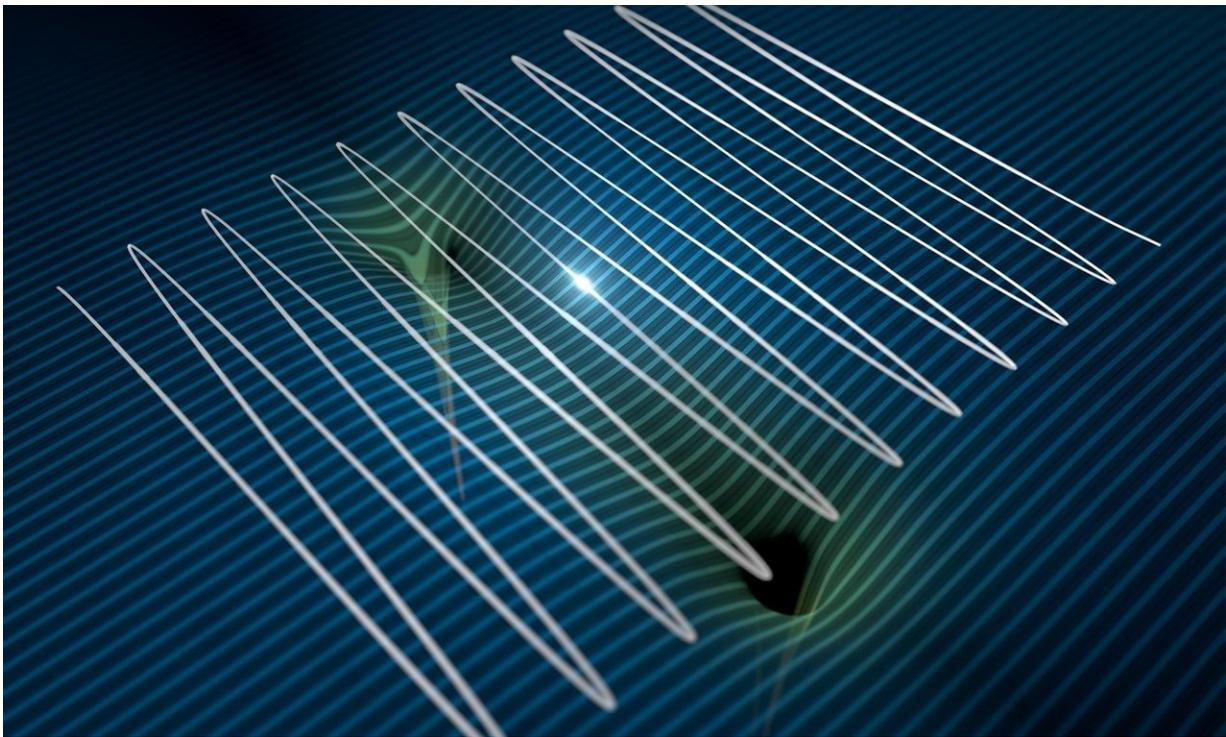


For the first time, researchers place an electron in a dual state—neither freed nor bound

April 16 2018



Schematic illustration of the Kramers-Henneberger potential formed by a mixture of the atomic potential and a strong laser field. Credit: UNIGE - Xavier Ravinet

Atoms are composed of electrons moving around a central nucleus to which they are bound. The electrons can also be torn away via the

powerful electric field of a laser, overcoming the confining force of their nucleus. A half-century ago, the theorist Walter Hanneberger wondered if it were possible to use a laser field to free an electron from its atom without removing it from the nucleus. Many scientists considered it to be impossible. However, it has now been successfully confirmed by physicists from the University of Geneva (UNIGE), Switzerland, and the Max Born Institute (MBI) in Berlin, Germany.

For the first time, researchers controlled the shape of the [laser](#) pulse to keep an electron both free and bound to its [nucleus](#), and were at the same time able to regulate the electronic structure of the atom. What's more, they also made these unusual states amplify laser light and identified a no-go area. In this area, nicknamed "Death Valley," the physicists lost all their power over the electron. These results shatter the usual concepts related to the ionisation of matter. The results have been published in the journal *Nature Physics*.

Hanneberger's hypothesis proposed that if an electron were trapped in the laser, it would be forced to pass back and forth in front of its nucleus, and would thus be exposed to the electric [field](#) of both the laser and the nucleus. This dual state would make it possible to control the motion of electrons exposed to both electric fields, and would let the physicists create [atoms](#) with a new electronic structure tunable with light.

Leveraging the natural oscillations of the electron

The more intense a laser is, the easier should it be to ionise the atom—in other words, to tear the electrons away from the attracting electric field of their nucleus and free them into space. "But once the atom is ionised, the electrons don't just leave their atom like a train leaves a station—they still feel the electric field of the laser," explains Jean-Pierre Wolf, a professor at the applied physics department of the UNIGE Faculty of Sciences. "We thus wanted to know if, after the

electrons are freed from their atoms, it is still possible to trap them in the laser and force them to stay near the nucleus, as the hypothesis of Walter Hanneberger suggests," he adds.

The only way to do this is to find the right shape for the laser pulse in order to impose oscillations on the electron that are exactly identical, so that its energy and state remain stable. "The electron does naturally oscillate in the field of the laser, but if the laser intensity changes, these oscillations also change, and this forces the electron to change its energy level and thus its state, even leaving the atom. This is what makes seeing such unusual states so difficult," adds Misha Ivanov, a professor at the theoretical department of MBI in Berlin.

The physicists tested different laser intensities so that the electron freed from the atom would have steady oscillations. They made a surprising discovery. "Contrary to natural expectations that suggest that the more intense a laser is, the easier it frees the electron, we discovered that there is a limit to the intensity, at which we can no longer ionise the atom," observes Misha Ivanov. "Beyond this threshold, we can control the electron again." The researchers dubbed this limit "Death Valley," following the suggestion of Professor Joe Eberly from the University of Rochester.

Confirming an old hypothesis to revolutionise physics theory

By placing the electron in a dual state that is neither free nor bound, the researchers found a way to manipulate these oscillations as they like. This enables them to work directly on the [electronic structure](#) of the atom. After several adjustments, the physicists were able to free the electron from its nucleus and then trap it in the electric field of the laser, as Walter Hanneberger suggested. "By applying an intensity of 100

trillion watts per cm^2 , we were able to go beyond the Death Valley threshold and trap the electron near its parent atom in a cycle of regular oscillations within the [electric field](#) of the laser," Jean-Pierre Wolf says. As a comparison, the intensity of the sun on the Earth is approximately 100 watts per m^2 .

"This gives us the option of creating new atoms dressed by the field of the laser, with new electron energy levels," explains Jean-Pierre Wolf.

"We previously thought that this dual state was impossible to create, and we've just proved the contrary. Moreover, we discovered that [electrons](#) placed in such states can amplify light. This will play a fundamental role in the theories and predictions on the propagation of intense lasers in gases, such as air," he concludes.

More information: Mary Matthews et al, Amplification of intense light fields by nearly free electrons, *Nature Physics* (2018). [DOI: 10.1038/s41567-018-0105-0](#)

Provided by University of Geneva

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