Laser empties atoms from the inside out

EurekAlert!

An international team of plasma physicists has used one of the world's most powerful lasers to create highly unusual plasma composed of hollow atoms.

The experimental work led by scientists from the University of York, UK and the Joint Institute for High Temperatures of Russian Academy of Sciences demonstrated that it is possible to remove the two most deeply bound electrons from atoms, emptying the inner most quantum shell and leading to a distinctive plasma state.

The experiment was carried out using the petawatt laser at the Central Laser Facility at the Science and Technology Facilities Council (STFC) Rutherford Appleton Laboratory to further understanding of fusion energy generation, which employs plasmas that are hotter than the core of the Sun.

The results are reported in the journal *Physical Review Letters*.

A hollow atom occurs when an electron buried in an atom is removed, usually by being hit by another electron, creating a hole while leaving all the other electrons attached. This process creates plasma, a form of ionised gas. An X-ray is released when the hole is filled.

Normally the process involves removing electrons from the outer shells of atoms first and working inwards. The team of scientists demonstrated a new mechanism for creating hollow atoms that involved emptying atoms from the inside out.

The experimental work used an intense laser, which at one petawatt delivers approximately 10,000 times the entire UK national grid, delivered in a thousand-billionth of a second, onto an area smaller than the end of a human hair.

Dr Nigel Woolsey, from the York Plasma Institute, Department of Physics, at the University of York was the Principal Investigator for the experimental work.

Dr Woolsey said: "At such extraordinary intensities electrons move at close to the speed of light and as they move they create perhaps the most intense X-rays ever observed on Earth. These X-rays empty the atoms from the inside out; a most extraordinary observation and one that suggests the physics of these interactions is likely to change, as lasers become more powerful."

Analysis and theoretical work was led by the Los Alamos National Laboratory, USA and Osaka University, Japan.

The analysis showed the mechanism for hollow atom generation was not due to the collision of electrons or driven by the laser photons, but was driven by the resulting radiation field from the interaction.

Lead author Dr James Colgan, from the Los Alamos National Laboratory, said: "The conditions under which the hollow atoms were produced were highly non-equilibrium and the production mechanism was quite surprising. These results indicate that a little-explored region of physics is now starting to become accessible with the unprecedented intensities reached by the world's leading laser facilities."

Co-author Dr Alexei Zhidkov, from Osaka University, said: "This experiment has demonstrated a situation where X-ray radiation dominates the atomic physics in a laser-plasma interaction; this indicates the importance of X-ray radiation generation in our physics description. Future experiments are likely to show yet more dramatic effects which will have substantial implications for diverse fields such as laboratory-based astrophysics."

If the scientific and technological challenges can be overcome, fusion offers the potential for an effectively limitless supply of safe, environmentally friendly energy. The experimental work was designed to further scientists understanding of how intense lasers can create electron beams with speeds close to the speed of light, then use these beams to heat fusion fuel to thermonuclear temperatures.

Co-author Dr Sergey Pikuz, from the Joint Institute for High Temperatures RAS, said: "The measurements, simulations, and developing physics picture are consistent with a scenario in which high-intensity laser technology can be used to generate extremely intense X-ray fields. This demonstrates the potential to study properties of matter under the impact of intense X-ray radiation."

Co-author Rachel Dance, a University of York PhD physics student, said: "This was a very dynamic experiment which led to an unexpected outcome and new physics. The hollow atom diagnostic was set to measure the hot electron beam current generated by the laser, and the results that came out of this in the end, showed us that the mechanism for hollow atom generation, was not collisional or driven by the laser photons, but by the resulting radiation field from the interaction."

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