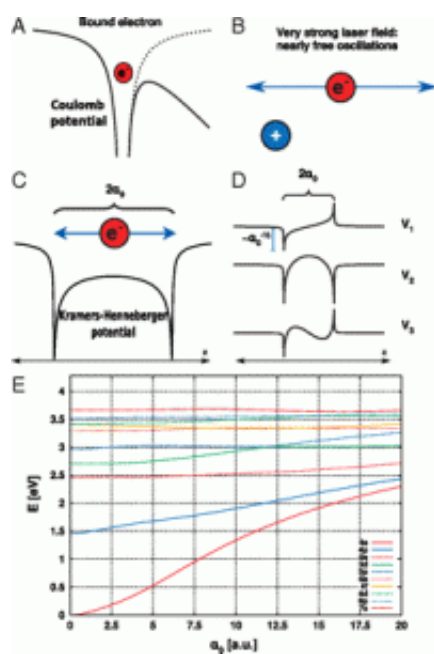


# Eye on ionization: Visualizing and controlling bound electron dynamics in strong laser fields

October 19 2011, by Stuart Mason Dambrot



The Kramers-Henneberger atom. (A) The binding potential well without (dashed line) and with (solid line) external superatomic electric field. (B) In the superatomic field the electron becomes almost free and its motion is dominated by the oscillations in the field with the amplitude  $\alpha_0 \propto 1/4 E/\omega^2$ , where  $E$  and  $\omega$  are the laser field strength and frequency, respectively. (C) The sketch of the Kramers-Henneberger potential and (D) its harmonics. The coordinate dependence of the KH potential  $V_0$  and its harmonics  $V_1$ ,  $V_2$ ,  $V_3$  is shown for a one-dimensional cut through the K nucleus, along the laser polarization direction. (E) The energies of the Kramers-Henneberger potassium atom vs. amplitude of oscillations  $\alpha_0$ . Copyright © PNAS, doi:10.1073/pnas.1105916108

(PhysOrg.com) -- Subatomic events can be remarkably counterintuitive. Such is the case in theoretical physics when, under certain specific conditions, atoms exposed to intense infrared laser pulses remain stable rather than undergoing the ionization expected from electric fields at least as strong as the electrostatic forces binding the irradiated valence electrons. Inspired by the observed acceleration of neutral atoms<sup>1</sup>, and other recent experiments<sup>2</sup>, researchers at the [Max-Born Institute for Nonlinear Optics](#) in Berlin have shown that, in theory, *angular resolved photoelectron spectroscopy* can be used to directly image these so-called *laser-dressed* stable atoms.

Today, intense laser pulses with electric fields exceeding the electrostatic fields binding electrons in [atoms](#) and molecules have become a routine tool with various applications. Performing research designed by Dr. Olga Smirnova, Dr. Felipe Morales, with Ms. Maria Richter and Dr. Serguei Patchkovskii, conducted in a so-called *numerical experiment* in which they exposed a potassium atom to a strong laser field and studied the resulting effects. “Naturally,” Morales and Richter explain, “one would think that hammering an atom or molecule with such pulses would lead to fast ionization and overall disintegration of the atomic system. We demonstrate that, surprisingly, the pulse may only flatten the atom, changing its shape without causing it to disintegrate.” Shape refers to the atom’s electronic structure.

“Specifically,” they continue, “the main advance of our work is to show how the electronic structure of this new distorted atom in a superatomic field – the Kramers-Hennerberger (KH) atom – can be directly imaged, within what are now standard experimental conditions.” The existence of the KH atom, although theoretically predicted more than 40 years ago by Henneberger<sup>3</sup> and since then the object of extensive research<sup>4</sup>, has so far remained unconfirmed experimentally. “What we are demonstrating with our work”, stress Morales and Richter, “is that the KH atom is not just an abstract concept formally introduced by theorists, but it is an

object, which can be experimentally detected.” In particular, their procedure is based on the calculation of angle resolved photoelectron spectra, which can be obtained with standard femtosecond laser pulses and velocity map imaging techniques<sup>2,5</sup>.

Paradoxically, the technique of photoelectron spectroscopy is commonly used in *weak field* experiments, in which the external fields are weaker than the intra-atomic binding fields. However, they demonstrate that the spectroscopic procedure may be applied to interpret the results of strong field experiments. “The analysis of energy- and angle-resolved photoelectron spectra obtained in our numerical experiment”, Morales and Richter note, “allowed us to reveal the signatures of the KH atom.” This accomplishes two things at once: their work demonstrates that strong-field [photoelectron spectroscopy](#) can be used to directly visualize the electronic structure of the KH atom and, conversely, the *well-defined* electronic structure of this exotic atom can be used in order to “read” strong-field photoelectron spectra.

While the group’s research is theoretical, their results are ripe with potential. “Indeed,” Morales and Richter say, “our findings can bring new ideas into the interpretation and the development of visualizing and controlling bound electron dynamics in strong laser fields in various strong-field processes, including a microscopic description of high order Kerr nonlinearities and their role in laser filamentation<sup>6</sup> – as well as other highly interesting areas in modern-day physics.”

“Given that this work is purely theoretical,” Morales and Richter conclude, “the question of possible applications will be answered through further research involving collaborations with experimental groups. Our future plans include, for example, the application of our methodology to different systems. We expect to achieve a better insight in interesting phenomena such as laser filamentation and to find explanations for other exciting experimental results by using our

approach.”

**More information:** Imaging the Kramers–Henneberger atom, Published online before print September 19, 2011, *PNAS* October 11, 2011 vol. 108 no. 41 16906-16911, [doi:10.1073/pnas.1105916108](https://doi.org/10.1073/pnas.1105916108)

## Related:

<sup>1</sup>Acceleration of neutral atoms in strong short-pulse laser fields, *Nature* 461, 1261-1264 (29 October 2009), [doi:10.1038/nature08481](https://doi.org/10.1038/nature08481)

<sup>2</sup>Photoelectron angular distributions from strong-field coherent electronic excitation, *Applied Physics B* 95, 245–259 (2009), [doi:10.1007/s00340-009-3431-1](https://doi.org/10.1007/s00340-009-3431-1)

<sup>3</sup>Perturbation method for atoms in intense laser fields, *Physical Review Letters* 21, 838–841 (1968), [doi: 10.1103/PhysRevLett.21.838](https://doi.org/10.1103/PhysRevLett.21.838)

<sup>4</sup>Atomic stabilization in superintense laser fields, *Journal of Physics B: Atomic, Molecular and Optical Physics* 35, R147-R193 (2002), [doi:10.1088/0953-4075/35/18/201](https://doi.org/10.1088/0953-4075/35/18/201)

<sup>5</sup>Strong-field ionization of lithium, *Physical Review A* 83, 023413 (2011), [doi:10.1103/PhysRevA.83.023413](https://doi.org/10.1103/PhysRevA.83.023413)

<sup>6</sup>Higher-Order Kerr Terms Allow Ionization-Free Filamentation in Gases, *Physical Review Letters* 104, 103903 (2010), [doi:10.1103/PhysRevLett.104.103903](https://doi.org/10.1103/PhysRevLett.104.103903)

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