PHYSICS OF SMALL RECOIL MOMENTA IN ONE PHOTON-TWO-ELECTRON IONIZATION OF HELIUM

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Atom of helium is the simplest three-body system bound by electromagnetic interactions. Investigation of ejection of the electrons in photoinization of helium provides information about interactions in this system in various configurations. Until recent time the high energy experiments provided information about interactions near the electron-nucleus coalescence point, where the distance between the nucleus and one of the electrons is much smaller than the characteristic size of helium atom. In case of the double photoionization this was connected with the "shakeoff" and "knockout" mechanisms of the process, which required one of the bound electrons to approach the nucleus. Thus the nucleus absorbed a large recoil momentum Q ($Q \gg 1$ in atomic units).

It was found long ago [1] that there is an alternative *quasifree* mechanism (QFM) which becomes increasingly important with the increase of the photon energy. The basic point is that while a single free electron can not absorb a photon, a system of two free electrons can. Thus the ejection of the bound electrons can take place with small recoil momentum $Q \sim 1$. The kinematical limits of the free process require that the mechanism can manifest itself only in the vicinity of the center of the spectrum, i.e. the relative difference of energies of the outgoing electrons $\varepsilon_{1,2}$ should be small, ($\beta \equiv |\varepsilon_1 - \varepsilon_2|/(\varepsilon_1 + \varepsilon_2) \ll 1$). Also, in the QFM the electrons are ejected almost "back-to back"' i.e. $t = \mathbf{p}_1 \cdot \mathbf{p}_2/p_1 p_2 \approx -1$, with $\mathbf{p}_i$-momenta of the outgoing electrons.

The free process is forbidden in the dipole approximation, this leads to quenching of the corresponding channel. On the other hand, the two other mechanisms are quenched by necessity to transform large momentum $Q \gg 1$ to the nucleus. The interplay of these factors leads to expected complicated shape of the spectrum of the double photoionization in the vicinity of its center at the photon energies of the order of 1 keV [2].

It appeared to be essential that the QFM is related directly to the behavior of the bound state wave function $\Psi(r_1, r_2, r_{12})$ at small distance between the bound electrons r_{12} [3]. It was shown that the QFM amplitude contains the factor $\partial\Psi/\partial r_{12}$ at $r_{12} = 0$, which is connected to the function $\Psi(r_1, r_1, r_{12} = 0)$ by the Kato cusp condition [4]. The latter appears to be very important for calculation of the QFM amplitude. As discussed in [3], some of the attempts to calculate the energy distributions in the central region with the functions which do not satisfy the Kato condition lead to publications containing erroneous results.

The distribution of the outgoing electrons in recoil momenta Q was measured directly in [5]. The photons carried the energies 450 eV, 800 eV and 900 eV. The experiments showed that the distribution obtains a surplus at small Q of about 1 a.u. The kinematics of these experiments enabled to separate the non-dipole contributions. Thus the observed surplus is entirely due to the non-dipole terms.

This stimulated us to calculate the QFM contribution to the differential distributions of the ejected electron in recoil momenta for the double photoionization of the ground state of the helium atom. We described the initial state by very accurate wave functions developed in [6] and satisfying the Kato condition. We demonstrated that the final state of the outgoing electrons provide a small correction which is of the order $4{\cdot}10^{-2}$ for $\omega = 800$ eV. This enabled us to describe the final state by the product of two nonrelativistic Coulomb functions.

As expected, the double differential distribution $d^2\sigma/dQ^2d\beta$ obtains the largest values at small $\beta \ll 1$ and in the region of small $Q \sim 1a.u.$ We calculated also the energy distribution of the angular correlation $d^2\sigma/dtd\beta$. As expected, the largest values are reached at $\beta \ll 1$ and t close to -1, corresponding to the electrons ejected in the opposite directions ("back-to back"). We obtained the distribution in recoil momenta $d\sigma/dQ^2$ and the angular correlation $d\sigma/dt$ which result from the integration of the corresponding double differential distributions over β. As expected, the distribution $d\sigma/dQ^2$ has a local maximum at Q about 1 a.u. At $Q = 0$ this distribution turns to zero just because the interval of integration over β vanishes. The angular correlation $d\sigma/dt$ has a sharp peak at $t = -1$, in agreement with the previous analysis.

The general picture is in agreement with the experimental results [5]. Unfortunately, the way of presentation of the results in [5]does not permit to compare the quantitative results.

The advent of new powerful light sources provides new possibilities for experimental studies of photoabsorbtion processes. In particular, more detailed investigation of photoionization by the photons caring the energies ω of about 1 keV is expected.

The QFM becomes more significant at higher values of the photon energies. At the values $\omega \geq c^2$, corresponding to relativistic outgoing electrons it provides the contribution to the total cross section of the same order as that of the shake-off. Investigation of the relativistic case is also one of the forthcoming problems. We dream that further research will move into relativistic region thus disclosing the fine structure of the central peak of the energy distribution. We hope also that contribution of the QFM to the total cross section, resulting in a slope of the double-to-single photoionization ratio will be measured.

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