Limitations in photoionization of helium by an extreme ultraviolet vortex

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Synopsis Photoelectron angular distributions from helium atoms are measured using the circularly polarized extreme ultraviolet vortex which has a helical wavefront and carries orbital angular momentum. While the violation of the electric dipole transition rules has been predicted for interactions between vortices and atoms, the photoelectron angular distributions are well reproduced by assuming electric dipole transitions only. This observation can be explained by the localized nature of the helical phase effect of the vortex on the interaction with atoms.

We report the experimental investigation on the photoionization of helium atoms irradiated with a circularly polarized extreme ultraviolet (XUV) vortex beam produced by a helical undulator [1]. The XUV vortex has a helical wavefront and carries orbital angular momentum (OAM) as well as spin angular momentum associated with it circular polarization. In recent years, several theoretical works have been reported on the photoionization and photoexcitation of atoms by OAM-carrying photons [2]. Differing from plane-wave photons, a violation of the standard electric dipole selection rules is predicted for vortex, as a consequence of the transference of the OAM to the internal degrees of freedom of the atom. In contrast to these advances in theory, to our knowledge, there has been no experimental work on vortex-matter interactions in the short wavelength regime, owing to the technical difficulty of producing brilliant and energy-tunable vortex beams.

The experiment was carried out at the undulator beamline BL1U of the 750-MeV UVSOR storage ring. Photoelectron angular distributions of helium atoms were measured using the circularly polarized XUV vortex beam at about 30 eV photon energy. The XUV vortex beams were produced by a helical undulator as the higher harmonics of its radiation because the nth harmonic off-axis radiation from a helical undulator carries OAM of $(n\text{-}1)\hbar$ per photon [3], as a result of the spiral motion of electron which naturally emits electromagnetic wave with a helical wavefront [4].

Figure 1 shows the angular distributions measured for the first, second and third harmonics, corresponding to plane-wave photons (l=0), and XUV vortices of l=1 and 2, respectively. While the violation of the electric dipole transition rules has been predicted for interactions between vortices and atoms, the photoelectron angular distributions are well reproduced by the dipole components alone, and non-dipole contributions are not detected within the experimental uncertainty. This observation can be explained by the localized nature of the helical phase effect of the vortex on the interaction with atoms, and demonstrates that non-dipole interactions induced by vortex are hardly observable in conventional gas-phase experiments.

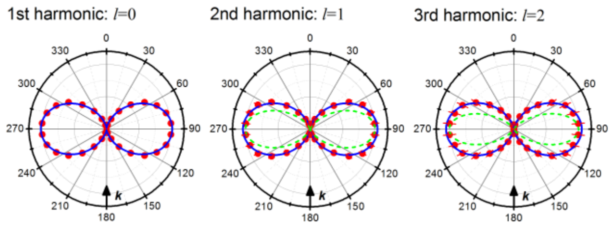

Figure 1. Photoelectrons angular distributions of helium atoms measured for the first, second and third harmonics from helical undulator. The solid curves represent fit assuming dipole transition. The dotted curves show the angular dependence of the photoelectron expected for non-dipole transitions.

References

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