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Acceleration of neutral atoms in strong short-pulse laser fields

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Kinematic manipulation of neutral atoms in inhomogeneous laser fields has been widely studied for weak to moderately strong laser fields. Here we report on experiments where we have investigated kinematic effects on neutral atoms using strong short-pulse laser fields with intensities up to 10^{16} Wcm^{-2} and pulse durations in the range from 40 to 120 fs. We measure deflections of neutral atoms, which correspond to ultra strong accelerations with magnitudes 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. The momentum transfer to the neutral atoms during the short interaction time is by far stronger than what one would expect from the dipole force acting on the ground state atoms. To explain our findings we first state that it is of vital importance for our investigations that atoms can survive strong laser pulses in long lived excited states. A quantitative model for the underlying excitation mechanism is based on an extension of the three step model of strong field atomic dynamics. In essence, it is a "frustrated tunnel ionization (FTI)" process, where the tunnel electron is oscillating strongly in the laser field but eventually recaptured into an excited state of the neutral atom after the laser pulse is over. The observed deflection of the neutral atoms can be attributed to the ponderomotive force that is acting on the quasi free electron during the laser pulse, in accord with the FTI mechanism. It converts quiver energy of the electron partially into centre-of-mass motion of the whole atom, since the ionic core and the tunnel electron are coupled by the Coulomb force. Observed deflections for He and Ne atoms for different laser parameters are in very good agreement with our theoretical predictions. Implications of our results for strong field physics and further prospects will be discussed.