PHYSICAL REVIEW A **77**, 067401 (2008)

Comment on "Photodetachment in a strong laser field: An experimental test of Keldysh-like theories"

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(Received 12 November 2007; published 11 June 2008)

In a recent paper [B. Bergues, Z. Ansari, D. Hanstorp, and I. Yu. Kiyan, Phys. Rev. A **75**, 063415 (2007)], there is the statement: "Our results unambiguously show that the length gauge is the proper one to use in the frame of the strong-field approximation." This statement is contested, based on the fact that contrary conclusions from comparisons with experiments have already been demonstrated.

DOI: 10.1103/PhysRevA.77.067401 PACS number(s): 32.80.Rm, 32.80.Gc

A recent paper by Bergues *et al.* [1], concludes that: "Our results unambiguously show that the length gauge is the proper one to use in the frame of the strong-field approximation." This conclusion is examined and rejected here on the grounds that it is contradicted by evidence from existing comparisons with experiments.

The claim made in the paper being commented upon is so unequivocal that a single contrary example is all that is necessary to negate the claim. In fact, two clear counterexamples will be cited here. One is related to another paper from the same group that reported on the results of experiments done on photodetachment of the fluorine negative ion by circularly polarized light [2]. It was shown recently [3] that the photoelectron spectrum could not be matched at all by a length-gauge analog of the strong-field approximation (SFA), but that a velocity-gauge approach gave reasonably good agreement with the experimental spectrum. A much older presentation will also be cited [4], where photoionization of ground-state helium by both linearly and circularly polarized light resulted in spectra [5] that were matched perfectly (that is, to within experimental error bars) by the velocity-gauge SFA.

Brief remarks will be useful as an introduction to gauge considerations in the nonperturbative treatment of strong-field laser phenomena. The velocity gauge is based on the Coulomb gauge that is universally employed in nuclear and particle physics for the treatment of electromagnetic interactions. The Coulomb gauge employs a scalar potential for longitudinal fields (such as the Coulomb field) and a vector potential for transverse fields (such as the laser field). That is, the laser is represented by the vector potential $\mathbf{A}(t,\mathbf{r})$. When the dipole approximation is applicable, $\mathbf{A}(t,\mathbf{r})$ is replaced by $\mathbf{A}(t)$, and the Coulomb gauge is then referred to as the velocity gauge. Within the dipole approximation, a transverse field can be approximated by a quasistatic electric field, leading to the approximate description of the laser field by the scalar potential $-\mathbf{r}\cdot E(t)$. This is called the length gauge. Analytical strong-field approximations are known not to be gauge invariant.

In the paper [2] by the same group that presented Ref. [1], the measured peak intensity in the laser focus was stated as 2.6×10^{13} W/cm^2. They also presented in Ref. [2] a momentum distribution of the photodetached electrons that gives a direct measure of the ponderomotive energy of the electrons. This follows from the well-known [6,7] and well-tested principle that electrons ionized by a strong field will take on essentially classical characteristics. In Ref. [2], the measured momentum distribution of the photoelectrons provided a direct measure of the dominant ponderomotive energy of the electrons that corresponded almost exactly to 2.6×10^{13} W/cm^2. In other words, there were two independent measurements of the peak intensity in the experiment. These two measurements are consistent with each other, but they preclude the intensity that had to be posited to allow a fit to the length-gauge theory. A fit to the velocity-gauge theory at the well-established peak intensity of 2.6×10^{13} W/cm^2 was quite reasonable [3]. However, a fit [2] to a length-gauge version of the SFA required the assumption of a peak laser intensity 45% higher, at 3.8×10^{13} W/cm^2, in contradiction to the two independent measures of the peak field intensity.

It may be useful to give a summary of how the momentum distribution of photoelectrons detached by circularly polarized light gives a direct measure of the peak intensity of the laser. The details of this are given in a recent paper [3]. When an electron is detached by a laser field from an atom or ion, the quantum process of detachment occurs much faster than any classical motion of the electron that may follow the detachment process. This disparity in time scales means that all quantum conditions will be satisfied before classical motion in the field of the laser occurs. With circular polarization, as in Ref. [2], this means that each photon that transfers its energy to the electron also transfers its full angular momentum, and all of these angular momenta are aligned. In strong-field conditions, the final electron has a kinetic energy approximately equal to the ponderomotive energy U_p. The threshold energy condition thus requires at least $2U_p$ of energy. The resulting energy and angular momentum correspond to the classical dynamical parameters associated with the detached electron circulating around the atom in a circular trajectory in a plane perpendicular to the laser propagation direction. These energy and angular momentum parameters are not altered by subsequent classical interactions. The classical $\mathbf{v}\times\mathbf{B}$ magnetic force is zero because $\mathbf{v}$ is parallel to $\mathbf{B}$. The net electric force acting on the electron is zero because the electron probability density is uniformly distributed around the atom. Therefore, the quantum ionization condition that the electron has a kinetic energy of approximately U_p is unaltered when ponderomotive forces (too small to matter during the laser pulse) eventually transport the detached electron to the spectrometer. A momentum distribution of the detached electron will thus have exactly the appearance of Fig. 2 in Ref. [2], and the peak ponderomotive energy can be deduced directly therefrom.

That is, the velocity gauge gives a reasonable description of the photodetachment of F^-, but the length gauge, with its impossible need for a higher intensity, is unable to do so. This result is sufficient to refute the primary conclusion of Ref. [1].

All velocity-gauge calculations reported in Refs. [4,3] were done with solutions of the rate equation employing the SFA theory of [8], as applied according to the prescriptions set forth in Refs. [9,4] for integrating over spatial and temporal intensity distributions in the laser focus, in such fashion as to incorporate depletion effects.

This remark about accounting for spatial and temporal distributions as well as depletion is especially relevant to the results reported in Ref. [4]. The successful description of the photoelectron linear and circular polarization spectra from the ionization of ground-state helium, described in Ref. [4], followed upon an unsuccessful attempt by the experimentalists who produced the data [5] to use the SFA. The difference was entirely due to the proper employment of spatiotemporal intensity distributions in Ref. [4].

The successes of the velocity gauge theory thus cover photodetachment [3] as well as photoionization [4]; both circular [4,3] and linear polarizations [4]; and *s* [4] as well as *p* [3] initial angular momentum states.

The conclusion of Ref. [1], that their "... results unambiguously show that the length gauge is the proper one to use in the frame of the strong-field approximation...," is insupportable.

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