Where are helium atoms in molecule?

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Frankfurt physicists have once again contributed to resolving a disputed matter of theoretical physics. Science has long since known that, contrary to the old school of thought, helium forms molecules of two, three or even more atoms. Exactly what helium consisting of three atoms looks like, however, has been disputed by theoretical physicists for about 20 years. Besides the intuitive assumption that the three identical components form an equilateral triangle, there was also the hypothesis that the three atoms are arranged linearly, in other words in a row. As the group of scientists led by Prof. Dr. Reinhard Dörner and his graduate student Jörg Voigtsberger report in the current edition of the prestigious journal *Nature Communications*, using the COLTRIMS reaction microscope, they were able to demonstrate that the truth lies in between.

"Nature gets out of it quite elegantly here: We looked at the helium molecule" under our reaction microscope, and it was found that He_3 is like a cloud," says Voigtsberger, whose dissertation is the source of the publication results. "It makes no difference whether it's linear or triangular or another configuration: all are equally probable, as is typical for quantum mechanics." Moreover, Voigtsberger and his coworkers' results put an end to an idea carried over from school days: The He_3 molecule does not consist of a solid structure, as is the case, for example, with the hydrogen molecule H2 and the carbon dioxide molecule CO2, in which the individual atoms quasi impinge directly on one another. In contrast, He_3 is like a cloud - the distance between the atoms is roughly ten times the atomic radius.

Finally, Voigtsberger and Dörner report that one variant of the He_3

molecule behaves in an unusual way: normal helium atoms consist of two protons and two neutrons. If one of the three helium atoms is replaced by the lighter isotope, which consists only of two protons and one neutron, then the molecule will be in a so-called quantum halo state: the lighter isotope is further away from the other two atoms than should be possible according to classic physics. "One can visualise this as ping pong balls in a soup bowl," explains Dörner. "Normal atoms collect at the bottom of the bowl, at a minimum of the potential. If they overcome the potential mountain, in other words the wall of the bowl, they will be completely separated from the molecule. Thus the lighter helium isotope is, as it were, outside of the bowl but, due to the quantum mechanical tunnel effect, it still "notices" the atoms in the bowl and cannot simply fly away."

The COLTRIMS reaction microscope, with which the experiments on helium molecules were conducted, has already demonstrated its versatility many times: in 2013, Dörner's work group had already been able to resolve a dispute of theoretical physics. In that case, the COLTRIMS experiments proved that the position of the Danish physicist Niels Bohr in the "Einstein-Bohr debates" 80 years ago was correct and, shortly before that, other physicists from the atomic physics work group used COLTRIMS to "film" the destruction of a molecule by a strong laser pulse - a reaction so fast that it cannot be captured by an ordinary camera.

More information: J. Voigtsberger et al., Imaging the structure of the trimer systems 4He3 and 3He4He2 in: *Nature Communications*, 5:5765, DOI: 10.1038/ncomms6765

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