation (SFA) in their calculation was defined as follows:

- The ground state except of energy, the contribution from the bound state of the system is neglected.
- In the continuum, the electron is treated as a free particle of movement without binding potential effect of the atoms in the laser electric field (Lewenstein et al., 1994).

Single Atom Ionization

The kinetic energy of ionizing electrons.

$$E_{kin} = \hbar\omega - E_b \quad (1)$$

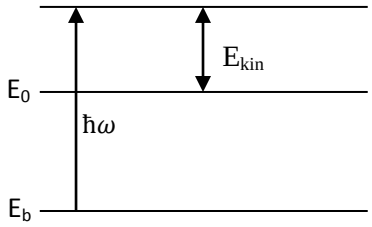

Figure 2. Single photon ionization process (Kulander et al., 1993; L' Huillier, 2002)

In the strong field regime, excitation and ionization dynamics are included in single-electron transitions. While atoms can lose a few electrons throughout single pulse, electrons are released consecutively. Even though it has been extensively research, there is no conclusive proof to excitation to whole atoms in strong fields. After an electron is excited in an atom, the binding energy of the remaining electrons is much higher (Kulander et al., 1996). Consequently, the laser field can significantly affect them until they reached much high intensity. Then, the first electron has been emitted (Bransden et al., 1992; Fittinghof et al., 1994).

In this process, the kinetic energy expression for ionization,

$$E_{kin} = N\hbar\omega - E_b \quad (2)$$

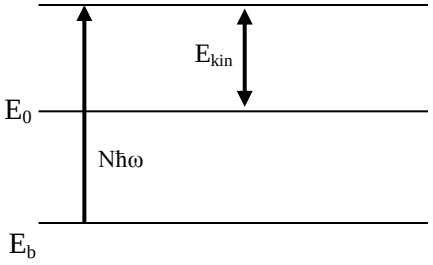

Figure 3. Multiphoton ionization (Kulander et al., 1993; L' Huillier, 2002)

Above Threshold Ionization

Electrons can achieve more than the minimum amount of energy required for threshold ionization in strong laser and optical fields. Rather than producing a single peak that can propagate, instead of producing a peak group containing the electron energy spectrum separated by photon energy, referred to as above threshold ionization (ATI) (Schafer et al., 1993; Schafer et al., 1995; Kulander et al., 1996; Sprangle et al., 2002).

In this process, the kinetic energy expression for ionization and the expansion ratio.

$$E_{kin} = (N + s)\hbar\omega - E_b \quad (3)$$

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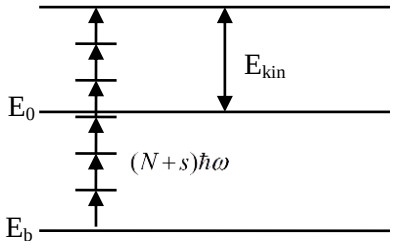

Figure 4. (N+s) ionized by photon absorption. (Kulander et al.,1993; L' Huillier, 2002)

High Harmonic Generation

In laser physics, high order harmonic generation is growing rapidly for the noble gases. If a laser pulse interacts with the atomic gas, emitting radiation at coherent frequency which can be exact multiples laser frequencies in the non-linear approximation. Because of only odd harmonics that is emitted in the atom with inversion symmetry. The strong harmonics decrease for the first few orders in the high intensity (>1013 W/cm^2) and low frequency regime, subsequently of a large plateau almost constant conversion efficiency, later sharp cut-off. When the light is used as active noble gases, the plateau extends well beyond the hundredth of 800-1000 nm wavelength. In addition, experimental evidence has been found in the HG from ions. HG provides a consistent source of XUV radiation having advantages over other known sources, such as synchrotron (Krause et al., 1992; L'Huillier et al., 1993; Kulander et al., 1996; Tong et al., 1997; Chirila, 2004).

Cut-off and Plateau

In recently, developed three-step model that combines the quantum and laser atom physics explain for intense fields phenomena. In this model, the Coulomb potential and the laser field is formed the electron from the ground state of the atom which is first tunnel through the barrier created by the laser field. Its further movement can exhibit classic behavior and substantially in phase with the oscillation of the laser.

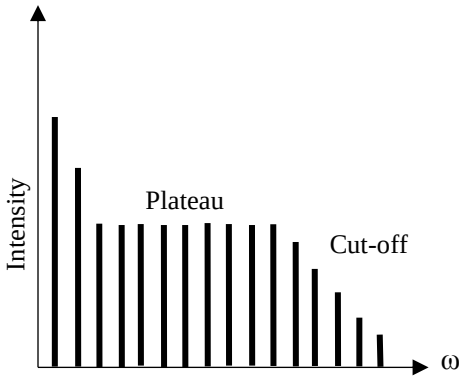

Figure 5. Plateau and Cut-off region (Becker et al., 1996)

A plateau is a frequency region with harmonics of comparable intensities. This is in contrast to strong decreases in intensity both for the lower lying harmonics and for the highest ones generated.

A cut-off region is an abrupt intensity decreases at the end of the plateau at harmonic cut-off that is estimated classically by the highest energy (Krause et al., 1992; Kylstra et al., 2001; Chirila et al., 2002).

THEORETICAL METHODS

Non-dipole and relativistic effects in multiphoton processes will be discussed in this section. The harmonic orders are evaluated by time-dependent dipole moment (Schafer et al., 1993; Kulander et al., 1996; Kylstra et al., 2001; Chirila et al., 2002; Joachain et al., 2003),

$$d(t) = \langle \Psi(t) | e\boldsymbol{r} | \Psi(t) \rangle. \qquad (4)$$

$\boldsymbol{A}(t)$ is in strong laser field dipole approximation and homogeneous space vector potential. The component of the electric field of the laser field is $\varepsilon(t) = \frac{d\boldsymbol{A}}{dt}$. While there is no magnetic field component, the magnetic field is $\boldsymbol{B} = \boldsymbol{\nabla} \times \boldsymbol{A} = 0$. In the single atom, Schrödinger wave equation for the $\hat{\boldsymbol{k}}$ linearly polarized strong laser field is as the following (Joachain et al., 2003):

$$\boldsymbol{i}\frac{\partial}{\partial \boldsymbol{t}}\Psi(\boldsymbol{r},t) = \left\{\frac{1}{2}\left[-i\boldsymbol{\nabla} + \boldsymbol{A}(\eta)\right]^2 + V(\boldsymbol{r})\right\}\Psi(\boldsymbol{r},t) \qquad (5)$$

$V(\boldsymbol{r})$ is bound potential of electron and $\boldsymbol{A}(\eta)$ is vector potential. Laser vector potential field is defined as follows:

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$$\boldsymbol{A}(\eta) = \hat{\varepsilon}(\varepsilon/\omega)\sin^2(\eta/4)\sin(\eta) \quad (6)$$

$$\eta = \omega t - \boldsymbol{k}\cdot\boldsymbol{r} \quad (7)$$

$$\lambda = 2\pi c/\omega = 800\ nm \quad (8)$$

Using the method of Taylor series $\boldsymbol{A}(\eta)$ are as follows,

$$f(z) = \sum_{n=0}^{\infty} \frac{f^{(n)}(z_0)(z-z_0)^{(n)}}{n!} \quad (9)$$

$$\boldsymbol{A}(\eta) = \frac{\boldsymbol{A}^0(\omega t)(\omega t - \boldsymbol{k}\cdot\boldsymbol{r}/\boldsymbol{c})^0}{0!} + \frac{\boldsymbol{A}^1(\omega t)(\omega t - \boldsymbol{k}\cdot\boldsymbol{r}/\boldsymbol{c})^1}{1!} + \cdots \quad (10)$$

Only the first two terms in our above equation would be enough for us, remaining terms can be neglected, so that

$$\boldsymbol{A}(\eta) \sim \boldsymbol{A}(\omega t) - \frac{\boldsymbol{k}.\boldsymbol{r}}{c}\boldsymbol{A}(\omega t)\ . \quad (11)$$

Scalar potential can be written in terms of the vector potential,

$$\boldsymbol{E}(\omega t) = -\nabla\phi(\boldsymbol{r},t) - \frac{\partial \boldsymbol{A}(\boldsymbol{r},t)}{\partial t} \quad (12)$$

The scalar potential is $\nabla\phi = 0$ and the vector potential is,

$$\boldsymbol{A}(\eta) \sim \boldsymbol{A}(\omega t) - \frac{\boldsymbol{k}.\boldsymbol{r}}{c}\boldsymbol{E}(\omega t). \quad (13)$$

Using Equation 13 in the Schrödinger wave equation can be written as,

$$i\frac{\partial}{\partial t}\Psi(\boldsymbol{r},t) = \left\{\frac{1}{2}\left[-i\nabla + \boldsymbol{A}(\omega t) + \frac{\boldsymbol{k}.\boldsymbol{r}}{c}\boldsymbol{E}(\omega t)\right]^2 + V(r)\right\}\Psi(r,t). \quad (14)$$

$$i\frac{\partial}{\partial t}\Psi(\boldsymbol{r},t) = \left(\frac{1}{2}[-i\nabla + \boldsymbol{A}(\omega t)]^2 + \frac{\boldsymbol{k}.\boldsymbol{r}}{c}[-i\nabla + \boldsymbol{A}(\omega t)]\cdot\boldsymbol{E}(\omega t) - \frac{1}{2}\left(\frac{\boldsymbol{k}.\boldsymbol{r}}{c}\right)^2 E^2(\omega t) + V(r)\right)\Psi(r,t). \quad (15)$$

$V(\boldsymbol{r})$ is interaction potential between atoms and ions in the core potential. In the above equation two non-dipole effects are seen easily. The first term is magnetic quadruple term, $\nabla.\boldsymbol{E}(\omega t)$, which defines magnetic dipole transition. The second term is $\boldsymbol{A}(\omega t).\boldsymbol{E}(\omega t)$ caused by the magnetic field and the drift the direction of propagation and defines high laser intensity of photons released by ion impact.

This theory is ignored $1/c^2$'s terms in the non-relativistic time-dependent Schrödinger wave equation is as follows,

$$i\frac{\partial}{\partial t}\Psi(\boldsymbol{r},t) = \left\{\frac{1}{2}[-i\nabla + \boldsymbol{A}(\omega t)]^2 + \frac{\boldsymbol{k}.\boldsymbol{r}}{c}[-i\nabla + \boldsymbol{A}(\omega t)]\cdot\boldsymbol{E}(\omega t) + V(r)\right\}. \quad (16)$$

In the Hamiltonian equation, the coulomb gauge transformation is equal to $\nabla\cdot\boldsymbol{A}(\omega t) = 0$, and the length of the gauge transformation function can be used:

$$\Psi_L(\boldsymbol{r},t) = exp[i\boldsymbol{A}(\omega t)\cdot\boldsymbol{r}]\Psi(\boldsymbol{r},t). \quad (17)$$

In this case, the Hamiltonian is defined by,

$$\hat{H}_L = \hat{T}_L\hat{H}\ . \quad (18)$$

Then the time-dependent Schrödinger wave equation is obtained as follows,

$$i\frac{\partial}{\partial t}\Psi_L(\boldsymbol{r},t) = \left\{-\frac{1}{2}\nabla^2 + \left[r - i\frac{\boldsymbol{k}.\boldsymbol{r}}{c}\nabla\right]\cdot\boldsymbol{E}(\omega t) + V(r)\right\}\Psi_L(\boldsymbol{r},t)\ . \quad (19)$$

Non-dipole time-dependent wave equation can be written as follows:

$$i\frac{\partial}{\partial t}\Psi_L(\boldsymbol{r},t) = H(t)\Psi_L(\boldsymbol{r},t)\ . \quad (20)$$

The total Hamiltonian, atomic hamiltonian and the interaction terms are written as,

$$H(t) = H_0 + H_{\text{int}}\ , \quad (21)$$

where

$$H_0 = -\frac{1}{2}\nabla^2 + V(\boldsymbol{r})\ , \quad (22)$$

$$H_{int} = \left[\boldsymbol{r} - i\frac{\boldsymbol{k}.\boldsymbol{r}}{c}\nabla\right]\cdot\boldsymbol{E}(\omega t)\ . \quad (23)$$

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For an atom and ion, the initial eigenstates of H_0 is defined as $\phi_0(\boldsymbol{r},t)=\phi_0(\boldsymbol{r})\exp(I_p t)$, where I_p is the ionization potential. It is used length gauge transformations that are obtained by the solutions of the Schrodinger wave equation which gives time and location-based Lippmann-Schwinger equation. This equation provides Green's function $G^{+}(\boldsymbol{r},t;\boldsymbol{r}',t')$ and Lippmann-Schwinger wave function given by (Reiss, 1980; Bethe, 1957);

$$\Psi_L=\phi_0(\boldsymbol{r},t)+\int dt'\int dr' G^{(+)}(\boldsymbol{r},t;\boldsymbol{r}',t')H_{\text{int}}\phi_0(\boldsymbol{r}',t') \qquad (24)$$

In Strong Field Approximation (SFA) Time Depend Dipole Moment

The total dipole moment for a strong laser field is (Lewenstein et al., 1994; Becker et al, 1996; Kylstra et al., 2001; Joachain et al., 2003):

$$d(t)=d_s(t)+d_a(t)+d_e(t)+d_{c-c}(t). \qquad (25)$$

In this model for harmonic generation, laser-atom interaction dipole moment can be defined as follows;

$$d(t)\sim\langle\phi_0(r,t)|r|\Psi_L(\boldsymbol{r}',t')\rangle+c.c \qquad (26)$$

The eigenstates $\phi_0(\boldsymbol{r},t)$ for the Lippmann-Schwinger equation can be used,

$$d(t)\sim -\int_{-\infty}^{t}dt'\int dr dr'\phi_0^*(r,t)rG^{(+)}(r,t;r't')H_{int}\phi_0(r't')+c.c\,. \qquad (27)$$

When interaction free electron with laser field, it is superimposed an oscillatory motion on its drift motion in the field. Such functions are defined Volkov Green function $G^{+}(\boldsymbol{r},t;\boldsymbol{r}',t')$ (Lewenstein et al., 1994; Schafer et al., 1995; Chirila, 2004):

$$G^{(+)}(\boldsymbol{r},t;\boldsymbol{r}',t')=-i\theta(t-t')\int dp\Psi_p^L(\boldsymbol{r},t)\left[\Psi_p^L(\boldsymbol{r},t)\right]^*. \qquad (28)$$

Where $\Psi_p^L(\boldsymbol{r},t)$ is the Volkov wave function:

$$i\frac{\partial}{\partial t}\Psi'_P(\boldsymbol{r},t)=\frac{1}{2}\left(-i\boldsymbol{\nabla}+\boldsymbol{A}(\omega t)+\frac{1}{c}\left[-\boldsymbol{\nabla}\cdot\boldsymbol{A}(\omega t)+\frac{1}{2}A(\omega t)^2\right]\boldsymbol{k}\right)^2\Psi'_P(\boldsymbol{r},t) \qquad (29)$$

The most common definition of dipole moment is

$$d(t)\cong-\int_{-\infty}^{t}dt'\int drdr'\phi_0^*(r,t)r$$

$$\{i\int dp\Psi_P^L(r,t)[\Psi_P^L(r,t)]^*\}H_{int}\phi_0(r't')+c.c. \qquad (30)$$

$$d(t)\cong-i\int_{-\infty}^{t}dt'\int drdr'\phi_0^*(r,t)r$$
$$\left(\int d^3p\frac{1}{(2\pi)^{3/2}}exp\left(i\boldsymbol{\pi}(p,t).\boldsymbol{r}-\frac{1}{2}i\int^t dt''[\boldsymbol{\pi}(p,t'')]^2\right)\right)\times$$
$$\frac{1}{(2\pi)^{3/2}}exp\left(i\boldsymbol{\pi}(p,t).\boldsymbol{r}-\frac{1}{2}i\int^t dt''[\boldsymbol{\pi}(p,t'')]^2\right)^*$$
$$\times H_{int}\phi_0(r't')+c.c. \qquad (31)$$

To write a simple form of the above integral, the following definitions are used:

$$\boldsymbol{d}_{\boldsymbol{rec}}^*(\pi,r;t)=$$
$$\int\frac{dr}{(2\pi)^{3/2}}exp(-i\boldsymbol{\pi}(p,t).\boldsymbol{r})(-r)\exp(-I_p(t-t'))\phi_0^*(\boldsymbol{r}), \qquad (32)$$

$$\boldsymbol{d}_{ion}(\boldsymbol{\pi},\boldsymbol{r};t)=\langle\Psi_p(\boldsymbol{\pi},t')|H_{int}|\phi_0(\boldsymbol{r}',t')\rangle$$
$$=\int\frac{dr}{(2\pi)^{3/2}}exp(-i\boldsymbol{\pi}(p,t).\boldsymbol{r})H_{int}exp\left(-I_p(t-t')\right)\phi_0(\boldsymbol{r}). \qquad (33)$$

In the above equation, it can be used the $\phi_0(\boldsymbol{r},t)=\phi_0(\boldsymbol{r})\exp(I_p t)$ function where is the ionization potential I_p,

$$d(t)\cong-i\int_0^t dt'\int d^3p d_{rec}^*[\boldsymbol{\pi}(\boldsymbol{p},t)]$$
$$\times\exp\left(-i\frac{1}{2}\int dt''\left[\boldsymbol{\pi}(\boldsymbol{p},t)\right]^2+\left(-I_p(t-t')\right)\right)$$
$$\times\boldsymbol{d}_{ion}\left[\boldsymbol{\pi}(\boldsymbol{p},t')\right]+c.c \qquad (34)$$

The above equation was written in exponential terms were as (Chirila et al., 2002);

$$S(\boldsymbol{p},t,t')$$
$$=\int dt''\left[\frac{1}{2}\left[\boldsymbol{\pi}(\boldsymbol{p},t)\right]^2+\left(-I_p(t-t')\right)\right] \qquad (35)$$

This is the most general definition of the dipole moment. This integral is solved by using saddle point methods (Chirila et al., 2002).

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$$d(t) \cong -i \int_0^t dt' \int d^3p \boldsymbol{d}^*_{\boldsymbol{rec}}[\boldsymbol{\pi}(\boldsymbol{p},t)] \exp\left(-i\boldsymbol{S}(p,t,t')\right) \boldsymbol{d}_{\boldsymbol{ion}}[\boldsymbol{\pi}(p,t')] + c.c \quad (36)$$

$$d(t) \cong -i \int_0^t dt' \left(\frac{2\pi}{\varepsilon + i\tau}\right)^{\frac{3}{2}} \left(1 - \frac{1}{c^2}(\hat{\boldsymbol{\varepsilon}}.\boldsymbol{p_s})^2\right)^{-\frac{1}{2}} d_{rec}[\boldsymbol{\pi}(p,t)] exp\left(-i\boldsymbol{S}(p,t,t')\right) d_{ion}[\boldsymbol{\pi}(p,t')] + c.c \quad (37)$$

Multiphoton processes are very complex dynamics where the results are often caused some negligences and errors made in this approach may be in good harmony with quantum calculations (Alp, 2008). Also, trajectories views are generally difficult to remove a complex time-dependent wave function which provides details of excitation dynamics. Therefore, this method commitments to the ionization potential in strong field, benefit to understanding the biggest differences between dipole and non-dipole spectrum. Under this approach it has been neglected the relative effects in this model. This relativistic effects which are formed by Milosevic et al., and they have been evaluated using the analytical results in Klein Gordon equation. In the dipole approximation, non-dipole and relative calculations for compared with spectrum of high-photon energy at the cut-off point are insignificant. The source of this quantum effect is the additional kinetic energy that is obtained from the electron returned that pulses to drift along the direction of propagation. Some non-relativistic and non-dipole effects are ignored in this calculation, for example, $1/c^2$ term increases the kinetic energy contributing to the inertial mass. Consequence, these additional terms in the relativistic findings influence a small displacement of the cutoff region where reduce low energies (Kulander et al., 1993; Lewenstein et al., 1994; Joachain et al., 2003; Chirila, 2004; Miloševic et al, 2006).

ATTOSECOND PULSE SYNTHESIS

HGG's another fascinating application is the production of attosecond pulses. Attosecond science allows us to transfer the electrons methods and optical concepts. In the field of a laser pulse time can be used when the electron-ion collisions or re-collision. Attosecond optical pulses produce a medium-density gas. In this process, the electron wave package tunneled by wave function. If electrons re-collides, it may interfere with the part of the bound wave function how provides consistency at the level of a single atoms (Hentschel et al., 2001).

The production of attosecond pulses from high harmonic has two forms. To combines many harmonics which is produced by attosecond pulse train, it can be used the broad plateau from the spectrum (APT). Another important case how is synthesized from a single attosecond pulse generated harmonics (Becker et al, 1996; Chang, 2004; Cao et al., 2006).

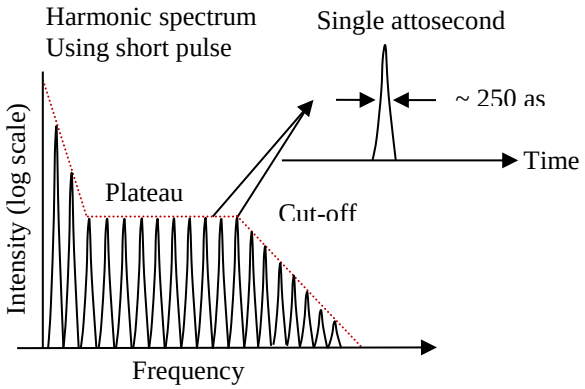

Figure 6. Single attosecond pulse generated to harmonic spectrum (Becker et al., 1996).

A typically HHG spectrum emphasizes that increasing harmonic order when the signal intensity declined significantly in the first few low orders. In this feature, the intensities of the HHG spectrum remain constant for many orders to form a plateau, ultimately, the cutting region is sharply reduced for the highest orders. HHG discrete nature and wide range of spectrum suggests a potential for generating attosecond pulse train (Chang, 2004; Murakami, 2006).

CONCLUSIONS

In dipole approximation, Lewenstein and co-workers who were examined the effects of non-dipole theory within SFA. This review paper shows that the time-depend dipole moment d(t) solution of the ion in the laser field by using the non-relativistic and non-dipole Volkov wave functions. In this approximation, when focusing on a high intensity in a low-frequency laser pulse, the electric field between the atomic nucleus and the electron in the atom, the laser's electric field can be compared or even exceeded. In this case, through this process known as high-order harmonic generation, extreme radiation, which is

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the time scale of the electronic processes with duration in the attosecond field may be emitted (10^{-18} s). HHG is one of the potential applications in the synthesis of high harmonic into attosecond pulses. Since this theory is successful, the attosecond pulses that are going to capture electron dynamics expand the available attophysics. Thus, attosecond science opens new opportunities for collision physics and optical science. In the optical point of view, the new technology produce the shortest optical pulses and generates a shorter wavelength coherent light that can be produced. The details of the spectrum which stems from the particular orbit or their superposition. The arrival at the atomic position coincides with the other ionization times or the rescattering times of certain orbitals, while the other is the attosecond pulses of the other application which is unaffected. Therefore, attosecond pulse does not prevent a particular quantum orbit caused that is also ionization alone.

Thanks to the high harmonic generation, the attosecond pulse with many application fields has been obtained. Today lasers pulses are serve very different purpose and very sensitive process. Rays, from short wave -X-rays- to long wave-infrared rays-are scattered in all areas of the electromagnetic spectrum. These lasers are very fast acting chemical reactions examined step by step. An important result of using this laser type is to analyze the structure of the disease-causing molecules and are developed new drugs.

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