e - H collisions in a resonant monochromatic or bichromatic laser field

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Atomic transitions induced by a resonant laser field continue to attract a great deal of attention, in view of the importance of these processes in plasma heating by intense electromagnetic field, optical pumping, cooling of atomic beams, and other areas. Recent studies of the changes in the atomic structure and or in radiative transitions brought in by a resonant bichromatic laser field have been stimulated by the discovery of new effects resulting from quantal interferences, such as the occurrence of dark states, of laser induced continuum structures and of resonance enhanced ionization. Some control of these effects, i.e. some manipulation of the multiphoton dynamics of the atom, can be achieved by modifying the relative phase of an incident two color field with commensurable frequencies (coherent control), or by varying the field intensities or frequencies (incoherent control). However, in certain cases the only way to gain information about the structure and behavior of the system is through scattering experiments.

The purpose of this work is to study the transitions in hydrogen between the levels $nl \to n'l'$ (with $n, n' = 1, 2$ and 3) in laser-assisted collisions with fast incident electrons. During the collision a *net* number N of photons are transferred between the electron-atom system and the laser field. We consider the e-H system embedded in a monochromatic or bichromatic linearly polarized laser field, with the polarization vectors oriented in the direction of the momentum transfer $\mathbf{K}$. The non-perturbative Born-Floquet theory is applied with a complex Sturmian discrete basis-set expansion method [1], thus allowing us to take into account the whole spectrum in the dressing of the target. The "wavenumber" κ of the Sturmian functions should be chosen so as to describe correctly the atom decaying in the laser field. In addition, it is necessary to adjust the range of the (exponentially decreasing) Sturmian basis functions in order correctly to reproduce the relevant part of the atomic spectrum. The numerical method for the evaluation of the Born-Floquet scattering amplitude described in Ref. [2] is used.

When the atom is irradiated by light of moderate intensity whose frequency matches a transition frequency between the two levels, the adiabatic quasienergy curves are very distorted by the mutual coupling in a narrow region of wavelengths, where the real parts exhibit an avoided crossing. Within the two-level model, the resonant states can be expressed as linear superpositions of the unperturbed states to which the resonant states reduce in the low-intensity limit. The resonant states interchange their character, i.e. their symmetry, at the crossing.

The one-photon coupling between the $n = 2$ and $n = 3$ levels governs the aforementioned small-angle e-H scattering in a broad range of wavelengths around the resonance. The cross sections for these processes reflect the behaviour of the eigenenergies in the resonant region.

Thus the $N = 0$ cross section for the elastic electron scattering by a state which evolves adiabatically with the laser frequency evolves into the corresponding cross section for electron scattering by the other resonant state, as the resonance is passed. We have recently proposed a method for investigating Rydberg states based on this feature, using resonant laser-assisted elastic electron-atom scattering [3]. The method relies on the adiabatic evolution of the laser field throughout the resonance, and its subsequent adiabatic switch off out of the resonant region. Furthermore, if we assume that the resonant states are represented by diabatic states, along which the initial character of the states is preserved, the cross section for a particular scattering process shows a pronounced maximum (or minimum) in the resonant region. This is a consequence of the fact the "mixed" resonant state acquires a larger (or a smaller) spatial extension when one approaches the resonant frequency, due to the increasing contribution of the other resonant state. The small-angle elastic e-H cross sections with $N = \pm 1$ increase in the vicinity of resonances, since in these conditions both the resonant field and the projectile induce a dipole transition in the atom.

The analysis of inelastic e-H scattering is more complicated [4]. For the sake of simplicity we consider here only transitions between the diabatic states. In the forward direction, the largest $N = 0$ cross sections correspond to processes in which the projectile induces a dipole transition in the atom, similarly to the scattering without the field. On the other hand, the largest $N = \pm 1$ cross sections correspond to processes in which both the radiative field and the projectile induce a dipole transition in the atom. In addition, if the radiative process brings directly the initial or final state into resonance with an intermediate state, the collision is resonant with an increasing cross section in the resonant region; otherwise it is non-resonant and the corresponding cross section decreases in this region. We note that the cross sections for scattering processes involving $3s$ and $3d$ states as the initial or final states, do not reduce to the analogous field-free cross sections when $I \to 0$, since in this limit the eigenvectors in general are superpositions of atomic states with the same principal quantum number and parity.

The one-photon $1s - 2p$ resonant coupling influences the e-H scattering at much higher frequencies than the $2s - 3p$ and $2p - 3d$ couplings do. The qualitative behaviour of the cross sections is similar to the analogous ones discussed above.

Finally, in order to investigate the modifications of resonance structures in the cross sections induced by a bichromatic field, we will study the e-H collision in a coherent superposition of a fundamental field, whose frequency corresponds to a resonant frequency between the $n = 2$ and $n = 3$ levels, and its third harmonic. The last field almost brings the $n = 1$ and $n = 2$ levels into a two-photon resonance at much higher intensity than the one-photon coupling does. We will vary the relative phase of the two fields in the region of the $2s - 3p$ resonance, as well the intensity of the second field. The results for each combination of parameters of the fields will be presented at the Conference.

[1] M. Dörr, C. J. Joachain, R. M. Potvliege and S. Vučić, *Phys. Rev. A* **49** 4852 (1994).

[2] S. Vučić and R. Hewitt, *Phys. Rev. A* **56** 4899 (1997).

[3] S. Vučić, *Phys. Rev. A* **60** 2296 (1999).

[4] S. Vučić, *Phys. Rev. A* **51** 4754 (1995).