Acceleration of neutral atoms in intense short laser pulses

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Synopsis We report experimental results on a new acceleration mechanisms for neutral atoms in a strong laser field (I = 10^{16}W cm^{-2}). A simple model can explain the observed accelerations with magnitudes as high as 10^{14} times Earth's gravitational acceleration.

We report on experiments where we have investigated kinematic effects of strong short-pulsed laser fields on neutral atoms. We measure deflections of neutral atoms in laser fields with intensities up to 10^{16}W cm^{-2}, which correspond to an ultra-strong acceleration as high as 10^{14} times Earth's gravitational acceleration. This is - to the best of our knowledge - by far the strongest acceleration of neutral species in external fields. For instance, the new force exceeds those which are used in atomic laser cooling experiments by typically eight orders of magnitude. The experiments have become possible through a recent observation that atoms can survive strong laser pulses in an excited state, where they can be detected directly [1]. Thus, with a position sensitive detector we can measure atomic beam deflection if, during the laser pulse, sufficient momentum is transferred to the atoms. In Fig.1 we show a result for a beam of He atoms intersected by a high intensity pulsed laser beam, where we have measured the distribution of laser excited He atoms with a position sensitive detector located $\sim$ 0.38 m downstream from the interaction region. The distribution of excited atoms along the laser beam direction (z_D axis) is as expected whereas the distribution in radial r_D direction is surprising. We find that it originates from the accelerating forces of the laser field on the neutral atom.

The observed action on neutral atoms during the short interaction time can be quantitatively explained by a simple model based on the three step model of atomic strong field dynamics. The survival mechanism has been dubbed "frustrated tunnel ionization" [1] and has also been found in molecular dissociation in strong laser fields [2]. In essence, it is the recapture of the tunneled electron after the laser pulse is over which is responsible for the excitation. During the laser pulse, the ponderomotive force is acting on the quasi free electron converting quiver energy of the electron partially into centre-of-mass motion of the whole atom. Observed atomic deflections can be fitted within this model with excellent agreement. Besides the fundamental observation of unprecedented acceleration of neutral atoms in external fields we envisage a mapping of the laser intensity distribution in an intense focussed beam, an important information, which is otherwise hardly to obtain.

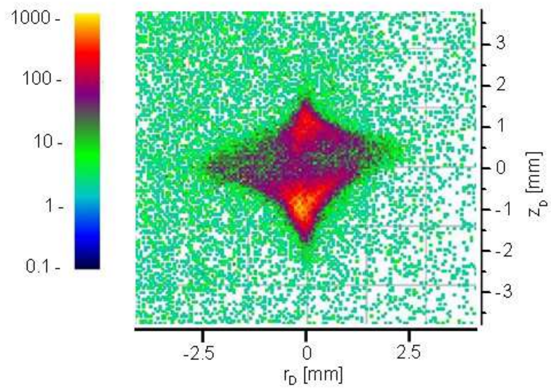

Fig. 1. Shown is the distribution of excited He atoms for a laser pulse with I = 4.2x10^{15} W cm^{-2} on a logarithmic scale.

References

[1] T. Nubbemeyer *et al.*, Phys. Rev. Lett. **101**, 233001 (2008).

[2] B. Manschwetus *et al.*,Phys. Rev. Lett. **102**, 113002 (2009).

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