Time-Resolved Ultrafast Electron (e, 2e) Momentum Spectroscopy

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Synopsis The (e,2e) process is analyzed for the case of an ultrafast electron pulse incident upon a target prepared in a time-varying, coherent superposition of states. Conditions under which time-resolved target momentum densities can be obtained from experimental measurements are discussed. Results for coherent electronic motions in both the H atom and the H_2^+ molecule are used to illustrate the capability of an ultrafast electron pulse to image time-dependent target electron dynamics. We then propose the use of an ultrafast electron (e, 2e) measurement to image a controllable, laser-driven coherent electron population transfer in lithium atoms using currently available femtosecond electron pulses.

The last decade has seen growing interest in attosecond science [1-3], one of whose goals is to image time-resolved electron dynamics. Nowadays, electron pulses with femtosecond (fs) durations have been reported [4, 5]. Recently, single-electron pulses with a full width at half maximum (FWHM) duration of 28 fs have been demonstrated [6] and a scheme for reaching attosecond resolution by optical gating [7] has been proposed. Simulations of electron scattering processes employing attosecond duration incident electron pulses, whether treated simply as potential scattering [8] or more rigorously as coherent scattering [9-11], have demonstrated the ability of such ultrashort electron pulses to image electronic motions in target atoms and molecules.

We demonstrate here that attosecond electron pulse (e, 2e) processes are capable of directly imaging time-dependent momentum space densities $\rho(\mathbf{q},t)$ of coherent states of both the H atom and the H_2^+ molecule. The symmetric-noncoplanar setup [12] is chosen since measurements are directly related to $\rho(\mathbf{q}_z,t_d)$, which is measured by varying the detector azimuth angle φ (see Fig. 1).

Since current electron pulse durations are still insufficient to resolve electronic motions that are typically of fs order or less, we have investigated an electronic motion whose duration can be controlled to be longer than existing electron pulse durations: specifically, adiabatic passage of the Li atom's valence electron from the 2s to the 2p state by means of a frequency-chirped laser pulse [13]. Our simulations [13] demonstrated the imaging of this laser-driven electron population transfer by means of ultrafast electron diffraction. We expect the (e,2e) process can similarly image the time-dependence of this transition.

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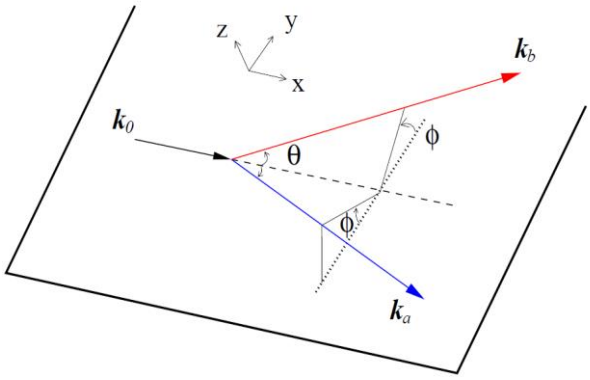

Figure 1. The symmetric-noncoplanar setup. The momenta of the incident, scattered, and ejected electrons are denoted by $\mathbf{k}_0$, $\mathbf{k}_a$, and $\mathbf{k}_b$, respectively.

References

[1] F. Krausz and M. Ivanov 2009 Rev. Mod. Phys. **81** 163
[2] P. Salières *et al*. 2012 Rep. Prog. Phys. **75** 062401
[3] M.F. Ciappina *et al*. 2017 Rep. Prog. Phys. **80** 054401
[4] M. Aidelsburger *et al*. 2010 Proc. Natl. Acad. Sci. USA **107** 19714
[5] J. Hoffrogge *et al*. 2014 J. Appl. Phys. **115** 094506
[6] A. Gliserin *et al*. 2015 Nat. Commun. **6** 8723
[7] M. Kozák *et al*. 2017 Nat. Commun. **8** 14342
[8] H.-C. Shao and A. F. Starace 2010 Phys. Rev. Lett. **105** 263201
[9] H.-C. Shao and A. F. Starace 2013 Phys. Rev. A **87** 050701(R)
[10] H.-C. Shao and A. F. Starace 2013 Phys. Rev. A **88** 062711
[11] H.-C. Shao and A. F. Starace 2014 Phys. Rev. A **90** 032710
[12] M. A. Coplan *et al.* 1994 Rev. Mod. Phys. **66** 985
[13] H.-C. Shao and A. F. Starace 2016 Phys. Rev. A **94** 030702(R)

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